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of the

United Nations Scientific Conference on the Conservation and Utilization of Resources

17 August – 6 September 1949, Lake Success, New York

Volume III, Fuel and Energy Resources

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Descriptive material on the background organization and participation in the Conference is to be found in Volume I, Plenary Meetings, as follows:

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25 August 1949

Chairman:

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Review of Techniques for Oil and Gas Discovery

G. M. LEES

ABSTRACT

The general principles of oil accumulation are already well known by the cumulative experience of 90 years, and discovery techniques have reached such a degree of effectiveness that there is reasonable certainty that the world's demand for oil supply will be met for many years to come. No fundamentally new discovery methods are expected, but undoubtedly existing techniques will be greatly refined. Geophysical methods have supplemented surface geological mapping in discovery of concealed anticlinal or other types of structures which may be oil-bearing. There are other classes of oil accumulation, such as stratigraphical traps, which can only be found by a combination of geological studies and liberal wildcatting.

In exploration of new territory remote from proved oil-fields, a geological appraisal can only give a qualified appreciation of oil possibilities. Oil-source rocks cannot be determined with certainty and the testimony of actual oil indications is still valued above theoretical deductions. The hazards of oil exploration can be substantially reduced, but not eliminated, by thorough geological studies and geophysical surveys ahead of test drilling.

The outstanding success of oil discovery in the United States has been largely because of the intensity of the search. Scientifically directed exploration has been greatly helped by data from wildcats drilled for non-technical reasons which give important control of geological deductions and geophysical interpretation. No other country has been subjected to such intensive exploration and immense scope for new discovery still remains in many parts of the world.

INTRODUCTION

Ninety years have passed since the first well was drilled specifically for oil by Col. Drake. Since the oil-fields have been discovered throughout the world and a total of 58.216 million barrels have been extracted up to the end of 1948. My subject is a review of the technique of oil discovery but as an introduction it is important to study the curious distribution of oil discovery throughout the world; to ponder on the degree to which this distribution is governed by known and unassailable geological facts; and to wonder whether there still is scope for important additions to the list of producing countries. To what extent is the leading position of the United States due to a dispensation of a kindly Providence and to what extent is it due to superior discovery methods and more intensive search?

The cumulative world crude-oil production to the end of 1948 was 58,216 million barrels, and of this total the United States has contributed 37,099 million barrels or 64 per cent and is currently producing at the rate of 59 per cent of the total. Oil has been or is being produced from 42 countries in the world but 96 per cent of the total has come from the following twelve countries,[1] each of whose cumulative production has exceeded 300 million barrels:

Country	*Cumulative total (in million bbls.)*	*Cumulative in per cent of total world production*	*1948 daily rate (in bbls.)*	*1948 rate in per cent of world*
United States	37,099,169,000	63.8	5,510,000	59.0
USSR	6,015,000,000	10.3	600,000	6.4
Venezuela	4,536,260,000	7.8	1,338,760	14.3
Mexico	2,369,627,000	4.1	160,000	1.7
Iran	1,932,401,000	3.3	520,200	5.6
Romania	1,202,586,000	2.1	83,200	0.9
N.E.I.	1,141,192,000	2.0	86,900	0.9
Colombia	440,180,000	0.8	64,880	0.7
Argentina	409,027,000	0.7	64,000	0.7
Iraq	407,235,000	0.7	73,460	0.8
Trinidad	368,986,000	0.6	55,160	0.6
Arabia	346,000,000	0.6	390,570	4.2

Source: Figures given are quoted from L. G. Weeks, *Bull.* A.A.P.G. June 1949, p. 1124.

I shall attempt a short analysis of this disequilibrium of the world's production in my concluding remarks.

DISCOVERY METHODS

During the ninety years in which experience in oil-field discovery has accumulated, new techniques have developed and new sciences have been called in to aid, and yet, to a surprising degree, *plus ça change, plus c'est la même chose.* Drilled depths have increased from 69 ft. in the case of the Drake well to 20,521 ft. in the Superior Oil Company well in Wyoming in 1949, and yet the average depth of oil production the world over remains sluggishly around 3,000 to 5,000 ft. with a negligible proportion from over 10,000 ft. To what extent does this increased drilling capacity add to possible new discovery and are our geological discovery tools as highly tempered as are those of our engineering brethren? It is now possible to discover and develop oil-fields in shallow water far from coast lines; to what extent will the world's oil resources be increased by this great engineering feat?

The ninety-year history may be divided into three successive phases of dominant discovery technique, although, of course, with much overlapping. They are:

(1) Seepage-drilling and wildcatting.
(2) Geological mapping.
(3) Geophysical mapping of concealed geology.

It is quite impossible to assign, with any degree of exactness, the proportion of total discovery to each method, particularly as many discoveries are by combination of two or even all three systems. The first two have been responsible for the bulk of past discovery, but geophysical methods are now dominant and will be increasingly so in the future. Geophysical surveys, however, are only an indirect method of discovery in that they determine underground structural forms which may be oil-bearing if other geological conditions are favourable, but they do not report directly on oil as such. Perhaps eventually a direct method may be developed, but at present there seems little

[1] A newcomer among oil producers, namely Kuwait, has not been included in this list as its cumulative total is so small. Its current production, however, is 240,000 barrels per day or 2.6 per cent of the world rate.

prospect. Geochemical prospecting, which is in essence micro-seepage detection, has been tested extensively both in the USSR and in the United States but results have hitherto been disappointing. Research continues but there is no basis for an expectation that this method will ever be an important contributor towards new discovery.

SEEPAGE-DRILLING, WILDCATTING AND SO TO GEOLOGICAL METHODS

The early discoveries in the United States, Germany, the USSR and elsewhere were achieved by drilling actually on seepages or on trendlines of seepages, and many shallow fields of considerable value were discovered. Wildcatting, or blind drilling, extended the discoveries beyond the immediate vicinities of seepages, but activity during the early decades of oil history was confined to the general area of known oil or gas indications.

This phase is commonly regarded as the unscientific phase of oil search, but this is perhaps ungenerous to the old pioneers. Experience was cumulative, and slowly there emerged certain general principles which guided further exploration in many cases. The common occurrence of seepages along anticlinal lines was first made clear, in 1842, by W. E. Logan's observations in the Gaspé region of Canada; in 1860 H. D. Rogers and in 1861 T. Sterry Hunt correlated newly-discovered fields with anticlines. The credit for the anticlinal theory of oil accumulation is commonly accorded to I. C. White, as he was the first to define the general principle of the gravitational separation of gas from oil and oil from water in descending sequence down the flank of an anticline; and he was also the first geologist to apply theory successfully to practice.

Seepage-drilling and wildcatting continued through the last three decades of the century, but little by little cognizance was taken of the accumulation of facts emerging from experience. All seepages did not directly point the way to oil-fields, and although all anticlines did not prove to be oil-bearing, a sufficiently high proportion did so to establish the anticlinal hunt as the most successful discovery method. In the United States the decades 1910 to 1930 were the heyday of the geological search for anticlines by mapping of surface outcrops, or in some cases by core drilling for structural information. By 1930 most oil seepages and most visible anticlines had been explored and geology began to take a new turn. The discovery of hidden anticlines became the pursuit of the geophysicist, and the geologist commenced a new regime of intensive stock-taking of his cumulative experience. It had been found through the years that many oil-fields, including some in the major category, were controlled by circumstances other than anticlinal structure. Faults could break the continuity of a porous reservoir bed and cause a barrier to further up-dip migration of oil and so give rise to an accumulation; a pinch-out or a lensing of a sandstone into shale, or a truncation of a sandstone by an impervious shale could similarly occasion a concentration of oil.

The most spectacular and important example of this type of oil-field is the giant East Texas field discovered by a wildcatter in 1930. This oil-field was a chance find and it demonstrated that some great oil accumulations might not be susceptible of discovery by any scientific method, either geological or geophysical, at that time. It is true that the possibility of a wedge-out of the Woodbine sand in that general East Texas region had been envisaged, and hence the possibility of an oil accumulation under "stratigraphical trap" conditions but there was no means of localizing within wide limits a search for such a condition.

Geological research in the United States during recent years has concentrated more and more on detailed stratigraphy, on detailed correlation involving a work-over of the results obtained in many areas long thought to have been explored to exhaustion. Micropalaeontology, using foraminifera, ostracods, etc., sedimentary petrology, study of rock textures and other aids such as electric logging, have all contributed towards more exact correlation from well to well and so allowed detailed studies of past sedimentary conditions to be made with the discovery of stratigraphic-trap fields as the objective. But, and the "but" requires much emphasis, such studies cannot be projected very far from known data either from outcrop or from drilled wells, and this brings me to the importance of the wildcatter in the American exploration scene. The yearly review of exploration results in the United States carried out by F. H. Lahee shows the ratio of success to dry holes among wells located by various methods, and in 1948 the wildcatter is assigned a success of 1 in 31, but the value of these wildcats is not limited to the discoveries actually made. The information value is of immense benefit, and without it the degree of success which is attributed to geology, namely one in nine, or to geophysics one in five, would not have been possible. The wildcatter is an important actor in the American scene and sufficient credit is not given to him for the part he plays. Geophysics depends for its success on correct interpretation of geological structure and stratigraphy; it can never be used with confidence at any distance from firm control either by outcrops or by drilled holes; and if it were not for the wildcatter a much more liberal programme of information drilling would be required to supplement geophysical surveys and geological speculations.

The development of exploration in the United States differs from that in any other country in the world largely by this wildcatting factor—and the discovery rate and productivity of the United States is importantly influenced thereby. The United States unquestionably has some selected areas of outstanding oil richness, but a great proportion of its oil is contributed from a multitude of small fields, the discovery of which depends on the intensity of the effort. Experience the world over has demonstrated abundantly that most areas having a thickness of some thousands of feet of sedimentary rocks of mixed organic shales, sandstones and limestones have, in varying degree, some oil promise; and a sufficiently intensive search usually brings its reward.

In my discussion of the development of geological control of oil search as arising directly from the experience of the earlier seepage and wildcat-drilling period, I have had the United States scene particularly in mind. Elsewhere in the world the present phase is in many cases still at the seepage or anticline mapping stage. In evaluating a concession in a territory hitherto unproved, the existence of seepages is always a comfort to the geological eye. Intensive research work on oil-source rocks has failed to provide any certain clue to whether or not a group of beds may be oil-bearing, and the old-fashioned, perhaps unscientific criterion of seepages or oil-impregnated rocks is still a great confidence-giver. As in the United States, many of the older fields were found by seepage-drilling, in Russia, Germany, Persia, and elsewhere. In many countries remoteness of position or other factors have hampered development, and the geological mapping stage is still in action. In this case the aid of air photogeological interpretation is of immense value to the surveys, not only reducing the physical effort required in ground-survey, but by providing additional detail perhaps not discernible by ground-survey. The value is greatest in tropical forest country, as low ridges or drainage patterns may be interpreted into a structural pattern on the aerial photographs in a way not possible by ground-survey alone.

Aerial photogeology is not, of course, a substitute for ground-survey but only an aid, though an important aid. It does not tell the whole story, and the geologist on the ground must determine the ages of the formations by their contained fossils, and study the succession for possible source and reservoir-rock conditions, and so forth.

The evaluation of oil prospects in a hitherto untested region bristles with hazards. So often all the geological desiderata may seem to be fulfilled, and yet... I often wonder how geological choice would have fallen if the various possible oil-bearing provinces of the United States had been put to auction before any exploration by drilling had taken place but with the geological structure and characteristics already known. I think I should have chosen the Rocky Mountain front (disregarding the geographical handicap), as all the text-book conditions seem to be abundantly favourable; and yet the ratio of oil-bearing to barren anticlines has proved disappointingly small, and the oil quality in many equally disappointing. Being wise after the event, could this have been anticipated? My answer is "no", it could only have been resolved the hard way. In the Iraq-Iran foot-hillzone, corresponding to the Rocky Mountain front in general structural position, the ratio of productive anticlines to barren has proved to be attractively high. In the forested foot-hill zone, corresponding to the Rocky Mountain front in major companies are now engaged in an extensive search in a zone abounding in excellent anticlines and oil seepages. And the answer is a question mark.

GEOPHYSICAL METHODS

Where the solid geology of an area is obscured from view by a mantle of alluvium, by forest, swamp or sea, or even where surface outcrops only tell part of the structural story by reason of inconformities or other complexities, geophysical methods for extending our penetrating vision have been developed with outstanding success. Necessity is truly the mother of invention, but so far the oil industry cannot claim credit for any new geophysical invention—only for adapting principles discovered by pure scientific research and for improving enormously the instruments and interpretation technique.

The three geophysical methods in current use depend on the gravity, magnetic and seismic principles. The gravity method can detect buried anticlines by a minute increase of the force of gravity. It was first used in the discovery of the Egbell field in the old Austria in 1915 by H. de Böckh using an Eötvös torsion balance, and in 1921 it was used extensively in Hungary by the Anglo-Iranian Oil Co. (and a boring drilled as a result missed the Lispe oil-field by a very small margin). In 1924 the torsion balance was introduced into the United States and had early successes in the discovery of salt domes in the Gulf coast. During succeeding years the importance of the gravity method was established in many parts of the world, but the slowness of operating the torsion balance was a great handicap to its usefulness. Eventually gravity-meters were developed with the necessary sensitivity until at the present day there is a wide choice of such instruments available. They are a remarkable triumph of instrumental design and their portability, speed of operation and reliability are quite outstanding. Gravity surveys in shallow marine areas are now commonplace, a further tribute to instrumental skill.

The second geophysical method to be employed in oil-finding was the magnetic method. By careful measurements of differences in the earth's magnetic field certain deductions may be made of regional trends under favourable conditions. The method was cheap to operate, and magnetic surveys were frequently carried out in partnership with other methods. Unfortunately the underground factors producing magnetic differences are usually too complex and too frequently caused by deep-seated effects for the results to be used with confidence for depicting geological structure in shallow sedimentary rocks. Recently, as a result of brilliant research development by the Gulf Oil Company, a magnetometer has been developed which can give a continuous record when towed by an aircraft. An extensive survey was carried out by a group of companies in the Bahama Islands but the results have proved to be difficult of interpretation. An indication of whether or not magnetic anomalies are of shallow or deep-seated origin can be obtained but in no case, as yet, have the results been put to the test.

Electric methods, using electrical conductivity of shallow concealed strata, have been used in oil-finding under certain favourable circumstances. A refinement of this, known as the Tellural method, has been developed during the war years by the Schlumberger Company. In this case fleeting earth currents induced from extra-terrestrial sources are used, and success has been achieved in certain favourable conditions, notably in the north Pyrenean foot-hills.

The most important of all geophysical methods is without question the seismic. The first use of seismic principles for oil-finding by setting up earth vibrations by artificial explosions and recording the arrivals, is to the credit of Professor Mintrop in Germany in 1920. From about 1924 onwards the method was adopted by oil companies in Persia, the United States and many other parts of the world, and the technique was greatly improved as experience accumulated. The early surveys used the refraction principle, that is, the vibration which had travelled along a high velocity medium at depth was recorded, but as time went on a modification of the method led to a use of reflected vibrations somewhat analogous to echo sounding at sea. Reflections, however, are fickle and in some areas of operation no good reflections can be obtained, either because of unfavourable surface conditions or because of complex underground structure. Refraction methods are still used in such refractory circumstances and many notable successes have been achieved.

The geophysical methods described above are all indirect approaches to oil-finding. They determine the rock structure, they locate hidden anticlines or salt domes in which there may or may not be oil, but they do not in any way register directly on the oil as such. An attempt to locate hidden oil-fields directly has been made by geochemical means, first in the USSR and later in the United States and elsewhere. I have described how many oil-fields were discovered in the early phase by drilling on seepages. It is a reasonable expectation that a buried oil accumulation sufficiently sealed by an impervious cover to prevent leakage of oil to the surface may have a slow leakage or breathing of gas to the surface, perhaps so dispersed as not to be detectable by the senses. If detection of such micro-seepages were possible chemically, or via local enrichment of certain bacteria, it might lead directly to hidden oil pools, and this seemed a most promising line of research. Unfortunately, results have not led to important success up to now, and while further experience may improve the method, no firm prediction is possible at present.

Much concentrated thought has been given to other possible means of direct detection of buried oil accumulations, but nothing is remotely in sight. Petroleum is singularly inert and nothing on the lines of a Geiger counter is likely to be applicable.

DISCOVERY METHODS OF THE FUTURE

I like to think of myself as a reasonably active-minded speculator and an optimist (an oil geologist must be that), but I find myself singularly barren of new ideas under this heading. My prescription may seem unenterprising as it is only:

"The Mixture as Before — Shake the Bottle well".

The modern world is so overwhelmed by scientific marvels and new discoveries that it may seem a confession of inadequacy to admit that the oil industry has not developed a new exploration method during the past quarter century or so. Yet its methods, geological and geophysical, have been developed to such a degree that a great flood of oil has been poured out to serve the needs of a mechanical world in ever-increasing quantity. Experience in the earth lore of oil-fields and in the technique of discovery is cumulative, and the hidden geology of many little-known regions of the world has been and is being revealed by the incessant hunt. The needs of succeeding generations will surely be met from the world's abundant resources but discovery will inevitably become increasingly more difficult.

The great United States looms large above all other countries for the size of its exploration effort. This country has found more oil than any other country, partly because of a beneficent Providence, but partly because it has tried harder. Geological and geophysical research has brought its reward in full measure. Geological thinking is being directed ever more intensively towards the discovery of "infilling" fields, oil accumulations governed by stratigraphic traps between the bigger discoveries of the past. Studies of palaeogeography and sedimentary history are being made, with a continuous flow of new discoveries as the reward. Geophysical aids already proved are being improved and will continue to be improved, but added to all this is the other important American exploration tool, the wildcatter! Neither speculative geological thinking nor interpretation of geophysical results can be trusted very far from the firm control of a drilled well or of outcrop, and the missing link which has enabled a new discovery to be made is often supplied by the wildcatter, the man who drills without scientific guidance, either on hunch or to fulfil some lease obligation. No country outside the United States has bred the wildcatter so prolifically, and in consequence this discovery tool is lacking. In Soviet Russia, for example, an exploration location must be scientifically justified and controlled and, ideally, it should lead to a success; but, if a liberal amount of wildcatting were to be combined with scientifically controlled wells, who knows, perhaps the great Russian plains west of the Urals and perhaps extensive areas of Siberia might be as richly oil-bearing as much of the American mid-continent.

The spectacular discoveries of the post-war years have been in the countries forming the prolific Middle East province. The value of the Iraq-Iranian oil-field zone has been established by stages since the first discovery of Masjid-i-Sulaiman in 1908, but the scale of its importance was not at first realized. The first discovery was by seepage-drilling, the next group of fields by geological mapping combined with confidence from seepage and the present stage is the combined geological-geophysical. The Arabian oil-fields are of very different geological character, both structural and stratigraphical, but they are equally of giant dimensions. The early discoveries were by surface geology and the later by gravity and seismic survey or by shallow information drilling.

The Middle East oil-fields are on such a scale and the ratio of oil-bearing to barren anticlines so favourable that a new standard of oil richness has been revealed. It may be asked whether the world may not contain many other equally rich oil provinces as yet unknown, and what are the prospects of improving our capacity of prediction. The answer is that there are few regions of the world in favourable geographical setting which have not been geologically explored in varying degree and there seems little likelihood of other "Middle Easts". But there is every chance of a great volume of oil from a wide spread of prospects elsewhere, not individually of major size but in the aggregate of great importance; as an example, Western Canada is the latest area to come into the limelight.

The new-found technique of marine drilling will certainly enable substantial additional oil reserves to be developed, but the total value of continental shelves has been considerably exaggerated. In most cases the shelf is only a seaward extension of the adjacent land mass and in the world as a whole there are a limited number of important oil-fields in coastal zones with shallow marine areas adjacent. The increase in drilling depths now possible must also lead to many deep discoveries, but not in the ratio of increase of depth. For a number of reasons the depths between 10,000 and 20,000 ft. will not be so prolific as were the levels from grass roots to 10,000 ft. In many oil-bearing areas basement rocks are met at lesser depths than 10,000 ft.; in deeper levels the productivity per unit volume of pore-space will be less because of surface shrinkage of the crude, and porosity may be somewhat less. Drilling costs to such depths are so much greater that only an expectation of substantial results will justify the costs, and, superimposed on all this, the discovery of deep objectives is immeasurably more difficult by both geological and geophysical methods, and the clue of seepage is mostly absent.

In summary, my expectation is that the discovery tools of the future are not likely to be importantly different from those of the present—namely, intensive geological study and speculative geological thinking, combined with intensive geophysical application. Undoubtedly many refinements and improvements of all methods will be made, but no new method or principle of search is remotely in sight at present. The wildcatter *pur sang* or, in his absence, geological information drilling, will be as important in the future as in the past. All these tools may be improved in sharpness and temper but they must be fitted to a common handle whose name is confidence.

Consideration of the Techniques of Oil and Natural Gas Prospecting[1]

L. MIGAUX

ABSTRACT

Of all the extractive industries the oil and natural gas producing industry is the one in which prospecting expenses are highest (30 per cent of the selling price in 1947). Considerable efforts have been made to rationalize prospecting and as a result, the *a priori* chances of success of exploratory boreholes have been increased fivefold.

These results have been obtained by the co-ordination of a very large number of techniques which may be divided into geological or geophysical, depending on whether the study is made from very near at hand or from a distance. The techniques of *surface geology* are intended to give as complete a picture as possible of the geometrical and petrographical properties of the strata near the surface and to show clearly all the features which make exploration in depth possible. *Geophysical* techniques generally provide a more or less exact picture of the geometrical forms of the same sites in depth. By extending the geological surface studies, to the sections provided by drilling, the techniques of sub-surface geology define the forms and enable one to determine the development of the facies in depth. The synthesis of the results of these three methods gives as exact a picture as possible of the distribution of the porous and pervious features in the ground, and enables exploratory boreholes to be drilled with the greatest possible chances of success. Present developments are directed towards the co-ordination of existing techniques rather than towards the creation of new techniques.

Of all the minerals of fundamental economic importance—coal, ores, oil—the natural hydrocarbons were the latest comers. Systematic prospecting for them began less than one hundred years ago, ninety years ago to be exact. At first, methods of prospecting were uncertain and empirical: they did not begin to be scientific until the beginning of the twentieth century. But they have made rapid progress, above all since 1920, and it may be said that in the last thirty years a body of knowledge has been built up which, although still incomplete, makes this difficult field of research an example to the others.

An essential feature of the production of crude oil and natural gas is the relatively high cost of prospecting for new fields, and these costs are increasing as work is carried on in fields which are more difficult to discover. Discovery costs have risen in the United States of America from 15.3 cents per barrel in 1935 (11.5 in 1936) to 62 cents in 1946 (59 in 1947. (1) [2] During the same period the average price of crude oil (for instance, on the Texas Gulf coast) rose from $ 1.15 to $ 2.01 per barrel. That is to say that in twelve years discovery costs have risen from 10 per cent or 13 per cent of the selling price to 30 per cent of the selling price. Enormous sums are expended yearly on the exploration of hydrocarbons ($ 938 million in the United States of America alone in 1947) (2) and it is understandable that great efforts should be made to reduce these costs.

The main item in these costs is still the drilling of exploratory boreholes, as the majority of them are unsuccessful. If costs are to be reduced, exploratory boreholes must be drilled where the chances of success are greatest; the element of chance must be reduced to a minimum. This is the aim of the present exploration techniques as a whole, and it must be acknowledged that they are near to achieving it. From 1859 to 1928 the proportion of successful to unsuccessful exploratory boreholes was only 1 in 24. During the period from 1938 to 1943 the proportion was: 1 in 20.6 for wells drilled in accordance with non-technical considerations; 1 in 6.1 for wells drilled in accordance with geological considerations; 1 in 5 for wells drilled in accordance with geophysical considerations; 1 in 4.4 for wells drilled in accordance with geological and geophysical considerations. (3)

From the above facts alone one can imagine what the 1947 exploration costs would have had to be, if, instead of 5,397 dry holes as against 1,378 productive wells (as was the case in the United States of America) there had been more than 31,600 (1,378 x 23) dry holes, as would have been the case had the 1900 techniques been employed. At $ 50,000 per well the saving is $ 1,300 million and amply justifies the expenditure of less than $ 200 million involved in the use of these techniques.

There are three closely connected stages in the exploration of oil or gas deposits:

(1) The selection of the area to be explored;

(2) The selection of sites for exploratory boreholes; and

(3) Supervision of the drilling so as to ensure that it actually strikes a deposit.

These three stages involve varied techniques which are usually placed in two main categories: geology and geophysics. The distinction between these two categories was so well marked thirty years ago that certain geophysicists considered that they were capable of radically replacing the geologists. It was gradually realized that all these techniques, both geological and geophysical, could not be truly efficacious unless they supported and supplemented one another, and that their results should be considered as a whole in a synthesis which is necessarily geological in spirit. Furthermore, geology which originally used the hammer and compass, has improved and expanded its techniques which now make wide use of physics and mensuration, so that the distinctions between geology and geophysics are now far less marked.

In short it may be said that a technique is geological if the sample studied can be handled by the technician; it is geophysical if the study is necessarily made from a distance. In all cases the object is, at least in stages 1 and 2, to obtain information on a yet unknown part of the substratum; the geologist attempts to build up that information by extrapolation of knowledge directly gathered elsewhere, the geophysicist by interpreting measurements made directly but from a distance.

[1] Original text: French.

[2] Numbers in parentheses refer to items in the bibliography.

At the present time there is no certain method of detecting the existence of oil or gas deposits from a distance. If such a method existed, it would definitely replace all the other techniques now in use. It was hoped to achieve that aim by the systematic study of micro-indices or geochemistry (analysis of the hydrocarbon content of the soil near the surface) and by biochemical methods which may be summed up as the use, as a reagent, of various living species. (4) But the results are still extremely uncertain. In the absence of this method, the possibility of deposits must be deduced by indirect methods.

The first question which arises in an entirely new exploration is whether the area in question is or is not likely to be oil-bearing. This question cannot be answered in the absolute nor has any certain criterion been discovered for classifying the series into oil-bearing and non-productive. On the other hand, the work on this question has gradually led to the formation of certain general conclusions, which are admirably summed up in the introduction to Levorson's article on "Possible Future Oil Provinces of the United States of America and Canada". Broadly speaking, it may be said that the greater the volume of sediment, the greater are the chances of a sedimentary basin containing oil; but the nature of the rock content, the actual knowledge of indications, the number of inconformities in the interior of the basin and the structure also play an important part. The *a priori* chances of a new basin will be judged, to the extent to which all these factors are known, by comparison with the facts as established in similar basins elsewhere.

In an oil-bearing basin, the oil is essentially a migratory mineral. Its present position is not closely related to that of the source rocks: it depends essentially on the structure of the reservoir rocks and their over-burdens. All deposits are collected in rock which is both porous and pervious and from which the water pressure underlying the deposit cannot force it out because an obstacle, the closure, is in the way. This closure is essentially an impervious rock or one less pervious than that of the deposit. Hence, the aim of the preparatory work, both geological and geophysical, is the exact and detailed determination of the distribution in space of the porous and pervious features.

The classical techniques of surface geology will yield these data as regards the strata immediately below the surface. These techniques may be summed up as: preparation of topographical maps on which all the observations will be plotted, either by aerial photographs or by the old methods; accurate drawing up of outcrop maps, either directly on the ground, from aircraft, or, when the outcrops are indistinct or concealed by the ground, by means of shallow wells. Detailed study of the nature and properties of such outcrops by means of detailed sections showing the thickness of the various strata and their dip, and laboratory study of all the data for their determination and location. Petrography: percentage of recognizable mineral elements, micro-chemical study, determination of the rare elements of the sands, acid tests, spectrography—determination of the texture of the rock, of its cement; measurement of porosity and permeability, of the sand percentage, granulometry of the particles (shape, dimensions, colour, lustre, wear), granulometry of the loams, analysis of the clays by thermic means or by X-rays. Paleontology: determination of the macrofossils, microfossils (foraminifera), statistics of shell remains, study of siliceous organisms.

In some cases it is possible with this exact knowledge of the surface to make a hypothetical reconstruction of the formations in depth. But in most cases this is impossible owing to unconformities which are, moreover, the rule in the productive areas where they frequently provide the traps in which form petroleum collects. It is then that the geophysical techniques are used and their results interpreted. These techniques also are well known and a survey of their present development will be found, for instance, in the *Review of Petroleum Geology* of the Colorado School of Mines. (5) The measurement of gravity anomalies by means of a gravimeter is the method now universally employed for rapidly obtaining general data on the formations of basins and also for locating the zones of structural anomalies (anticlines, faults, saline domes). Its disadvantage is that the rocks do not in any way modify gravitation and that the gravimeter is influenced not only by the structure of the sedimentary formations but also by the structure of the crystalline bed. It has become still easier to map the magnetic anomalies since the use of the air-borne magnetometer was discovered. But that map corresponds even less with the structure of the sedimentary matter than in the case in gravimetry.

Electrical methods are little used in the United States of America but may, nevertheless, be very useful in many cases. Their disadvantages are the reverse of those of the above method: they often do not penetrate very deep (although depths of 1,500 and even 2,000 metres are easily exceeded at the present time). By contrast, they have the advantage of using a physical property of the earth, electric resistivity, which is very sensitive to the variations in the facies. In their most modern form, which has been developed in France since 1940 and is known as the telluric method, they can be used for general exploration and sometimes compete successfully with gravimetry. This is also a method of detailed study which is of use in the case of structures with sharp dips. Seismic refraction, which has again come into favour, is comparable in its principles with electrical methods: the results are slightly less accurate but more expensive, and its penetration in depth is also not very great. Seismic reflection is the best method for reconstruction of formations in depth (at least when they are not too complex). By using this method, where applicable, the geometrical structure of the various strata can be determined with considerable accuracy to a very great depth, and this is the reason for its widespread use. Of the $ 105 million expended in the United States of America on surface geophysics in 1947, $ 90 million were spent on seismic methods. (5) Its uses, which are often limited by the fact that the blast holes have to be drilled, cannot but increase as a result of the use of the Poulter method of shot-drilling with external charges, which has recently been perfected.

The various geophysical methods provide little more than information on the characteristics of the formations. But data on the horizontal development of the properties of the various strata, that is, the development of the facies, would also be essential for a full knowledge of the substratum. As has been said, electrical methods alone can provide that information but necessarily in outline. The data gathered on the surface must therefore be supplemented by the data obtained by sub-surface geology. Such data are gathered by applying geological techniques to samples obtained from boreholes, which may be exploratory boreholes or special sampling boreholes (coreholes, slim-holes, stratigraphical boreholes). As it is often not possible, for financial reasons, to carry out the continuous mechanical coring of such boreholes, a whole series of well logging or surveying techniques has been developed and it is proposed merely to enumerate them: "electrical coring, radioactive coring, neutron coring, induction coring, recording of drilling velocities, thermic coring, measurement of the orientation of dip of the strata etc." The methods of obtaining cores through the interior of drill rods (wireline coring) and of taking samples from the walls of boreholes (sidewall sampling) are also known. In the absence of a core, the cuttings and the mud itself are continously examined. All these methods are also used in the third stage of discovery, that is, to ascertain whether the borehole is actually passing through an oil or gas deposit; in addition, the various testers are used.

To sum up, surface geology provides guidance in the choice of the area to be explored. The geophysical techniques provide an outline of the substrata in that area. Sub-surface geology provides fuller information on these structural data based on the result of drilling and, at the same time, furnishes information on the development of the facies. The general synthesis of all the knowledge acquired gradually gives a more or less accurate picture of the substratum and leads to the goal. (6)

Is it possible to hope for progress in the near future in the immense undertaking of oil discovery? The answer is a bold "yes", though not because of new tools: unless the unexpected happens, the only thing to be expected now are improvements in technique, which would have more effect on the cost than on the results. On the contrary, much progress is still possible in the mastery of all the numerous tools which are now available for oil exploration, in the co-ordinated use of these tools and in the synthesis of information. Under the spur of necessity, the science of oil exploration will not fail in the task of providing the world with oil during the coming decades.

Bibliography

1. *The Petroleum Data Book*, 1948, page C.22.
2. *Ibid*, pages E.87–E.90.
3. V. G. Gabriel, "Mathematical Chance of Finding Oil", *Oil Weekly*, 21 May 1945.
4. For example see: St.V. Thyssen, "Geochemische und Pflanzenbiologische Zusammenhänge im lichte der angewandten Geophysik", *Beiträge zur angewandten Geophysik*, vol. 10, no. 1 (1942), pages 35–84.
5. Colorado School of Mines, *Review of Petroleum Geology*, vol. 43, no. 3 (July 1948), pages 86–111.
6. H. H. Suter, "Relative role of some geological tools in oil exploration", *Bulletin of the American Association of Petroleum Geologists*, November 1948.

Techniques and Results of Aeromagnetic Surveying

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ABSTRACT

The air-borne magnetometer is a high-speed, low-cost reconnaissance geophysical instrument which can be used to produce magnetic maps of the same order of accuracy as those produced by ground methods. It is not well suited for making small detailed surveys or for use in mountainous areas. It is particularly useful in areas which are difficult to traverse on foot, and in combination with radio and radar location systems can be used to conduct surveys over water or other unmapped areas.

The surveys are made at a rate of 6,000 to 9,000 miles per month by a three-man or four-man crew in a small twin-engine airplane. The field data are compiled at a rate of a half to 3 traverse-miles per man-hour.

The air-borne magnetometer has received much publicity, but most of the articles have been either discussions of the instrumentation or sensational stories of its use. During the last five years the U.S. Geological Survey has completed more than 300,000 traverse miles of aeromagnetic surveys, and is now in a position to evaluate from actual experience, the accuracy, usefulness, applicability, and economy of the air-borne magnetometer as an instrument for geophysical prospecting.

The over-all accuracy of the results of the air-borne magnetometer can be most easily discussed by comparison with that of the more familiar ground magnetometer of the Schmidt type. The results of an aeromagnetic survey are compiled into a magnetic contour map or a series of magnetic profiles of the same type as those obtained by ground methods. The interpretation of these maps and profiles involves the same fundamental theories that for years have been applied to the results of ground surveys. Although geophysical ground magnetic surveys usually measure variations in either the vertical or horizontal components of the earth's magnetic field, aeromagnetic surveys measure variations of the total field. However, assuming both the aerial and ground maps to be accurate, there is theoretically no difference in their usefulness. This ideal, however, is at present impossible to fulfil. Therefore, between the two types of survey there exists a difference in usefulness that depends upon their relative accuracy.

In practice the two methods do not compete but complement each other. The usefulness of either method is dependent not only upon cost but upon quality of results. Therefore, let us consider the factors which affect the accuracy of the final results obtained by each method. This over-all accuracy or ability to make and duplicate a true magnetic map is dependent upon both the precision of magnetic measurement and the accuracy of position measurement. Thus, the factors affecting both must be considered in making a comparison of the results of the two methods.

The sensitivity and accuracy of the best air-borne and ground magnetometers are comparable. The precision of a magnetic measurement, however, is dependent not only upon the accuracy and sensitivity of the instrument used but also upon the accuracy of the corrections for instrument drift and diurnal variation. These corrections are best made by frequent measurements at a base station and therefore the precision of the final magnetic measurement is to a considerable extent dependent upon the elapsed time between measurements at the desired point and at a base station. By using a system of magnetic base lines which correspond to the network of base stations used in ground work, it is possible with the air-borne magnetometer to reduce this elapsed time to a few minutes and thereby obtain a measurement which requires practically no correction for instrument drift or diurnal variation.

Ideally the accuracy of position of a ground survey can be very high; the position in three dimensions of one station with respect to another can be determined with the accuracy of the surveying methods employed, from the precision of a transit and level to that of pace and compass and pocket aneroid. The accuracy of position of an aerial survey, on the other hand, is restricted by several factors, chief of which is the accuracy of the map of the area flown. Under favourable conditions it is possible to determine the plumb point of the plane on a good aerial photograph within 30 ft. If the base map is good, it is possible by photogrammetric methods to locate the plumb point on it to the same accuracy, but this involves considerable labour, and only rarely is the base map of sufficient quality to warrant it. In practice the points are generally transferred by matching or by trisection from the locations appearing on the photograph to the corresponding locations on the base map, and are in error from fifty to several hundred feet, depending upon the quality of the photographs and the scale and local accuracy of the base map.

The elevation of the plane is determined by a barometric altimeter, or better by a radio altimeter, which measures height above ground. The latter provides a measurement accurate to within five per cent, but the absolute elevation is of course dependent upon the quality of the base map.

The accuracy of position in three dimensions of an aeromagnetic map is only in rare cases within 50 ft. Not only does this error affect the over-all accuracy of the aeromagnetic map in the same way that similar errors affect a ground-survey map, but the particular method of base control used in aeromagnetic maps may also introduce an error into the magnetic measurement.

The magnetic base station used in ground work is a point determined by a stake or other identifying marker, but in aeromagnetic work the magnetic base line is only an imaginary line in space. In the ground survey, the base station can be reoccupied exactly and independently of the positional accuracy, but in the aeromagnetic survey a point on the base line can be reoccupied only within the accuracy of the positional measurement. This can of course introduce a magnetic error into the final aeromagnetic map. Great care is taken to reduce this effect by establishing magnetic base lines in areas where high positional accuracy can be attained and where the magnetic gradient is low; generally the error in the final aeromagnetic map is less than one contour interval.

Another important factor that affects the relative quality of ground and aeromagnetic maps is the type of measurement. A ground survey is made by a system of station measurements with interpolation between stations. The air-borne magnetometer is continuously recording, so continuous profiles are used. If these are flown at right angles to the magnetic trends a minimum of interpolation is required.

The factors which affect the quality of the aeromagnetic surveys of course affect their usefulness. It has been found that the most satisfactory use of the air-borne magnetometer is as a high-speed, low-cost reconnaissance instrument which localizes areas for more detailed work by slower and more expensive geological or geophysical methods. The air-borne magnetometer has been used in this way over the swamp-covered arctic slope in Alaska as a guide in gravimetric and seismic surveys in the search for oil. It has been used in the wooded and comparatively inaccessible Adirondack Mountains region of New York to locate magnetic deposits in advance of detailed surface magnetic work. It has also been used in the drift-covered Lake Superior area to provide a framework that will enable the geologist to trace formations underground in spite of sparse outcrops. These are only a few examples, yet they are indicative of the wide range of application.

The usefulness of the air-borne magnetometer depends, however, upon the results desired and the possibility of attaining them. Obviously it cannot be used in a small detailed survey where accuracies of location within a few feet are required. Likewise, it generally cannot be used where the diagnostic magnetic features are small, complex, or of near-surface origin, for the shallow or small anomalies attenuate even at low altitudes and merge to the extent that they lose their diagnostic character. These disadvantages may be partly overcome by the use of a helicopter which permits somewhat better location and much lower flight, although generally at a sacrifice of range and at increased cost. Because the U.S. Geological Survey can operate only one aircraft and because it is our belief that any aerial survey should be followed by detailed surface work, we have elected to sacrifice the increased precision and lower flight level for greater range and less cost. In this regard, a choice exists depending upon the particular requirements of the work to be done.

The air-borne magnetometer has limited usefulness in mountainous areas where flight in any type of aircraft is difficult. Two alternatives are presented; one, high flights at a fairly constant barometric elevation that clears most obstacles; or, two, lower flights which attempt within the capabilities of the aircraft to maintain a constant elevation above ground. In the first case, a reasonably accurate map can be made, but frequently at such an elevation that the diagnostic anomalies are too attenuated to be useful. In the second case, the map may be inaccurate because of the necessary violent manoeuvres of the plane which increase the position error and thereby introduce the magnetic errors previously discussed.

Before undertaking a survey in such a mountainous area it is usually possible to determine from the attenuation rate of the expected anomalies and from the flying characteristics of the plane a rough measure of the accuracy and magnetic detail of the final map, and thereby to decide upon the value of the work. It has been our experience that reasonably accurate surveys approximately 1,000 ft. above ground can be made in areas where the relief does not exceed 2,000 or 3,000 ft., if the anomalies are not too complex. We have found, however, that such a survey is not worthwile if made at an elevation near the service ceiling of the plane, because at this level the operation of the plane becomes very difficult. With our small, heavily loaded twin-engine plane this ceiling is about 10,000 ft. above sea-level.

Obviously the most productive projects for the air-borne magnetometer are those in relatively flat areas which are difficult to traverse on foot, but it must be remembered that for accuracy of position there must be a sufficient number of photographically identifiable points. In other words, a featureless plain or an area with a homogeneous forest cover could not be accurately surveyed without the use of electronic mapping devices.

However, these conditions seldom exist, as there is usually some distinctive vegetation pattern which can be used for identification.

Various radio and radar location systems have been used successfully to conduct aeromagnetic surveys over water or other unmapped areas, but the added cost is high, generally at least double the total cost. An entirely satisfactory map can be made in this way, however, at considerably less expense than by surface methods.

The cost of an air-borne survey depends upon many factors, including the cost of equipment and fuel, salaries of personnel, and efficiency of operation. As these factors may vary widely the cost can be analysed best by considering the rate at which the work can be accomplished.

The flight work requires a plane, preferably twin-engined, capable of carrying three or four persons, and the magnetometer equipment which in our work weighs 400 lb. For efficient operation it is best to have a plane with at least six hours' range so that a minimum of flight time is lost in transportation between the airport and the survey area.

The pilot should have considerable experience in photo mapping and low-level flight work such as crop dusting, and should be able to interpret photographs rapidly. He is usually assisted by a co-pilot. The magnetometer operator should be completely familiar with the equipment and able to make minor repairs in flight. He should be also an experienced geophysicist who can make changes in flight pattern indicated by the measurements. An observer is usually carried to take the check points needed for coordinating the records obtained. This four-man flight crew averages about 90 hours of survey flying a month, that is exclusive of base lines, turns, and flights to and from the area.

The speed of compilation of the aeromagnetic information into a magnetic-contour map depends upon the survey system employed, the scale and quality of the maps, complexity of the anomalies, and upon the skill of the compilers, but varies between a half and three traverse-miles per man-hour.

The cost and amortization of the equipment are factors which are highly variable and must be considered individually, but it should be remembered that both initial investment and overhead are high. Therefore, efficiency can be obtained only by large-scale operations.

The total cost, per mile, of our aeromagnetic surveys in the United States has averaged about one-tenth of that of the ground work, but in diffiicult terrain the cost may be less than one-hundredth of that of the ground work.

In summation it may be stated that for large areas the air-borne magnetometer used intelligently provides a means of producing a low-cost and reasonably accurate magnetic map which can be used to delineate localities for more expensive and detailed ground work, both geological and geophysical. It does not eliminate the need for ground magnetic surveys, but rather relieves the load of reconnaissance work and enables the ground magnetometer to be used more productively on detailed work. Perhaps the best proof of its usefulness is that fact that the U. S. Geological Survey has operated air-borne magnetometers for more than four years and is now planning an installation in a larger plane to assure greater safety in mountainous areas and to increase efficiency of operations by increased range.

New Developments in Drilling Equipment and Techniques

I. S. SALNIKOV

ABSTRACT

This paper discusses thel atest improvements in rotary drilling of deep oil wells in the United States. It deals with new types of steel and power units for drilling equipment, the use of diamond bits not only for coring but for regular drilling through hard formations, and the many new problems encountered at depths up to 20,000 ft.

In addition the author covers the newest developments in muds and their use, cements and plastics in cementing operations, and logging apparatus. Figures are given on the costs of deep drilling, and suggestions for lowering those costs are made.

Man, in his ever-increasing search for crude oil to meet the world's expanding demand for petroleum products, has not only explored further and further into remote regions, but he has also drilled deeper and deeper into the earth. Colonel Drake's first well at Titusville, as everybody knows, was only 69½ ft. deep. And only twenty years ago, 9,000-ft. wells were considered an epic achievement.

But every year since oil was discovered in the United States in 1859, the wells have gone deeper. The first 15,000-ft. well was drilled in 1938. Since the Second World War four wells in succession have set new records below that depth, and as this is written a well in Wyoming has gone past the 20,000-ft. mark, a depth that was almost impossible with pre-war equipment.

The first oil-well drilling equipment was the cable tool rig which, in one form or another, has been used to punch holes in the ground since the beginning of recorded history. The standard cable tool method was used in the United States almost exclusively to drill for oil and gas until 1900. A year after that the rotary drilling method came into general use in this country, and as it was improved it succeeded the standard cable tool as the major drilling method in the United States and almost everywhere else.

Although the standard cable tool is still used, and improvements have added to its effectiveness, its use is now limited to a few areas. On the other hand, there has been a steady and continuous improvement in rotary drilling equipment, and there is no reason to believe that the end of its improvement is in sight. As long as there is any possibility of oil at great depths, we can be sure that rotary equipment and techniques will be improved to get at that oil.

The demand for new oil resources, and deeper wells, has forced our industry to improve drilling techniques and to maintain a search for new methods which will be able to penetrate sedimentary formations to a greater depth at a reasonable cost. The fact that there are now wells deeper than 15,000 ft. demonstrates that this work has been successful. The present record is the result of combined efforts by producers, contractors and equipment manufacturers. Working together, they have contributed many improvements to the rotary drilling method to make it suitable for drilling to great depths.

The most important developments in rotary drilling are:

1. Unitization and portability of drilling rigs and equipment,
2. Better quality steel for drilling equipment,
3. Improved equipment and machinery design,
4. Improvement of drilling muds,
5. Better understanding of hydraulics in mud systems,
6. Proper application of weight on the bit and rotating speeds.

The present high operating costs of drilling rigs place a premium on operating speed. Days lost in tearing down, moving and rigging up are a heavy financial burden. Numerous improvements, designed to reduce the time required to move rigs from one location to another, have been introduced over the past several years. Today we have standardized layouts, unit skids for pumps, boilers and shale shakers, and standard piping manifolds fitted with quick make-and-break joints and connexions. Moving a battery of steam boilers on one skid from one place to another, skidding derricks or moving an entire rig in a few packages saves time—and money. In fact, savings up to 50 per cent have resulted from well-planned layouts and properly designed and equipped rigs.

Portability was first developed for small rigs capable of no greater depths than 5,000 ft. Today, however, 10,000-ft. rigs are built so they can be moved, dismantled or re-erected easily.

While unitization and portability have made drilling more economical, they have not added much to the depths the bits can reach. It took improvements in the quality of steel to do that, for as wells went deeper the high temperatures and pressures encountered at great depths imposed more and more mechanical problems, problems that former steels could not handle.

Let's look at some of these problems. Drill pipe of API Grade E 75,000 lb. per square inch minimum-yield-strength is not suitable when drilling to the depths now being attained. For security and safety drill pipe with a minimum yield strength above 100,000 lb. per square inch is necessary.

Fortunately, as a result of war-time research in the United States, such steels became available to our industry. A number of high-yield strength strings of drill pipe have been manufactured for testing in deep drilling. SAE 4340 nickel chromium molybdenum steel is being tried for drill pipe and tool joints in deep-well experiments. Normalized and drawn state is being used for drill pipe, and normalized-quenched-drawn form for tool joints.

SAE 4340 steel is also suitable for the manufacture of casing. The yield strength of this steel is 25,000 lb. per square inch higher than the N-80 grade, the highest tensile strength steel casing that has heretofore been available. With tubular goods made of SAE 4340 steel, a casing string of 9-5/8 in. size can be set at 15,000 ft.; 8-5/8 in. strings to 16,000 ft.; and 5-1/2, 6-5/8 and 7-5/8 in. strings at 20,000 ft. A string of 7 in. casing made of SAE 4340 steel was recently set at 19,765 ft.

The trend toward deeper drilling has of course resulted in taller and stronger derricks. The Derrick Committee of the American Petroleum Institute recently established the following tentative specifications on high derricks for deep drilling:

Height	189 ft.
Water table opening	$7\frac{1}{2}$ ft.
Base square	$37\frac{1}{2}$ ft.
Derrick capacity	900,000 to 1,500,000 lb.
Gin pole capacity	20,000 lb.
Rated actual wind velocity	100 miles per hour

With such a derrick drill pipe could be racked in either 120-ft. lengths composed of four Range 2 joints, or 130-ft. lengths of three Range 3, joints. If we assume that 5-in. OD drill pipe, internal upset and threaded for API 4-1/2 in. internal flush tool joints, is used for drilling to 20,000 ft., the weight of a full length of drill pipe would be approximately 220 tons.

The drill pipe and casing loads at 20,000-ft. depths are too great for the usual 1-1/4-in. drilling wire lines. For this reason the trend is toward heavier, 1-3/8 or 1-1/2 in. diameter wire lines. In fact, 1-1/2 in. line was used for the 20,000 ft. well in Wyoming. Line of this size provides a safety factor of 4 or better in drill pipe service, and a safety factor of 3 or better in casing service.

In power plants there is a trend toward internal combustion engines, especially in the designs of deep-drilling rigs. There was a time when power rigs were handicapped by the lack of large power units, suitable control equipment, and power pumps of sufficient size. Today a variety of units with up to 750 h.p. is readily available for outfitting almost any size rig. And, in addition to providing the horsepower required, the new engines are better designed, smaller, and lighter.

In combination with air clutches and hydraulic drives the present power units can be controlled and handled with ease. And, in parallel with these developments, equipment manufacturers have developed large-size power pumps and a means of operating such pumps in multiple assemblies. Seven hundred hydraulic horsepower power pumps are now available to the industry. Two such pumps can provide reasonable fluid circulation in the deepest drilling operations.

War-time expansion of diesel manufacturing has made available to the oil industry a large selection of diesel engines suitable for use on power drilling rigs. Light-weight, high-speed diesel units equipped for dual fuel operation have found wide acceptance by drilling operators and oil producers. Hydraulic drives, in the form of hydraulic couplings and torque converters; radially operated air clutches for use in frequently engaged and disengaged rig drives; and air controls of engine throttles, clutches, hydraulic couplings, and other services have also been developed by the industry in recent years.

A new semi-automatic, power-operated rig was recently tested on a well in the Gulf Coast area. It included remotely-controlled power-operated drill pipe tongs, spinner, stabber and racking equipment. Most of the physical effort of making round trips with drill pipe was eliminated. The operations of tonging, spinning, stabbing and racking the pipe on the floor were controlled through hydraulic and electric valve levers and push buttons. With such machinery, back-breaking work is eliminated and round trips are made without the drill pipe being touched by the drilling crews. Equipment of this nature may eventually be of great value in reducing drilling costs.

The industry's studies of drilling muds and hydraulic systems are also contributing continually to better drilling techniques. Recent developments include wider applications of oil-base muds in well completions and wider use of starch muds, sodium silicate muds, carboxymethylcellulose etc., to combat drilling problems encountered in areas that cannot be drilled with natural or lightly treated drilling muds.

Development of these new muds makes it possible to drill oil-bearing formations below the heaving shales which drillers could not penetrate with regular drilling muds and former techniques. Today, heaving shales are not a barrier to the development of many oil fields, and the use of improved muds has thus permitted substantial additions to our crude oil reserves.

The most important new developments in drilling soft to medium-hard formations are increases in circulation rates and higher bit-nozzle fluid velocities to improve penetration rates. Heretofore, improvements in bits consisted largely in design changes of cutting edges and the use of better steels to allow a maximum amount of hole to be drilled between bit changes. Present day commercial-type drag bits are equipped with heat-treated drop forged steel blades and tungsten carbide inserts applied to the face and edges of the blades. The drilling fluid nozzles in most current designs are replaceable steel alloy tubes, usually one per blade, ranging in size from 7/8 to 1-3/4 in. bore. This design usually results in fluid nozzle velocities of 50 to 200 ft. per second.

Some recent experimental work has established two new hydraulic relationships in drag bit drilling. The first is that penetration rates are directly proportional to the circulation rate when the nozzle velocity is constant. Second, the rate is directly proportional to the nozzle fluid velocity at constant circulation rates. These studies and relationships point out that the fastest rate of drag bit drilling with any particular rig can be obtained when all the horsepower available on the rig for mud circulation, above that required to maintain a safe annular return velocity, is used to increase the bit nozzle velocity. Thus far these investigations have included two-blade drag bits at rotary speeds up to 175 r.p.m. Three-blade bits, high rotary speeds, and the application of higher fluid nozzle velocities to rock bits are being investigated.

In general, recent developments in this line appear to indicate that in soft drilling with fishtail bits, high circulation rates and high nozzle velocities, in combination with moderate weight on the bit and moderate rotating speeds, will provide high rates of rock penetration. In drilling medium or moderately hard formations, high rotary speeds, up to 400 r.p.m., in combination with higher circulating rates have substantially increased penetration rates. In hard rock drilling the best practice appears to be a combination of relatively high weight on bottom with moderate rates of mud circulation and normal rotary speeds.

Another of the problems encountered in deep drilling concerns the difficulties of identifying oil and gas shows at great depth. The need for good oil reservoir data has also stressed the importance of better methods to secure information about formations penetrated in drilling operations. As the identification and evaluation of formations assumes greater and greater importance, new equipment and techniques are being devised and perfected.

However, in spite of new developments, no single method of well-logging is able to serve all needs. At least two must be used on each well to make a complete record of the formations penetrated. Sometimes more than two must be used, depending on conditions encountered and information desired. The following logging methods are now generally used in this country.

1. Formation (cuttings and cores);
2. Electric;
3. Radioactivity;
4. Mud analysis;
5. Rate of penetration;
6. Caliper;
7. Temperature;
8. Geochemical and fluorographic.

Formation sampling methods and devices comprise ditch sampling, coring and side-wall sampling. With equipment now available geologists and engineers can obtain samples from almost any point in the borehole either while the formation is being drilled or after it has been drilled through. Recent sampling developments include the application of diamond bits and diamond core barrels, the use of punch core barrels to obtain samples from unconsolidated sands, improvements in side-wall sampling tools and techniques, and electro-drill coring.

The application of diamond core bits and core barrels by the petroleum industry was stimulated by operations in the Rangeley Field, Colorado, a few years ago. In that field diamond coring was used to overcome the difficulties met in drilling through a producing section of extremely hard Weber sandstone approximately 750 ft. thick. The successful application of diamond core bits and core barrels provided full information on the entire producing formation. In addition, it resulted in substantial savings to the operator, for in this instance diamond coring proved to be cheaper than regular drilling.

From Rangeley, the use of diamond bits spread to other areas. As the use of diamond bits has expanded, there has also been a substantial advance in methods of manufacture. The most important developments along this line include the use of an improved matrix for setting and supporting the diamonds, and the manufacture of core barrels up to 90 ft. in length.

Recently diamond bits have been used to penetrate extremely hard formations, such as silicious sandstone, chert, hard sharp sand and dolomitic limestone. In these instances diamond core bits are used instead of regular rock bits in routine drilling operations. The resulting cores are an extra advantage.

Improvements in side-wall sampling equipment have given the operator considerable assurance that, in the event prospective oil horizons are missed during rapid drilling operations, he can secure suitable formation samples after reaming and electric-logging the hole. Among the many devices recently developed for this purpose are (*a*) punch-type side-wall samplers, (*b*) percussion-type samplers, (*c*) mechanical rotary-type coring tools, and (*d*) electrically driven side-wall samplers. The equipment and techniques for side-wall sampling are fast enough and dependable enough to procure samples from either soft or hard formations at any interval of the well.

Another development of interest to the industry is electro-drill coring. In this method a unit, consisting of bit, core barrel, electric motor, pump and sample compartment, are run on an electric cable to the bottom of the well. With its power supplied from the surface, the electro-drill unit can take cores at any depth. Its use is limited only by the extremely high temperatures found at great depth in some areas. Although it is a comparatively new development, it has been used successfully on numerous coring jobs in the mid-continent area.

At present electro-drills are used mainly for coring. They can, however, be conveniently adapted, in combination with diamond bits, to drill very hard formations. It is believed that drilling by coring with diamond bits operated by electro-drill units will increase, especially in areas where formations are predominantly hard sandstones and limestones.

Electric logging is next in importance after formation sampling. Electric logs are valuable for correlation, determination of fluid content in sands where no other data are available, and to determine the thickness of formations. Portable units are the latest development here.

Radioactivity logging techniques, or the gamma ray and neutron methods, are receiving wider favour and attention by the industry. They have proved to be valuable additions to the art of well logging. Radioactive logs are used largely in remedial work, to locate possible oil and gas horizons behind the casing in wells that have not been logged before. They are also valuable in locating shale streaks in producing horizons, and in tracing cement channelling behind the casing. They are unique because with them it is possible to log through casing under conditions where no other logs can be recorded.

Mud logging is a method of evaluating and identifying oil and gas shows in formations being drilled. A recent improvement in gas detector design makes it possible to determine the percentage of methane separately from hydrocarbons of higher molecular weight. The method is very reliable, but unfortunately it gives only a qualitative evaluation of the formations. It is also the most expensive of all logging methods.

Rate of penetration, caliper and temperature logs also provide useful information leading either toward better drilling, or evalution of various factors in connexion with cementing and well-completion operations. Geochemical and fluorographic well logging have received some attention, and have been used commercially, but are not yet considered very important. The principal claims made for these methods are that they can predict the presence of gas and oil considerably ahead of the drill. The validity of this claim has yet to be proven.

As we all know, oil wells used to be completed in the first oil-producing sand penetrated by the drill. The object of cementing in early drilling operations was to place an impervious seal at the casing shoe, between the casing and the wall of the borehole. Today, however, the procedure often is to drill through several producing horizons, set casing through all the producing sands found in such drilling, and to seal the annular space between the casing and the borehole to a point at least 500 feet above the topmost producing zone.

To meet these conditions, as well as other problems of well-cementing arising from deeper drilling, it has been necessary to improve cementing equipment and technique. During the last ten or fifteen years the industry has developed stage cementing, squeeze cementing, bulk cementing, and plastic cementing. (The application of plastics in place of cement is generally confined to workover or remedial use.) Numerous new tools, such as wall scratchers, screens, packers, and stage and bulk cementing equipment have been invented, and better cements have come on the market. Among the new cements now available are acid soluble, quick setting, slow setting, gel type, and high temperature cements. The recent successful cementing of 7-inch casing between 19,000 and 20,000 ft. in Wyoming is indicative of the developments in equipment and techniques.

Until the advent of plastics, regular oil-well cements were used in repair and remedial work in oil wells. Now, however, a substantial part of this work is performed with the aid of thermo-setting plastics which are available in temperature ranges between 70 degrees and 300 degrees F., and setting-time ranges of 1 to 16 hours. Plastics have good bonding properties and can easily be injected into the pores and fractures of formations. They can be introduced into the well either in pure state or in mixtures, by either bailer or pump methods.

In spite of improvements in drilling technique and drilling equipment which, together, have contributed greatly to improved efficiency and reduced drilling costs, the average well-drilling costs have more than doubled in the last ten years, in this country. This increase has been due to higher wages, higher investment costs of drilling equipment, higher cost of materials and supplies, and the greater average depth of wells.

Production from 10,000 to 12,000 ft. is now fairly extensive. There are over 125 oil-fields producing between these limits, demonstrating the practicality of such wells. It was reported that as of 31 December 1948, the United States petroleum industry had drilled a total of 561 wells below 12,000 ft. Of these, 3 were drilled between 17,000 and 18,000 ft.; 5 between 16,000 and 17,000 ft.; 13 between 15,000 and 16,000 ft.; 45 between 14,000 and 15,000 ft.; 95 between 13,000 and 14000 ft.; and the rest between 12,000 and 13,000 ft. Of the 561 deep wells we have drilled, 284 were drilled in the last two years. The drilling of these wells has resulted in the discovery of 32 fields, 14 of which were discovered in 1948.

When we begin discussing the cost of these wells, we must remember that well-drilling costs are approximately proportional to the number of days required to drill a well. This, in turn, depends to a great extent on the hardness of the formations that are penetrated. In 1948, the drilling time for 149 wells below 12,000 ft. averaged 162 days per well, an improvement of 18 days compared with 1947.

Assuming that the operating cost of a deep rig is $ 2,000 per well per day, the average cost of deep wells in 1948 was about $ 325,000 per well. This is a reduction of $ 36,000 per well, or slightly more than 10 per cent, compared with 1947.

Most of our deep drilling today is carried on in the Texas-Louisiana coastal area where formations are soft. These two states accounted for about 75 per cent of all the deep wells drilled in 1948. To be economically successful, producing zones in hard formation areas must be of the highest quality in order to compensate for the high drilling costs. Deep drilling costs in hard formations are estimated to be 50 to 150 per cent greater than those in soft formation areas.

Relative costs and drilling times of soft, medium-hard, and hard deep drilling operations in the United States are illustrated by the following summary of 1948 averages.

	No. of wells	*Average depth*	*Days to drill average well*	*Estimated cost at $ 2,000 per rig per day* $
Louisiana-Texas (soft)	7	13,057	158	316,000
California (med. hard)	12	13,383	280	560,000
Oklahoma (hard)	100	13,323	357	714,000

We expect that drilling operations outside the United States will be substantially more expensive than those above. Such operations are increased by transportation charges when equipment from the United States is shipped, plus the cost of moving heavy equipment where roads and railroads are not available, and the expense of maintaining camps, shops and other facilities in the field. It is estimated, therefore, that drilling costs under such circumstances may be increased by 50 per cent or more.

On the basis of past experience one can foresee reductions in deep drilling costs as equipment and techniques are developed to cope with new problems encountered in deeper and deeper drilling. However, it can be also expected that costs will show an over-all increase as long as drill pipe remains the principal means of transmitting power from the surface to the bit at the bottom of the well.

No drilling method that depends on drill pipe to transmit power can be improved enough to overcome completely the ever-increasing cost of deeper drilling. And, in addition to pipe cost, the larger and heavier rigs required are expensive.

There has, therefore, been a growing demand for new methods of drilling holes in the ground. This demand has culminated in a research organization known as Drilling Research, Inc., whose purpose is to look into possible new drilling methods. In addition to the turbo-bit type, which has been under study for some years, a number of interesting schemes have been proposed, and some of them partially tested. The new ideas include percussion drilling, successive use of explosives, and fusion piercing or burning holes through underground formations. Some of these methods show a degree of promise at shallow depths, but the main problem to be solved is still one of economics.

A drilling method requiring minimum investment, low maintenance cost, only two or three men to operate, and capable of drilling holes to any depth, would be a welcome addition and a suitable substitute for the present rotary drilling method.

Such a method is not yet in sight. The problem of finding a new drilling method will undoubtedly be difficult, and will take a long time. Even so, it will not be more difficult than many of the other problems which we have succesfully solved in the past thirty years.

There is much oil still to be found. The ingenuity of the oil industry has made petroleum the most important single source of energy in the United States, and other countries are relying more and more on oil for their energy requirements. We here believe that, just as we have done in the past, we will be successful in finding enough oil, and getting it to the public economically, for many, many years to come.

Bibliography

J. P. Nolley, George Cannon and D. Ragland, "Relation of Nozzle Fluid Velocity to Rate of Penetration with Drag Type Rotary Bits", *World Oil*, September 1948.

Ernestine Adams, "Production Depth Record Shattered", *Petroleum Engineer*, February 1949.

Thad Randolph, "Application of Oil Base Muds in the Mid-continent Area", *Oil and Gas Journal*, 27 May 1948.

George Cannon and R. S. Sullins, "Problems in Drilling of Abnormal Pressure Formations", *The Oil Weekly*, 27 May 1946.

Karl J. Klapka, "Drilling with Industrial Diamonds", *World Oil*, October 1948.

Arthur W. McCray, "Diamond Coring of Chert, Limestone and Dolomite of West Texas", *Petroleum Engineer*, March 1948.

J. E. Kastrep, "Side Wall Sampling Tools and Equipment", *World Oil*, December 1948.

"World's Deepest Wells Economics and Engineering", *Oil Forum*, May 1949.

J. E. Brantly, "Factors Governing Rotary Drilling Rates", *World Petroleum*, March 1948.

Nickolas A. D'Arcy Jr., "Deep Well Breaks Four Records", *Petroleum Engineer*, September 1948.

J. R. Mahan, "Drilling Rigs for Deep Wells", *ibid.*, February 1949

New Methods, Instruments and Equipment Used in the Production of Oil and Gas in Venezuela[1]

MINISTERIO DE FOMENTO, CARACAS, VENEZUELA

This paper is concerned with drilling procedures, types of well completion and the rigs which have been used in some Venezuelan oil fields to deal with special local conditions.

It can be stated without exaggeration that the Venezuelan oil industry has made genuine progress and introduced important innovations in the methods and equipment used in areas where conditions are distinctly unfavourable. It is this that has made possible the development of one of the richest oil-producing regions of Venezuela, the coastal fields of the Bolívar District. This paper is divided into two parts, the first dealing with the west of Venezuela and the second with the east.

WESTERN VENEZUELA

Most of the wells owned by the Creole Petroleum Corporation are situated in the waters of Lake Maracaibo. The wells of the Mene Grande Oil Company lie in a one-kilometre strip along the shore of the lake while those of the Venezuelan Oil Concessions, with the exception of well VL-1, are all situated on terra firma.

Drilling operations in the lake began in 1925. The first wells were sunk in water 3 to 5 metres deep (10 to 16 ft.), the derricks being mounted on piles and wooden foundations. The wood was, however, quickly destroyed by an aquatic wood-borer known as the *teredo*. Moreover, the system was too expensive, as piles and foundations had also to be used for auxiliary equipment, boilers, staging for pipes and so forth.

As a way out of these difficulties, the Raymond Concrete Pile Co. began to use concrete piles for foundations, but it was found that the new method was still expensive owing to the great number of piles which had to be used. Later, in order to make drilling more flexible, the idea of mounting the auxiliary equipment on specially designed barges was adopted, thus helping to reduce drilling costs. Finally, the Creole Petroleum Corporation perfected the reinforced concrete piles and steel platforms which are now widely used in lake operations in the State of Zulia.

The monolithic reinforced concrete piles are manufactured in three sizes:

1.16 in. square section × 69 ft.; 275 lb./ft.
2.20 in. „ „ × 99 ft.; 425 lb./ft.
3.24 in. „ „ × 133 ft.; 600 lb./ft.

Piles of these sizes have been used in depths of up to 60 feet or even more with the addition of small 11 ft. extensions. For greater depths it was necessary to construct special piles or caissons built in hollow sections; the inner tube is formed by welding together two half cylinders 15 in. long and 1/4 in. thick, which are then covered with a 4 1/2 in. layer of concrete reinforced with 1/2 in. reinforcing rods. The caissons are then

[1] Original text: Spanish.

erected by joining these sections after allowing 15 days to set. The sections are 4 ft. 2 in., 4 ft. 10 in. and 5 ft. 6 in. in diameter; some have 8 in. reductions. The lower end of the caisson is fitted with a metal point to assist penetration of the lake bottom. Generally the larger diameter sections placed at the lower end of the caisson penetrate the lake bottom to give proper support, the 8 in. reductions remaining in the water so as to minimize the effect of water on the caisson.

When it is decided to place a pile or caisson in a given place, tests are carried out with a 24 in. trial pile in order to determine the penetration, nature of the bottom etc. The results are then studied in order to determine the length of pile required. The piles are transported on barges while the caissons which, being hollow and watertights float, are placed in the water and towed to the spot. Normally three piles are driven at each corner, two vertical and one sloping; they can carry a load of up to 200 tons. In the case of caissons, only one is used at each corner.

The piles are driven by means of a steam pile driver. The caissons are placed in position under a load of 200 tons although the weight of the caisson itself which varies from 80 to 160 tons (empty and full of water), also helps to penetrate the muddy bottom of the lake.

The cost of pile foundations is $ 15,000 and of caisson foundations $ 42,000, the cost per foot being $ 4.50 to $ 6.58 and $ 15.48 to $ 23.96 respectively.

The auxiliary equipment is mounted on barges specially designed to cope with the peculiarities of lake drilling. The first barges constructed for the purpose and still in use, proved to be too small which meant that time was lost because of storms on the lake. To reduce this difficulty, the Creole Company constructed bigger barges (110 ft. × 60 ft. × 18 ft.) of 300 tons displacement; these are used in conjunction with steam drilling rigs.

Heavy rigs are required to drill wells to depths of up to 15,000 ft. and to operate them a barge has been designed to carry a maximum load of 542,000 lb. of pipe, 1,150,000 lb. of ready use mud (2,500 bbls.), 240,000 lb. of clay for mud (2,400 sacks) plus the weight of ancillary equipment.

Steam-driven rigs are generally used in Lake Maracaibo. Good results have been obtained with 130 ft. (usually 120 ft.) derricks. Some companies have however used diesel equipment and the possibility of using diesel electric rigs is now under consideration. After long research, it is planned to use heavy 6 cylinder, 2 cycle, 360 r.p.m. diesel electric rigs.

In drilling operations in the lake, a 17 in. bit is used to drill the first 250 ft. when a 13 3/8 casing is run and cemented. Drilling is then continued with a 12 1/4 in. bit to a depth of 800ft.; a 9 5/8 in. casing is then placed in position and cemented from the surface to the bottom. An 8 3/4 in. bit is then used to drill the final depth; 5 1/2 in. casing is run and cemented from the surface to the bottom. Normally a 2 1/2 in. casing is placed inside the 5 1/2 in. casing which is gun-perforated at the oil-bearing horizons. In the case of double wells, production from the upper and lower horizons is separated by means of packing between the 5 1/2 in. and 2 1/2 in. casings; side-door chokes are also used to measure pressures in the 5 1/2 in. casing.

To eliminate the risk of explosions caused by the collision of boats, such as the lake tankers, with wells situated in the water, especially in high-pressure areas, use is made of safety valves located at the bottom. To date the Otis FB valve has been used with good results although use is also being made of the FJ type in spite of the fact that it is difficult to remove from the well when it jams. These valves are operated by differential pressure, i.e., they close when the difference of pressure between the upper and lower part of the valve exceeds a certain value.

Formerly, instead of the 5 1/2 in. casing, a combination of 6 5/8 in. and 8 5/8 in. was used; this was difficult to handle in the case of wells with more than two productive sands. Unperforated tubes were therefore adopted and subsequently gun-perforated. However the new method raised the question whether this type of well completion could produce such high indices of productivity as those obtained with combined tubes. It was subsequently found that the production indices were dependent rather on the characteristics of the prolific sands encountered.

In some parts of the State of Zulia, the Mene Grande Oil Company (MGO) and the Venezuelan Oil Concessions (VOC) have used strainers and gravel packing to prevent choking of the wells with sand. Strainers were used by VOC in 1936 with somewhat unsatisfactory results; later, use was made of gravel packing using the standard methods of:

(*a*) Mechanical circulation;
(*b*) Pre-packing pipe;
(*c*) Lined pre-packing pipe.

Methods (*a*) and (*b*) were employed by MGO and (*c*) by VOC.

In method (*a*) a 6 5/8 in. casing is introduced into the well with a No. 20 strainer after reaming the shaft with a drill up to 12 in.; approximately 31 ft. above this tube, a second 6 5/8 × 12 in. tube with 12 in. holes drilled around the circumference is placed in position; 67 ft. of 6 5/8 in. tube, unperforated and with a lead 6 5/8 in. × 8 5/8 in. E.I.W. plug or seal is placed in position and lagged with canvas to 9 in. O.D. so that it can be fitted inside a 10 in. tube.

The 6 5/8 in. × 12 in. tube is then lowered to 3 ft. above the bottom valve to permit the return of the fluid from the injection tube after the gravel is deposited when the flow is reversed. In this method water is used to carry the gravel after reversal of circulation; the gravel consists of quartzite sand from which the ferrous stone has been washed; its diameter varies from .32 in. to .046 in., and it is fed at the rate of two sacks every three minutes to avoid choking. Good results have been obtained by the use of this method and increased daily production has been secured from sanded wells treated in this way. In addition the number of periodical cleanings required by the wells has been reduced, with a resulting reduction in maintenance costs.

Method (*c*) has also been used by the Mene Grande Oil Company, but the wells so treated have never been able to produce a volume equal to that produced prior to the use of pre-packing lined tubes. This is attributed to the fact that the diameter of the well shaft has to be reduced which leads to reduced production.

Method (*b*) has been used by VOC with great success. It was applied to a well which originally produced 887 barrels a day and which later fell off considerably until it was completely filled with sand. After cleaning, production never rose to more than 75 barrels a day. A 6 5/8 in. × 4 3/4 in. tube with .028 in. grooves was then fitted. The 4 3/4 in. portion was fitted with 7 in. diameter sleeves and filled with gravel. Oil was used as circulating medium. The well was then pumped for a day and a half until it began to produce through the casing at the rate of 400 barrels a day. This method also completely arrested the sanding up of the well.

Of the three methods applied, gravelling by mechanical circulation appears to be best as regards increasing production since reaming of the well shaft increases its diameter and packing the outside of the 6 5/8 in. tube with gravel produces an increase in permeability and the exposed area of the productive sand round the tube. Nevertheless, the use of pre-packing tube is simpler and therefore less subject to mechanical hitches.

The Shell Group has experimented with oil-base muds in some of the fields it operates. The arguments in favour of this type of mud are based on the fact that its physical characteristics enable it to form protective layers on the well sides better than those obtained with other drilling muds, with small infiltration of water. Further, the protective layers are more easily washable even in the case of wells with very low differential pressures. Oil-base muds do not affect formations with a tendency to disintegrate or crumble. Hence when this type of mud is used, drilling in shales is quicker since the particles cut by the bit are larger and do not disintegrate; this avoids clogging of the bit and the interruption of drilling. Another advantage of this mud is that it is possible to obtain samples uncontaminated by water in order to determine the original water in the pool being drilled.

The oil-base mud used by the Shell Group was prepared by the company's chemists and has given excellent results in the fields near Lake Maracaibo, such as Mene Grande, Gabimas, Lagunillas etc. However, this type of mud is not used throughout the whole drilling operation; wells are begun with water-base mud until the top of the productive formation is reached. The water-base mud is then replaced by the oil-base mud and drilling is continued until the final depth.

The oil-base mud has been used principally in the low-pressure areas in the Bolívar District where pressures vary from 50 to 500 lb. per square in. Normally wells drilled with this mud are more easily brought into production and give an initial production rate higher than that obtained in wells drilled with water-clay mud. The weight of the mud used is in most cases 60 lb. a cubic foot although in some cases mud of as much as 75 lb. a cubic foot has been used. The viscosity is better than that obtained with water-clay muds; viscosities of 320 seconds Marsh funnel have been easily obtained.

The composition of the mud used by Shell, which is patented, was invented by Mr. R. A. Henkes, a resident of Maracaibo; the ingredients are as follows:

(*a*) Oil 15 to 22 degrees API as fluid base.

Heavy oils are better since they require less carbon-black, asphalt (blown) and barytes, although for heavy muds light crudes give better viscosity after the addition of the weighting material.

(*b*) Lamp black to give the mud gelic and plastic properties is used at the rate of 1 to 2 per cent by weight for crudes of 17.4 to 19 degrees API. The type of lamp black used is of great importance; that manufactured by the Monsanto Chemical Co. is considered to be the best.

(*c*) Mexphalte B-115/115 asphalt manufactured by Shell, is added to the mud at the rate of 1 to 2 per cent by weight to obtain plastic and peptic properties in heavy muds. This ingredient is not mixed directly with the mud but is dissolved in gas oil at the rate of one part of asphalt to two parts of gas oil.

Ingredients (*a*), (*b*) and (*c*) are used when it is desired to obtain muds without weighting material. Otherwise the following substances are also added:

(1) 1.5 per cent by weight of soap as a stabilizing agent; this is mixed with an equal quantity of water and then added to the mud.

(2) Ground oyster shells as weighting material. This product is known as Empire Shell Flour Lime and is manufactured by the Pacific Portland Cement Co.

In some cases mica flakes are added to prevent loss of mud.

The disadvantages of oil-base mud are as follows:

(1) All rubber connexions deteriorate rapidly.
(2) Fire hazard.
(3) Special facilities are required for storage and transport.
(4) Special instruments are required for electric logging.
(5) It is impossible to correlate electric logging in oil-base muds with electric logging in water-clay muds.

The following results show the effect of oil-base mud and water-clay mud on the production of a well.

No. of wells	*Mud used*	*Average original production bbls.*	*Average decline in production* First 6 months *per cent*	*Average decline in production* Second 6 months *per cent*
3	Clay	100	0	25
4	O.B.M.	200	14	8

Because of the disadvantages of the use of oil-base mud, the Shell Group has devised emulsion muds which have given excellent results chiefly because of their lower cost and because they possess many of the advantages of oil-base muds. These emulsions are prepared by mixing ordinary water-clay mud with an alkaline emulsifying solution and asphalt-base oil. These emulsified muds have been used with success in Colombia and other countries where the product is patented as well as in Venezuela.

Well cementation methods in Venezuela are the same as those used in the United States of America; nevertheless there are some special features due to the drilling conditions encountered in Lake Maracaibo. One of these is the use of suitably equipped barges for cementing. A typical barge of 80 ft. × 36 ft. × 7 ft. is equipped with a storage capacity for 3,000 bags of cement. It also contains an endless belt operated by a steam turbine, a mixer with two 50-barrel tanks, three 12 ft. × 6 3/4 in. × 14 in. reciprocal oil-well pumps to remove water during cementing and capable of exerting pressure of 2,000 lb. per square in. It also has water, mud and steam lines and the necessary connexions to connect them with the lines of the drilling barge.

In addition to this barge, a more modern and suitable barge of 100 ft. × 40 ft. × 7 ft. has been designed. Cement is stored in two 600-bag tanks which are fitted with helical gears to discharge the cement automatically and take it to the feeders. A further 3,000 bags of cement can be stored round the tanks. The equipment consists of four steam-operated reciprocating pumps (14 ft. × 5 in. × 12 in.).

The most important feature of the new barge is the automatic or mechanical cement mixing which eliminates the need for labour. In mixing, the speed of the helical gears in the cement tanks and the speed of the pumps is controlled by means of a gauge. This barge is also cheaper to operate since it only requires a drilling crew to handle it while the original type required two crews, one of which was borrowed from other wells being drilled. For cementing operations requiring less than 600 bags of cement, the new barge has the advantage that the cement can be stored in the tanks before the work is begun.

EASTERN VENEZUELA

Although the drilling and completion of wells and the transportation of the oil produced in the fields of eastern Venezuela raise difficult problems, drilling operations continue at an increasing rate since new fields are discovered as the new prospecting concessions are surveyed.

On 1 April 1949, a total of 55 teams were in operation, 22 operating and 33 prospecting teams.

Drilling Rigs. In the east of Venezuela drilling activities will continue for many years since the favourable area remaining to be prospected is vast and the existing fields are not yet completely exploited. These circumstances have given the operating companies an opportunity to unify and standardize to the utmost the drilling rigs used.

At present rotary drilling is used exclusively. Rigs varying from the light to the ultra-heavy are used. Steam engines (12 in.

Drilling Results and Samples Before and After Using Diamond Bits

Well RPN-15 El Roble

Type of bit	*Size*	*Drilling interval*	*Feet drilled*	*Samples obtained*	*per cent*	*Time of rotation*	*Feet per hour*	*Points on bit*	*Speed of rotation r.p.m.*	*Remarks*
Hu–HFCH	7⅝	10,824–10,829	5	0 ft. 8 in.	13.3	6.5	0.77	1	50	
Hu–HFCH	7⅝	10,829–10,840	11	7 ft. 10 in.	71.2	9.0	1.22	1–1½	50	
Hu–W7R	8½	10,840–10,840	—	—	—	9.0	—	1–4	60	16 ft. reamed
Hu–W7R	8½	10,840–10,867	27	—	—	14.0	1.9	2–4	50–60	
Hu–W7R	8½	10,867–10,916	49	—	—	20.0	2.5	4	50	10 ft. reamed
Hu–HFCH	7⅝	10,916–10,932	16	13 ft. 5 in.	83.9	10.5	1.52	1–1½	50	
Hu–W7R	8½	10,932–10,952	20	—	—	13.0	1.54	3–4	50–70	16 ft. reamed
Hu–W7R	8½	10,952–10,981	29	—	—	15.0	1.93	4	50	
Hu–W7R	8½	10,981–10,988	7	—	—	6.5	1.08	4	60–70	
Diamond bit		10,988–11,024								
Hu–W7R	8½	11,024–11,037	13	—	—	6.0	2.17	2–3	50–60	
Hu–W7R	8½	11,037–11,069	32	—	—	15.5	2.06	4	50–60	
Hu–HFCH	7⅝	11,069–11,078	9	8 ft. 0 in.	88.9	7.0	1.29	1–2	50	
Hu–W7R	8½	11,078–11,121	43	—	—	18.0	2.39	4	50–70	9 ft. reamed
Hu–W7R	8½	11,121–11,133	12	—	—	12.5	0.96	3–4	60–70	
Hu–HFCH	7⅝	11,133–11,137	4	4 ft. 0 in.	100	5.0	0.80	1–2	50–70	
Hu–W7R	8½	11,137–11,145	8	—	—	11.0	0.73	3–4	50–60	4 ft. reamed
Hu–W7R	8½	11,145–11,172	27	—	—	17.0	1.59	2–5	50–60	
Hu–W7R	8½	11,172–11,210	38	—	—	12.0	3.16	3–5	50	
Hu–HFCH	7⅝	11,210–11,220	10	10 ft. 0 in.	100	6.0	1.67	2	65	

Summary sampling operation

Well RPN-15 El Roble

Description of Equipment:
Head: Size 8⅜ × 4⅜
Type Williams Pattern
Maker Wheel Trueing Tool Co.

Sampler: Size: 6⅝ O.D. × 25 o 50
Type: Deely
Maker: Drilling & Service, Inc.

Shaft: Size 8½ in. — Shaft Depth 10,988 ft.
Casing: Size 9⅝ in. — Depth 8,260 ft.

Accessories: Drill pipe: 4½ in. 16.6 lb./ft.
Bit holder: six 5¾ O.D.
Others: Stabilizer

Mud: Type starch mud
Weight 12.4–12.5 lb./gal.
Viscosity 70–85: Seg. 1000 cc.
Filtration 0.7–1.0 cc./30 Min./100 1pc.

No. of bit	*Interval*	*Feet sample*	*Obt.*	*Per cent obt.*	*Time of rotation*	*Minutes per ft.*	*Bit weight (lb.)*	*Circulation of mud r.p.m.*	*g.p.m.*	*Pres.*	*Remarks*
1	10,988–10,998	10 ft. 0 in.	9 ft. 4 in.	93	90	9.0	8,000	40–60	140	850	25 ft. Sampler on stabilizer. Pressure increased to 1,100 lbs. per sq. foot.
2	10,998–11,006	7 ft. 0 in.	8 ft. 0 in.	100	60	8.6	8,000	60	140	600	Bit withdrawn.
		1 ft. 0 in.			60	60.0	8,000	60	140	600	50 ft. Sampler on stabilizer Pressure reduced to 500 lb. per sq. ft. Bit withdrawn.
	11,006–11,010½	0 ft. 6 in.			15	30.0	8,000	60	150	850	25 ft. Sampler on stabilizer.
		3 ft. 0 in.	4 ft. 6 in.	100	35	11.7	15,000	60	150	850	Pressure reduced to 625 lb. per sq. ft.
		11 ft. 0 in.			25	25.0	15,000	60	150	850	Bit withdrawn.
	11,010½–11,022	6 ft. 6 in.	11 ft. 2 in.	97	100	15.4	8,000	60	140	850	25 ft. Sampler on stabilizer.
		5 ft. 0 in.			110	22.0	8,000	60	140	850	Circulation lost at 11,017. Pipe raised 900 ft. and circulation recovered. Pressure increased 900 lb. Pipe withdrawn.
Bit No. 2	Total	24 ft. 0 in.	23 ft. 8 in.	98.5	405	16.9					
3	11,022–11,024	2 ft. 0 in.	1 ft. 11 in.	95.6	24	12.0	3,000	50–55	140	600	25 ft. Sampler on stabilizer.

× 12 in. or 14 in. × 14 in.) are used. Each rig is equipped with two mud pumps (7 3/4 in. by 20 in.) for circulation and an auxiliary 7 3/4 in. × 18 in. pump. The steam for the steam engine is supplied by two or three 125 or 150 horsepower boilers with a pressure of 270 to 300 lb. per square in. The drill pipe generally used is 4 1/2 in., 16.6 lb. per foot. The remaining equipment: hook, crown block, travelling block, swivel joint etc., are selected in the light of the intended operations.

Diesel rigs are used where water and fuel gas are scarce.

Skidding of rigs. In fields where the terrain is suitable, drilling rigs are skidded or dragged from one place to another. This procedure has made it possible to reduce the amount of time spent in erecting and dismantling equipment thereby reducing the cost of operations.

Drilling technique. A form like, or similar to, the attached is used by companies to keep a permanent record of all operations in the drilling of the well from the beginning of operations until the well is completed and the rig dismantled.

The type of bit to be used, the weight on the bit, the speed of rotation of the drill pipe and in general any other factors which have to be taken into account in drilling can be determined by analysing the forms after competition of the first wells in a field.

As is to be expected, the above factors vary from one field to another. An account is given below of the procedure adopted in the El Roble field where the deepest wells in the east of Venezuela occur:

Depth	*Speed of rotation*	*Weight on bit*
0-300	150	2-4,000
300-8,500	100	8-11,000
8,500-18,000	60-80	15-18,000

Drag bits are generally used to drill the first 800 to 1,000 ft. where the first outer casing is fixed and cemented. Except in the case of some deep wells in which diamond bits were used, wells are drilled with rock bits.

Diamond bits. In the east of Venezuela, the use of diamond bits for sampling is in the experimental stage. Diamond bits were used for the first time in well RPN-15 in the El Roble field in the State of Anzoátegui. This well was selected because it was necessary to penetrate the Merecure formation (Oligocene) consisting of thick, hard or fairly hard quartzite sandstone, the grains being fine or granular, intercalated with very thin layers of hard black carbonaceous shale. In this field rock bits have averaged 15 to 20 ft. per bit and 1 to 2 ft. per hour of rotation. In some cases the figures have been 1 ft. per bit and 6 in. per hour of rotation. The results obtained with diamond bits are summarized in the attached tables.

As can be seen, in this first trial diamond bits did not give good result, the reason being not the bit itself, but pieces of metal which were found in the bottom of the well. Diamond bits were also used to drill wells RPN-19 and 20. The results were not encouraging.

Formation sampling. The many faults and discontinuity of the sands in the fields of eastern Venezuela have necessitated a long sampling period before wells are completed. In fields where the sands are not consolidated, samples are taken after running and cementing the last string of casing. In such cases, a 2-foot section is perforated with 4.5 mm. holes to carry out the test and a hook plug with production tubing (2 in. or 2 1/2 in.) is used.

The above procedure has the disadvantage that if the interval tested produces water or oil, pressure cementing is necessary to close the perforations. Therefore, wherever possible, samples are taken while the well is being drilled.

Fluid used in drilling. Drillers pay careful attention to the drilling fluid since maintenance of the mud in proper condition ensures more representative samples and a better guarantee of success in formation sampling and in running and cementing the casing. Further the productivity of the well is increased.

Daily mud samples are taken and analysed in the laboratories. The weight of the mud, its viscosity, pH value, thickness of layer, filtration loss, salt content, sand content etc. are determined and the results noted on special forms in order to record and correct any abnormalities that may arise.

In shallow wells water-base mud has been used with good results. In the Santa Bárbara-Jusepín area of the State of Monagas, advantage has been taken of the presence of colloidal shales to weight the mud, thus reducing the consumption of baryte.

In drilling deep wells use is made of drilling muds which form a thin layer and have a very low filtration loss. The practice is to drill the first 3,000 ft. approximately with water-base mud and then to add chalk and quebracho until a pH greater than 11.5 is obtained. This mud has a filtration loss of 2 to 4 centimetres and forms a 1/32 in. layer.

In very deep wells in which filtration losses are undesirable, the pH value is raised to more than 12.5 and starch is added to the mud described above. Both yuca starch, manufactured in Venezuela, and imported corn starch have been used in the San Joaquín area of the State of Anzoátoegui. In the east of Venezuela it is also the practice to use oil-base mud to drill the productive section. Oil-base mud is used primarily in areas where the sands have low porosity and very low permeability.

Casing. The size of the casing used in wells varies in accordance with the depth and completion of the well. The types used in various fields are given below.

Santa Bárbara-Jusepín Area:

For wells from 8,000 to 9,000 ft. deep, 10 3/4 in. tubing for the first 2,000 ft. and 7 in. to the bottom.

For wells less than 8,000 ft. deep 9 5/8 in. for the first 600 ft. and 5 1/2 in. to the bottom.

San Joaquín Field:

For wells from 7,000 to 9,500 ft. deep, 13 3/8 in. casing for the first 800 ft., 9 5/8 in. to 3,000 ft. and 5 1/2 in. to the bottom.

For wells less than 7,000 ft. deep, 9 5/8 in. casing for the first 800 ft. and 5 1/2 to the bottom.

El Roble Field:

For deep wells, 20 in. casing from 200 to 300 ft., 13 3/8 in. to 2,800 ft., 9 5/8 in. tubing from 8,000 to 9,000 ft. and 5 1/2 in. to the bottom.

Guario Field:

13 3/8 in. casing up to 1,200 ft., 9 5/8 in. to 6,000 ft. and 6 in. to 9,000 ft.

Nipa Field:

10 3/4 in. casing up to 1,200 ft., 7 in. to 8,300 ft.

Santa Rosa and Santa Ana Field:

13 3/8 in. casing to 1,000 ft., 10 3/4 in. to 5,000 ft. and 5 1/2 to 10,750 ft.

Guara Field:

For wells to be completed in two sands, 5 5/8 in. and 5 1/2 in.

For wells to be completed as producers from three sands, 10 3/4 in. and 7 in.

Cementing practices. Special attention has always been given to cementing since it is a well known fact that defective cementing frequently involves the loss of the well as well as loss of time. Cementing operations are carried out by private companies under the supervision of the oil company's engineers.

Cementing of first casing. The cementing of the first casing generally presents no difficulties. The quantity of cement mixed is greater than the quantity theoretically required to fill the space between the well walls and the casing. The extra amount used is determined in the light of experience and varies from field to field.

The loss of circulation experienced in some fields due to the presence of low-pressure superficial water sands has been eliminated by adding a small quantity of bentonite to the cement (approximately 2 per cent). It is necessary to wait at least twenty-four hours before drilling the cement plug left at the bottom of the casing.

Cementing of final casing. The last string of the casing is generally run and cemented throughout the whole productive section.

In order to place a homogeneous column of cement behind the casing and so to eliminate pressure cementing, which is necessary where gas, oil and water sands are in close proximity, most companies have decided to equip the casing string with centralizers and reversible wall scrapers which are installed as follows:

A. At bottom joint:

(*a*) Two scrapers one foot apart placed immediately above the cementing shoe.

(*b*) A centralizer is then placed two feet above the cementing shoe, the lower collar being completely welded to the casing.

(*c*) Three scrapers are then installed at equal distances between the centralizer and a point 6 feet from the top of the joint.

B. In the subsequent joints and throughout the section to be filled with cement, centralizers and scrapers are placed as follows:

(*a*) In joints 30 ft. long, two scrapers per joint and a centralizer for each three joints.

(*b*) In joints from 40 ft. to 45 ft. long, 3 scrapers per joint and a centralizer to each two joints.

The company's private reports show that in nine out of ten cases, the use of centralizers and scrapers has eliminated the pressure cementing required to isolate productive sands from adjoining water sands.

Partial cementation. Briefly, this method consists in the insertion of special cementing shoes in the casing so that cement can be placed in predetermined sections. The object of this method is as follows:

1. To eliminate the high pressure to which sands are subjected when large quantities of cement are mixed.

2. To avoid placing cement opposite the sands in which the well is completed. This type of cementing has given excellent results in the Quiriquire field.

Pressure cementing. If the space between the horizons in which the well is to be completed contains water sands or if there is any doubt regarding the results of cementing, pressure cementing is used.

When pressure cementing is to be used to isolate water sands, a 2 ft. section near the water sand is gun-perforated with 8.5 mm. holes (two holes to the foot). The Yowel plug or a cement retainer is inserted in the tube in the 2 in. or 2 1/2 in. tube, and is fixed approximately 10 feet below the perforations. The formation is broken. Then, keeping the circulation joint open, cement is mixed and pumped into the 2 1/2 in. tube. When all the mud and the first four barrels of water of the seven used before the cement, have been pumped into the annular space, the circulation joint is closed and the cement slowly but surely forces itself through the perforations in the casing until the final desired pressure is reached.

If the final desired pressure is not reached, the cement is pumped through the perforations and another batch of cement is forced through the perforations eight hours later. Whenever the pressure of the cement exceeds 2,000 lb. to the square in., 800 to 1,000 lb. to the square in. pressure is applied to the annular space with the object of preventing possible fracture of the casing.

Pressure cementing tests. When it is necessary to drill the cement plug left in the casing after pressure cementing, the usual practice is to test the cementing. The test consists in the application of a predetermined pressure to the cemented portion. To be satisfactory, the pressure must remain constant for not less than ten minutes. The test pressure is determined experimentally for each interval.

Pressure cementing to close off water or gas sand. The procedure adopted in such cases is the same as that described above, except that a larger quantity of cement is mixed since the section opened for the test is generally longer. A final pressure of 4,000 to 5,000 lb. a square in. is required if the cementing is to be regarded as satisfactory.

To ensure that the cemented intervals have been satisfactorily closed, it is usual to carry out pressure tests and dry tests when the cement opposite the intervals is drilled.

The pressure test is similar to that carried out on cementing to isolate water sands.

The dry test, more positive than the pressure test, consists in a test of the intervals. For this purpose the tester is fixed a few feet above the interval it is desired to test. If after opening the tester, only a small current of air, disappearing after a few minutes, is observed, it is considered that the interval is satisfactorily sealed. In these tests the 2 1/2 in. tube is usually filled with a quantity of water which exercices a pressure on the interval equal to that to which it will be subjected when the well is in production.

Well completion practices. The type of completion is generally determined by the number of sands in the productive section. Both simple and multiple completions are frequent in the fields of eastern Venezuela.

Simple completion. Wells are completed in one horizon when the section contains only one productive sand.

In the earliest days of the oldest fields, the practice was to complete wells as producers from one horizon. Later one or more sands were allowed to produce through a common casing.

Multiple completion. The first two-horizon completion was carried out in 1939 and has since then gained preference so that most wells are now completed as producers of two horizons.

Advantages of multiple completions. If each zone produces separately, the initial production of the well is increased and the original investment is therefore recovered in a shorter time.

Multiple completion affords better control of each pool since the sands of differing pressures and productive characteristics can be separated.

General dual completion procedure. After running and cementing the final casing through the productive section, the intervals opposite the selected sands are gun-perforated. A plug inserted in the production casing is then fixed between the two open intervals and the well is put into production.

In some fields the final casing is run and cemented a little above the lowest productive sand after which the interval opposite the second selected sand is gun-perforated. With this method better production is obtained from the lowest sand if it is allowed to produce in an open tube.

As in a satisfactory dual completion, there must be complete separation of the two horizons, some operators make a practice of carrying out a communication test before moving the drilling rig.

To carry out the communication test, the two horizons of the well are closed to enable the pressures to become normal and then the pressure recording pump is run down to the bottom of the well. After recording pressure at the bottom, the topmost horizon is opened for production for a short time and the pump is withdrawn. If the pressure at the bottom remains constant, the two horizons are perfectly separated and the completion is regarded as satisfactory.

The following are some of the causes of faulty dual completions:

Plugs. The rubber used to separate the horizons generally deteriorates owing to the high temperature at the bottom or owing to movement due to differences of pressure between the two horizons.

As a partial remedy, use has been made of plugs which are permanently fixed in the casing and fitted with two lead rings and two rubber rings.

The material of which these plugs are made can be drilled without difficulty.

Communication between zones caused by the circulation joint or the side-door chokes. The use of non-recoverable plugs in dual completions makes it necessary to add a left-hand thread circulation joint or side-door choke in the production casing to enable the well to be washed.

In many cases sand and mud prevent proper closing of the circulation joint or installation of the plug in the proper position.

Defective cementation. In most cases, defective cementation is the cause of communication between the two zones.

The use of centralizers and reversible wall scrapers has made it possible to insert a homogeneous column of cement and prevent the establishment of communication through the outer part of the casing.

Three-horizon completions. Three-horizon completions were originated because of the shortage of steel during the war years and were encouraged by the excellent results and experience gained in the use of dual completions. The first three-horizon well was completed in August 1941.

Equipment and method used. The following equipment is used in three-horizon completions:

An intermediate string of 4 in. casing;
A rubber plug;
A disc plug;
Special seat for production casing;
A 2 in. production casing string.

A 7 in. casing string is run and cemented throughout the productive section. The chosen sections are then gun perforated.

The 4 in. casing string is then placed in the well. While it is being run, the rubber plug, the special seat for the 9 in. casing and the disc plug are inserted in the casing in the order mentioned and so fixed that the first plug can be inserted between the lowest and intermediate horizons and the second plug between the intermediate and topmost horizons. Above the special seat for the 2 in. casing, located between the two plugs, a perforated section of tube is inserted so that the fluid from the intermediate horizon can be fed into the 4 in. casing.

The 2 in. production casing is then placed in position and fixed in the special seat after which the well is put into production and the plugs are installed.

Economic results. The Mene Grande Oil Company, the only company which has completed three-horizon wells, gives the following results based on forty-nine wells completed as three-horizon producers:

Type of completion	*Initial production bbls.*	*Steel required lb.*	*Lbs of steel per barrel oil*	*Well cost $*	*Cost per barrel of oil*
Simple	402	247,000	615	65,000	162
Double......	804	247,000	308	65,000	81
Triple	1,206	318,000	264	70,000	58

Disadvantages of triple completions. The following are the most significant disadvantages of triple completions:

1. Difficulty of obtaining pressure in the top of producing horizons.
2. Repairs take longer and are more expensive.

The average length of drilling operations in wells completed in 1948 in the San Joaquín, El Roble, Santa Rosa, Santa Ana, El Toco, Jusepín and Mulata fields is given below.

Operation	*No. of days* San Joaquín	El Roble
No. of wells	5	3
Feet drilled	6,003	9,975
Sample feet	98	371
Erection	4.46	17.61
Drilling	51.34	133.92
Sampling	2.99	27.37
Facing	1.71	6.23
Cementing	10.94	31.73
Electric logging	1.49	3.01
Repairs	1.27	5.43
Completion and tests ..	4.19	59.27
Miscellaneous	6.50	41.12
Dismantling	1.71	2.64
Total time	86.80	328.33
Feet per day..........	70.45	32

Operation	*No. of days* Santa Rosa	Santa Ana	El Toco
No. of wells	2	2	4
Feet drilled	8,806	8,538	7,727
Erection	8.50	17.45	13.45
Drilling	119.20	107.45	51.28
Fishing	23	17.50	2.35
Cementing	36.75	18.10	31.55
Electric logging	2.95	1.30	1.68
Secondary cementing	24.90	4.65	16.57
Completion and tests	55.30	20.75	39.52
Repairs	13.15	12.90	10.60
Miscellaneous	23.10	15.40	16.65
Dismantling	1.15	2.35	1.78
Total time	308.00	217.85	167.43
Feet per day	28.6	39	46

Operation	*No. of days* Jusepín	Mulata
Erecting	1.00	1.66
Drilling	8.62	12.84
Sampling	0.23	1.81
Facing	0.41	0.54
Cementing	3.37	3.72
Electric logging	0.53	0.68
Repairs	—	0.28
Completion and tests	4.46	14.19
Miscellaneous	6.76	6.27
Dismantling	0.50	0.68

Operation	*No. of days* Jusepín	Mulata
Total time	25.88	42.67
Total depth	4,666	5,975
Feet drilled	4,645	5,853
Time drilling	206.88	308.16
Feet per hour	22.45	43.87

Bibliography

PAUL REED, "Métodos de perforación en el Oriente de Venezuela", *Petróleo Interamericano*, May 1946.
PAUL REED, "Procedimiento de perforación en el Distrito San Joaquín, Venezuela", *Petróleo Interamericano*, August 1946.
PAUL REED, "Prácticas de perforación empleadas on Jusepín", *Petróleo Interamericano*, September 1946;
"Diamond bit coring—El Roblo", Annual Internal Report for 1948 of Creole Petroleum Corporation.
R. E. JOHNSON, "A survey of results of casing cementation using wall scratchers and casing centralizers", Internal Report of Mene Grande Oil Co.
J. ZABA, "Terminaciones de pozos perforados con equipo rotatorio", *Petróleo Interamericano*, February 1946.
J. ZABA, "Aspectos económicos y mecánicos de las terminaciones múltiples", *Petróleo Interamericano*, October 1947.
HOYT AUSTING, Multizone completion in Eastern Venezuela", Internal Report of Mene Grande Oil Co.;
"Recientes Innovaciones facilitan la Perforación", *Petróleo Interamericano*, vol. 6, no. 12.
"New Drilling Barges", *Petróleo Interamericano*, vol. 5, no. 9.
"Cementing Practices", *Petróleo Interamericano*, vol. 5, no. 7.
"Safety Valves", *Petróleo Interamericano*, vol. 5, no. 6.
HUGH WIND, "Importance of Bolivar Coastal Fields in World Production", Creole Pet. Corp. Pamphlet.

Petroleum Production from Continental Shelves

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ABSTRACT

The continental shelves include one-twelfth of the world's total ocean areas and may possibly contain deposits totalling over one-half trillion barrels of oil.

Attempts to reduce discoverable deposits to recoverable reserves have begun off the coasts of Louisiana and Texas on the United States shelf in water as deep as 60 ft. and although experience has been limited by time, success appears to depend upon the reduction of presently indicated costs, the maintenance of a market price high enough to support extraordinarily high costs and the ability of operators to secure properties of a sufficient size and on terms allowing efficient operation.

The chief physical problems, drilling site preparation and transportation, arise from wind, waves, and currents, and become more difficult and expensive to solve as water depths and distances from shore and operating bases increase.

INTRODUCTION

A continental shelf is by definition a land mass submerged in less than 600 ft. of water. At that point, approximately, the sharp increase in slope of ocean bottom marks the true edge of the continents.

The continental shelves of the world cover 11,800,000 square miles, roughly one-twelfth of all ocean areas. Mr. W. E. Pratt estimates the volume of possible oil-bearing sediments there present to be 30 million cubic miles and, by comparison with the volume of such sediments already explored in the United States, the oil deposits in place on the world continental shelves might be ten times the 53,000 million barrel reserve developed in that country, or a total of over 500,000 million barrels.

EXPERIENCE ON UNITED STATES CONTINENTAL SHELF

For the purposes of this discussion comments refer to the United States continental shelf of the Gulf of Mexico adjacent to the states of Texas and Louisiana, where it lies parallel to a prolific petroleum province.

The existence of some petroleum deposits on this part of the continental shelf has been realized for several years. One field has actually been producing in open water for ten years; others lie at the water's edge and several are situated beneath the delta of the Mississippi River, which is in effect a river-built dike extending nearly across the shelf.

Although some fifty continental shelf wells have been drilled or projected since the middle of 1945 when the present trend of operations began, there has been insufficient time to evaluate the over-all efficiency and economics of developing and producing continental shelf fields even in relatively shallow water and at favourable locations where operations have been difficult and extremely expensive.

The term "relatively shallow water and at favourable locations" refers to wells which have been located in as much as sixty feet of water, seventy miles from base, and nearly thirty miles from the shoreline. Under these conditions preliminary figures indicate that the completed wells are costing several times as much as their counterparts on land, and indications are that production costs will be several times those expected in recovering petroleum from similar deposits under dry land. With present methods in use, operations would be still more difficult and expensive in deeper water and at more distant locations on the continental shelf, but there is reason to believe that technique development will make it possible physically to carry such operations into increasingly difficult conditions. Final physical limitations such as water depths can not be set at this time.

As a result of continental shelf development since the middle of 1945, several petroleum deposits of probable importance have been discovered, but the conversion of known and probable petroleum accumulations on the continental shelf to useful reserves will obviously depend upon a complicated system of factors, a few of which may be mentioned as follows:

1. The reduction of development costs by maximum width of well spacing in the reservoir resulting in the elimination of wells unnecessary for efficient operation. Additional reduction in per-well development costs should come about through increasing the number of wells which can be served by extremely costly items such as shore facilities, transportation, and drilling site platforms. Technical advances made possible by experience now being gained should also be a great factor in reducing development costs.

2. The reduction of production costs through the improvement of all operating techniques and by the maintenance of maximum efficient production rates.

3. The maintenance of market prices for production at levels which will support the extraordinarily high costs.

4. The ability of operators to secure offshore properties of a sufficient size and on terms allowing efficient operations.

Attempts to extend development and production operations to deeper waters and to locations farther from operating bases will usually result in increased difficulty in making discoverable deposits usable reserves. Physical problems will become more acute and costs will become higher, disadvantages which must be balanced, at least partially, by improved techniques and better planning if discoverable deposits are to be recovered.

Operating Problems. In drilling and producing operations conducted in open water, the well-recognized major physical problems encountered in addition to those on land are those of the natural elements: the winds, the waves, reaching their maximum under the driving of tropical hurricanes, and ocean currents. Even in their absence, they are a constant threat requiring preparation for the most severe conditions. Auxiliary operations, such as transportation and drilling site preparation, because of them, become major operations from technical and financial viewpoints, even when normal conditions prevail.

Drilling Sites. Preparation of the offshore drilling site involves the construction of work space for drilling machinery, for storing the drilling supplies needed to maintain operation, and for the accommodation of the various auxiliaries of a development operation.

The design of a fixed platform for an offshore drilling site involves the consideration of a number of unusual loading conditions. Winds and waves set up lateral forces which are larger than for usual land structures and pose difficult design problems.

The vertical loads which must be carried by a platform will vary according to the depth of the well which will be drilled from it but they will usually require heavy deck construction. Transverse forces of wind and waves add to the vertical loads on the legs, and the resultant loads necessitate careful design of leg bracing for maximum stiffening and minimum wave energy absorption, particularly where water depth exceeds twenty feet.

The ocean bottom itself affords a rather difficult problem in the determination of its competency to assume the drilling site loads as transmitted to it by a platform. The general information available on ocean bottoms is meager and that indicative only of surface characteristics, so costly testing is necessary before final design can be selected.

The effect of water depth on the design of a drilling site platform is considerable. The lowest deck should be high enough to clear the greatest wave that may reasonably be expected in the depth of water present on location. For instance, in 40 ft. water in the Gulf of Mexico we may reasonably expect a 32 ft. wave, of which 24 ft. will be above mean water level. Adding to that a possible 5-ft. storm tide, a height of twenty nine feet above mean water level is obtained for the bottom of the lowest deck. If platform legs piercing the ocean bottom are used, the leg length from this deck to a point of fixity at the mud line or below dictates to a considerable extent the amount of bracing which must be supplied to provide stiffness in these legs.

In order to function effectively, the drilling site must be provided with all the facilities and utilities of a district headquarters; power for many auxiliaries and lights, water for drilling and domestic purposes, a fire system, warehouse, tool rack, repair facilities, communication systems, and adequate facilities for unloading personnel and heavy materials from floating equipment. If delays in operation and disruption of work schedules are not to be experienced, living and mess accommodations must be provided for the personnel on the site.

Drilling site facilities may all be accommodated on a large fixed platform or by a minimum sized platform with a floating tender carrying all equipment and facilities whose operation can tolerate the movement of the sea.

Sea Transportation. Sea transportation also is of primary importance in offshore operations. A glance at the map of the

Gulf of Mexico shows the few deep-water ports available, brings out the necessity for seaworthiness of all craft used, and emphasizes the problem of elapsed time in transportation.

Although maximum weather conditions are of primary importance in considering operations in open water, the more moderate wind and wave conditions are of almost as much importance as they will affect the continuity of operations, chiefly through transportation. If proper precautions are not taken serious damage can occur both to equipment being handled and to the handling craft, and the danger of injury to landing or embarking personnel is very high.

Radar, two-way frequency-modulated radio, and forecasts on the state of sea and weather are proving of considerable benefit in maintaining safe operation of transportation in off-shore operations.

Drilling Equipment and Techniques. Although open water drilling may eventually require radical changes in drilling equipment, the changes will be gradual. Attention must first be given to the development of smaller items of equipment and technique required for specific emergent problems of water operations. Emergencies will be more serious than in the most exacting operation on land and, as a consequence, critical equipment must be backed up by a stand-by or by replacement parts that can be installed with no interruption of service.

Field Development. With the completion of a satisfactory petroleum producer on an off-shore project, the problems of field development begin to occur.

The number of wells that can be drilled from a platform depends upon the depth of the production, the desired reservoir well spacing, the ability to drill correctly sloped holes and the cost of drilling them.

The minimum surface spacing of wells on a platform depends on judgment and experience in setting conductor strings and drilling the vertical portion of wells without subsurface interference. Six-foot centres are probably a minimum for wells 10,000 ft. or deeper and 10 ft. is more satisfactory.

With the completion of the first producing well, there comes the problem of protecting the drilling and producing site from the consequence of damaging the wellhead equipment by drilling operations, from the ignition of escaping hydrocarbons, and from the various other hazards connected with drilling and producing in close proximity. Completions should be made on a level below the drilling level and wellheads completely protected from falling equipment.

Producing Operations. In the transition from drilling to producing operations it will be found that at least a part of most facilities required for drilling will be needed also for production, particularly when the cost of removing parts of them and replacing them for well repair work with a rig is considered. During production operations, transportation costs will continue to be high by land standards, and the reduction of cost in this connection will depend to a considerable extent on proper planning, the developments made in transportation equipment, and on the volume of work. If several operations can be served by a common transportation system, the cost to each should be reduced.

The transportation of well fluids on a permanent basis involves the solution of a complex physical and economic problem. Initially for all locations floating transportation will be used, but pipe lines to shore should prove more economical, particularly for locations near shore.

Abandonment. Upon the abandonment of an operation, it will be necessary to remove all navigational hazards. Wells should be carefully plugged and in general, platforms removed to a depth of five feet below the mud line.

SUMMARY AND CONCLUSIONS

The continental shelves of the world are of tremendous area and include large volumes of possibly petroliferous sediments. The work to date in exploring such sediments on the continental shelf of the United States adjacent to the states of Louisiana and Texas indicates that considerable deposits of petroleum exist there but that their recovery will depend on the satisfactory solution of a broad complex economic and technical problem because the cost of operations to recover these deposits is initially much greater than that for comparable recovery on shore.

Bibliography

1. W. E. Pratt, "Petroleum on Continental Shelves", *AAPG Bulletin*, vol. 31, no. 4, pages 667–669.
2. M. H. Parks and J. C. Posgate, "Offshore Drilling and Development", Paper for Presentation to a Group Session on Drilling and Production during the Twenty-eighth Annual Meeting of the American Petroleum Institute, in the Stevens Hotel, Chicago, Illinois, November 10, 1948.

Summary of Discussion

The Chairman stated that the meeting might be divided into two parts: the first would be devoted to an examination of papers dealing with general methods of geological and geophysical prospecting for oil and gas discovery; the second part would be devoted to the examination of papers dealing with research, boring and exploitation techniques.

The discussion would therefore first be on the papers prepared by Mr. Lees, Mr. Migaux and Mr. Balsley.

Mr. Ion presented the paper prepared by Mr. Lees on a "Review of Techniques for Oil and Gas Discovery". The ninety-year history of oil prospecting had known three successive though overlapping phases: first, the position of wells had been determined by non-technical methods (seepage-drilling and wild-catting), then by geological mapping and finally, for the previous thirty years approximately, by geophysical mapping.

Prevailing circumstances forced one to conclude that no direct revolutionary method for the detection of oil would probably make its appearance in the near future. However, by improving, as far as possible, the geological and geophysical methods and instruments currently available, it might be hoped to find a considerable amount of oil in the many regions being prospected.

Mr. Ion stressed that the success of the search for oil in the United States was due, to a large extent, to the intensity of prospecting. Scientific prospecting had received valuable assistance from wild-catting: wells bored under those conditions had enabled considerable information to be obtained for geological deductions and geophysical interpretation. However, it should not be forgotten that wild-catting entailed constantly increasing expenses, which few prospectors could afford.

So far as the scientific future of exploration was concerned, Mr. Ion was convinced that science would not fail in its task and would render possible the discovery of huge reserves of oil; he wished to stress two principles which, in his opinion, should always be respected by all those engaged on the search for oil: (1) free exchange of the most important data; (2) the closest co-operation between members of the group of technicians interested in discovery problems, in other words, in addition to the geologist and the geophysicist, the oil technician, the chemist, the physicist, the microbiologist, the interpreter of aerial photographs, etc.

Mr. Blondel presented the paper prepared by Mr. Migaux on "Consideration of the Techniques of Oil and Natural Gas Prospecting". He indicated that, in their main lines, Mr. Lees' and Mr. Migaux's papers had many points in common; in presenting the latter he would therefore limit himself to stressing a few essential points.

As Mr. Migaux pointed out, the distinction between the geologist and the geophysicist, which had been so well marked some years ago, had diminished considerably. It had been gradually realized that all techniques, both geological and geophysical, were not truly effective unless they supported and supplemented one another, and that their results should be considered as a whole which was necessarily geological in spirit. The essential distinction between pure geology and pure geophysics lay in the fact that, in the first case, the sample studied could be handled by the technician, while, in the second case, the study was necessarily made from a distance.

Mr. Blondel found himself obliged to point out certain differences in views between Mr. Lees and Mr. Migaux. The latter considered that electrical methods, in general little used, might be very useful in many cases. In their most modern form, which had been developed in France since 1940 and was known as the telluric method, they could be used for general exploration and sometimes competed successfully with gravimetry. Mr. Blondel thought that electrical methods should be more generally used.

Mr. Migaux's conclusion was identical with Mr. Lees', namely, that it was possible to hope for progress in the near future in the immense undertaking of oil discovery, but that, unless the unexpected happened, the perfecting of revolutionary methods should not be expected.

The Chairman thought, like the authors of the papers which had just been presented, that a radical transformation of existing techniques should not be expected. The important problem to be solved was that of improving the possibilities of discovering oil; for that, the establishment of aeromagnetic surveys would be of considerable assistance; Mr. Balsley's paper dealt with that subject.

Mr. Balsley presented his paper on "Techniques and Results of Aeromagnetic Surveying".

The air-borne magnetometer was not entirely new: it was merely an improved version of the magnetometer which had been in use for many years. Its great advantage was that it provided an instrument for quick and economical geophysical studies. The results obtained were sometimes difficult to interpret, but that could not be imputed to the method of use.

He explained why the air-borne magnetometer was not well suited for making small detailed surveys of use in mountainous areas; he showed, on the other hand, that the instrument was particularly useful in areas which were difficult to traverse on foot; in combination with radio and radar location systems, the air-borne magnetometer could be used to conduct surveys over water or other unmapped areas.

He drew attention to the cost of aeromagnetic surveying: it had been found in the United States that the total cost per mile of aeromagnetic surveys had averaged about one-tenth that of ground surveys; in difficult terrain the cost might be less than one-hundredth.

To sum up, it might be stated, in spite of the criticisms which had been made of the air-borne magnetometer, that it could provide a low cost and reasonably accurate magnetic map which could be used to delineate localities for more detailed, but more expensive groundwork. Aeromagnetic and ground surveys did not duplicate or oppose each other; on the contrary, they supplemented each other and enabled the greatest profit to be obtained from their rational use.

The Chairman, on behalf of all the members, congratulated the authors of the papers which had just been presented, as well as the speakers who had summarized them. He invited delegates to express their opinions on the questions raised.

Mr. Ion stressed the similarity between Mr. Lees' and Mr. Migaux's conclusions on the distinction between the geologist and the geophysicist; it must be hoped that the team spirit was such in every case that that distinction remained purely academic.

Mr. Lowson noted that even in the United States where exploration was carried to its extreme, no methods were yet available to justify the statement that oil really existed where its presence was suspected.

Mr. Hubbert expressed the interests he had felt in the papers presented. He approved of all their conclusions regarding the circumstances that might be hoped for in the immediate future.

He wondered whether it would not be advisable to take up again, at the following meeting, the discussion on the estimation of reserves of oil and gas.

The Chairman said that that question might be discussed again at the end of the meeting if the agenda permitted.

Mr. Blondel recalled Mr. Lees' and Mr. Migaux's conclusions, on the absence of revolutionary methods and on the work of the geologist and the geophysicist. He thought that an important question, that of chemical analysis, had been neglected. It was in the possibility of using chemical analysis that the difference between the geologist and the geophysicist lay. It had been wondered, in France, whether it would not be possible to carry out chemical analysis from a distance. Such a conception had been utopian 30 years before, at a time when chemistry and physics had been considered as two entirely separate sciences; there was no longer any frontier between those two fields and it had been thought that it would perhaps be possible to determine from a distance the chemical characteristics of bodies: studies were being carried on in France on that subject; no conclusion could be presented at the current stage of research.

Mr. AGUILAR wished to stress the most important points in Mr. Lees' and Mr. Migaux's papers. The question of exchanging information was of particular importance: there were in all countries national professional groups to promote such exchanges of information; it would be desirable for an international society consisting of as many countries as possible to be established, for exchange of scientific and technical knowledge was becoming more and more necessary. He thought, like the preceding speakers, that the distinction between geologist and geophysicist was tending to disappear, because the geologist was becoming more and more the geophysicist. He recognized that at the moment there were no signs of any revolutionary method in the search for oil deposits; he thought such a method might be discovered if the aim of the search was modified. Attempts were being made currently to determine the geological conditions which indicated the possible existence of oil-bearing strata; a method would have to be conceived whereby the presence of oil might be established. As far as aeromagnetic surveys were concerned, he thought that that was a method in the first stage of its evolution and on which it would be premature to pass final judgment; its interest however was undeniable.

The CHAIRMAN indicated, in reply to Mr. Aguilar's remarks, that great hopes had been placed in geochemistry as a method of direct prospecting; unfortunately the practical results so far obtained had not been so good as might have been wished; nevertheless geochemistry was for the moment a method on which might be built, if perfected, the hope of a more certain indicative value respecting oil deposits.

Mr. GESTER approved of the conclusions which had been expressed on the competence of the geologist and the geophysicist respectively. He thought that geochemistry should not overlook the value of biochemistry; that field had great possibilities and it was to be hoped that it would be explored as far as possible.

In conclusion, he stated that, although the geologist and the geophysicist played a very important part in the search for oil, all the other technicians and scientists whose collaboration was indispensable should not be forgotten.

Mr. HUBBERT indicated that the scientific knowledge of a technician should be determined by the character of the phenomena he had to study. In the search for oil, the problem, in addition to being a geological one in the conventional sense, was also a chemical and a physical one; the geologist should therefore have an extensive knowledge of these two fields. To the extent that this is achieved, the distinction between geologists and geophysicists largely disappears.

Mr. WEAVER recalled that experience showed that oil was found in certain districts which fulfilled particular conditions; that led him to emphasize the importance of large-scale studies, which provided fundamental data on the general structure of the terrain; those studies might be carried out with the help of the air-borne magnetometer, the value of which could not be sufficiently emphasized, or with the help of gravimetric procedures or by seismic refraction. He was convinced that those large-scale studies were of greater general interest than detailed studies of certain points.

Mr. AGUILAR thought that some geologists should also become mathematicians in order to assist in detailed exploration; others, however, should retain their own poetical and imaginative character for it was necessary to "guess" the structure of the terrain.

Mr. WEEKS noted that the applications of geology in the field were constantly and rapidly changing and expressed his agreement with Mr. Hubbert's opinion that geological training in the colleges should give special emphasis to the fundamental subjects.

He did not, however, agree entirely with the statement which had been made by Mr. Ion in presenting Mr. Lees' paper, to the effect that there were no new tools on the horizon. In Mr. Weeks' view, a great new field for study was to be found in the analysis of oil occurrence. Something like 80 per cent of the oil in the world occurred in about 20 per cent of the basin sediments. There were certainly reasons for this phenomenon, just as there were reasons why gold, or salt, etc. occurred in certain places. Natural control of oil occurrence extended not only to the basins but to the major elements of the deposition basin's form or architecture. He believed that geologists could go a long way through the further analysis of these factors.

The CHAIRMAN announced that the second topic, an examination of the prevailing situation with regard to the discovery, drilling and production of oil, should be taken up.

Mr. SALNIKOV read his introductory paper on "New Developments in Drilling Equipment and Techniques".

He said that increasingly deep drilling had become necessary in order to discover the increasing quantities of oil which the world required. The rotary drilling method, which had made possible the drilling of very deep wells, had come into use only after 1900; it was, however, very costly. In recent years, the improvements in drilling equipment had made possible the penetration of strata to great depth. Such advances in techniques, which, however, had considerably increased drilling costs, had enabled producers to drill a large number of very deep wells. Thus, at the end of 1948 there had been 561 wells more than 12,000 ft. in depth in the United States. Three of those wells were more than 17,000 ft. deep; one, in Wyoming, reached 20,000 ft. The drilling of those wells had resulted in the discovery of 32 oil fields. Most deep drilling was currently carried on in the Texas-Louisiana coastal area, where formations were soft. Deep drilling in hard formation areas would be worth while only if it led to the discovery of particularly rich pools. The cost of drilling hard formations was from 50 to 150 per cent higher than that of drilling soft formations.

Drilling in areas outside the United States might be reckoned as considerably more expensive than within it. To the ordinary cost of operation would have to be added the freight cost of importing equipment from the United States and the considerable expense of carrying heavy material in regions inadequately provided with railways and roads.

It might be expected that drilling at increasing depths would become possible as equipment and techniques were improved. So long as existing methods were retained, however, operating costs might be expected to rise.

Some new method of drilling must therefore be found requiring limited investment, low maintenance cost and the employment of a crew of no more than two or three men. If such a method could be used for drilling to any desired depth, it would be an excellent substitute for the existing rotary method. Undoubtedly, to find such a method would be hard, but no harder than many of the difficulties which the oil industry had overcome in the course of the previous thirty years.

There was much oil still to be found. The ingenuity of the United States oil industry had made petroleum the most important single source of energy in that country and its importance was increasing similarly in other countries. It could be expected that oil would be found in sufficient quantity, as it had been in the past, and that it would be made available to the public at reasonable prices for many years to come.

Mr. Cirigliano presented the paper prepared by the Venezuelan Ministry of Development on "New Methods, Instruments and Equipment Used in the Production of Oil and Gas in Venezuela".

He emphasized that the oil industry in Venezuela, which operated under distinctly unfavourable natural conditions, had succeeded in making important innovations in both methods and equipment. The reinforced concrete piles and steel platforms currently used in lake operations in the State of Zulia, for example, had been introduced for the first time in Venezuela.

Another innovation was the use of safety valves to prevent accidents caused by collision between tankers and underwater installations.

Mr. Parks presented his paper on "Petroleum Production from Continental Shelves". He pointed out that the continental shelves included one-twelfth of the world's total ocean areas and might possibly contain deposits totalling more than 500 thousand million barrels of oil.

The principal operations were carried out on the United States continental shelf in the Gulf of Mexico, where it lay parallel to a prolific petroleum area. Operations had begun in 1945 and some fifty wells had already been drilled or planned. Nevertheless, even in relatively shallow water and at favourable locations, at a maximum of 60 ft. of water and nearly 30 miles from the shoreline, operations had been difficult and extremely expensive. There was reason to believe, however, that technical development would make it possible to exploit wells situated at depths and at distances from the shoreline greater than those which currently appeared possible.

The design of fixed platforms for drilling involved a number of difficulties caused by wind and wave pressures and by the need to place the lowest deck high enough to clear the greatest wave. It must be pointed out that the drilling platform must hold not only the equipment itself but also accommodation for the entire personnel; it thus made up a completely self-contained small town.

Transport was also a very difficult question in view of the lack of deep-water ports in the Gulf of Mexico. The use of radar and frequency-modulated radio and forecasts on the state of sea and weather had made it possible to maintain operation of transportation with the greatest possible safety.

The operation of under-sea fields also gave rise to special problems, particularly with regard to the protection of existing wells against possible damage from drilling operations.

In conclusion, when an operation was abandoned, all potential navigational hazards had to be removed.

Mr. Parks summarized and concluded by pointing out that work previously carried out in exploring sediments on the continental shelf of the United States indicated that considerable deposits of petroleum existed, but that their recovery depended on the solution of a broad, complex economic and technical problem because the cost of operations to recover those deposits was initially much greater than that for comparable recovery on shore.

The Chairman opened the discussion on the papers just submitted.

Mr. Uren thought that the papers read left nothing to be desired in the accuracy of their presentation. He would therefore confine himself merely to developing the ideas presented with regard to certain techniques of oil production which he thought important, but upon which the authors of the papers had not been able to dwell owing to lack of time.

A number of new techniques certainly could improve results: directional drilling, use of which had recently been developed in California for drilling deposits of crude oil, could undoubtedly be used in drilling the continental shelves in the Gulf of Mexico but required extremely accurate well surveys. Electrical logging, currently used in a considerable proportion of the wells, was one of the greatest advances achieved in the past twenty years; and, finally, methods which made it possible to assess the geological structure of the ground (orienting cores, etc.). Moreover, more attention could be paid to methods of well completion.

Mr. Salnikov had placed great weight on the technique of deep drilling, but it must be remembered that in the previous year the average depth drilled had still been about 1,250 metres. Less than two per cent of the wells had been more than 4,000 metres in depth. As the cost of drilling in the previous year had totalled 1,500 million dollars, it could be appreciated that drillers would try to reduce such costs; they should not, however, become over-fascinated by deep drilling. The improvement of the technique of drilling in general would bring the greatest saving.

The reduction of costs was not therefore necessarily a matter of seeking new technical methods. Production could be increased and drilling costs consequently reduced, by better management, by recruiting better trained staff, by spending less rig time and by improving cementing, well logging and the accuracy of well surveys. Drilling costs from 50 cents to $1.25 per minute, but drilling occupies less than half of the time.

In California improved management and working methods had made it possible to drill wells after the war at little more than the pre-war cost, although the price of the construction materials and labour had doubled.

Moreover, great attention should be paid to the spacing of wells, in order to reduce oil and gas wastage. A desire to produce cheaply frequently leads an operator to employ unsuitable methods. Such was the explanation of the low rate of oil currently recovered.

The Chairman observed that Mr. Uren's final remarks raised the broad question of the exploitation of oil reserves. The study of ways to eliminate methods which depleted reserves and unduly increased operating costs was desirable.

Mr. Ion commented upon Mr. Parks' paper. Production from deposits in the continental shelves, although of considerable interest, had its disadvantages. In that connexion Mr. Lees had stated that the shelf was in most cases merely an extension of the adjacent land mass and that only a few large oil deposits in the entire world were situated in coastal areas extending into the shallows.

With regard to gas wastage, he drew Mr. Uren's attention to a paper which would be submitted on behalf of the Anglo-Iranian Oil Company at the following meeting.

Mr. LIETZ raised another aspect of the question — the effect of multiple drilling upon the productivity of oil pools. He warned against the temptation to use low-grade, cheaper muds. Using oil-base muds admittedly meant risking an additional expense of 20,000 dollars per well drilled, but the use of low-grade mud would bring in only half of what the well might have produced.

Mr. AGUILAR wondered whether, in view of the operating cost for oil from the continental shelves, it was to the general interest and particularly to the interest of posterity that those deposits should be developed while large fields remained unexplored on shore. He wondered, moreover, how producers and commercial interests throughout the world could be ensured access to new markets for oil.

New Techniques for Increasing Production of Oil and Gas

26 August 1949

Chairman:

FRANCISCO MEDINA-OLIVIERI, *Jefe Departamento Técnico de Concesiones y Conservación*, OFICINA *Técnica de Hidrocarburos*, *Ministerio de Fomento*, Caracas, Venezuela

Contributed Papers:

Conservation in Production
D. COMINS, Anglo-Iranian Oil Company Limited, London, England

Conservation in Production of Petroleum
WILLIAM J. MURRAY JR., Chairman, Railroad Commission of Texas, Austin, Texas,. U.S.A.

New Oil and Gas Production Techniques in Venezuela
Ministerio de Fomento, Venezuela

Advances in Efficiency of Oil Recovery
MORRIS MUSKAT, Director, Physics Division, Gulf Research and Development Co., Pittsburgh, Pennsylvania, U.S.A.

Secondary Recovery of Petroleum
PAUL D. TORREY, President, Lynes, Inc., Houston, Texas, U.S.A.

The Swedish Shale Oil Industry
E. SCHJÅNBERG, Research Director, Swedish Shale Oil Co., Ltd., Orebro, Sweden

Oil from Oil Shale — Experience in the United States
R. A. CATTELL, Chief Petroleum and Natural Gas Branch, Oil Shale Research and Demonstration Plant Branch, United States Bureau of Mines

Oil Shale in Brazil
ANIBAL A. BASTOS, Geologist, National Department of Mineral Production, Brazil

Summary of Discussion:

Discussants:

Messrs. LOWSON, MURRAY, CIRIGLIANO, MUSKAT, BRUNDRED, HOGG, LIETZ RICHTER, CATTELL, ABREU, JACQUE

Programme Officer:

MR. J. H. ANGUS

Conservation in Production

D. COMINS

ABSTRACT

Long-term experience covered in the paper is limited:

(*a*) To limestone reservoirs, over 98 per cent of Anglo-Iranian Oil Company's total production of over 2,000 million barrels (nearly 300 million tons) having been from these, and

(*b*) To fields operated under "unit control".

After reference to the large Kuwait sand-fields and the small English sandstone fields, the inherent differences between sand and limestone reservoirs are discussed. The economic importance of three overriding factors in the evolution of operating techniques in the Iranian limestone fields is emphasized, these being freedom of reservoir connexion as a result of fissuring, unified control of natural producing units, and provision of facilities for scientific investigation.

Techniques outlined cover:

1. The development of oil-fields with the minimum number of wells.

2. Control of production distribution and of movements of gas-oil and oil-water interfaces in reservoirs to prevent production of any free gas or water and to conserve reservoir energy.

3. Multistage gas separation for gasoline retention in lieu of treatment plants and estimation of forward flowing pressures from energy considerations.

4. Recycling of temporarily surplus residue to reservoirs to increase refinery flexibility and to recover valuable light fractions of reservoir crude which would otherwise be left behind in gas domes.

The policy running through these techniques is shown to be prevention rather than cure and the economic results are demonstrated by reference to behaviour of the older Iranian fields.

The presentation of this contribution has been approved by the directors of Anglo-Iranian Oil Company, Limited.

From 1911, when production started from the first of the Company's fields, Masjid-i-Sulaiman in Iran, to the end of 1948, the crude oil production of Anglo-Iranian Oil Company, including its share of the production of associated and subsidiary companies, has exceeded 2 billion barrels (nearly 300 million tons). During 1948 the rate of production averaged over 600 thousand barrels per day.

Roughly 98 per cent of total production and 89 per cent of the 1948 production has been from limestone reservoirs and 93 per cent of total production and 86 per cent of the 1948 production, has been from oil-fields under the undivided control of the company.The remainder was from fields which, by agreement between the owners, have been operated under unified economic and technical management.

Against this background two facts stand out. Firstly, it is only in respect of limestone reservoirs that any major contributions to the subject of "conservation in production" can be made with the backing of long-term experience. Secondly, the company has had long and perhaps unparalleled experience in the operation of great oil-fields as natural economic units, uncomplicated by the conflicting interest of multiple independent operators owning sections of such units. By a "natural unit" is meant the whole of any underground accumulation of oil, of which any part is affected in any way by production from any other part.

In so far as sand-fields are concerned, the Company's only operating experience is that which has been gained by cooperation with the Gulf Oil Company in the recent rapid development of the great and prolific Kuwait oil-field and, at the other end of the scale, in the exploitation of the small oil-fields which have been developed in England during the past ten years.

In the former, the technique of running and cementing casing throughout the whole productive series and employing "gun perforation", i.e., shooting of bullets through the casing and cement, to bring the prolific sands in this field on to production from such intervals as may be desired in each well, has proved to be economic; as providing selective flexibility in completion of wells, avoiding complications due to sand inflow when on production, and leaving wells in such condition that any gas or water encroachment can be readily cemented off in the future. Potentially productive intervals, for gun perforation if desired, are readily recognizable on this field by means of "electric logging", system of underground surveying of reservoir rocks by which their porosity, permeability and nature of fluid content are indicated by variations in electrical response. This technique is a substantial time and money saver, as greatly reducing the amount of slow and expensive mechanical "coring" otherwise necessary to obtain similar information during the actual drilling of the wells.

As regards the English oil-fields it may be mentioned in passing that routine "shooting" of the comparatively unprolific sandstones with large charges of explosive and "secondary recovery" by means of water injection to the peripheral edge water of sandstones which have been depressured by production, have both proved to be of economic benefit in maintaining or increasing production.

Before discussing experience in limestone reservoirs, it is perhaps desirable, for the benefit of readers unfamiliar with the business of producing oil, to observe that, although there are of course all gradations of limestone and of sand or sandstone reservoirs, it is as true as any generalization can be that in limestone reservoirs porosity and permeability are, on the average, much less and fissuring liable to be much greater. The result is that even though limestone wells, when fed by fissures, are liable to be of higher and more sustaining productive capacity, the amount of oil *in situ* expressed as a percentage of the reservoir rock, is normally less than in sand-fields. Furthermore, the recovery of this oil involves two systems, that of the fissures and that of the porous limestone, whereas in an ideal homogeneous sand-field it is almost entirely a question of recovery from pores. Although the percentage recovery of oil from fissures is very high indeed, the permeability of limestone is often so low that very little oil can be recovered from it directly into the exposed borehole of producing wells; recovery is a matter of drainage from the pores via the vast area of fissure surfaces exposed to them, and thence to the wells.

The scope of this paper does not permit any fuller dissertation of these questions. It is however essential to any proper understanding of the economic development in the limestone fields which are the main subject of this "experience paper" to appreciate that reservoir connexion is much freer in them than in sand-fields, thus greatly facilitating observation of the results of any particular operation.

This exceptional freedom of limestone reservoir connexion was recognized in the Masjid-i-Sulaiman oil-field about 1923 and later proved to extend over distances measurable in tens of miles. This, and the facilities for "unit control" resulting from the concessionary terms granted by the Iranian Government and for scientific underground control immediately instigated by Lord Cadman (late chairman of the company), have been the major factors in the evolution of the company's technical policy.

The overriding economic importance of unit control and of a scientific approach to the problems of oil-field development and production has, for many years, been increasingly recognized by the oil industry as reducing overheads and ensuring maximum utilization of the forces of nature and maximum conservation of natural resources.

The important techniques bearing on conservation of production which have since been evolved in the Iranian fields to date are outlined below. It cannot be stated that these are "new techniques"; they have been in operation long enough to stand the test of time. On the other hand, they still represent current practice and are being applied in varying degree, not only in the new fields being developed by the company, but by other companies operating similar limestone fields in the Middle East. No attempt is made to cover the accountancy of these techniques, this being impracticable, for each is part of an integrated whole. In any case, as will be apparent, the economic benefits are far beyond question. The Masjid-i-Sulaiman field for example, during the 38 years it has been on production, has yielded over 800 million barrels and is still producing 70,000 barrels per day without pumping equipment, gas compression plants to lift the crude, or water separation plant. These facts are evidence enough.

The touchstone of economy in operation of fields remote from industrial development, such as these in the Middle East, is that the techniques involved should be simple and result in a minimum of operating staff; for the number of men in the front line of drilling and production is a small proportion of the number employed in ancillary services necessary to maintain them, both at the fields and on the lines of communication. The essential simplicity of the following operations should not however deflect attention from the necessity for maximum scientific exactitude in obtaining and interpreting underground information:

1. The oil-bearing limits above oil-water level of a new structure are delimited and blocked out with as few widely spaced wells as possible.

The initial location of these is based on geological and geophysical conceptions of structure tied in with petroleum engineering estimates of the probable depth of oil-water level, based on regional water pressure considerations. Co-operation is essential – the drilling of the discovery oil well in the Naft Safid field was due to pressure estimates indicating that oil-water level would be far below apparent structural closure to the water zone between this field and the adjacent Haft Kel field. In the same field however a subsequent jump of ten miles, based on structural estimates, was successful in striking the narrow oil annulus between the overlying gas dome and the underlying water.

Risk of failure to prove oil in delimitation wells is readily accepted since, as described later, a failure will in any case fit into the pattern of production control as an "observation well".

The economic benefits of this technique are that information is rapidly obtained to enable some preliminary assessment of reserves to be made, and a balanced production drilling programme and production plant scheme to be formulated.

2. Production wells are in the first instance spaced at one to two-mile intervals. "Observation wells", which are left shut in, are provided, some fortuitously, at initially much wider intervals. In these wells gas, oil and water pressures, and the position of the gas-oil and oil-water interfaces are observed periodically.

3. Based on these observations:

(*a*) Close estimates are made of reserves and therefrom the economic optimum rate of offtake from the field is determined, a practical rule of thumb figure being five per cent per year.

(*b*) The percentage of this production to be drawn from different sections of the field is so allocated as to ensure uniform and horizontal change in the gas-oil and oil-water interfaces, these allocations being revised as necessary as field depletion proceeds.

4. Further production wells are then interspersed between the initial ones in areas where this is necessary to produce the area quota, unless this can be wholly achieved by acid treatment of the original wells. The depth at which these wells reach the producing formation is chosen to ensure maximum life, in so far as this can be assessed at the time from the observations of the rate of change of the levels of the gas-oil and oil-water interfaces as a result of production from the field.

The maximum rate of production from individual wells at any given time is limited by the area quota and by the proximity of the falling gas-oil and rising oil-water interfaces. Furthermore, routine checks are made to ensure that the producing gas-oil ratio does not exceed that corresponding to the gas in solution in the reservoir crude as determined from bottom hole pressure samples. An electrical check is made to ensure detection of any trace of water in the crude.

The economic benefits of 2, 3 and 4 are:

(*a*) Minimum number of wells. For example, only 43 wells, including observation wells, have ever been completed in the great Haft Kel field which was fully developed on these lines. After producing over 800 million barrels during the past twenty years, over 75 million barrels were produced from this field in 1948 from 20 production wells.

(*b*) Nil production of water. Nil production of free gas, with consequent maximum conservation of free gas in the reservoirs and of energy available to lift the crude to surface.

(*c*) Any necessity for surface plant for water separation, for lifting of crude, or for gas recompression in order to maintain reservoir pressure and production by natural flow, is therefore eliminated.

5. Surface plant expenditures are reduced by dispensing with plant for recovering gasoline from the gas produced. Instead, the bulk of gasoline fractions in the gas is retained in the crude delivered to pipelines bij a technique of "multi-stage gas separation", which merely requires a number of separators operating in series in progressively decreasing pressure stages, the number of these being usually seven. This process also retains some lighter fractions temporarily which are separated at the refinery and usefully used in place of liquid fuel.

Determination of the inherent energy in the reservoir crude and the results of a mathematical investigation into losses of energy during flow to surface, combined with ability to forecast the future drop in reservoir pressure from extrapolation of measurements in observation wells, enables such plants to be engineered with sufficient confidence that future flowing pressures will be adequate for their operation.

6. A technique which has so far only been carried out on a major scale in the Masjid-i-Sulaiman field, is the recycling to the reservoir via the gas dome of any products temporarily surplus to refinery requirements. The bulk of such products has been residue, of which over 100 million barrels have been recycled during the past twenty years. As this amount constitutes about one-third of the remaining recoverable reserves in this field and yet the crude produced still contains less than 4 per cent of reproduced residue, it is clear that interchange, presumably by diffusion, has taken place in the reservoir between residue injected to fissures and the light reservoir crude remaining undrained from the pore system of the gas dome as distinct from the fissure system.

The economic value of this technique, as providing great flexibility in refinery operation without excessive tankage, needs no emphasis, but it is also a unique means of conservation of production in the sense that valuable fractions of reservoir crude, which would otherwise not have been recovered, are in fact recovered.

In conclusion, it will be noted that the thread which runs through all these techniques, apart from the last named, is prevention rather than cure — prevention of redundant drilling, prevention of water trouble, prevention of waste of gas and of reservoir energy and prevention of loss of gasoline fractions from the crude produced.

Bibliography

(Confined to Iran limestone fields)

1. Sir JOHN CADMAN, "Unit Operation in Persia" introducing paper by D. COMINS, "Unit Operation in Oilfields", *A.P.I. Bulletin*, 9th annual meeting, section III (December 1928), pages 31–32 and 32–36.
2. C. J. MAY, "The Efficiency of Flowing Wells", *Journal I.P.T.*, vol. 20, no. 125 (March 1934), pages 214–247.
3. D. COMINS, "Some Applications of Metering in Oilfield Operations", *Journal I.P.T.*, vol. 24, no. 173 (March 1938), pages 140–169.
4. H. S. GIBSON, "Multistage Stabilization of Crude", A.I.M.E. *Transactions:* Petroleum Division, vol. 136 (1940), pages 25–36.
5. H. S. GIBSON, "The Production of Oil from the Fields of Southwestern Iran", *Journal Inst. Petrol.*, vol. 34, no. 294 (June 1948), pages 374–398.

Conservation in Production of Petroleum

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ABSTRACT

Most petroleum reserves are found in minute pore spaces of reservoir rock. The oil has no inherent ability to expel itself from the pore spaces but must be displaced by some fluid, generally gas or water. Reservoirs are classified according to the displacing medium employed: dissolved-gas drive, gas-cap drive, and water drive. Dissolved-gas drive is inefficient with recoveries from 15 to 30 per cent of the oil in place; gas-cap drive recoveries usually range from 30 to 50 per cent, but may reach 80 per cent under proper conditions and control; water-drive recoveries range from 60 to 80 per cent. Through excessive rates of production and inefficient gas-oil and water-oil ratios, reservoirs which possess natural gas-cap or water drives may be converted to inefficient dissolved-gas drives. Conservation in production, therefore, largely rests upon utilization of a natural water drive or gas-cap drive, if present, and conversion of an inefficient dissolved-gas drive into an artificial water or gas-cap drive through injection of water or gas. It has been estimated that average efficiency of recovery to date has been less than one-third. Although much additional research into improved techniques of recovery is needed, methods already developed and proven practical could greatly increase average recovery if uniformly practised.

INTRODUCTION

The use of petroleum hydrocarbons is becoming increasingly important to the economy of most nations. Increased dependence upon petroleum-fueled internal combustion engines in transportation and agriculture, increased use of petroleum hydrocarbons for domestic heat and light, and increased synthesis of rubber, explosives, plastics, fertilizers, glycerine and other important chemical compounds from petroleum hydrocarbons have contributed to the greater economic significance of oil and gas. Since exhaustion of the world's supply of petroleum reserves would adversely affect a considerable portion of its population, conservation in production of petroleum is of importance not only to the producing areas of the world but also to the consuming areas.

The author of this paper shares the view of those who have been responsible for setting up this conservation congress that there is an imperative need for world-wide conservation of all of our natural resources if civilization, as we know it, is to survive. This writer also agrees that there is a lag between scientific development of conservation techniques and general application of these techniques.

This is particularly true of oil recovery. Although it is recognized that there exists an urgent need for further research and for scientific advancement in petroleum-conservation techniques, it is nevertheless believed that uniform application, in the oil-fields of the world, of those techniques of efficient operation which have already been discovered and proven practical would vastly increase the ultimate recovery of oil from these fields.

Consequently, confronted with the problem of surveying briefly a subject which would require volumes to cover adequately, and facing the further difficulty of an audience of divers training and experience, this author has concluded that the cause of conservation would be best served by endeavouring to present with technical accuracy, but in lay language, the basic principles of oil-recovery mechanics, so as to convince all readers of the need for, and benefits from, oil-conservation practices. This necessarily precludes complete discussion of recent technological developments which would be desirable if the audience consisted only of petroleum experts.

In writing this paper, the author has drawn upon the accumulated technical experience of the petroleum industry in its world-wide operations and the vast and rich field of technical literature describing these experiences. The author has had first-hand experience as an oil-field worker, consulting petroleum engineer, independent producer, and public official administering waste-prevention regulations. This experience has been helpful in preparing this paper; however, the conclusions presented herein are not original with the author, but to the best of his knowledge represent the consensus of opinion of petroleum engineers and production technologists. An adequate bibliography of the literature upon which this paper has been based would be as long as the paper itself. Consequently, reference is given only to a few selected articles of general nature and petroleum bibliographies from which one can find adequate coverage of the literature on any particular phase.

MECHANISMS FOR OIL RECOVERY

The objective of conservation in production is considered to be securing maximum ultimate recovery from the reservoir consistent with sound economics. Since the conservation practices described herein are those which may be performed at a profit, that is, the increased yield of oil and gas exceeds in value the increased costs, it must follow that failure to practice these conservation techniques uniformly is evidently based upon a lack of understanding of fundamental petroleum-reservoir mechanics. Such lack of understanding may rest with the oil producers, royalty owners, landowners, regulatory bodies, government officials, legislative bodies or the general public; and it is immensely important that all such groups have a better understanding of the fundamentals of sound conservation practices.

Underground petroleum reservoirs have been popularly termed "oil-pools" for so long that, as a consequence, a general misconception exists that oil occurs in underground rivers or lakes from which it may be drained as from a tank. Instead, oil is found almost universally in the minute interstices of porous rock such as sandstone or limestone. Oil contained in such pore space is like water in a sponge and has no inherent ability to expel itself. It must be ejected by some displacing fluid. A displacing fluid is necessary, not only as the source of energy to force the oil through the tiny connecting channels between pore spaces, but also to occupy physically the pore space vacated by the oil produced. This is the only mechanism by which oil can be recovered unless the reservoir rock is to be mined and its oil content then extracted. Such mining in most of the reservoirs throughout the world is prohibitively expensive.

Conservation in production of petroleum therefore requires the efficient utilization of the displacing mediums which are available to recover the oil. It is natural, then, that oil reservoirs should be classified according to the expulsion mechanism utilized. The classifications generally employed by technologists are: (1) dissolved-gas drive, (2) gas-cap drive, and (3) water drive.

DISSOLVED-GAS DRIVE

Oil in its natural state in an undergound reservoir is always compressed, the pressure generally being proportional to depth and approximately equivalent to the hydrostatic pressure of a column of salt water of equal depth, or approximately one-half pound per square inch per foot of depth. There is almost always found associated with oil substantial quantities of natural gas, either completely or partially dissolved in the oil. The dissolved gas, aside from being a source of energy, has the physical effect of reducing the viscosity of the oil and rendering it more fluid and mobile.

When more gas is present than can be dissolved in the oil under reservoir temperatures and pressure, the excess gas occupies the pore spaces in the upper portion of the reservoir which is then termed a "gas cap". The gas in this gas cap is also under pressure and may therefore serve both as a displacing medium for ejecting oil and, because of its expansibility, as a source of energy.

The source of pressure under which both the oil and gas are confined is almost always hydrostatic, being transmitted to the oil through the water forming the lower seal of the oil accumulation. Under favourable circumstances, this confining water may be made to enter the oil zone, flushing oil from the pores and acting like gas as a displacing fluid and source of energy.

In some reservoirs, all of the gas present is dissolved in the oil, there being no excess to accumulate as a gas cap, and the column of water which originally caused the oil and dissolved gas to be compressed has been sealed off from the oil reservoir by geologic factors. Production from such a reservoir, because of the relatively low compressibility of a liquid, quickly reduces the reservoir pressure below the saturation pressure and gas begins to come out of solution. Each bubble of gas coming out of solution throughout the reservoir rock must occupy pore space formerly occupied by oil, and consequently displaces this amount of oil into the producing wells.

This initial escape of gas from solution results in efficient production of oil for a relatively short period of time until the percentage of free gas distributed throughout the reservoir, measured in terms of total reservoir pore space, reaches a certain critical level, usually in the range of 5 to 20 per cent. At this critical level, the free gas which has come out of solution and has hitherto remained stationary as tiny bubbles distributed throughout the reservoir pore spaces, now begins to move towards the well bores along with the oil; and being several times as fluid and mobile as the oil, it escapes from the reservoir through the producing wells far out of proportion to the amount of oil produced.[1]

[1] Space does not permit a discussion of the phenomena relative to the flow of two and three fluid phases through a porous medium, but

The production of this gas further lowers the reservoir pressure, causing more dissolved gas to come out of solution which, in turn, increases the viscosity of the oil and reduces its ability to flow through the reservoir pore spaces. With the continued decline in pressure, gas escapes more rapidly as relative permeability increases and sweeps a lesser portion of the more viscous oil with it into the well bores. This continues until the gas dissolved in the oil has been dissipated, at which time production substantially ceases because the reservoir is devoid of any displacing fluid to force oil from its entrapment in the pore spaces of the reservoir rock. This type of producing mechanism is known as dissolved-gas drive and is relatively inefficient, with recoveries generally ranging from 15 to 30 per cent of the oil initially in place.

GAS-CAP DRIVE

In the second classification of reservoirs there is, as in the first case, essentially no movement of water into the oil-bearing and gas-bearing reservoir; but in this case, gas in excess of that amount which can be dissolved in the oil under reservoir conditions lies in a gascap above the oil. In such a reservoir, by opening the well bore only to the lower oil-bearing portion of the producing formation, it is possible to obtain a selective production of reservoir fluids so that only oil and the gas which is dissolved in it are produced from the lower portion of the reservoir, while the gas in the gas cap expands downward and displaces oil out of the pore spaces into the well-bore. This producing mechanism is called gas-cap drive. So long as it is possible to prevent the escape into the well-bore of the free gas contained in the gas cap, it is an efficient producing mechanism with recoveries which range from 30 to 50 per cent and occasionally as high as 80 per cent of the oil in place.

WATER DRIVE

In the third category are petroleum reservoirs which are surrounded by large volumes of compressed water occupying contiguous and continuous portions of the porous rock in which oil has accumulated. Initial production of oil brings about a reservoir pressure differential which results in movement of water into the oil-bearing portion of the reservoir, displacing oil out of the pore spaces and forcing it ahead of the encroaching water front into the producing well. After the initial pressure differential has been established, it is possible, if the total production of fluids, i.e., oil, gas and water, is restricted to the rate at which water enters the reservoir, to maintain the reservoir pressure with little further decline. The high level at which the reservoir pressure is thereby maintained retains most of the gas in solution, and the oil consequently remains fluid and mobile. Since water wets the reservoir rock, it more efficiently displaces oil from the capillary pore space than any other displacing medium. A reservoir produced under the above conditions is said to be a reservoir under water drive, and this represents the most efficient of all natural producing mechanisms. Recoveries usually range from 60 to 80 per cent of the oil in place.

GRAVITY DRIVE

In addition to the three classifications described above, some technologists employ a fourth called "gravity drive". Gravity is an important factor in maintaining segregation between gas, oil and water, and it makes possible the selective production of fluids which is important to efficient recovery. However, gravity is so rarely the only source of energy in recovery that this fourth classification is not generally employed.

COMBINATION GAS-CAP AND WATER DRIVES

Combination gas-cap and water drives are prevalent. In such cases, the maintenance of a fixed gas-oil contact, while the oil-water contact moves upward, is generally the most efficient. A combined downward expansion of the gas cap and upward influx of water is frequently employed and can be almost as efficient. However, any shrinkage of the gas cap and upward movement of oil into the gas-saturated zone results in severe loss in ultimate recovery, since the oil wets the reservoir rock and capillary attraction prevents its subsequent recovery.

FACTORS INVOLVED IN EFFICIENT PETROLEUM RECOVERY

EFFICIENCY OF MECHANISM OF RECOVERY

From the discussion of the three basic types of control, it is apparent that the dissolved-gas drive is inherently inefficient. It is a depletion type mechanism. There can be no selective withdrawals of fluids. The displacing medium, dissolved gas, comes out of solution throughout the reservoir and cannot be prevented from escaping from the reservoir except under very special conditions to be discussed later. The gas-cap and water-drive reservoirs represent displacement rather than depletion mechanisms. The forces have direction. They each maintain a portion of the reservoir continuously saturated with oil, and by opening the bore hole only to this zone, it is possible to selectively produce fluids from the reservoir.

Gas-cap and water drive under proper conditions, many of which are controllable by man, can be almost equally efficient and are several times more efficient than dissolved-gas drive. The need for avoiding dissolved-gas drive, if possible, is therefore apparent. It should be emphasized that, although gas-cap and water-drive reservoirs represent conditions created by nature, it is possible, by unintelligently and inefficiently utilizing the natural sources of reservoir energy, to convert such a reservoir from an efficient water or gas-cap drive type into an inefficient dissolved-gas-drive type.

If, in a water-drive reservoir, oil is produced from the reservoir at a rate more rapid than water can move in to replace the produced oil, then the reservoir pressure must inevitably decline; gas comes out of solution and escapes from the reservoir; and the oil, stripped of its dissolved gas, becomes more viscous and flows with greater difficulty through the pore spaces. There is, consequently, a further lowering of pressure and further dissipation of dissolved gas, with the result that a reservoir which could have been produced with a high ultimate recovery under a water drive may by overly rapid rates of production be produced under the very inefficient dissolved-gas drive.

Likewise, in a reservoir producing under a gas-cap drive, if sufficient care is not taken to open the well bores only to the oil-saturated zone and gas from the gas cap is allowed to escape with the oil, or worse still, if gas is produced from gas wells drilled into the gas cap of the oil reservoir, then the gas in the cap may be dissipated and the oil finally produced under the inefficient dissolved-gas drive.

the relationship between permeability and saturation of the various fluid phases is well described in the literature on relative permeability.

Not only may man change efficient natural-reservoir producing characteristics into inefficient methods of production, but he may also change inefficient reservoir drives into more efficient mechanisms of recovery. It is sometimes possible, in the case of a dissolved-gas-drive reservoir, to shut in wells located in the upper portion of the reservoir and by slow rates of production from the lower portion of the reservoir to allow the gas which comes out of solution to accumulate in the upper portion of the reservoir so as to form an artificial gas cap and thereby convert to a gas-cap drive. This method is only occasionally possible, but it is frequently practical through the injection of the produced gas into the upper portion of the reservoir to build an artificial gas cap. This procedure is known as pressure maintenance, secondary recovery, or repressuring and can very materially increase ultimate recovery. Moreover, it is profitable in many solution-drive reservoirs to inject water, either into the lower portion of the reservoir, around the periphery of the reservoir, or at one end of an elongated reservoir so as to create an artificial water drive. This procedure is generally called "water flooding" and frequently results in more than doubling the ultimate recovery.

With the realization of the importance of utilizing one of the two efficient displacing mechanisms of reservoir control rather than the inefficient depletion type, the need therefore becomes apparent to recognize as early as possible the type of drive which a newly discovered reservoir possesses. As soon as an oil reservoir has been completely outlined, it is possible to determine by analysis of the data obtained in drilling whether or not a gas cap exists. It is, however, more difficult to determine whether an effective water drive is present. This frequently can be inferred from a comparison with similar reservoirs located in the area. As a general rule, but by no means devoid of exceptions, reservoirs in the same general area, producing from the same type of structure and the same geologic horizon, will have the same type of drive. However, there is no way of proving whether or not a water drive exists except by observation of reservoir performance as production goes forward.

"Material balance" calculations, excellently described in the technical literature, utilize observed reservoir and production data and furnish a quantitative determination of the rate of water influx into an oil reservoir. In the absence of material balance calculations, it is possible to determine the existence of a water drive by observing reservoir pressure decline at various rates of production. If a water drive is present, the decline per unit volume of oil produced will be less at lower rates of production.

If neither a gas-cap nor water drive is present, then by elimination it becomes evident that the reservoir must operate under a dissolved-gas drive.

RATE OF PRODUCTION

Having analysed the various types of reservoir producing mechanisms and compared their relative efficiencies, a discussion should follow of the factors controlled by man which affect efficiency of recovery. One of the most important is rate of production. Its effect on a water-drive field is believed apparent from the discussion which has already been presented. It is also important in a gas-cap drive reservoir because the oil must be produced slowly enough to allow a continual gravitational segregation between oil column and gas cap. At too rapid rates, gravitational segregation is not maintained, and gas is given an opportunity to "cone" downward into the well bores, thereby inefficiently exhausting the displacing medium. Rate of production is not as important in a solution-drive field as in the other two types of drive, but the only way to attain efficient recovery is through creation of an artificial gas-cap or water drive, and rate of production, therefore, again becomes important.

Recognition of the importance of rate of production in efficiency of recovery has resulted in common use of the term "MER", standing for "maximum efficient rate". A more accurate term probably would be "maximum rate of efficient production". In all reservoirs, regardless of type of drive, the efficiency of recovery, other factors being constant, varies inversely with the rate of production. The relationship between rate of production and efficiency of recovery varies from one type of reservoir mechanism to another and varies between different reservoirs having the same type of recovery mechanism. In any given reservoir, it is generally found that there is a region where an increase in the rate of production does not materially decrease the ultimate oil recovery, but that after a certain rate of production is reached, further increases seriously, and at an accelerating rate, operate to the detriment of the reservoir and result in a materially reduced ultimate recovery.

The rate of production at this transition region is referred to as the MER. As a general rule, MER's are in the range of rates which will produce 4 or 5 per cent annually of the expected ultimate recoverable reserves. There are fields the MER for which, based purely upon engineering principles, would be in the range of 1 per cent annually of their expected recoverable reserves, but practical economic considerations dictate a higher rate of production. It is rare that a field can efficiently produce more than 5 per cent of its recoverable reserves annually, and any rate in excess of this figure should be considered wasteful unless exceptionally conclusive evidence to the contrary can be presented.

RATIO OF GAS AND WATER PRODUCTION TO OIL PRODUCTION

In addition to rate of production, the ratio of gas and water production to oil production materially affects efficiency but is subject to a considerable degree of control. Production of gas in excess of the quantity dissolved in the oil is generally inefficient. A solution ratio should be determined for each reservoir, but generally it will be found to be less than 1,000 cub. ft. of gas per barrel of oil. Consequently, ratios above this level are undesirable although sometimes unavoidable.

When the natural characteristics of a reservoir render impractical the selective production of oil so as to avoid gas-oil ratios above solution ratio, it is generally feasible to return the free gas produced with the oil to the gas cap of the reservoir which, in a solution-drive field, will establish an artificial gas cap.

Although its importance as a displacing medium is not always recognized, production of water from a reservoir has essentially the same effect on pressure decline as the production of equal volumes of oil or gas, and serious loss in ultimate recovery can result from excessive water-oil ratios.

In some water-drive fields, it is impossible or impractical to selectively produce oil without producing large quantities of water, and in such cases it is usually feasible to return the water to the producing reservoir. The East Texas field serves as an example. It was possible from the physical standpoint to selectively produce the oil with relatively small quantities of water, but divergent ownership made it impractical to do so. Consequently, a co-operative water injection programme was instituted which is presently returning about 500,000 barrels daily of produced water to the oil-bearing reservoir. Such water injection is probably nearly doubling the MER for the field, and may increase ultimate recovery by about 500 million barrels.

CO-OPERATION BETWEEN OR REGULATION OF PRODUCERS

The discussion this far has dealt with a consideration of reservoirs as a whole. Most oil reservoirs in the United States have divers ownership. Consequently, the reservoirs can be operated as a whole only through co-operative arrangements between the various producers. Divers ownership does not alter the basic principles of conservation; it simply makes attainment of these conservation principles more complex. Regulation by a public authority and co-operation between producers have represented the best approach so far to reconciliation of divers ownership and efficient practice. A compromise between complete conservation and confiscation of individual property rights must be reached in most cases.

For example, regulatory bodies generally penalize the allowable of wells producing with inefficient ratios but do not require that they be shut in. Similarly, gas wells located in the gas cap of an oil reservoir are allowed to produce at severely restricted rates.

Co-operation between producers frequently attains a more satisfactory solution of equities and a higher degree of conservation than can be accomplished through regulations. Such co-operation takes various forms. As has previously been discussed, the operators in the East Texas field have joined together to organize a co-operative water injection company which takes the water produced throughout the field and returns it to the reservoir. In other cases, the operators co-operatively build plants to collect and process the gas produced incident to the production of oil and either co-operatively market or re-inject this gas into the producing reservoir. In still other cases, operators are able to reach an agreement by which all of their separate interests are "pooled" or "unitized" so that the field may then be produced as a whole and each operator receives his *pro rata* portion of the revenue. Such unitization is generally found to be most feasible and desirable where a pressure maintenance programme of gas or water injection is involved.

PRODUCTION PRACTICES FOR NATURAL GAS

Space permits only a limited discussion of efficient production practices for natural gas. Gas occurs in two fashions—associated with crude oil and in separate reservoirs where no oil is found. The role of associated gas in the production of oil has already been discussed. This is its most important function. After production, it should be reserved for injection into the producing reservoir if needed to increase oil recovery. If not needed for injection, it should be collected, processed for its liquefiable hydrocarbon content, and the remainder delivered to a market whenever economically possible.

Efficient production of non-associated gas is relatively simple. It should, of course, never be wasted into the air. Underground leakage by reason of improper well completion or corroded pipe should be avoided. Deep, high pressure reservoirs, having a high content of liquefiable hydrocarbons, must be produced without pressure decline in order to avoid "retrograde condensation", a phenomenon well described in the literature. If such a reservoir has an effective water drive, it is only necessary that gas withdrawals be restricted to the rate of water influx. If no water drive is present, pressure should be maintained by gas or water injection until the liquefiable hydrocarbons have been recovered.

CONCLUSION

In conclusion, petroleum hydrocarbons have become increasingly important to the welfare of man. Although much progress has been made in efficient production practices, the record to date is that far more oil has been left underground than has been recovered. Much of the oil which we have been leaving underground can be recovered through a more efficient utilization of the two displacing fluids generally present, gas and water. Substitutes for petroleum can be obtained from coal and oil shales, but increased efficiency of recovery from natural petroleum deposits is a much cheaper and more satisfactory source of additional reserves. Better petroleum production practices will play an important part in the over-all conservation of natural resources so vital to civilization.

Bibliography

As stated in the text, a complete bibliography of the reference material for this paper would be too lengthy for presentation here. The first reference listed, therefore, is a relatively complete bibliography of petroleum literature in which reference to various phases of conservation may be found. The remaining publications listed are of general nature, and most of them contain bibliographies of the pertinent literature on the particular subject being discussed.

Reference bibliography

E. DeGolyer and Harold Vance, "Bibliography on the Petroleum Industry", Bulletin 83 of the Agricultural and Mechanical College of Texas, College Station, Texas, 1944.

Basic conservation principles

Special Study Committee of the American Petroleum Institute, "Standards on Allocation of Oil Production", The American Petroleum Institute, Dallas, Texas, 1942 (contains selected bibliography of 216 articles).

"Report of the Engineering Committee of the Interstate Oil Compact Commission", Oklahoma City, Oklahoma, 1941.

Gas Conservation Engineering Committee, "Report on the Production, Disposition, and Conservation of Oil Well Gas in Texas", submitted to the Railroad Commission of Texas, Austin, Texas, 1945.

Recommended current publications

"Journal of the Institute of Petroleum" (formerly Institute of Petroleum Technologists), published monthly, Manson House, 26 Portland Place, London, England.

"Drilling and Production Practice", annual publication of the Division of Production, American Petroleum Institute, 50 West 50th Street, New York, New York.

"Petroleum Development and Technology", *Trans.* Am. Inst. Mining Met. Engrs., 29 West 39th Street, New York 18, U.S.A.

Reservoir behaviour

R. J. Schilthuis and W. Hurst, "Variations in Reservoir Pressure in the East Texas Field", *Petroleum Development and Technology, Trans.* Am. Inst. Mining Met. Engrs., 1935, pages 114 and 164.

D. L. Katz, "A Method of Estimating Oil and Gas Reserves", *ibid.*, 1936, pages 118 and 18.

M. Muskat, "The Flow of Homogeneous Fluids through Porous Media", New York, McGraw-Hill Book Co., 1938.

T. V. Moore, "A Review of the Principles of Oil-Reservoir Performance", *Drilling and Production Practice* (1940), page 97.

M. Muskat, "The Determination of Factors Affecting Reservoir Performance", *ibid.*, 1940, page 115.

E. DeGolyer, "Production under Effective Water Drive as a Standard for Conservation Practice", *Petroleum Technology*, vol. 4, no. 3 (1941), Am. Inst. Mining Met. Engrs. Tech. Pub. 1340.

S. E. Buckley and M. C. Leverett, "Mechanism of Fluid Displacement in Sands", *Petroleum Development and Technology, Trans.* Am. Inst. Mining Met. Engrs., 1942, page 146.

William Hurst, "Water Influx into a Reservoir and Its Application to the Equation of Volumetric Balance", *Petroleum Development and Technology*, Am. Inst. Mining Met. Engrs., vols. 146 and 151 (1942).

W. A. Bruce, "Pressure Prediction for Oil Reservoirs", *loc. cit.*

New Oil and Gas Production Techniques in Venezuela

MINISTERIO DE FOMENTO, CARACAS, VENEZUELA [1]

ABSTRACT

At the beginning of this year, the technical staff of the Hydrocarbons Service of the Ministry of Development began a survey of the country's oil fields to determine the operating practices which should be used in each pool to increase the ultimate recovery of oil from the field.

The first survey completed related to production from the cretaceous in the Mara and La Paz fields. In both cases the existence of large domes of gas was proved by calculation and in order to increase the ultimate recovery of oil, the concessionaires were instructed to operate wells at a gas-oil ratio of 700 cub. ft. a barrel and to close wells with a high gas-oil ratio. These fields have been operated at the maximum rate of efficient production, 6,000 barrels a well a day in the case of Mara and 12,000 in the case of La Paz.

In spite of the lenticular character of the sands and the presence of main and cross faults which are outstanding features of the fields in the east of Venezuela, gas reinjection has been placed in operation. To date five plants to maintain pressure have been erected at a cost of $ 13,347,000.

Experimental operations have shown that the varying permeability of the sands has not caused channelling of the gas which would make reinjection unattractive from the economic point of view. It has also been found that better results are obtained from reinjection in faulted areas and areas where the permeability of the sand is low when a definite reinjection pattern is used, e.g., reinjection through a well at the centre of four other producing wells in a 5-spot pattern. The average total cost of gas reinjection and repressuring is three to five cents per thousand cubic feet of gas.

The proved oil reserves of the fields mentioned, not taking into account additional recovery by artificial means, has been estimated at 1,005,460,000 barrels as per 1 January 1949, the calculation being based on a recovery of 18 to 23 per cent of the oil originally available in the pools. The experimental plants now in operation have proved that, by the use of properly controlled gas re-injection, it is and always will be possible to step up oil recovery from a pool from 23 per cent to 32 per cent or more, which would correspond to a 40 per cent increase in the ultimate recovery of crude in the areas where the pressure is maintained.

OPERATING PRACTICES

Parallel to the advances in methods of drilling and completing oil wells in Venezuela, improvements have been made in the operating practices used in the country, particularly as regards practices affecting the efficiency of the operation of pools, practices which have an immediate bearing on the conservation of oil and gas.

Although the existence of oil and gas in Venezuela was known before 1912, it was not until 1920 that the country's importance as an oil producer was recognized by the industry.

In 1920 the Venezuelan Government introduced a petroleum law which was regarded as very favourable for the development of the country's oil resources as it provided an equitable basis for the parties concerned. The oil companies realized the magnitude of the country's oil resources and thanks to the Government's encouragement of foreign capital, prospecting was carried out at such a pace that by 1 January 1949 the country had a proved reserve of 7,643,751,000 barrels.

The history of oil and gas conservation in Venzuela is somewhat short since until a few years ago the available information regarding the oil deposits was scanty and unreliable. During the early days of drilling and production, little importance was attached to the problem of the behaviour of pools and the existence and more efficient utilization of their own energy. Venezuela and the oil field operators were then interested solely in the development of new reserves, the construction of pipe lines to transport the crude and the finding of markets for the ever-increasing production.

The years of experience of the application of methods of conservation and production control (proration) to oil field operation in the United States of America showed the Government and the operators that there is some loss in the efficiency of the recovery of oil from pools if the oil and gas are drawn off very quickly.

Working through the Technical Office of Hydrocarbons, the body responsible for dealing with oil problems in Venezuela, the Ministry of Development realized that the efficient recovery of oil from a pool is a complex problem which involves not only knowledge and application of the fundamental principles governing the flow of fluids through porous media but also knowledge of the sources of energy which cause the movement of the oil and gas to the wells from the sands and porous rocks of the pools, so that from this knowledge it might be determined what practices should be followed in raising the gas and oil. With this in mind, the Government trained a team of technicians who have specialized in the production and the refining of oil. The Hydrocarbons Service now has 26 specialized engineers, and another group is being trained in the United States of America.

Since the efficiency of oil recovery is largely dependent on the methods employed to use the energy of a pool itself, the energy which displaces the oil and gas from the sands and porous rocks to the wells, the technicians of the Technical Office of Hydrocarbons began, on 1 January 1949, a survey of Venezuela's known fields with a view to determining the operating practices which should be applied to each pool in order to increase the ultimate recovery of oil from the field.

STUDIES AND TRIALS

The first survey carried out related to production from the cretaceous in the Mara and La Paz fields, from which it was concluded that the oil in these deposits reaches the wells through expansion of the dissolved gas. The producing formations are very thick and the operators have decided that

[1] Original text: Spanish.

6,000 barrels a well a day is the maximum rate of efficient production in the Mara field and 12,000 in the La Paz field. In both cases, calculation of material balance showed that large domes of gas had formed and with a view to the complete utilization of the energy contained in the domes, the concessionaires were instructed to operate the wells at a gas-oil ratio equal to that originally existing in the pool or not greater than 700 cub. ft. per barrel of crude. They were also instructed to close any well which was producing at a ratio greater than that laid down and in order to balance the production of the field steps were to be taken to open other wells with a gas-oil ratio equal to or less than 700 if possible.

It is not at present intended to use gas reinjection in these fields; nevertheless it is believed that with the operation of wells at a gas-oil ratio of 700 cub. ft. or less, the expansion of the gas cap will assist in the recovery of most of the available crude. Even in high production wells, the gas-oil ratio has been maintained at 700 cub. ft. or less a barrel which is regarded as the optimum.

In 1948, the average ratio was 597 for the Mara field and 629 for La Paz. The latest gas-oil ratio tests, carried out in April 1948, showed that the average was 637 cub. ft. a barrel in Mara and 695 in La Paz.

Production from the cretaceous is still in the development stage and it is possible that later, if there is an excessive increase in the gas-oil ratio, the gas produced will be reinjected in order to conserve the gas dome.

Other tests of this kind have been carried out recently in the east of Venezuela, in the San Joaquín, El Roble, Jusepín, Santa Bárbara, Mulata and Quiriquire fields. These fields are of the gas solution type and the maximum recovery of oil obtainable by current operating methods will not exceed 18 to 22 per cent of the oil available in the pools. Any special production methods to obtain the maximum increase of oil recovery will have to be applied in these or similar fields (to date there are few pools where the oil flow is obtained by water drive).

The concessionaires have also realized that thousands of millions of barrels of crude are available and have begun to reinject gas in some pools to recover them.

The above recently concluded surveys of areas in the east of Venezuela show the existence of a number of pools in the same field as well as the lenticular structure of the producing formations which are crossed by faults of all kinds. Nevertheless, in spite of these difficulties, gas reinjection is being used in Santa Bárbara, Jusepín and Quiriquire and will be begun in Mulata as soon as the necessary piping is constructed.

EXPERIMENTAL CHARACTER OF OPERATIONS

Most of the plants now in operation have been designed on an experimental basis because of the peculiar characteristics of the sands. The permeability of most of the sands is very low. In the Quiriquire field, reinjection was begun by the Creole Petroleum Company in 1933 and as a result the decline of pressure has been retarded and production increased. The capacity of this plant is 10 million cub. ft. a day; it cost $ 933,000. Up to 1 March 1949, the field had produced totally 306,456,084 barrels of crude at a cumulative gas-oil ratio of 454 cub. ft. a barrel; more than 21,000 million cub. ft. of gas have been returned to the pools at a reinjection pressure of 700 lb. per square inch, giving a cumulative net gas-oil ratio of 385 cub. ft. a barrel. During February 1949 the total gas-oil ratio was 632 and the net ration 595. Reinjection cost 3 cents per 1,000 cub. ft.

Although the results obtained in this field may be misleading, it must be borne in mind that if reinjection had not been used the Quiriquire field would not have been capable of producing more than 300 million barrels at a gas-oil ratio of 454 cub. ft. a barrel but would have been exhausted at ratios of between 2,000 and 2,500 cub. ft. a barrel of oil.

Pressure maintenance experiments were begun in Jusepín in 1947. The plant, consisting of two 1,600 h.p. compressors, has a capacity of 10 million cub. ft. a day. This field was discovered in 1939 and in March 1949 had 449 oil wells. The cumulative production as of 1 March was 109,689,099 barrels of crude, 701,864 barrels of water and 195,797,275,000 cub. ft. of gas. In February the average daily production was 35,052 barrels at a gas-oil ratio of 3,333. The cumulative gas-oil ratio as of 1 March 1949 was 1,785 cub. ft. a barrel.

OIL-BEARING FORMATIONS IN JUSEPÍN

The two oil-bearing geological formations in Jusepín are La Pica (Miocene) and Carapita (Oligocene). La Pica is subdivided into 23 different sands, small in thickness but of great area. The sands are separated by shales and have been classified into four zones known as upper Sigmolina, middle Sigmolina, lower Sigmolina and Textularia. The sands are fairly continuous and of satisfactory porosity (20 to 30 per cent) but their permeability is somewhat low, in some cases as low as 100 millidarcies. The pools are combinations of structural and stratigraphic traps, formed by anticlines, the dips of synclines, monoclines and faults.

The outstanding characteristic of the Jusepín field, as of the Santa Bárbara and Mulata fields to the west of Jusepín, is the presence of numerous faults which divide the field into separate, independent blocks. Further, the relief of the structures is pronounced so that segregation of the gas has occurred and as a result wells in the higher part of the field have high gas-oil ratios.

Under present conditions, it is expected that with pressure maintenance recovery will be stepped up from 22 to 35 per cent, which would correspond to an increase of 40 per cent in the total recovery. At present most of the 10 million cub. ft. of gas reinjected go to sand J6. Reinjection in this sand began in August 1947, the sand being chosen because it was the most prolific sand in the Textularia zone and because it is so marked off by structural and stratigraphic traps as to make the operation feasible. The permeability of the zone ranges from 5 to 535 millidarcies vertically; the porosity is 31 per cent; the water originally contained is as much as 35 per cent and the average thickness is 34.5 feet.

In October 1948 reinjection was begun in sand J21 through well J41.

As of 1 March 1949 a total of 2,808,367,000 cub. ft. of gas has been returned to the pools, which has retarded the decline of pressure in sand J6 and increased production.

ADVANTAGES AND COST

The cost of the plant, including stabilization and desalination of the crude was $ 3 million and the cost of reinjection has been 3 cents per 1,000 cub. ft. of gas.

On the basis of the results obtained, the Creole Petroleum Company is examining the possibility of increasing the plant's capacity to 30 million cub. ft. a day.

A pressure maintenance and stabilizer plant has been completed in the Mulata field. It has a capacity of 60 million cub. ft. of gas a day, 20 million cub. ft. of which will be reinjected through the 16 wells in the Textularia zone. The characteristics of the Mulata pools are similar to those of Jusepín, the more so because some of the Mulata sands intercommunicate with the Jusepín sands. The plant cost $ 5,571,000; reinjection has not been begun.

The first reinjection scheme in the Jusepín area was that of the Sinclair Oil Company in the Santa Bárbara field. The plant began operations in September 1946 and because of the complexity of the structure and the existence of numerous faults, the plant was designed on an experimental basis but with a capacity of 25 million cub. ft., sufficient to give practical results.

The characteristics of the Santa Bárbara pools are similar to those of Jusepín and Mulata. The field has two productive zones and on 1 March 1949 had 148 wells producing in the Textularia zone and 116 in the Sigmolina zone.

The principal sand is of a thickness varying between 50 and 150 ft. and extends throughout the field.

Reinjection is carried out by means of the method using the "five-spot" or quincuncial pattern in which the gas is reinjected through a well in the centre of four other wells situated at the corners of a square. In other words reinjection has the effect of inundating the pool with gas and has proved to be very effective as not only has the well's period of production by natural flow been maintained but the fall of pressure has been retarded, increasing production. This method of reinjection is the best in pools crossed by faults.

By 1 February 1949, the Textularia zone had produced 23,644,544 barrels of crude, 1,234,796 barrels of water and 48,538,434,000 cub. ft. of gas with a cumulative gas-oil ratio of 2,053 cub. ft. per barrel. More than 436 million cub. ft. of gas have been reinjected.

By 1 February 1949 the Sigmolina zone had produced 25,709,185 barrels of oil, 1,935,997 barrels of water and 38,937,036,000 cub. ft. of gas at a cumulative ratio of 1,515 cub. ft. per barrel. More than 12,971,830,000 cub. ft. of gas have been reinjected.

The total cost of the plant is $ 1,510,000 and the cost of reinjection is 3.5 cents per 1,000 cub. ft. of gas.

Another important scheme recently put into operation is the Guara Oeste plant of the Mene Grande Oil Company. The plant began operations in 1948 and is now reinjecting gas to four pools. The capacity is 28 million cub. ft. a day and the cost $ 2,330,000. The cost of reinjection is 4 cents per 1,000 cub. ft. of gas. The plant is designed for compression, in three stages, from 50 to 150 lb. per sq. in. suction and 1,800 lb. discharge.

The Guara Oeste field was discovered in 1942 and the accumulation is controlled by the Guara Oeste fault. There are 460,000 acre feet of oil sand below an area of only 3,000 acres, the field being thus very compact. Forty producing sands have been found, the various horizons being separated by shale layers. Each horizon has well-defined gas-oil and water-oil interfaces. The wells drilled are completed in two or three zones.

The general reinjection plan calls for the injection of gas in well-defined but shallow lithological units. Reinjection is made through wells located on the high parts of the structure. Most of the deposits originally had gas domes. At present reinjection is being used in sands D3, D4, F7 and H.

By 1 January 1949, the Guara Oeste field had produced 109,390,084 barrels of crude, the average gas-oil relation for 1948 being 671 cub. ft. a barrel.

As has been said, the fields mentioned, like most of the existing fields in Venezuela are of the gas-solution type. In some of them there is small segregation of gas towards the upper parts of the structure. Because of the low permeability of the sands it has been necessary to produce from wells under high differential pressures.

The reserves of the fields mentioned, without the use of artificial secondary recovery methods, have been calculated at 1,005,459,900 barrels as of 1 January 1949, on the basis of a recovery of between 18 and 23 per cent of the oil existing in the deposit.

The experimental plants in operation have proved that it is feasible to carry out maintenance operations in highly faulted areas of low permeability and the results show that with properly controlled reinjection, the ultimate recovery can be stepped up from 23 to 35 per cent or more (i.e., a 40 per cent increase) of the total amount of crude originally available in the pools.

It has also been shown that the varying permeability of the sands has not caused channelling of the gas which would make the operations unattractive from the economic point of view. It has also been found that reinjection using a five-spot pattern gives better results in faulted areas of low permeability. The average cost of reinjection and pressure maintenance is at present 3 to 5 cents per 1,000 cub. ft. of gas.

The surveys carried out by the Government have proved that the time factor is most important in the application of conservation regulations which will be effective only if pools are treated as units while for proper conservation, the energy originating in the pools must be utilized to ensure maximum recovery in the field's crude.

In the case of fields of the gas-solution type, in order to operate wells with a low gas-oil ratio, drilling must be avoided in the high parts of the structure where high ratios are more likely; steps must also be taken to ensure that pools are drained in a uniform manner, high gas-oil ratio wells being closed.

Proper knowledge of the characteristics of a pool and of the fluids it contains is an essential prerequisite for the correct evaluation of the possibilities of artificially increasing the natural energy of pools. An accurate forecast of the ultimate recovery of oil obtainable by conventional operating methods is absolutely essential if the economic aspect of operations is to be properly estimated.

Advances in Efficiency of Oil Recovery

MORRIS MUSKAT

ABSTRACT

Definite improvements have been made during the last ten to twenty years in the efficiency and magnitude of oil recovery. This has come about by both laboratory and field investigations which have served to establish that oil production can take place by one or a combination of three basic physical mechanisms, namely, the solution-gas-drive, the water drive, and the gravity-drainage drive. The actual means which have given rise to the increases in oil recovery efficiency are comprised of (1) prevention of waste of reservoir energy, (2) supplementing the natural reservoir energy, and (3) the control of the producing mechanism. The over-all result has been that statistically a much larger percentage of reservoirs being developed currently are producing by the more efficient water drive and gravity-drainage mechanisms, as compared to the solution-gas-drive mechanism that characterized the early history of the oil-producing industry.

INTRODUCTION

Oil, as a natural resource for conversion to fuel and energy, is, with respect to our present civilization, an asset of limited original magnitude. The world's total proved recoverable reserves have been variously estimated as ranging from 75 to 80 billion barrels. Not being replaceable, except by substitution, it well behooves everyone to be concerned with the continued availability of this resource. Being confined in underground strata it must be brought to the surface or recovered before it can be utilized. It is the physical aspects of such recovery processes with which this paper will be concerned.

Symbolically, a discussion of advances in the efficiency of oil recovery could be presented very simply and briefly. By suitably defining a unit of efficiency one would need only to state the increase in efficiency which presumably has been achieved in recent years. Such a unit might be taken as the recovery factor or percentage of the available oil which is recovered by the producing operations. And the gain in efficiency would then be the increase in recovery factors associated with current operating practices over that pertaining to the early history of the oil-producing industry. A numerical expression of this kind, however, can only tell a very small part of the record of the industry, and, if not properly qualified and elaborated, would very likely be more misleading than enlightening. While as a means for expressing in a definitive manner the accomplishments of the oil-producing industry in increasing the oil recovery efficiency, we shall later give some indications of the possible relative magnitudes in numerical form, our primary objective will be a discussion of the physical processes and operating practices involved in oil recovery.

In a strict sense the term "efficiency" with respect to oil recovery is inherently inappropriate, although the usage of this term in the oil industry is quite common. For it implies a measure of the oil recovery related to the effectiveness of applying a fixed or given amount of total energy which may be available for the recovery processes. However, such energy as is available underground for oil expulsion at the time of the reservoir discovery is comprised of several different types, some of which are quite difficult to fix in quantitative magnitude. Moreover, the direct availability of such energy may be rate-sensitive, and its significance may be controlled almost entirely by economic factors. For example, an oil-producing formation may be completely surrounded by a virtually infinite aquifer which may possess energy of compression of almost unlimited magnitude. However, if the permeability of the aquifer or the paths of communication between it and the oil reservoir are severely restricted, the energy of compression of the water in the aquifer may have little practical significance as an economic measure of the energy actually available for oil expulsion. Finally, it is becoming rather widespread practice in the States to supplement the native energy originally available in a reservoir with additional energy for oil expulsion through the medium of gas or water injection. Under such circumstances the true significance of the term "efficiency" becomes very uncertain indeed.

As already indicated, therefore, a more appropriate practical measure of the effectiveness of the oil-producing operations is the total economic oil recovery per unit of initial oil content or reservoir volume. These are the "recovery factors" previously referred to. On the other hand, the term "efficiency" is, in a qualitative sense, quite descriptive and suggestive of the gross effectiveness of the oil recovery operations, and it will be used in this sense in the following to avoid the necessity of making explicit quantitative evaluations of the recovery factors with respect to each phase of our discussion.

The claim that the efficiency of oil recovery has been improved as a result of technical developments implies, of course, that such has been possible by virtue of the manner of operation of the reservoir. The latter presumably has been subject to the control of the operators of the field. To evaluate the physical significance of such improvements, however, it must be understood that there is much about oil reservoirs bearing on the problem of recovery efficiency about which the operator or operators have no control. The oil reservoir, as discovered, is a product of nature. Its depth, its geometry, the character of the oil-containing rock, the nature of the petroleum fluids, and the distribution of the fluids must be considered as initial conditions about which the one who is to produce the oil can do nothing but determine them as accurately as possible.

The reservoir may be a clean, continuous, and uniform sand, or it may be an argillaceous lenticular dispersion of sand lenses in a shaly or other non-productive rock matrix. It may be a massive intergranular limestone, or of an intermediate type dominated by a fracture system. It may be in free communication with bounding water reservoirs, or it may be completely sealed with initial pressures bearing no relation to the current hydrostatic head. It may be rather flat topographically, or it may have hundreds of feet of closure. It may have an average permeability in the range of 2 to 3 millidarcys, or one in the range of 2,000 to 5,000 millidarcys. It may have an average effective porosity of the order of 2 to 4 per cent, or one as high as 30 per cent. It may have connate water saturations as low as 10 per cent or as high as 60 per cent. It may contain an oil of 12 degrees API gravity, or one of 45 degrees API gravity. Its reservoir oil may be associated with such an excessive volume of gas as to be overlain by a large gas cap of value comparable to that of the oil section, or it may be so deficient in gas content that the bubble point pressure is as much as 2,000 lb. per sq. in. below the reservoir pressure.

All these and many other possible variations and characteristics evidently will influence to an important degree the resulting oil recovery. Generalized expressions or rules regarding recovery efficiency or recovery factors thus become quite meaningless. Indeed, the only sound starting point for evaluating reservoir behaviour lies in the recognition that each reservoir is, certainly in its quantitative aspects and often even in its gross freatures, a unique and individual oil-producing system, having its own inherent potentialities for oil production and susceptibility to control. The manner of development and operation must be tailored to suit the individual "personality" of the particular reservoir under immediate consideration.

TYPES OF RESERVOIR ENERGY AND PRODUCING MECHANISM

While no attempt will be made to give quantitative estimates of the energy contents of oil-producing reservoirs, with respect to their availability for oil production, it is important to have an understanding of the major types of energy available. These include the following: (1) The energy of compression of the oil and connate water within the oil reservoir itself, (2) the energy of compression and solution of the gas dissolved in the oil (and also water) within the producing stratum or in free gas zones overlying the oil-bearing formation, (3) the energy of compression of the water in bounding and intercommunicating aquifers, and (4) the gravitational energy associated with the relative elevation of the oil in the upper levels in the reservoir as compared to that at the points of exit into the producing wells. Other possible sources of energy are associated with the inherent compressibility of the reservoir rocks themselves, and the interfacial forces between the fluids contained in the rocks. These latter, however, are generally of such minor importance that they need be given consideration only under exceptional circumstances.

Of the four major types listed above, the energy of compression of the oil and water within the producing formation is usually the least important, although in highly undersaturated reservoirs the early history of the oil production is generally controlled by, and much of the actual reservoir liquid expulsion is replaced by, the expansion of the liquid phase within the reservoir pore space. In absolute magnitude, however, the total volume of oil that could be produced solely as a result of the original reservoir liquid expansion, if completely devoid of solution gas, would generally be only 2 to 3 per cent of the original oil content at the most. Hence, if this alone were to be the source and cause of the oil production it would be extremely seldom that such oil reservoirs would warrant commercial development.

The gas in solution and that overlying the oil-bearing formation as free gas and the energy associated with such gas may be and often are primary and controlling factors in oil production. When they are the predominant agency for oil expulsion the producing mechanism is termed a "gas drive", which is further specialized as "solution-gas drive" when there is no initial free gas phase involved. The oil expulsion under such conditions takes place both by the direct volumetric displacement of the oil resulting from gas evolution and expansion as the reservoir pressure declines, and the flow of oil associated with the flow of gas as both are directed toward the producing well system in accordance with the pressure gradients created by the producing operations. As will be further discussed later, the gas drive is often the most inefficient type of producing mechanism. However, it alone will provide in many reservoirs enough recovery for successful and profitable exploitation.

The energy of compression of the water in aquifers bounding and in communication with oil-producing reservoirs also may be a major factor in oil expulsion and recovery. The compressibility of the water itself will be only a third to a fifth of the compressibility of the reservoir oil. However, in the case of many reservoirs the bounding aquifers are of such large volumetric magnitude that the resultant total expansion capacity of the water they contain may greatly exceed the total volume of oil in the reservoir. Moreover, the physical processes in which water displaces oil from a porous medium generally lead to lower magnitudes of residual oil and hence greater recoveries than result from the gas drive mechanism. It is for this reason especially that the "water drive" producing mechanism, in which the water from the bounding aquifer is permitted to invade and displace the oil from the oil-productive formation, is often the most efficient recovery mechanism.

The force of gravity is ever present as a factor in oil production. It plays many roles. It gives rise to the initial segregation of the reservoir fluids, gas, oil and water according to their density, obtaining in the oil fields at the time of discovery. It is one of the controlling factors in operating difficulties such as water coning, in which bottom water may be prematurely drawn into wells producing at excessive rates. And it is the primary driving agency supplying the "gravity flow" into well bores which are substantially depleted of their natural reservoir pressure, providing the "settled" production of many stripper wells. More important still, however, with respect to the problem of ultimate oil recovery, the force of gravity may, under favorable conditions, be harnessed so as to result in a producing mechanism that often compares well even with the water drive. This type of gravity action manifests itself by the tendency for the free gas phase, formed by gas evolution during the course of production, to rise and segregate itself at the structural crest of the formation. Associated with this upward gas migration, and of more immediate importance with respect to oil recovery, is the countercurrent downflank drainage of the oil, the composite action leading to what is often termed "gas-cap expansion". The resulting producing mechanism is therefore usually called the "gas-cap expansion" or "gravity-drainage" drive. The particularly significant feature of this mechanism is that the residual oil left in the drained reservoir rock may be considerably lower than that resulting from gas-drive depletion, and of the same order as associated with oil displacement by water drive. It is primarily for this reason that the gravity-drainage mechanism also offers, when feasible, a highly efficient means for oil recovery.

ADVANCES IN OIL RECOVERY EFFICIENCY

With the above brief outline of the basic types of energy and physical processes available for oil production we can proceed with the discussion of the improvements that have actually been made in oil production and recovery. These have been essentially of three types: (1) the prevention of waste of reservoir energy, (2) supplementing the natural reservoir energies, and (3) the control of the producing mechanism.

It should be understood that these do not represent entirely independent procedures for increasing oil recovery. In actual application two or all three types may be applied in any particular field during the course of its production history. Nevertheless, this classification does serve to emphasize the different aspects of the over-all problem of producing an oil-bearing reservoir so as to achieve the maximum oil recovery.

Prevention of Waste of Reservoir Energy. Anyone who is at all familiar with the oil-producing industry in the United States knows that the terms "prevention of waste" and "conservation" represent cardinal principles in the policy of control of the oil-producing industry, both by regulatory bodies and by voluntary planning of the industry itself. Indeed, these terms are, in effect, the criteria for determining whether a given operating practice or plan is to be accepted as satisfying required technical engineering standards of efficient operation. In most of the major oil-producing states limitations are imposed on the rights of operators to produce gas independently of its effect on the production of oil, and in certain fields unlimited production of water is also restrained. From the legal standpoint many of the statutes pertaining to the control of oil production are expressly written with the objective of preventing waste of reservoir energy.

Let us look briefly into the technical basis for such policies. In its simplest form, the prevention of waste by restricting gas production will be self-evident in the case of an oil field overlain by a gas-cap. Since gas itself has a saleable value, the "law of capture", which controlled the oil industry in its earliest days, justified owners of the gas-cap to produce their wells at any rate they would find desirable and profitable in the light of their own market outlets, and without regard to the effect of such gas withdrawal on the recovery of oil from the underlying and adjoining oil reservoir. And such used to be the practice in the early history of the industry. Moreover, it was not uncommon for operators near the gas-oil contact to produce their gas wells at especially high rates so as to "pull up" into the gas-cap and into their wells oil from the oil zone.

From the point of view of oil recovery, however, such practices were evidently highly wasteful and tended to severely reduce the recovery of oil. For if the gas were not produced, but were allowed to act as a driving agent to displace the oil downflank the amount of oil recovery from the reservoir as a whole would be very materially increased, as both laboratory study and field experience have amply demonstrated. Moreover, in extreme cases where oil is induced to migrate into a gas-cap an additional loss of oil is caused, because only a part of any oil which invades an unsaturated rock can be physically recovered, short of mining. While the problem of shutting in gas wells or severely restricting their production has given rise to many moot legal questions, and has often had to be solved by compromise, it is now fully recognized in the States that uncontrolled gas production may result in greatly reduced oil recovery. It is also clear that the elimination of such practices in the last ten to twenty years has indeed prevented waste and served materially to increase the efficiency of oil recovery.

A somewhat similar type of waste prevention which is being widely applied as a result of an understanding of the physical principles of oil recovery pertains to the operation of so-called condensate fields. Condensate reservoirs may be considered, for the present purposes, as essentially equivalent to gas reservoirs containing especially high concentrations of condensable liquid hydrocarbons. They are being discovered with increasing frequency as drilling and development depths are increasing. Their peculiar feature is that, because the reservoir temperatures exceed the critical point of the composite hydrocarbon mixture, a reduction in pressure, such as would result from withdrawal of the gas, leads to a condensation of the heavier hydrocarbons into a liquid phase. This "retrograde" condensation increases as the pressure declines, up to a maximum, when the pressures are in the range of 1,000 to 1,800 lb. per sq. in., after which the condensed liquid phase tends to revaporize in part. If produced as a simple gas field, the loss in recovery of liquid hydrocarbons due to such retrograde condensation within the reservoir may, depending on the nature of the reservoir fluid composition and the temperature, amount to 30 to 60 per cent of the original liquid content. When this liquid phase forms in a porous medium as a reservoir rock, it remains trapped by the pore constrictions and does not flow into the producing wells, thus being lost to recovery.

The production of condensate reservoir gas without regard to these losses of condensable hydrocarbons has also been critically analysed from the point of view of waste prevention. As a result a method of "cycling" has been developed, wherein the pressure decline in the reservoir may be completely prevented or greatly retarded by returning to the reservoir the produced gas, after stripping from it its condensable products. This dry gas flows into the reservoir from the injection wells, sweeping ahead the condensate-containing reservoir wet gas toward the producing wells, and at the same time maintains the reservoir pressure to prevent or minimize the condensation of the liquid within the reservoir rock. Cycling operations are now being conducted in many condensate reservoirs throughout the States, and are undoubtedly leading to considerably greater recoveries of high-gravity oil and intermediate liquid hydrocarbons than would have been possible without cycling. Moreover, the regulatory bodies in several of our oil-producing states now require that cycling must be undertaken, if the reservoir conditions warrant, and will not permit the indiscriminate production and flaring or even sale of the condensate-containing gas with the consequent loss in oil recovery. Here, too, has been an important advance in the over-all efficiency of the producing operations of the industry.

The concept of conserving gas for the purpose of increasing oil recovery has been further developed and extended to apply to fields which are primarily of the solution-gas drive initially, that is, such as have no initial gas-caps. Through the process of gravity segregation such fields often develop free gas-caps during the course of production. The wells so enveloped by the gas-caps rapidly develop high gas-oil ratios. Since the continued production of such wells would create pressure differentials opposing the force of gravity drainage of the oil downflank, and lessen the value of the gas-cap as a storage supply of reservoir gas for future use in oil expulsion, restrictions are applied in many of the oil-producing States, and generally practised voluntarily by the oil producers themselves, to the production of such high gas-oil ratio wells. Gas-oil ratio "penalties" are imposed on the oil wells to limit the total amount of gas that can be withdrawn from them. Such measures, too, are leading to more efficient use of the original reservoir energy and to resulting increases in oil recovery.

While not as widespread as yet as the practice of controlling gas withdrawals, limits on water production are also becoming recognized as an important waste prevention measure. In water-drive fields the conservation of the energy and displacing power of the water may be comparable in importance to that of gas in gas-drive fields. Since the entry of water into an oil-producing reservoir usually takes place along its external boundary limits it tends to create a mass movement of the oil toward the interior of the field. To prevent the flooding of the oil from the property of the operators located near the edgewater boundary there is a natural tendency to produce the wells near the boundary, including both the oil and water, at such rates as to minimize the oil drainage toward the more distant parts of the reservoir. Such practice, however, would lessen the effectiveness of the water drive on the interior regions of the field and thus reduce their recovery potentialities. While the control of this situation also involves difficult legal problems of equity, there is a growing appreciation of the fact that the unlimited production of water at the front of an edgewater drive can do harm to the oil reservoir as a whole and should be restricted. In some fields definite cognizance of this principle has been given in the provision of compensations for the restriction of production near the water-oil boundary by allowing increased production by the same operator from wells in the interior of the field. Although the scale to which control of water production has been exercised is still small compared to that pertaining to the limitation of gas production, there is no doubt that in the future the prevention of waste due to unnecessary water withdrawals will become as significant as that due to the limitation of gas production.

Supplementing the Natural Reservoir Energy. From an operating standpoint perhaps the major change in the practice of the oil-producing industry related to increases in oil recovery in recent years has been the installation of programmes for supplementing the native reservoir energy by injection of gas or water. These are generally classified either as pressure maintenance operations or as secondary recovery operations. The former pertain to those which are undertaken during the primary producing period of the reservoir, whereas the latter refer to operations undertaken after the field has become substantially depleted of its own natural energy and can no longer support large-scale profitable production. While the differences between these operations are in a sense little more than those of degree, it is convenient to discuss them separately.

As the name implies, pressure maintenance operations serve the immediate purpose of maintaining the reservoir pressures while oil production continues, though in practice only a retardation in the rate of pressure decline is actually achieved in most cases. Such a change in the pressure history evidently requires a volumetric replacement for the space voidage caused by the oil and gas withdrawals. In most reservoirs this is accomplished by returning to the reservoir part or all of the produced gas or even adding "make-up" gas. While the maintenance of the reservoir pressure is of value in itself in prolonging the flowing life, maintaining higher well productivities, and minimizing the reservoir oil shrinkage and increase in its viscosity, the major objective is an increase in total oil recovery. The latter results primarily from the additional sweeping action provided by the injected gas as it continually replaces the evolved solution gas flowing to the producing wells. And under the favourable conditions of uniform reservoir characteristics and good structural relief, the injected gas may remain segregated at the structural crests to facilitate the action of gravity drainage. In such cases the increased recovery resulting from the gas injection operations may be as great as 50 to 75 per cent of that which would result by gas-drive depletion.

Water injection serves similar dual purposes, both in maintaining the reservoir pressures by supplementing the natural water drive and providing a full supply of water intrusion to flood out the whole of the productive formation. In contrast to gas injection, which has been applied or is being planned for perhaps 25 per cent of the major fields developed in the last ten years, water injection during the primary producing operations has not yet had widespread application. In fact, except for the large-scale water injection operations carried on since 1939 in the East Texas field, primarily as a means for water disposal, the first major pressure maintenance program by water injection tried in the States was that in the Midway field, Arkansas, begun in April 1943. However, additional projects of this type have since been undertaken, and their feasibility under suitable conditions is now well established.

It is of interest to note that while pressure maintenance operations are generally referred to as "conservation" measures, they actually minimize the direct use of the solution gas as an oil-expulsion agent within the reservoir. For the very process of maintaining the reservoir pressures means that the evolution of the dissolved gas within the formation is retarded, so that it can serve only the functions of preventing the oil shrinkage and maintaining a high oil fluidity. The gain in recovery arises from the fact that the injected gas or water is used with a higher oil displacement efficiency than would result from the action of the dissolved gas if it were allowed to escape within the reservoir as in the solution gas drive mechanism.

As already mentioned, secondary recovery operations—gas repressuring and water flooding—are quite similar to the corresponding pressure maintenance operations, except for the differences in the initial state of the reservoir. While the low reservoir pressure, reduced oil saturations, and higher oil viscosities tend to reduce the effectiveness of both the gas and water displacement processes, very profitable and successful results have nevertheless been achieved under favourable circumstances. For example, gas repressuring in the Delaware-Childers field, in Oklahoma, has resulted in additional oil recovery equivalent to about 50 per cent of that estimated for the primary producing operations. And water flooding has led to oil recoveries equal to the primary recoveries in both the Bradford and Alleghany fields of Pennsylvania and New York. Although the more efficient primary development and greater depths of recently discovered fields make it unlikely that many of them will be later subjected to secondary recovery operations, there is still a wide scope of application for these methods in fields discovered in the early history of the industry which were produced by the less efficient solution-gas-drive depletion mechanism. In fact, it has been estimated that in Texas alone there are 3,375 million barrels of oil potentially recoverable by secondary recovery operations.

Although the supplementing of the natural reservoir energy has been discussed here as a major development in increasing oil recovery, it is not to be inferred that fluid injection for pressure maintenance or secondary recovery is a universally effective or desirable operation. In each instance where such operations are being considered a detailed analysis should be made of the reservoir conditions in the particular field in question to determine the necessity and suitability of the reservoir for the proposed injection programme. In some cases it will no doubt be found that such injection is quite unnecessary for efficient recovery. And even where it would be desirable, it may well be that the reservoir is not susceptible to effective pressure maintenance or secondary recovery operations. There are indeed too many failures on record to permit any blind optimism of universal success. Special caution should be applied in the case of highly-fractured limestones in which a major part of the reserves lie in the intergranular matrix, and where the solution-gas-drive may be the only practical mechanism for substantial recovery. Likewise, the common generalization that water drives will give greater recoveries than the solution-gas-drive, though undoubtedly correct statistically, must be critically checked as to its validity in every particular reservoir of interest to ensure that it does not represent one of the exceptions where just the converse may happen to be true. As previously emphasized, each reservoir must be analysed and evaluated in the light of its own unique characteristics and should not be treated as if it were the product of a mass production assembly line.

Control of the Producing Mechanism. In a strictly technical sense the most fundamental aspect in which major progress has been made in achieving greater efficiency in the operation of oil reservoirs has been in the control of the producing mechanism. Such control is not of unlimited scope. For, as noted earlier, each oil reservoir is a distinct physical system of basic geometrical and physical properties imposed by nature. The operator must study them thoroughly to find out what it is he has to work with, but he has no choice in prejudging and establishing that it has "good" or "bad" characteristics. Nevertheless, in many reservoirs the operator to a large extent can predetermine and achieve a maximum oil recovery by so controlling the operations as to make the reservoir produce by whatever mechanism is best suited to its inherent productive potentialities.

An abnormally low or high initial reservoir pressure, as compared to the hydrostatic head, is generally good prima facie evidence that the reservoir is sealed from mobile intercommunication with any possible adjoining aquifers. Natural water drives are thus automatically eliminated, even though the productive formation might be otherwise suitable to effective flooding by water. If left to itself without control, the producing mechanism would then appear to be necessarily relegated to some type of gas-drive. But if the reservoir has a high degree of structural relief, high and uniform permeability, and if the oil is of moderate or high API gravity, the gravity-drainage mechanism becomes a definite possibility. Now this mechanism is basically rate-sensitive, in that its role as an effective recovery agent is largely controlled by the balance between withdrawals and down-flank gravity drainage. Hence, by restricting the withdrawal rates to the estimated magnitude of the rate of downstructure drainage, and locating the producing wells along the structural flanks, to facilitate the formation and expansion of a secondary gas-cap, the field can be produced by the gravity-drainage mechanism. Thus, instead of recovering only 20 to 30 per cent of the initial oil in place by uncontrolled solution-gas-drive operation, as much as 40 to 60 per cent of the oil content may be produced before abandonment.

Such a transformation of the producing mechanism may also be applied if the reservoir has an initial gas-cap. And it may be further facilitated or supplemented by gas injection. The important feature of such operations is that the reservoir itself is made to produce more efficiently by properly choosing and controlling the method of operation.

Occurring more frequently than the strictly closed reservoirs are those which are in communication with extended bounding aquifers. Here the degree of communication is the all-important criterion of the potential significance of the aquifer as supplying an effective water-drive. If the aquifer is very tight or if the zone of junction of the aquifer and oil reservoir is of such low permeability that its maximum rate of water supply would be equivalent to an oil withdrawal rate of only 0.1 per cent of the initial oil content per year, it will evidently be of little practical economic importance. The reservoir must then be treated as if it were effectively sealed and isolated from the aquifer. Such situations do occur. In most cases, however, the aquifers are able to supply water influx rates corresponding to oil withdrawal rates of reasonable magnitude, though they might fall far short of replacing "wide open" production rates. It is here again where the freedom of the operator in controlling the producing mechanism has been an important factor in increasing oil recovery.

In the early days of the oil-producing industry, the principle of unrestricted competition encouraged production at maximum rates from the greatest number of wells. Moreover, water was considered as a dangerous threat to oil production, with no potential value whatsoever. Outside of exceptional instances where the supply capacities of the aquifers were so great as to provide substantial water-drive action even under wide open flow conditions, the great majority of the early discovered fields were produced by solution-gas-drives, with their characteristically low recoveries. However, when an understanding developed of the inherently greater efficiency, in most reservoirs, of the water-drive mechanism, a situation greatly stimulated by the study of the East Texas field, attention became focussed on possibilities of encouraging the water-drive action. Here, too, the rate sensitivity of the water-drive mechanism provided the means for control. As a result, at the present time in most fields which are potentially subject to water-drive support the withdrawal rates are so restricted as to be comparable to the rates of water intrusion. These controlled operations have had the twofold effect of retarding the pressure declines and thus prolonging the flowing lives, and converting the potential gas-drives to the more efficient water-drive mechanism.

As a further step in facilitating the transformation of the producing mechanism to the complete water-drive it has become common practice to reinject into the productive formation the water produced with the oil. In the case of the East Texas field more than 1,000 million barrels of produced water have been disposed of in this manner, and the current rate of water injection is over 500,000 bbls. per day, as compared to an oil production rate of about 250,000 bbls. per day. The fact that there has been no net pressure decline in this field for the last seven years while more than 900 million barrels of oil were produced is convincing proof of the effectiveness of such operations. And, as previously mentioned, it has also been proved feasible to undertake water injection along the boundaries of reservoirs purely as means of maintaining the pressure and supplementing the natural aquifer invasion so as to ensure the operation of the complete water-drive mechanism.

It should be emphasized that such control of the producing mechanism as here discussed must be a co-operative activity of all operators in a field. While the regulatory bodies of the oil-producing States have fostered and encouraged such practices for the purposes of oil conservation, it has ultimately been the task of the actual operators in each particular field to apply

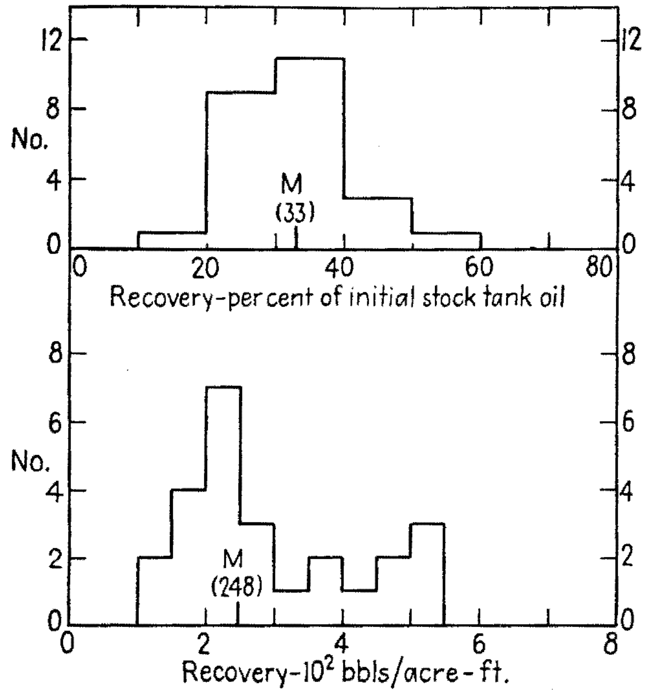


Figure 1. The frequency distributions of the recovery factors of twenty-five gas-drive reservoirs. M indicates median value.

them. In fact, in most of the major oil-producing States it is the practice of the operators themselves to recommend such rates of production as will lead to the most efficient recovery. And where supplementary measures must be taken, such are generally planned at the initiative of the operators, who then relinquish their individual competitive interests in favour of unitized operation for the benefit of the field as a whole. Indeed the rapid increase in the number of unitization plans for field operation undertaken in the last five years creditably reflects the deep feeling of responsibility of the oil-producing industry in the conservation of one of the nation's most important natural resources.

CONCLUSION

Having discussed the various principles and methods for increasing the efficiency of oil recovery, the question still remains: What have been the actual gains? Unfortunately, only a guess can be made. The only certain qualitative answer is that statistically a much higher percentage of the oil reservoirs discovered in the last twenty years are being produced by the water-drive and gravity-drainage mechanisms or under pressure maintenance than were those discovered before the early thirties. As to the numerical significance of this conclusion some inference can perhaps be drawn from Figures 1 and 2, which give a frequency distribution of estimated ultimate recovery factors, as per cent of initial oil and bbls./acre ft., of 25 gas-drive reservoirs and 69 water-drive sand reservoirs.[1] Little can be said for the statistical significance of such meagre data. Moreover, with respect to the gravity-drainage mechanism, reliable data are available on only several reservoirs at the most. Nevertheless, these figures and such other evidence as pertains to the matter suggest that reasonable over-all average recoveries for reservoirs which have been predominantly controlled by the gas-drive mechanism are probably in the neighbourhood of 30 per cent of the initial oil content, and about 50 per cent for water-drive and gravity-drainage reservoirs. Compounding another order of estimation with respect to the averages over the different producing mechanisms, a conservative evaluation would appear to be that in contrast to a gross average for all operations of 35 per cent recovery during the early history of the industry, that in the last ten years would perhaps correspond to an average recovery factor of about 45 per cent.

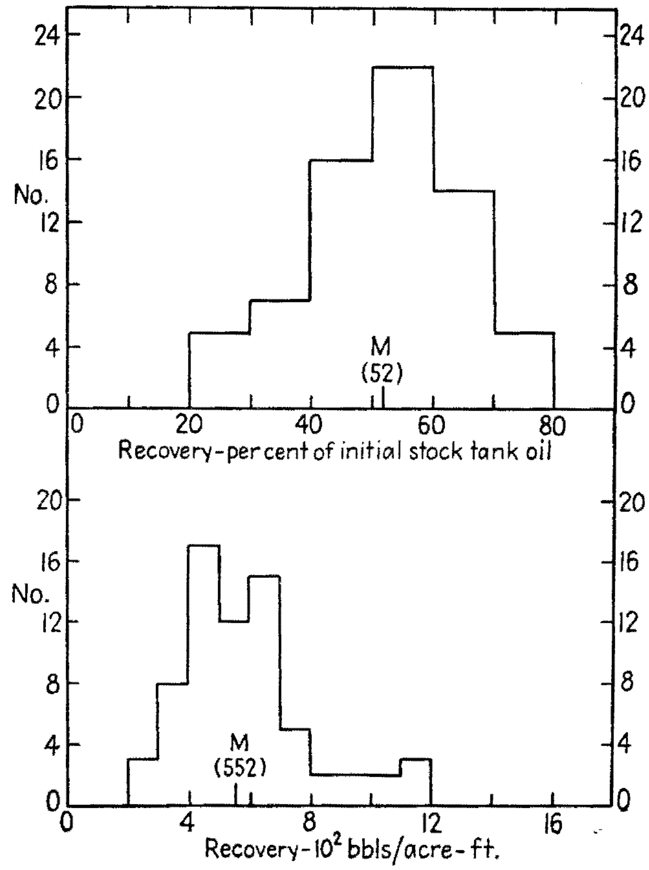


Figure 2. The frequency distributions of the recovery factors of sixty-nine water-drive reservoirs. M indicates median value.

If these estimates have any measure of validity they give reason both for satisfaction in past accomplishment and a challenge for future progress. While self-interest from both individual and national standpoints may well serve as the primary stimulus for achieving further progress, the writer is happy to note that this Conference is providing an equally fundamental motivation in sponsoring the development of increased resources for the world at large.

[1] These were plotted from tables of R. C. Craze and S. E. Buckley, A.P.I. Drilling and Production Practice, 144 (1945).

Secondary Recovery of Petroleum

PAUL D. TORREY

ABSTRACT

This paper considers the history of secondary recovery operations in the United States, the various methods that have been employed to increase recovery from oil-fields in which the primary reserve has been depleted, secondary oil reserves in the United States, the susceptibility of oil-fields to the application of secondary methods, and the costs of development and operation of secondary projects and some of the results that have been obtained.

The application of vacuum, air and gas injection, water flooding, and mining are methods that have been used to increase the recovery of oil.

The secondary oil reserves of the United States are estimated to be in excess of 7,000 million barrels.

Geologic conditions; permeability of the reservoir to the fluid phases; gas, oil, and water saturation of the reservoir rock; reservoir viscosity of the crude oil; and capillary and surface tension phenomena are important factors that should be considered in the formulation of plans for new secondary recovery operations. Core analyses, reservoir studies, and pilot-plant tests provide useful information for the evaluation of these factors.

Over-all development and operating costs of secondary water-flooding projects in Texas, Oklahoma, and Kansas have ranged from $ 1.32 per barrel to $ 1.55 per barrel of oil produced. Some of the results of secondary recovery operations are most impressive. In certain instances the recovery of oil has been doubled, and the production of oil has been preserved for many years.

INTRODUCTION

The following definition of secondary recovery by Johnston and van Wingen (1)[1] is used for the purpose of this paper:

"Recovery by any method (natural flow or artificial lift) of that petroleum which enters a well as a result of augmentation of the remaining native reservoir energy (as by fluid injection) after a reservoir has approached its economic production limit by primary recovery methods."

It is appreciated that there is a growing tendency to include all water and gas-injection operations, regardless of the time during the life of a reservoir in which they are commenced, within the scope of secondary recovery. Some change in definition, therefore, may be adopted generally in the future, and, in fact, is recognized by certain authorities at present.

From the foregoing definition it will be evident that there are four fundamental requirements for the application of secondary methods: (*a*) an injection well and (*b*) a producing well or wells all drilled into (*c*) a common porous and permeable oil-bearing formation through which (*d*) liquids or gases are forced under artificial pressure.

This paper considers the history of secondary recovery operations in the United States, the various methods that have been employed to increase recovery from oil-fields in which the primary reserve has become depleted, secondary oil reserves in the United States, the susceptibility of oil-fields to the application of secondary methods, and the costs of development and operation of secondary projects and some of the results that have been obtained.

The oil that may be produced by secondary methods does not require discovery, and the application of these methods serves to make available more of that which has already been found. For this reason, the additional oil which is so obtained does not have to return exploration and leasing expenses to yield a profit. The economic opportunities for secondary recovery, consequently, are sometimes more attractive than in the development of primary production. However, for both primary and secondary production, the amount of oil that can be obtained and the development and operating expenses will determine the success or failure of a project. Improvements in oil recovery technology and an increased price for crude oil are just as important in secondary operations as they are in primary production, and may enable the working of inferior reservoirs at a profit; in some instances, a successive reworking of a field is made possible. In this respect, secondary recovery operations resemble the mining of ores where an improvement in production methods or an increase in price will permit profitable recovery of lean or more difficult deposits.

Secondary recovery operations, although yielding only a small part of the oil production of the United States, nevertheless are an important factor in the business of oil production in several states. To a large extent they are confined to the older fields, where their use has maintained the production of oil far beyond the time when the natural decline of the wells would have enforced abandonment. Therefore, the application of secondary methods may be regarded as a true conservation measure, resulting in an increased recovery of oil which otherwise could not be obtained profitably, and in many cases in the preservation of natural gas reserves which might be dissipated.

HISTORY OF SECONDARY RECOVERY OPERATIONS IN THE UNITED STATES

The use of compressed or air-gas mixtures, gas, steam, water and other suitable fluids to increase the recovery of oil is about as old as the art of removing oil from the earth. Shortly after commercial oil production was discovered in Venango County, Pennsylvania, patents were issued covering mechanical devices and techniques designed to stimulate the extraction of oil from underground reservoirs. Many of these patents were based on inventions which involved the creation of a pressure differential in the oil reservoir rock either by the creation of a vacuum in producing wells or by the injection of fluids into the reservoir by means of input wells equipped especially for this purpose.

The first recorded use of vacuum was in the Triumph Pool, Pennsylvania, in 1869. It has been well established that an attempt to apply a combination of vacuum and gas repressuring was made in Clarion County, Pennsylvania, in 1895.

[1] Numbers in parentheses refer to items in the bibliography.

This project was unsuccessful on account of the tightness of the producing formation. However, shortly thereafter, combined vacuum and repressuring were employed successfully in Venango County, Pennsylvania.

The first known intentional injection of gas into oil-bearing rocks to increase production was accomplished by James D. Dinsmoor on the Benton farm, Venango County, Pennsylvania in 1890. In this operation gas from a lower formation was introduced into the Third Venango oil sand at a pressure of about 100 lb. per sq. in. The production of oil was more than doubled. Subsequently, repressuring operations that were sometimes combined with applications of vacuum, were carried on by Dinsmoor in the vicinity of St. Marys, West Virginia, and in other parts of Venango County.

In 1911 I. L. Dunn commenced the historic air and gas repressuring operations in the Chesterhill field, of southeastern Ohio, which have been described so ably by Lewis. (2) Only a few years later, in 1917, repressuring operations were started in the mid-continent region (Nowata County, Oklahoma), and subsequently the injection of air and gas has been employed to varying extent in practically all of the important oil-producing regions of the United States.

Until about 1935, water-flooding operations were far more restricted geographically in the United States than air and gas repressuring projects. However, as a source of crude oil supply, water-flooding has been of great importance in certain of the eastern States where a greater part of the production of oil is derived from the application of this method. It is reasonably certain that intentional water-flooding was initiated in the Bradford field, McKean County, Pennsylvania, and Cattaraugus County, New York. Effects of increased production from this source were first noted in 1907, although it is believed that floods were being operated secretly prior to that time. Because of the clandestine nature of most of the early water-flooding operations in northern Pennsylvania, little detailed information has been preserved on the results that were obtained, such as is available on the early air and gas injection operations in Pennsylvania, West Virginia, and Ohio.

Unsystematic water floods were commenced in Nowata County, Oklahoma, in 1931, which were followed, in 1934, by a systematic operation developed similarly to the methods employed in the Bradford field. The latter project established the effectiveness of water-flooding in the Bartlesville sand, and in succeeding years it has been followed by ever-expanding condary recovery activity in the mid-continent and south-tern regions.

tio ing for petroleum is the most ancient known produc-enlargem od. The early mining operations consisted of the pits or sh nt at the surface of natural seepages, and of shallow whic hort drifts into the outcrop of oil-bearing sands, from the accumulated oil could be removed by bailing. More recently, actual underground mining for petroleum has been practised in France, Germany and Japan, in fields where primary production has declined to a low level.

There have been several attempts to mine petroleum in the United States, the most recent being projects located in Miami County, Kansas, at Richards, Missouri, and at Rocky Grove, Venango County, Pennsylvania. These operations differ from the European mines in that no drifts or crosscuts have been dug into the oil-bearing formation, but rather the sand has been penetrated by a series of horizontal holes drilled in a cart-wheel pattern back of and away from the central shaft. None of these recent United States operations has been economically successful, but the Pennsylvania mine did provide a great deal of valuable scientific and technical information.

SECONDARY METHODS OF OIL RECOVERY

Vacuum. Although the application of vacuum is not regarded as a secondary method, according to the definition accepted in this paper, brief mention of vacuum is justified because it was one of the first methods to be applied purposely to wells to increase the production of oil. Vacuum consists of creating a pressure differential in the annular space of an oil or gas well by applying suction, thereby causing a movement of liquid and gaseous hydrocarbons toward the well bore. The amount of pressure differential that can be created by the application of vacuum is, of course, very limited in comparison to the injection of gas under pressure into the reservoir. It was soon recognized that production benefits resulting from the use of vacuum were not permanent, but it was maintained on many properties because of the increased richness of casing-head gasoline production.

Air and Gas Injection. Gas repressuring, in contrast to pressure maintenance, usually is applied in a field when the point of depletion by primary methods of production has been reached and oil no longer can be produced profitably. For this reason, in the older fields, many repressuring projects have a very humble beginning; and the engineer who may be called upon to supervise the secondary operation frequently will be confronted with a dismaying collection of antiquated and worn-out equipment, junked holes, wells in bad condition, and poor records.

Unitization of the field for air and gas injection purposes generally is desirable, and will result in lower development costs, maximum economy of operation and better control of reservoir performance.

In north-western Pennsylvania, where air and gas injection operations have been conducted on an extensive scale for many years, it is common practice to use old holes for producing wells and to drill and core new holes for injection purposes. Wide variations in permeability, which many times are present, are controlled by segregation of the sand body into two to five sections. This is accomplished by setting packers in such position that the air or gas can be injected into each sand section separately and under different pressures.

Usually an attempt is made to locate the intake wells so as to form as symmetrical a well-spacing pattern as possible in relation to the producing wells. However, more frequently the well patterns are irregular and the well spacing is variable. In some of the more recent, intensively developed projects in Venango County, Pennsylvania, the intake wells are located in the center of a hexagon formed by six producing wells at the corners. The common distance between the intake and producing wells is from 150 to 250 ft.

As a secondary recovery operation, the injection of gas into a partially depleted oil reservoir is essentially a continuous circulation of the gas into and through the producing formation. Since the gas is a non-wetting phase, it will pass through pore channels already open by the previous removal of fluids from the reservoir, and will tend to move the remaining oil by viscous drag rather than by direct displacement, such as takes place by the action of an expanding gas cap.

The rate of movement of a gas drive will be proportional to the pressure gradient established in the reservoir. The movement of the gas through the reservoir serves continually to reduce the oil saturation and results in a very rapid increase in permeability to gas, producing what may soon become a prohibitively high gas-oil ratio. This effect is responsible for the relatively low efficiency of the gas-drive recovery process, and limits definitely the amount of oil which can be obtained by gas injection.

The chief justification for the injection of gas is that it will make available additional oil at a commercial rate that probably would not be obtained otherwise because of the low rate of production which prevails toward the end of the primary production phase. In other words, gas injection serves to accelerate recovery during the late life of a field, by retarding the normal rate of decline.

The history of air and gas repressuring in many parts of the United States is very similar. When primary production of oil by conventional pumping methods is no longer economically justifiable, the operator must make some change in practice or abandon his property or field. Since a minimum investment in new wells and production equipment are generally required for the injection of air or gas, repressuring by these fluids has been found to be the cheapest method for maintaining or increasing the production of oil. As a result, profitable production can be maintained, and the ownership of the working interest in wells, properties, and possibly entire fields preserved to the producers until conditions may become more opportune for the application of some other secondary method, such as water flooding.

Water flooding. The process of water flooding consists of applying water under pressure to an oil-bearing formation by means of specially equipped intake wells. It has been most successful in fine-grained, tightly-cemented sands, which are frequently characterized by high residual oil content after the primary phase of production. In the initial stage of water flooding an oil bank is formed ahead of the advancing water if the mobility[1] of the oil concurrently is greater than that of the water. The initial stage is followed by a viscous drag stage at which time the permeability of the reservoir surfaces to oil is greatly reduced and the permeability to water is greatly increased, which results in high produced water-oil ratios.

Most water-flooding operations are developed on what is known as the "five-spot" pattern, with the producing oil-well located in the centre of a square formed by water input wells at the four corners. Other patterns have been employed to a lesser extent, but the theoretical flooding efficiencies of the various patterns are so close that the convenience of the "five-spot" usually encourages its use.

The spacing between water input and producing wells has been determined in the past largely by long experience. In some of the earlier "five-spot" developments in northern Pennsylvania the distance between input and producing wells was as low as 150 ft. More recently, distances of from 225 to 250 ft. have become common practice, which results in a considerable reduction in development expense. Experience in the Bradford field (Pennsylvania) has shown that there has been no appreciable decrease in the oil recovery obtained from the wider spaced floods, although a longer period of time has been required to obtain the total recovery. However, in many fields the lack of continuity of individual beds of the reservoir rock might cause the trapping of considerable oil if much wider spacing should be employed, and for that reason there seem to be rather definite practical limitations to further expansion of well-spacing patterns.

The time required to deplete the wider spaced flooding projects, of course, can be reduced by the use of higher injection pressures. However, there is a limit to the pressure that can be applied because of the tendency of the rocks to break or rupture under excessive pressures. It has been found that pressure-parting of the rock can be avoided if the bottom-hole injection pressure does not exceed about 1.25 lb. per sq. in. per foot of depth. Variations from this breakdown pressure can be attributed to differences in the strength and rigidity of the producing formation and the overburden.

Delayed drilling of producing wells for a predetermined period after the injection of water into the reservoir has been commenced has resulted in a much improved recovery of oil where a wide range of permeability exists. However, the water must be introduced into the sand at a balanced rate through each intake well so as to prevent an off-centre concentration of oil within the pattern.

When the producing wells of some of the first delayed floods were drilled it was found that they would flow on account of a build-up of pressure in the reservoir. This discovery immediately suggested that complete secondary recovery might be obtained by flowing if some backpressure could be maintained on the producing wells. Flowing secondary production has been practised successfully on a few properties in Pennsylvania and on several properties in Oklahoma and Kansas where permeability and viscosity relations are favourable for the injection of substantial quantities of water. The advantages of flowing over conventional production by pumping are found in the economy of cost and in the economy and simplicity of operation. Experience with flowing projects indicates that there is no loss in ultimate recovery under comparable conditions.

Mining: Excepting the operation at Rocky Grove, Pennsylvania, attempts at oil mining in the United States have been on such a small scale that no standard technique has been developed, similar to some of the foreign operations. The information that has been obtained from the United Sta[...] mines, therefore, has not been adequate to determine whe[...] mining operations might be economically feasible in [...] country. Data on the Rocky Grove operations have not [...] released, but it may be assumed that it was a failure [...] of cessation of the development programme.

No attempt was made at Rocky Grove to excav[...]e the oil-bearing rock as has been done in various European o[...]perations, where a recovery of 40 per cent of the original oil co[...]ntent of the reservoir has been reported. Such recovery is definitely superior to most of the secondary recovery operations in the United States, and encourages the belief that the feasibility of mining for petroleum is this country clearly justifies further investigation.

SECONDARY OIL RESERVES

The estimation of secondary oil reserves in the United States that can be made at the present time can be regarded only as a first approximation, and, undoubtedly, will be revised from time to time just as estimates of the total proved primary

[1] "Mobility" is defined as the effective permeability of a reservoir rock to the fluid phase divided by the reservoir viscosity of that phase.

	Per cent		Approx. per cent
SiO_2	42 to 46	C	18
Al_2O_3	12.5 to 14	H	2
Fe_2O_3	8 to 9	S	7
MgO	app. 0.9	H_2O	1
CaO	app. 1	Ash	73
K_2O	app. 4	Calorific value,	
Na_2O	0.4 to 1.0		2,100 kcal./kg

THE VARIOUS PYROLYSIS METHODS

At Kvarntorp four different methods are used. The shale is heated without access of air either in retorts or direct in the ground (Ljungström's process). The pyrolysis produces gases which are then cooled by water or air in condensation plants in which oil and water condense. The non-condensable gas contains some 20 per cent of hydrogen sulphide and this is removed (by the IG alkazide process) in three sulphur recovery plants, where elementary sulphur is produced. A quantity of light gasoline accompanies the purified gas and this gasoline is washed out by means of cold heavy oil in a light gasoline plant, installed next to the sulphur apparatus.

The gas cleansed of hydrogen sulphide and gasoline is used as fuel, partly in certain of the pyrolysis retorts and partly in the steam power plant for steam production. The quantity of steam not required for the running of the works is converted into electric energy, part of which is consumed in the works and part of which is fed to the public distribution system.

The shale to be treated in the retorts is quarried by surface mining, loaded on an electric railway and transported to a coarse crushing plant. The coarsely crushed shale is taken by way of a belt conveyor and screening device to the dressing house, where the bituminous limestone accompanying it is picked out. The shale is then crushed to its final size. The crushed shale is carried by belt conveyor to a screening plant, installed above silos, where it is sorted into three classes of nuts:

(1) > 27 mm. for IM and Rockesholm retorts;
(2) 5—27 mm. for Bergh retorts;
(3) < 5 mm. waste.

From the silos the shale is delivered to the various retorts.

Bergh system: There are three retort houses, two of which are designed for dealing with approximately 400 tons of shale per day each and one for approximately 600 tons of shale per day.

The smaller retort houses each contain 1,120 retorts, about 2 metres high and with an inside diameter of 2 decimetres. The large house contains 1,680 retorts of the same size.

The shale passes through the retort and is there heated to pyrolysis temperature, at which oil-bearing gases are formed which are drawn out through a pipe inserted in the mi the retort. The coke residue falls out on a grate whe burned and the combustion gases pass outside the re way of exhaust steam boilers to the chimney. I this w contents of the retort obtain directly the heat required execution of the process.

The ash is ejected on a band conveyor and n th way of an ash bunker to a rope conveyor and t

Rockesholm system: This retort house is desig for ing with 550 tons of shale per day and consists r each about 9 metres high and 7 decimetres diar

The shale passes through the retort and is he pyrolysis gases formed are drawn direct to a cond The coke formed is not burned but is conveyed a labyrinth to a separate coke-burning plant.

Around each retort there is a combustion cha bottom of which gas burners are placed for combu non-condensable gas, which thus furnishes the req lysis heat.

Industrimetoder system: At Kvarntorp there are ovens, each designed for dealing with 600 tons o day. The oven consists of a long tunnel through loaded with shale are passed. Alongside each tu there are three furnaces in which non-condensable are burned. The hot flue gases are then made to pass through a bundle of tubes running along the tunnel. The gases deliver their heat to the shale cars but have no cont with the retort atmosphere. The pyrolysis gases are dra off in the usual manner to the condensation plant. The co is not burned here but, as with the Rockesholm retorts, is conveyed to the coke combustion plant.

Ljungström system: In the Ljungström method the shale is not mined and the method in general is best applied to an area which has a covering stratum of limestone. The whole field that is to be dealt with is divided into hexagonal sections with 2.2-metre sides, at the corners of which holes are drilled through the soil, the limestone and the shale stratum. Iron pipes are inserted in these holes and in each pipe is fitted an electrical resistance insulated from the pipe wall by quartz sand. Electric current is connected and heating of the shale layer takes place. In the centre of the hexagon a hole is drilled through which issue the oil gases formed. The oil gases are collected by means of a piping system and are conveyed to the condensation plant.

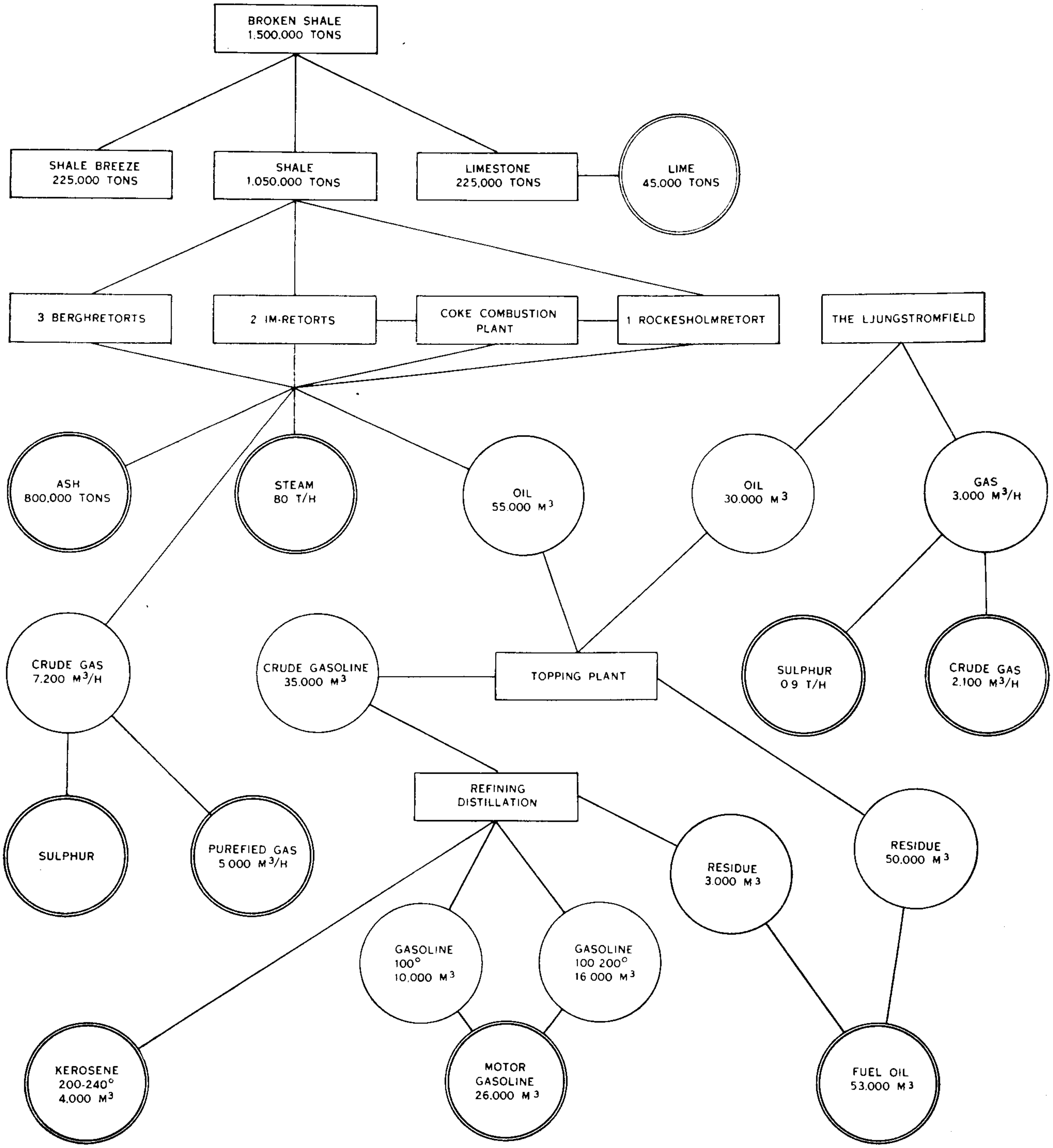
After the oil has been condensed out at the different retorts it is pumped into crude oil tanks. The crude oil is then passed through a topping plant where gasoline and kerosene are separated from the residual fuel oil. The gasoline and kerosene fractions are then subjected to chemical refining with subsequent fractional distillation.

Quantities of Shale Worth Mining of Various Oil Contents in the Kvarntorp Area

	Shale outcrop with 5 to 7 per cent oil content		*Shale beneath limestone stratum 5 to 5.5 per cent oil content*		*Total*		
	Sq. km.	*mill. tons*	*Sq. km.*	*mill. tons*	*Sq. km.*	*Shale in mill. tons*	*Oil in mill. tons*
Area within 3 miles radius of shale oil works at Kvarntorp	14.5	270	14.7	360	29.2	630	35
Other shale-bearing areas in Närke	—	—	—	—	—	1,000	50

The composition of the shale varies according to the depth and the place from which it is taken, but on the average the analysis for the Kvarntorp shale may be regarded as representative.

Production Chart, Swedish Shale Oil Co., Ltd. Örebro, Sweden



Coke combustion plant: In two of the retort processes and in the Ljungström method the caloric content of the coke is not utilized. To do this, i.e., to burn the coke, is an extremely difficult technical problem, as the coke is a very poor fuel, mainly on account of the high ash content (85 per cent), low calorific value (approximately 1,100 kcal./kg.) and of its sintering at so low a temperature as approximately 950 degrees C. In the Bergh retort the coke is burned, as mentioned, with simultaneous cooling of the fuel layer with air. The combustion per square metre of grate area is very limited, however. It would be better if it were possible by indirect cooling to carry away the heat that is superfluous for combustion. It would then be possible with an economic surplus of air to ensure a temperature suitable for combustion. The final solution of the problem has been that suitably shaped heat-absorbing steam-generating surfaces are inserted in appropriate places in the fuel layer itself (the La-Mont principle). The steam generated is superheated in a special compartment (32 atm., 450 degrees C.). The plant consists of 40 furnace shafts, of which 32 are designed for steam generation and 8 for superheating, together with 5 exhaust steam boilers for utilizing the flue gas heat. Motor pumps, circulation pumps, feed water tank and steam domes are assembled separately.

Present annual capacity of the works: The works are at present built for a capacity as shown on the production chart. Owing to shortage of power, however, operation of the Ljungström plant is stopped for the time being.

THE OIL

The multitude of different hydrocarbons that are present in the shale oil, together with the presence of organic oxygen and sulphur impurities, makes the separation and determination of the individual compounds impossible, unless it be a question of the particularly volatile and fairly simply composed fractions. The analysis must be limited to more or less accurate estimation of the different classes of substances that are present, but this task also involves difficulties, due to part of the olefins being so sensitive that polymerization and indefinable processes easily set in, leading to the formation of tar and resinous products which interfere with further treatment. Consequently we have considered only agents by means of which especially reactive substances may be removed in the least possible spoiled state.

A comparison between the gasolines obtained from the different retorts and from the Ljungström plant shows that the retort gasolines are very like each other with approximately 55 per cent olefins, 25 per cent paraffins, 10 per cent naphthenes and 10 per cent aromatics, whereas the Ljungström gasoline has some 15 per cent less olefins but 15 per cent more paraffins. The sulphur content of the retort gasoline is 1.2 to 1.3 per cent whereas in the Ljungström gasoline it only amounts to 0.8 per cent. Thorough investigation of the sulphur impurities has been made. The sulphur impurities listed below have been isolated and identified: hydrogen sulphide, methyl mercaptan, carbon disulphide (only in retort gasoline), dimethyldisulphide and trisulphide, diethyldisulphide, ethyl mercaptan and isopropyl mercaptan, thiophene, α- and β-methylthiophene and higher homologues, thiocresols and alkylated thiophenes.

Eighty to ninety per cent of the sulphur impurities in the gasoline consist of thiophene and its homologues, if the lowest fractions are excepted where mercaptan and carbon disulphide predominate. The mercaptan content decreases rapidly with increasing boiling point of the gasoline and butyl mercaptan presents only traces. The phenol content of the gasoline amounts to 2 to 3 kg. per cubic metre.

The composition of the heavier oil has not yet been determined in detail. It has been ascertained, however, that all the oils are particularly rich in aromatics and poor in paraffins. This applies especially to the retort oils. The olefin content is relatively high. The sulphur content is 1.7 and 1.2 per cent for the retort and Ljungström oils respectively. The phenol content amounts to 1 to 2 per cent. Owing to the low aromatic content the specific weight is 0.98 or 0.92 respectively. The pour point is low.

Despite the apparent unsuitability of the crude oil's composition for the production of transformer oil, investigations with this object were undertaken, and the results proved surprising, as transformer oil of very good quality was obtained. Two methods have been employed, the solvent extraction method and the hydrogenation method. The quality and yield of transformer oil depend on the preliminary treatment of the crude oil, the solvent, the extraction process and the final refining of the raffinate.

From low temperature extraction with furfural in a multistage process of gently topping a crude Ljungström oil, refining subsequently with oleum, caustic soda and clay treatment, there is obtained a yield of approximately 9 per cent by weight based on crude oil. This yield applies to a transformer oil with a flash point of $>$ 115 degrees C., a Sligh number $<$ 0.25 and an acid number after oxidation of 0.6. Along with the transformer oil some quantity of good motor lubricating oil should also be obtainable. The above particulars apply to a Ljungström oil. A retort oil gives much less yield and is useful for making transformer oil only after hydrogenation.

The hydrogenation experiments carried out have been either continuous or intermittent, all over fixed catalysts. The hydrogenation was performed at 200 atm. and 375 degrees C. The catalysts were produced by compressing into tablets suitable sulphides of molybdenum or tungsten containing sulphides of chromium or cobalt. A light sulphuric acid refining of the hydrogenated oil gives a transformer oil of high class. The above applies equally to retort and Ljungström oils.

The heavy oil has been examined with regard to its wood impregnation properties. Toxic and mycologic tests have indicated that the shale oil can very well compete with creosote in this respect. This applies particularly to an oil reinforced with 4 to 5 per cent of the phenols extracted from the gasoline.

THE ASH

Metal extraction

The shale ash's content of potash and aluminium is about 4.5 and 15 to 20 per cent respectively, calculated as oxides. The problem of recovering potash and alumina was subjected to investigation by several methods. In the Hedvall-Nordengren method a fine-grained mixture of ash and lime is heated in an autoclave at 20 atm. for 4 hours. This causes the lime to react with the ash in forming calcium aluminium silicates, and the potassium content of the ash is liberated as a hydroxide solution. The trials at Kvarntorp on a medium-sized scale, however, gave the result that both the filtering velocity and the potash concentration in the soaking solution were rather low. For this reason high evaporation costs must be taken into consideration, so that potash production by this method can only be justified by an emergency situation in the country.

Another method that has been tried for extracting the potash and alumina content of the shale is the Hultman-Collenberg method by which the shale coke is smelted under such conditions that the greater part of the iron is obtained in the form of a relative high percentage silicious iron with the simultaneous formation of a slag that is granulated and extracted with dilute sulphuric acid. A yield of 90 per cent Al_2O_3 and 80 per cent K_2O is obtained. By the addition of potassium sulphate the potassium alum is precipitated with a content of only 0.003 per cent Fe_2O_3 and 0.02 per cent SiO_2. It can be split up by heating under pressure or be precipitated with sodium sulphide. The smelting process is rather expensive and it does not seem the method would pay unless it were possible at the same time to extract some heavy metals, e.g., uranium, vanadium and molybdenum. Such methods are now being worked out.

Building materials

Light concrete: Light concrete is produced in other parts of the country from shale ash and lime burnt in kilns in the field. These materials are ground to a meal which is mixed with water and aluminium powder added. After some time the mass swells and becomes so firm that it can be cut into blocks, which are then heated under 10 atm. steam pressure for about 15 hours. The material gets a strength of 60—70 kg./sq. cm. with a volume weight of 0.7. Trials have been made with burnt out ash from the waste heaps at Kvarntorp, furnace-burnt coke and lime, ash sintered with lime, both together and mixed in charges, and ash direct from the Bergh retorts. In none of these cases have acceptable results so far been attained. The best results have been obtained when ash and lime have been sintered together by charges. In conjunction with these trials, purely theoretical investigations have proceeded at Chalmers' University of Technology. For example, activity and solubility experiments have been made with various ashes. Certain differences have been observed in these, but no relation between these and the properties of the light concrete samples made from the different ashes has existed.

Bricks: The basic materials for the making of the bricks are ash, lime, water and chemicals. These materials are well mixed and the water quantity is arranged so that the consistency of the mixture is suitable. The less water that can be used the better. The grain size of the ash and the lime and especially the quality of the latter are of decisive importance for the properties of the brick. Fully burnt ash from the ash-heaps gives the best brick. The quality of the bricks is greatly dependent on the manufacturing procedure itself. Systematic trials have been made to investigate all the factors that affect the properties of the bricks. Treatment with steam (1 atm.) at about 80 degrees C. for some 20 to 24 hours after moulding had some advantages. Chemical admixtures hasten the binding process, give higher strength of the brick (about 200 kg./sq. cm. for a volume weight of 1.4—1.5) and decrease the influence of the quality of the lime.

Investigations and analyses made up to now suggest that the heat conductivity is somewhat lower than for wall bricks of corresponding strength and volume weight, that the frost resistance with steam-treated brick is fully equivalent to that stipulated for facing bricks, that the water absorption is not greater than for fired bricks and that salt precipitation only occurs if too much chemical is added. As regards shrinkage and swelling, everything indicates that this brick meets the standards placed on light concrete, which should be regarded as satisfactory.

Cement: Trials have been made to see if the shale ash can possibly be employed to eke out cement. Concrete was made of pure cement and of cement blended with a certain quantity of shale ash ground to different grades of fineness, shingle and water. The cubes were tested after 28 days. It was found in the tests that the ash did not remain an inert material but participated in some manner in the binding and hardening. The fineness of the grinding was of great importance. An admixture of 25 to 40 per cent very finely ground ash (< 0.6 mm.) could be permitted without the strength properties being appreciably deteriorated. A small lime content had the effect that the concrete was inclined to swell while the frost resistance was decreased and the hardening was delayed. Admixture of the chemicals employed in the brick making had no noticeable effect on the strength.

THE PYROLYSIS GAS

The Swedish shale would seem to be the most rich in gas in the world, i.e., the shale which gives the greatest quantity of gas per ton on pyrolysis, therefore the problem of utilizing the gas has been one of the most important for the company. The composition of the gas from the various retorts will be seen from the table below.

Composition of Gases

(In percentages)

Data	*Bergh*	*IM*	*Rockesholm*	*Ljungström*
H_2S	17	28	15	25
CO_2	9	6	12	5
CO	1	1	1	0.5
O_2	0.5	0.2	0.5	0.1
N_2	35	14	25	2
H_2	15	15	27	18
C_nH_{2n}	3.5	10	4	4
C_nH_{2n+2}	19	26	17	45.5

As an average for the retorts, some 60 cub. metres crude gas per ton shale may be counted on. The content of hydrogen sulphide in the gas is approximately 18 per cent and is recovered as elementary sulphur in three sulphur plants. The purified gas has a calorific value of about 4,500 kcal./cub. metres. This gas constitutes, of course, a good fuel and is at present utilized for this purpose after washing out all the light gasoline, but it would be more economical if the hydrocarbons could be isolated and utilized separately. The gas residue would still be usable as fuel gas.

The attention of the laboratory therefore was directed at an early stage to efforts to recover the hydrocarbons. Various methods were examined and absorption with light oil under pressure was finally adopted. It was mainly the C_3 and C_4 hydrocarbons that are extracted. The mixture of these (gasol) consists of about 30 per cent olefins (10 per cent propylene and 20 per cent butylene) and 70 per cent paraffins (30 per cent propane and 40 per cent butane). A plant for extraction of this mixture of hydrocarbons is under construction and is estimated to yield 7,000 to 8,000 tons per annum (without the Ljungström plant). The gasol will first be sold as a domestic and industrial fuel but it is possible that production of chemicals will also be put in hand. The products that can be derived from gasol are well known and simple and can in part be obtained also from other raw materials. Kvarntorp will therefore select a small number of products, for the production of which especially good conditions are present.

A considerable laboratory work has already been devoted to this and semi-commercial trials in producing alcohols, ethers and ketones have been made. All these products are solvents of high class. They may in turn form raw materials for the manufacture of several other highly refined products.

The table overleaf contains the quantities of different products obtained in the various methods on the pyrolysis of 1 ton of 5.6 per cent shale.

FUNDAMENTAL RESEARCH

It is of the greatest importance that all the factors that influence the quantitative and qualitative results of the oil production should be fully known. The most important of these factors are the pyrolysis temperature and the heating speed. Other factors that probably affect the process are the presence of water vapour, gas pressure, presence of de-gassed shale coke etc.

In the first preliminary pyrolysis experiments certain observations were made which indicated that the changing of the kerogen into oil and gas did not take place in one stage but in

Production	*Bergh*	*IM*	*Rockesholm*	*Ljungström*
Crude oil in kg	40	44	43	36
Light gasoline in kg	4.5	4	7	4
Sulphur in kg	12	11	16	12
Crude gas in cub. metres	60	33	100	40
LPG-gas in kg	7	6	9.5	8
Crude gas in Mcal.	300	300	450	380
Steam in Mcal. (incl. coke combustion)	400	325	325	—
From crude oil and light gasoline there is obtained:		*Litres*		
Gasoline	8.5	10.5	12	19
Fuel oil	35	37	36	23
Waste oil	2.5	3.5	4	5
Consumption:				
Low-pressure steam Mcal.	225	40	150	—
Fuel Mcal.	—	350	250	275 kwh.

at least two, that is via an intermediate substance, which theory was also supported by extraction experiments on shale with trichlorethylene. Intermediate substances could be extracted before the actual oil formation had set in, which indicates that the kerogen's first conversion is a different reaction from the oil formation. The extracts had high boiling points and could not be distilled. As they were chemically rather indifferent, resort was made to separate them by means of chromatography.

Special interest has been directed to the formation of some pyrolysis products present in the oil and the water, viz: hydrogen sulphide, water, carbon dioxide and substances with nitrogen content. The velocity of formation for these substances at various temperatures is different from that of the chief components of the pyrolysis gas. These substances are not formed in the same reactions or from the same initial material as the hydrocarbons but in secondary reactions, which have great economic and technical importance, however. It is enough to consider the sulphur recovery from the gas and the sulphur impurities in the oil.

In connexion with the above pyrolysis and extraction experiments, certain investigations are being made concerning the treatment of shale with chemicals, mainly oxidation of shale with nitric acid. The experiments and results so far can only be regarded as preliminary. The research is continuing and the chemical structure of the kerogen and the intermediate products will be studied more closely. Direct numerical relation between the various variables cannot be obtained until a larger amount of material is available. By continuing the research, a deeper insight should be gained into the reactions that lead to the oil formation, while at the same time the connexion between the pyrolysis conditions and the formation of various by-products may be shown. It may of course be conceivable that by suitable combination of various processes a higher yield of organic substance could be obtained from the shale than has hitherto been possible with pyrolysis alone.

New pyrolysis methods are being tried out at present. The primary problem is to find a method by which the breeze which is not utilized at present can be burned. The principles which have found application in America with catalytic cracking will be studied in the first place. Experiments have also been made in America with shale, but in this case it should be observed that the American and Swedish shales are probably altogether different.

Hydrogenation of shale has been studied, from which it appeared that the oil yield could be very appreciably increased by hydrogenation in rotary autoclave with a temperature of about 400 degrees C. and an initial pressure of 20 atm. The oil obtained was heavy, and the gasoline recovered had a low sulphur content and low content of olefins. These hydrogenation experiments will be continued in conjunction with the pyrolysis and extraction experiments.

To investigate the thermal effects and the heat of reaction on pyrolysis of shale, an automatic adiabatic high temperature calorimeter has been designed and constructed. Preliminary tests have given promising results. If a graph is plotted with the temperature as abscissa and the total amount of heat consumed in the reaction in calories as ordinate there is obtained for shale a curve with three distinct maximums. The first maximum lies at about 140 degrees C. This is due probably to certain hydrate water being split off. A second maximum lies at 360 degrees. This corresponds to the pyrolysis reactions. The third maximum at 500 degrees must probably be attributed to certain gas reactions.

For shale coke also there are obtained certain maximums and minimums.

DEVELOPMENT POSSIBILITIES

The good results obtained in combustion of the shale coke, from the IM and Rockesholm retorts, in the manner described above, have provided inducement for the employment of the method in the Bergh retorts as well. The capacity for these is entirely determined by the speed with which the ash can be burned and removed. With the object of being able to increase the combustion of coke in the grates installed in the retorts, steam coils have been inserted in the coke bed. Practical trials have indicated that the shale through-put – and therefore the oil, gas and steam production–can be increased two and one half times by a small reconstruction of the retorts. The annual capacity of the works, if the Ljungström plant were not running but with the gasol plant in operation would then be, in cubic metres: fuel oil, 63,000; gasoline, 16,500; sulphur, 22,000; lime, 45,000; gasol, 13,000; and 75,000 million kwh. in electric energy.

When the electric power situation is such that the Ljungström field can be started up, this can be loaded without any great extra investment with 24,000 kw., which would enable the following additional production, in cubic metres, to be obtained: fuel oil, 18,000; gasoline, 13,500; sulphur, 7,000; gasol, 4,800.

In this case the power must be bought from outside. Further extension of the retort plants and the Ljungström field is not possible without at the same time extending all the ancillary installations, such as transport and crushing departments, sulphur plant, gasol plant and refinery.

ECONOMIC CONSIDERATIONS

It is quite clear that it is difficult to operate a plant for Swedish shales economically in normal times, and it is only thanks to measures of rationalization and extending the manufacture of by-products that this can be made possible. Conditions are not lacking for this, as seen from the account given above, but it must be remembered that the difficulties are great and that hard competition is to be expected from abroad.

The wages account is at present some 50 per cent of total costs and can hardly be cut down until further mechanization and rationalization have been carried out. It must be borne in mind that production up to now has run parallel with a big programme of extensions, so that it has not always been easy to distinguish the costs which would normally be considered as operating costs from those which should be reckoned as investment. The plant was put up at a very quick rate and very little was known at that time of the various methods. It is only by benefiting from experience gained that the continual work of extension and improvement could be carried out.

At present there is no doubt that, with increased capacity of the Bergh retorts, the oil produced in these retorts will be able to compete as regards price with imported oil. No appreciable improvement of the other retorts can be anticipated just now. Greater hopes may be entertained in this respect, on the Rockesholm retorts than on the IM retorts, the oil from which comes out now at a rather higher level of price than with the other retorts. It is not impossible that both these types of retorts will be replaced by Bergh retorts. The economy of the Ljungström field is almost entirely governed by the price of electric power.

With the volume of production amounting to some 110,000 cubic metres of oil as indicated above and with increased recovery of by-products, the plant should give an appreciable profit capable even of covering interest and amortization on the investment, after it has fulfilled its emergency mission.

Oil from Oil Shale - Experience in the United States[1]

R. A. CATTELL

ABSTRACT

The Bureau of Mines is conducting an oil-shale research and demonstration-plant programme. Other Government agencies, industry, and educational institutions are co-operating. Studies indicate that 100,000 million barrels of oil may be recovered from shale in the best 1,000 square miles of the Green River formation in Colorado, and much oil will be available from an additional 15,500 square miles of that formation in Colorado, Utah, and Wyoming.

A highly mechanized system of Underground quarrying has been developed to mine shale for 60 cents a ton. Research is developing fundamental information concerning the characteristics of oil shale and shale oil. Tests with several types of retorts are being conducted at the demonstration plant near Rifle, Colorado, and at privately owned plants.

Low-boiling shale-oil distillates have a hydrocarbon composition similar to cracked petroleum products' but include substances that are characteristic of coal tars. Hydrogenation will improve these distillates so they can be refined by conventional means to produce satisfactory substitutes for petroleum products.

Estimates indicate that shale oil can be produced with continuous retorts at costs below $ 2.00 a barrel. Research and development should continue to make shale oil available when it is needed for the Nation's welfare.

INTRODUCTION

A high degree of co-operation between Government agencies and private industry has characterized experience in the United States during the past five years in studying oil-shale reserves, mining and crushing oil shale, producing shale oil, and manufacturing shale-oil products, to develop information needed to enable oil shale to supplement supplies of petroleum.

Pursuant to the Synthetic Liquid Fuels Act, approved 5 April 1944, the Bureau of Mines has conducted an intensive research and demonstration-plant programme. (1)[2] The Army, Navy, Geological Survey, and other Government agencies have co-operated fully, and specialists from private industry and educational institutions have devoted much time and energy to advance the studies. Co-operative efforts have been directed toward core drilling, crushing tests, research on retorting and refining, and pilot-plant processing of oil shale and shale oil. Meanwhile, several industrial concerns have conducted independent research and development.

OIL-SHALE RESERVES

Studies in recent years have shown that earlier estimates of the oil-shale reserves of the United States were very conservative. The Nation's outstanding reserve is in the Green River formation, which was deposited during middle Eocene time in the beds of large lakes over an area of about 16,500 square miles in Colorado, Utah, and Wyoming. (2) (3) The richest deposits cover approximately 1,000 square miles in the Piceance Creek Basin of north-western Colorado. In that area, the main oil-shale measure is about 500 ft. thick and has an average Fischer assay (4) of about 15 U.S. gallons of oil a ton. (5) This is a deposit, in place, of more than 300,000 million barrels of oil.

The lower part of the main oil-shale measure consists of a continuous series of beds, known as the Mahogany Ledge, which is 70 to 110 feet thick and has an average Fischer assay of about 30 gallons a ton. Recent core drilling has indicated that this series in the 1,000 square miles may yield 100,000 barrels of oil, allowing 25 per cent for mining losses. Although that estimate is for the best series of beds in the best-known and apparently the most-favourable area, it represents only a part of the oil that ultimately will be available from the Green River formation.

OIL-SHALE MINING

It was evident from the beginning that production of shale oil will not be economic unless shale can be mined at a very low cost. Large-volume operations and a high degree of mechanization are necessary.

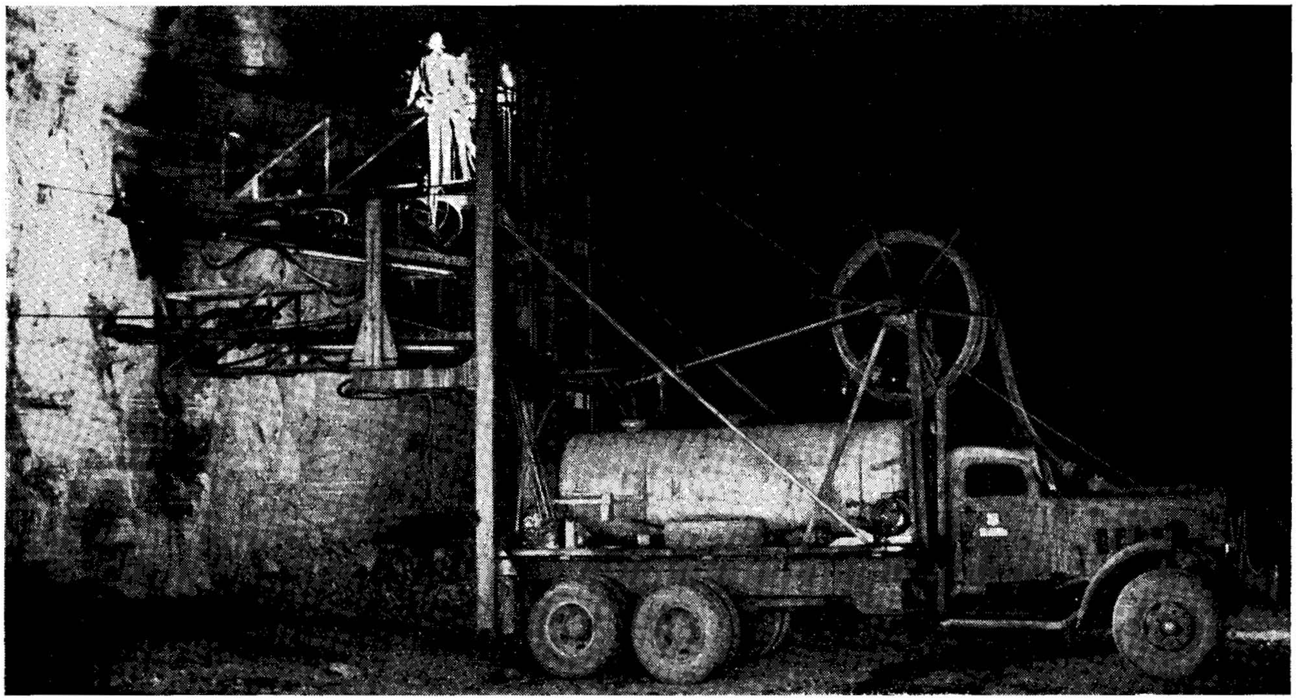
The oil shale of the Green River formation is not a true shale, but a strong, tough marlstone that lies in massive horizontal beds. In the area west of Rifle, Colo., the main oil-shale measure crops out in an almost vertical cliff at an elevation of 8,000 to 8,500 ft., about three miles north of the Colorado River and about 3,000 ft. above the river bed (Figure 1).

[1] Work on manuscript completed 1 April 1949.

[2] Numbers within parentheses refer to items in the bibliography.

Bureau of Mines, U.S. Department of the Interior

Figure 1. Aerial view of the Bureau of Mines Oil-Shale Demonstration Plant near Rifle, Colorado. The plant is at the right centre, the housing area in the left foreground, and the mines are at the base of the steep cliff at the upper left, 2,200 feet higher than the plant.



Bureau of Mines, U.S. Department of the Interior

Figure 2. Multiple-drill carriage in operation on the top level of the Bureau of Mines underground quarry

Barodynamic and demonstration tests of the roof stone over the Mahogany Ledge showed that rooms at least 60 ft. wide can be run safely without timbering. (6) (7) Therefore, the Bureau devised a mining method on the principles of underground quarrying. The Mahogany Ledge is mined in three benches, with a 60 ft. roof span and pillars 60 ft. square staggered in one direction, thus recovering three-quarters of the shale. Only the upper and middle benches are being developed in the Bureau's demonstration mine.

The heading on the top level is drilled horizontally by four percussion drills mounted on a multiple-drill carriage operated by two men (Figure 2). An 80-hole round 15 ft. deep is drilled in one shift, and the holes are charged from an adjustable elevated platform mounted on a tractor. About 1,500 tons is broken in one blast, and the shale is loaded by an electric shovel into 15-ton diesel trucks for transportation from the mine. The middle bench is drilled vertically with percussion drills mounted on another type of drill carriage. The roof and sides of pillars are scaled from a platform on a travelling crane (Figure 3).

Analyses of production tests indicate that an output of 100 tons of shale per man-shift of underground labour and 50 tons per man-shift of total mine employees can be attained. In an operation on a scale of 150,000 tons a day, shale can be mined and conveyed to a retorting plant at a cost of about 57½ cents a ton. An additional 1½ cents a ton would provide a return of 4 per cent a year on the average unamortized part of the estimated initial capital investment of $34 million required to develop and equip the mines.

RESEARCH ON OIL SHALE AND SHALE OIL

Laboratory and small pilot-plant studies of oil shale and shale oil in progress at the Bureau's Petroleum and Oil-Shale Experiment Station in Laramie, Wyo., are correlated intimately with the work at the Oil-Shale Demonstration Plant near Rifle, Colo. In addition, close technical contact is maintained with private industry and with the Bureau's research on petroleum. Studies have been made of the composition of

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Figure 3. Portable scaling rig used in removing loose rock from the roof and pillars of the Bureau of Mines underground quarry

oil shales, kerogen and shale oil, (8) and specific heats, (9) mineral constituents, and other properties of oil shale and spent shale have been determined. Research has been conducted on rates at which kerogen is converted to oil under different conditions of extraction by thermal solution and conventional heating. Other studies have included rates of shale-oil cracking, hydrogenation of shale oil, and the characteristics of by-products from oil-shale operations.

A few of the conclusions drawn from this research are:

(*a*) About 500,000 B.T.U. is required to retort 1 ton of average Colorado oil shale;

(*b*) The olefins in shale-oil naphtha are predominantly of the straight-chain type;

(*c*) Shale oil contains a high percentage of heterocyclic molecules;

(*d*) The tar acids in the shale oil contain phenol, cresols, and some xylenols and higher-molecular weight homologues;

(*e*) The tar bases contain substituted pyridines and quinolines;

(*f*) Most of the sulphur is in the form of substituted thiophenes; and

(*g*) Good-quality crystalline and microcrystalline waxes can be extracted from Colorado shale oil.

The research has shown that kerogen contains enough hydrogen to produce a better product than the hydrogen-deficient oil usually obtained, if the reactions can be controlled properly.

RETORTING OIL SHALE

N-T-U retorts: The two N-T-U retorts, each with a charging capacity of 40 tons, have been operated by the Bureau since May 1947 under a wide variety of conditions to study the effects of variables such as air rate, recycle-gas rate, ratio of air to recycle gas, particle size, and grade of shale. During this operation about 8,000 barrels of oil was produced, and yields under the most favourable conditions have been from 85 to 90 per cent of the Fischer assay. (1) (10)

The N-T-U experimental programme was completed on 1 March 1949, and the retorts were placed in a standby condition. Any additional N-T-U operation will be for cost studies or to produce oil for refining or other uses.

Royster-process retort: Concurrently with the experimental N-T-U operation, the Bureau conducted tests from January to September 1948 on a smaller batch unit known as the Royster-process retort. In that process noncondensible gas heated in pebble stoves is circulated through the shale bed. This work has provided data and experience for the design and operation of continuous retorts. (1) (10)

Gas-flow retort: The Bureau's experimental retorting programme is now concentrated on a pilot plant for continuous operation, known as the gas-flow retort. In this unit, which is similar to the Grand Paroisse, shale descending through the retort is preheated by flue gas and then raised to the retorting temperature by noncondensible gas from the retorting operation which flows horizontally through the shale. The cycle gas containing hydrocarbons from the shale passes to a condenser where the oil is removed. The part of the gas from the condenser that is to be recycled is brought to the retorting temperature by heat exchange with products from the combustion of fixed carbon in the spent shale. (1) (10)

Concurrently with tests of the gas-flow retort, the Bureau is making engineering and cost studies of continuous retorts of other designs.

Union Oil retort: The Union Oil Co. of California has designed a retort which incorporates the internal-combustion and down-draft principle of the N-T-U retort but is continuous. A hydraulic piston at the bottom of the retort pushes the shale upward through the preheating, retorting, and combustion zones, and the spent shale is removed in the form of hot clinker by a scraper at the top of the retort. The air and gases drawn downward through the retort carry the oil vapours into the cool shale, where they are condensed. (11) The Bureau of Mines has supplied shale for the tests under a co-operative agreement with the company.

Fluidized shale-retorting process: Pursuant to a co-operative agreement between the Standard Oil Development Co. and the Bureau of Mines, that company has reconstructed its fluid-catalyst-cracking pilot plant at Baton Rouge, La., to process oil shale, and tests are being made. One thousand tons of crushed shale was supplied by the Bureau, with the aid of the Department of the Navy, and representatives of the Bureau are observing the tests.

In this process crushed raw shale and hot spent shale from a burner vessel are carried by steam into a retorting vessel where the shale body is maintained in a "fluidized" state. Thus heat for retorting the raw shale is supplied by solid-to-solid contact with hot spent shale. The volatilized products from the retort pass overhead to a product-recovery and treating system. Spent shale containing fixed carbon is withdrawn continuously from the bottom of the retort and carried by a stream of air into the burner vessel where it is maintained in a "fluidized" state and the fixed carbon is burned to supply the required heat. (12) (13) (14)

Thermofor shale-retorting process: The Socony-Vacuum Oil Co., Inc., has developed a process for continuous retorting of a moving column of lump shale which flows by gravity through zones where the shale is successively preheated, retorted, burned free of carbon, and cooled. These effects are achieved by controlled use of air and gas recycling, and the zones are sealed with steam. (15) (16) This process has been tested in a pilot retort with a capacity of 1 ton a day, and development work is continuing.

Retorts for commercial operation: Selection of retorts for commercial operation will require compromises between the advantages of (*a*) mechanical simplicity, (*b*) high throughput, (*c*) large particle sizes of shale which reduce crushing cost, and (*d*) high recovery of available heat energy; and the disadvantages of (*a*) dilution of oil vapours with products of combustion which reduce the recovery of the light ends of the oil, (*b*) expensive heat-exchange and condensing equipment, (*c*) shale "fines" which are difficult to separate from the oil and may cause difficulty in disposal of spent shale, and (*d*) uses of steam or cooling water which require large water supplies. Economy in the use of water is imperative in western Colorado where water is scarce and is allocated mainly to irrigation and municipal uses.

As the residence time required to bring the interior of a particle of shale to the temperature at which kerogen is converted to oil is a function of the particle size, no retort can be expected to process shale with a wide range of sizes. In crushing shale to any desired range, an appreciable volume of particles below the minimum will be produced. Therefore, it seems likely that an integrated commercial oil-shale operation will use more than one type of retort, or separate units of one type will be adapted to different sizes of shale, in order that shale of all particle sizes may be retorted.

REFINING SHALE OIL

Shale oil differs from petroleum in that it contains a high proportion of olefinic hydrocarbons, and nitrogen and oxygen compounds that occur rarely in petroleum are present in relatively large amounts. Low-boiling distillates from shale oil have a hydrocarbon composition similar to cracked petroleum products but include substances that are characteristic of tars from coal carbonization.

Studies by the Bureau and private industry have shown that shale oil can be used as heavy fuel oil with relatively simple refining, but treatment before conventional refining will be required to convert it into satisfactory substitutes for other products now derived from petroleum. For the manufacture of high-quality gasoline, kerosene and other products, some form of hydrogenation may be desirable to upgrade shale-oil distillates into the equivalent of good natural crude oil which can be processed by conventional means.

The Bureau's demonstration plant at Rifle includes a small refinery with units for thermal cracking, low-temperature sulfuric acid treating, and sodium plumbite sweetening. (1) Studies of hydrogenation are being pursued in collaboration with members of the Bureau's staff who are working on hydrogenation of coal.

ECONOMIC CONSIDERATIONS

At present the estimates of mining costs are on a reasonably firm basis. The cost of the shale in place, although small, is indeterminate, and costs of retorting and refining still involve many uncertainties. Therefore, the following should be considered tentative estimates only.

Bureau of Mines estimates indicate that $2.40 a barrel would cover the cost of mining, crushing, retorting, and all related utilities and facilities, exclusive of employee housing, to produce crude shale oil near Rifle from shale assaying 30 gallons a ton with N-T-U retorts on a scale of 100,000 barrels a day. This estimate includes depreciation at a rate of $6\frac{2}{3}$ per cent a year, but does not include return on the investment. (1) Continuous retorts of types mentioned in this paper should produce oil at a considerably lower cost.

The Socony-Vacuum Oil Co., Inc., has estimated retorting costs with equipment of the Thermofor type at $1.10 a barrel when processing shale assaying 30 gallons a ton. This estimate includes 20-year depreciation, 10 per cent profit on investment before taxes, and no credit for excess power. Allowance for costs of mining would raise the estimated cost of the crude shale oil to about $1.95 a barrel.

Murphree has estimated that 16.6 cents a gallon will cover the cost of the gasoline produced when shale oil is processed to yield a maximum of gasoline with an octane number considerably higher than that of the present premium grade. This estimate includes cost of housing for employees, 15 per cent for capital charges based on mining and manufacturing investments and transportation investment peculiar to the plant, and the cost of shale at $1.00 a ton. (17)

Schroeder has estimated that 5½ cents a gallon ($2.31 a barrel) of total products will cover the cost (including depreciation, but not including return on investment) of producing 850,000 barrels a day of shale-oil products composed of 116,000 barrels of gasoline and liquefied petroleum gases, 215,000 barrels of middle distillate, and 519,000 barrels of fuel oil. (18) This estimate assumes that shale assaying 30 gallons a ton will be processed in continuous retorts.

It seems, therefore, that with demands for petroleum products increasing, costs of finding new oil rising, and technologic advances promising to reduce the cost of products from oil shale, research and development should be pressed forward, so shale oil can be made available whenever it is needed to promote the Nation's welfare.

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Bibliography

1. *Synthetic Liquid Fuels, Part II—Oil from Oil Shale*, 1948 Annual Report of the Secretary of the Interior, Report of Investigations 4457, Bureau of Mines, January 1949, 56 pages.
2. Wilmot H. Bradley, *Origin and Microfossils of the Oil Shale of the Green River Formation of Colorado and Utah*, Prof. Paper 168, Geological Survey, 1931, 58 pages.
3. D. C. Duncan and N. M. Denson, *Geology of Naval Oil Shale Reserves 1 and 3, Garfield County, Colorado*, Oil and Gas Investigations Series Preliminary Map 94 (in 2 sheets), Geological Survey, 1949.
4. K. E. Stanfield and I. C. Frost, *Method of Assaying Oil Shale by a Modified Fischer Retort*, Report of Investigations 3977, Bureau of Mines, October 1946, 11 pages.
5. Carl Belser, *Oil-shale Resources of Colorado, Utah and Wyoming*, Tech. Pub. No. 2358, Amer. Inst. Min. and Met. Engrs., Petroleum Technology, May 1948, 11 pages.
6. Tell, Ertl, *Oil-shale Mining*, Tech. Pub. No. 2359, Amer. Inst. Min. and Met. Engrs., Petroleum Technology, May 1948, 8 pages.
7. E. D. Gardner, *Mining Program, Bureau of Mines, Oil-shale Project, Rifle, Colorado*, Report of Investigations 4269, Bureau of Mines, April 1948, 19 pages.
8. John S. Ball, G. U. Dinneen, J. A. Smith, C. W. Bailey and Robin Van Meter, "Composition of Colorado Shale-Oil Naphtha", *Industrial and Engineering Chemistry*, March 1949, pages 581–587.
9. R. J. Shaw, *Specific Heat of Colorado Oil Shales*, Report of Investigations 4151, Bureau of Mines, November 1947, 9 pages.
10. J. D. Lankford and Boyd Guthrie, *Oil-shale Processing*, Tech. Pub. No. 2360, Amer. Inst. Min. and Met. Engrs., Petroleum Technology, May 1948, 12 pages.
11. Homer Reed and Clyde Berg, *Development of Union Oil Retorting Method for the Recovery of Shale Oil*, Presented before Petroleum-Mechanical Engineering Conference of the Amer. Soc. of Mech. Engrs., Amarillo, Texas, October 1948, 12 pages.
12. Forrest H. Blanding and Bruno E. Roetheli, "Retorting Oil Shale by the Fluidized Solids Technique", *Oil and Gas Journal*, February 15, 1947, pages 84, 86 to 88 and 96.
13. E. V. Murphree, E. J. Gohr and A. F. Kaulakis, "The Fluid Solids Technique—Applications in the Petroleum Industry", *Jour. of Inst. of Petr.*, vol. 33, No. 286 (October 1947).
14. E. V. Murphree, "Natural Gas, Coal, Oil Shale as Sources of Liquid Fuels", *Oil and Gas Journal*, April 8, 1948, pages 66, 68 to 70, 95 and 96.
15. J. W. Payne, C. H. Lechthaler and E. V. Bergstrom, "Oil Shale Retorting—Principle of TCC Process Applied to Develop Continuous Operation in which Shale is Heated by Counter-Current Flow of Product Gas", *National Petroleum News*, January 2, 1946, page R-36 to R-39.
16. T. P. Simpson, Personal communication.
17. E. V. Murphree, "The Synthetic Fuels Picture", *World Oil*, February 1, 1949, pages 46 to 50.
18. W. C. Schroeder, *Synthetic Fuel Plants*, Presented before the Petroleum-Mechanical Engineering Conference, Amer. Soc. of Mech. Engrs., Amarillo, Texas, October 1948.

Oil Shale in Brazil

ANIBAL A. BASTOS

ABSTRACT

This paper deals with the shale-oil resources of Brazil. The author briefly considers the known occurrences of oil shale in several regions of the country, giving chemical analyses and, when possible, information as to tonnage and mining conditions. He emphasizes two regions as the most attractive for shale-oil production: the Paraíba valley in the State of São Paulo and the Iguassu valley, near São Mateus, in the State of Paraná.

The oil shale occurring in the Paraíba Tertiary basin is being investigated by the Conselho Nacional do Petroleo, in order to examine the possibility of producing hydrocarbons in that well-developed valley, not far from the city of São Paulo.

In Paraná a project of investigation has been suggested by the *Instituto de Biologia e Pesquisas Tecnológicas*, but the funds needed to carry it through have not yet been granted by the State Government.

As Brazil is very short of coal of good quality, and petroleum has not yet been discovered in large quantities, the investigation of the shale-oil possibilities is advisable.

According to present knowledge, Brazil is very short of fuel reserves. Although the country contains extensive areas where oil may be found, adequate investigation is lacking and oily strata have been verified in only a limited area in the State of Bahia. Here reserves at some 17,800,000 barrels have been estimated in the middle and lower Amazon Valley which has a large paleozoic basin; the Acre area in that valley, not far from producing areas in Peru (Pachitea Field) and the Marajó Island with a thick sedimentary basin are promising areas in northern and western Brazil. The petroleum possibilities of the Maranhao basin is now under investigation by the *Conselho Nacional do Petroleo*. In Sergipe geophysical parties are making investigations and drilling is being carried on.

It is very probable that oil will be discovered in these areas or somewhere on the north-east coast or in the Gondwana beds in southern Brazil, but many people, who are not very confident of the oil possibilities of these territories, favour the utilization of bituminous shales for the production of oil.

Let us review briefly the known occurrences of oily shales in Brazil. As the shales can be utilized only where extraction can be carried out on a large scale and the material can be delivered at very low costs, we will consider only the out-crops which appear to have some importance.

MARANHAO STATE

In this State shale oil is known to occur in Codó, where a bituminous marl was mentioned many years ago by Gonzaga de Campos. An analysis made by Theophilus Lee showed the following percentage composition:

Bitumen	36.53
Clay material	22.61
Limestone	40.86
	100.00

This material called attention to the possibilities of oil production many years ago. Samples sent to the Instituto Nacional de Tecnologia were analysed by Froes Abreu, who found the following percentage composition:

Moisture	2.4
Volatile matter	24.4
Fixed carbon	5.7
Ash	67.5
	100.0

According to Froes Abreu and R. Roquette this material is not true oil shale, but a clayey limestone impregnated with bitumen.

Employing destructive distillation the analyses of two researchers obtained between 81 and 175 kg. of oil per ton depending on the impregnation of the sample. The average of seven distillations gave 109 kg. (30.9 gallons) of oil per ton.

Some data about this oil are given below:

Specific gravity (at 27 degrees C)	0.927
Flash point	57 degrees C
Fire point	78 degrees C

Distillation:	
Normal pressure distillation:	
From 80 degrees C to 200 degrees C	12.3
From 200 degrees C to 275 degrees C	19.9
Vacuum distillation:	
From 200 degrees C to 300 degrees C	19.4
From 300 degrees C to 360 degrees C	32.2
Residue	14.4
Not condensed and losses	1.8
	100.0

The organic matter is not bitumen, but a kerosene-like material, as shown by the analyses made of the rock after the elimination of the carbonates by dilute HCl. No detailed field investigation has been made in order to estimate the reserves of this material which crops out near the city of Codó, State of Maranhao. Should this deposit be sufficiently large and permit extraction by open-cut, it would be possible to consider exploitation for local consumption and the supply of the neighbouring states of Pará and Pianuí.

In Barra do Corda as well as in several places in the valley of Manoel Alves Grande River, occurrences of oily shale have been reported but so far no detailed studies have been made.

CEARÁ STATE

Oily shales are known to occur at Chapada do Araripe, South Ceará, in the cretaceous beds. This occurrence has been investigated by S. Froes Abreu, who made a reconnaissance work in the area Crato–Jozzqiro–Sant'Anna and collected samples for laboratory investigation. According to available data these shales are very rich, producing approximately 50 gallons of oil per ton, but outcrops known until now show only a very thin layer of no economic interest. Abreu mentions a thickness of some inches only, but even if larger beds should be found these deposits do not look very suitable for economic exploitation.

ALAGOAS STATE

Many outcrops of oily shales on the coast of Alagoas have been described by several geologists. Branner (1)[1] and Oliveira (2) made special references to those deposits, and the latter promoted a general survey of the area, publishing the results in the paper "Rochas Petrolíferas do Brazil". The principal outcrops at Alagoas are known to occur in the localities of Bica da Pedra, South Maceió, and Riacho Doce, Camaragibe and Maragogi, North Maceió. The shales are generally multi-folded, dipped downward and emerge at surface near the sea. They yield between 24 and 34 gallons per ton; some attempts at their utilization were made on a small scale many years ago, but because of difficulties of mining, these shales do not appear to merit consideration for large-scale shale-oil production. The beds are generally thin and lie at or below the water level, this creating difficult problems in mining on a large scale.

BAHIA STATE

Oily shales are known to occur in many places in this State, as in Reconcavo, near Ilheos, near Camamu, near Itapicuru, but they have no commercial importance. The occurrences are not large enough, nor are the shales rich enough to be considered as a raw material for oil production. In Marahu, there occurs a material called "turfa de Marahu" or "Marahunito" which has been closely examined by several geologists and chemists. Gonzaga de Campos made a very accurate study of this material (3) showing the yield and nature of the products. According to his analyses, the yellow "turfa" gives by distillation 114 gallons of oil per ton; in his opinion the recovery of the oil would prove profitable. More recent work on that deposit has demonstrated that the rich material tested by Gonzaga de Campos occurred only near the surface, and that in the lower parts the material is higher in ash and gives much less oil, according to the analyses made in the *Instituto Nacional de Tecnologia*. The high-grade material collected by Gonzaga de Campos was analysed by the chemist Lee who quoted the following results:

Moisture	2.58
Volatile	70.09
Fixed carbon	10.20
Ash	17.13
	100.0

The following analyses are of the material examined in the *Instituto Nacional de Tecnología.*

	a	b	c
Moisture	10.1	10.8	38.7
Volatile	41.0	59.9	35.3
Fixed carbon	6.4	10.8	9.5
Ash	42.5	18.5	16.5
	100.0	100.0	100.0

[a] Average sample of the gray material.
[b] Gray stratified material.
[c] Average sample of the material *as received.*

According to Abreu, the average yield of oil of the "Marahunito" is around 60 gallons per ton, but after the tests of Nero Passos (4) the interest in this deposit has decreased, because it was proved that there is only a very small reserve not reaching one million tons.

[1] Numbers in parentheses refer to items in the bibliography.

SAO PAULO STATE

In the Paraíba valley, in the State of Sao Paulo, the Tertiary (pliocene) basin contains large quantities of oil shales in layers of various thicknesses up to two meters. This occurrence has been known for many years, as the shales crop out at several points near Tremembé and Pindamonhangaba.

The area of occurrence has an actual length of 2,400 km., situated between the lands of Mantiqueira and Quebra Cangalha and stretching from the town Aparecida to Caçapava.

In 1881 a privilege for their exploitation was granted by the Government to Charles Normanton, who arranged to install a plant for the production of illuminating gas to supply the city of Taubaté. Twenty Scottish retorts were installed in Taubaté but the plant stopped operations after one year, owing to financial difficulties (5). The reserves of this area are not yet known but according to many observers, they seem to be very large. The *Conselho Nacional do Petroleo* has just started a full investigation in that area in order to fix the tonnage, the grades and the yield of oil of the Paraíba valley oil shales. According to many analyses already published, the average yield of oil in that area amounts approximately to 22 gallons, which is roughly equivalent to the sbales explored in Scotland.

Should the reserves of the Paraíba valley be found easy to mine and reach the 100 million tons estimated in the reports of the researchers, a shale-oil industry could be established there which would have a considerable market, absorbing the entire production in the valley, in the city of Sao Paulo, situated only 154 km. from Taubaté.

Some analyses of the Paraíba valley oily shales are given below:

Moisture	6.9	7.5	8.8	6.0
Volatile	25.2	24.6	23.7	22.6
Fixed carbon	6.4	6.9	2.4	2.1
Ash	61.5	61.0	65.1	69.3
	100.0	100.0	100.0	100.0

Shale oil produced in the Taubaté plant:
Specific gravity at 28.5 degrees C. = 0.863.

Viscosity Engler at 28 degrees C	1.8
Viscosity Engler at 50 degrees C	1.2
Flash point	72 degrees C
Fire point	97 degrees C
Calorific power	10,450 calories

Distillation of the crude oil

144 degrees to 220 degrees C	9.2
220 degrees to 310 degrees C	37.8
310 degrees to 390 degrees C	42.0
390 degrees to 395 degrees C	4.7
Residue	4.1
Losses	2.2
	100.0

IRATI SHALES

In the Gondwana sedments of southern Brazil, the Irati group of the Permian beds contains thick layers of black oily shales. One may presume that the Irati layers are generally from 30 to 60 metres thick, containing shales, dolomitic limestone and chert, the faces changing from chiefly clayey to mainly lime. In the State of Sao Paulo they are mostly lime whereas in southern Paraná and northern Santa Catarina they are predominantly clayey with rich organic shales.

Analyses of Irati oil shales

	a	b	c	d
Moisture	2.4	2.7	5.3	2.2
Volatile	16.2	21.7	19.5	15.4
Fixed carbon	—	12.4	11.7	7.6
Ash	—	63.2	63.3	74.8
	100.0	100.0	100.0	100.0
Oil per ton (kg.) ..	81	101	91	—

[a] Shale from Três Barras, Santa Catarina.
[b] Shale from São Mateus, Paraná.
[c] Shale from São Gabriel, Rio Grande do Sul.
[d] Shale from Fazenda Diamante, São Paulo.

The most important areas of Irati oily shale outcrops in Sao Paulo are known near Angatuba, near Guaru and Tatuí. Near Angatuba a small shale-oil plant was built during the last war but operations were stopped in the experimentation phase. In the State of Paraná many outcrops of Irati shale are known to lie in a belt some 360 km. long and 20 km. wide, between the rivers Itararé and Iguassu.

The estimated reserves of the Irati oily shales in Paraná, according to Reinhard Maack, amount to 200,000 million tons from which 16,000 million tons of shale-oil could be recovered. This quantity would be sufficient for Brazilian consumption during 6,400 years on the basis of the actual rate of consumption.

In Sao Mateus, in the valley of the Iguassu river, these shales crop out in large quantities, in very favourable conditions to be mined by open-cut. A small plant was working there for many years supplying gasoline and fuel oil for local consumption. In the State of Santa Catarina the oil shales of Irati stretch from north to south in Permian formation. There they show the same physical characteristics, the identical chemical composition as the other shale layers of this country. When freshly broken, the surface produces a strong odour of oil. The position of the layers is generally horizontal and the topographic scarp shows favourable conditions for good, easy and economical exploitation.

The resources of Santa Catarina have not been examined yet but our present knowledge of the southern region makes us believe that they have the same value as those of Paraná.

In Rio Grande do Sul an exploration of these shales was initiated several years ago near Sao Gabriel, but without any success.

CONCLUSION

According to present knowledge of oily shale occurrences, only the reserves in the Paraíba valley of Sao Paulo and in Paraná, Santa Catarina and Rio Grande do Sul seem to be large enough for industrial exploitation.

As we have mentioned before, the government agency, the *Conselho Nacional do Petroleo*, is just beginning to investigate the extension of the deposits and the quality of the different layers of the shale.

In Paraná the *Instituto de Biologia e Pesquisas Tecnológicas* has asked the State Government for funds in order to conduct adequate investigation and to establish the basis for future utilization of these deposits which contain a potentially enormous quantity of oil.

It is evident that much work has to be done and much money has to be spent before conclusions can be reached, but in any case, in a country not very well supplied with fuel reserves, these enormous deposits of shales, containing about 33 per cent of organic matter and giving 2,600 calories per kg., could furnish energy to the country in the near future.

Successful utilization of the oily shales must be based on the study of those areas where the shale can be mined at very low costs; success depends as well on improvement of the new technique of distillation, and also on the need for petroleum in Brazil. Should petroleum be discovered in large quantities in the Paraná basin, in southern Brazil, the question of the utilization of the shales would have to be postponed.

Bibliography

1. J. C. Branner, "The oil bearing shales of the coast of Brazil", Am. Inst. Min. Eng. *Transactions*, vol. 30 (1900), pages 537–554.
2. Euzebio P. de Oliveira, *Rochas Petrolíferas do Brazil*, Serviço Geológico e Mineralógico, Bulletin no. 1, Rio de Janeiro, Imprensa Nacional 1920.
3. Gonzaga de Campos, *Reconhecimento geológico e estudo de substâncias bituminosas na bacia do Marahu*, São Paulo, 1902.
4. Nero Passos, "Turfa de Marahu, Estado da Bahia", *Mineração e Metalurgia*, vol. 1, no. 2 (1936), Rio de Janeiro, pages 72–80.
5. S. Froes Abreu, "Rochas Oleígenas do Brazil e seu aproveitamento", Ministério do Trabalho, Indústria e Commércio, Instituto Nacional de Tecnologia, Rio de Janeiro, 1936.
S. Froes Abreu, "Os xistos pirobetuminosos como reserva nacional", Departamento Nacional da Produção Mineral, Serviço de Fomento da Produçao Mineral, Avulso 30, *Mineração e Metalurgia*, no. 14, July- August 1938.

Other references:

Instituto de Biologia e Pesquisas Tecnológicas do Paraná, "Industrialização do xisto pirobetuminoso do Paraná", *Boletim de Divulgação*, Curitiba, 1948.

A. I. Oliveira, "Combustíveis sintéticos", *Mineração e Metalurgia*, vol. 13, no. 6 (November-December 1948).

D. Guimaraes, "Nota sôbre os folhelhos betuminosos de Tremembé", *Rev. Minerio, Combustivel, Transporte*, vol. 1, no. 9 (1928), Rio de Janeiro, 1928.

Summary of Discussion

The Chairman announced that the meeting would be devoted to the examination of various new techniques for increasing the production of oil and gas, namely, conservation in production, secondary recovery, and the production of oil from oil shale. Having emphasized that Venezuela was the second largest petroleum-producing country in the world, he gave details of its annual production, exports, estimated reserves and of the types of petroleum produced.

The meeting was then shown a short film on the use of helicopters for bringing the necessary material and equipment to oil-fields in swampy areas.

Mr. Lowson introduced and summarized the paper prepared by Mr. D. Comins, of the Anglo-Iranian Oil Company on "Conservation in Production". The paper emphasized that unit control of an oil-field, of whatever type, would ensure in the long run more economic recovery of the oil and probably result in a greater ultimate recovery than was likely when the same single reservoir was exploited by a number of independent operators who were competing to obtain as much as possible out of their respective sections. Unit control meant the planning, by one central authority, of production operations for a single reservoir unit, namely, an oil reservoir of which any part was affected by production from another part. It also implied that planning should be on a scientific basis, having due regard to the characteristics of the oil reservoir and its behaviour during depletion and that policies which would reduce harmful effects to a minimum should be adopted. Those were the methods described in the paper presented by Mr. Comins; they had been applied consistently in developing and producing the large limestone reservoirs of southwest Iran. All those techniques were based on the principle that prevention was better than cure and stressed the need for careful planning.

Mr. Murray presented and summarized his paper on "Conservation in Production". Having emphasized that oil had no inherent ability to expel itself from the pore spaces of reservoir rock in which it was found and that it had, therefore, to be ejected by some displacing fluid, he reviewed the merits of the three methods currently used for that purpose, namely, dissolved-gas drive, gas-cap drive, and water drive. The best recovery results were achieved by the water-driven method and the lowest by the dissolved-gas drive method. Conservation in production, therefore, largely rested upon the utilization of a natural water drive or gas-cap drive, if present, and the conversion of an inefficient dissolved-gas drive into an artificial water or gas-cap drive through injection of water or gas. Considerable progress had already been made with improved techniques of recovery.

Mr. Cirigliano presented and summarized the paper prepared by the Venezuelan Ministry of Development on "New Oil and Gas Production Techniques in Venezuela". The aim of the Ministry had been to determine the operating practices which should be used in each pool to increase the ultimate recovery of oil from the field. Indeed, the efficiency of oil recovery was largely dependent on the methods employed to use the energy of the pool itself, namely, the energy which displaced the oil and gas from the sands and porous rocks to the wells. Proper knowledge of the characteristics of a pool and of the fluids it contained was an essential prerequisite for the correct evaluation of the possibilities of artificially increasing the natural energy of pools.

Mr. Muskat presented his paper on advances in efficiency of oil recovery, stressing the physical processes and operating practices involved. While efficiency of oil recovery had been improved as a result of technical developments, in order to evaluate the physical significance of such improvements it must be understood that there were many characteristics of oil reservoirs over which operators had no control except to determine them as accurately as possible. The manner of development and operation must be modified to suit the particular features of the reservoir under consideration.

Mr. Muskat pointed out that there were four major types of energy available: (1) the energy of compression of the oil and connate water within the oil reservoir itself; (2) the energy of compression and solution of the gas dissolved in the oil within the producing stratum or in free gas zones overlying the oil-bearing formation; (3) the energy of compression of the water in bounding and inter-communicating aquifers; and (4) the gravitational energy associated with the relative elevation of the oil in the upper levels in the reservoir as compared to that at the points of exit into the producing wells. The oil was expelled from the reservoir by applying to the available energy one of three basic physical mechanisms — solution-gas drive, water drive and gravity-drainage drive.

Mr. Muskat then turned to the improvements in oil production and recovery falling into the following categories: (1) prevention of waste of reservoir energy which involved elimination of previous wasteful practices and adoption of such new methods of production as "cycling"; (2) supplementing the natural reservoir energies by the injection of gas or water; and (3) control of the producing mechanism.

After a brief review of pressure maintenance operations and secondary recovery operations in the United States by means of gas or water injection, Mr. Muskat turned to the question of control and transformation of producing mechanism which vitally affected efficient production of oil.

In conclusion Mr. Muskat drew attention to the diagrams at the end of his paper giving the frequency distributions of the recovery factors of gas and water-drive reservoirs.

Mr. Brundred introduced Mr. Torrey's paper on "Secondary Recovery of Petroleum", reserving his view on some of the points. He noted that the author had omitted a number of points, doubtless because of limitations in space and scope placed on the paper when it had been invited.

The paper considered the history of secondary recovery operations in the United States, the various methods that had been employed to increase recovery from oil-fields in which the primary reserve had been depleted, secondary oil reservoirs in the United States, the susceptibility of oil-fields to the application of secondary methods, and the cost of development and operation of secondary projects and some of the results that had been obtained.

Mining for petroleum, which was the oldest known production method, had been attempted in the United States on several occasions. None of the recent operations had been economically successful, although they had yielded much valuable scientific and technical information.

Among the methods which had been used to increase the recovery of oil were application of vacuum, air and gas injection, water flooding and mining. Improvements in oil recovery technology were just as important in secondary operations as in primary production because they enabled the working of inferior or depleted reservoirs at a profit.

With regard to secondary oil reserves in the United States, the current estimate of 7,000 million barrels would be revised in the light of future revisions of estimates of primary reserves. It was the author's belief that the physically recoverable secondary oil reserve of the United States might be that figure. Mr. Brundred concurred, stating that improved techniques had already added materially to secondary recovery reserves.

With regard to the susceptibility of oil-fields to secondary methods, it was pointed out that most of the successful secondary recovery operations in the United States were restricted largely to fields where primary recovery had been inefficient. Geological factors had an important bearing on the adaptability of an oil-field to secondary recovery operations. In connexion with the author's statement that laboratory and field observations had demonstrated that, when a sand contained less than 20 per cent oil saturation, practically no oil would flow through it, Mr. Brundred noted that some cores washed badly and that consequently it was often difficult to apply this observation with certainty in the field.

In conclusion the author reviewed the cost of secondary recovery operations which ranged from $1.32 per barrel to $1.55 per barrel of oil produced.

Mr. Brundred in connexion with one of the subjects not covered in Mr. Torrey's paper pointed out that his Company had carried out extensive studies of such matters as high-viscosity oils, aerated or oxidized oils, oxidized connate water, and cementing materials holding the sand grains together, treatment of hydrogen sulphide waters, electrolysis and its cure, the use of plastic-coated pipe and electric logging of old wells with no records. He added that he would be glad to supply further information in that regard.

Mr. Hogg emphasized the progress in efficiency achieved by the petroleum industry since its humble beginnings in the nineteenth century. As an example of such progress, he recalled that, whereas until recently enormous amounts of natural gas had been wasted daily through defective methods of petroleum recovery, that gas was currently utilized both for domestic and for industrial purposes. The lines employed in channelling natural gas carried up to 100 per cent of their maximum load not only during the peak winter months but also during the summer, when they injected gas into the reservoirs, thereby increasing oil recovery.

Conservation of petroleum reserves could be ensured by improved techniques in primary recovery and by secondary processes; in that connexion, Mr. Hogg felt that the discussion had laid insufficient stress on core drilling. He was confident that a more sustained market, better methods of recovery and greater engineering skills would lead to the optimum exploitation of reservoir energy.

Mr. Lietz felt that Mr. Torrey's paper was a very complete survey of the various factors connected with secondary recovery.

The methods employed in the majority of cases were gas injection or water injection. Experience had shown the necessity for drilling and coring the injection wells; it was often necessary, moreover, to drill regular five-spot grids.

As Mr. Torrey had pointed out, it was impossible even on a laboratory scale to recover all the oil contained in a reservoir. One of the conditions, therefore, for successful secondary recovery was a relatively high oil saturation of the reservoir under investigation. Furthermore, because of the large number of injection wells required and their relatively close spacing, secondary recovery could profitably be effected only from shallow reservoirs where the primary recovery had been obtained through expansion of dissolved gas. Since the original pressure in a reservoir was usually close to the hydrostatic head, and since the solubility of gas was virtually dependent on pressure, the amount of gas originally in solution in shallow reservoirs was comparatively small. It was therefore probable that primary recoveries from such reservoirs had been low and that a high residual saturation had existed when secondary recovery had been started.

In deeper reservoirs, considerably more gas was in solution. Thus more energy was available for moving the oil into the well bore. Primary recoveries from such reservoirs should therefore be greater than from shallow reservoirs.

Statistical evidence showed, however, that the amount of oil obtained did not increase in ratio to the depth of the reservoir. When a barrel of reservoir oil was brought to the surface, the gas originally in solution was set free; that circumstance, combined with the drop in temperature, caused the volume of liquid collected in the surface tank to be considerably less than one barrel. Such shrinkage could amount to 30 per cent or more. Moreover, at the end of the primary production period, the pressure in a reservoir dropped to approximately 200 lbs. and the remaining oil had been subjected to the same shrinkage process. Hence the residual saturation was normally smaller the deeper the reservoir, and the chances for successful secondary recovery were less.

In the light of current knowledge of production engineering, it was possible to ensure higher primary recovery through controlled withdrawals. The possibilities for secondary recovery, despite the examples mentioned by Mr. Torrey, appeared to be limited to relatively shallow reservoirs where primary recovery had been poor.

Mr. Lietz remarked in conclusion that, in view of such considerations as continuity of reservoirs, rock permeability and viscosity of oil, a reserve in the United States in excess of 7,000 million barrels would seem to be over-optimistic.

Mr. Richter, in the absence of Professor Schjånberg, drew attention to the salient points of the latter's paper on the "Swedish Shale Oil Industry".

During the Second World War, Sweden had been compelled to undertake the domestic manufacture of liquid fuel, and the only raw material which could practicably be used for such operations was oil shale. Large deposits of oil shale existed in Sweden, but the oil content was low. The shale most suitable for oil production was to be found in the province of Närke. The shale was sandwiched between a lower layer of sandstone and an upper layer of silurian limestone, over which there was a loose layer of soil with a thickness of between 10 to 27 ft. The shale seam consisted of two layers, some 27 ft. thick; the average oil content of the lower layer was 6.5 per cent and of the upper layer 4.5 per cent. About a million metric tons of shale were processed annually in that region by the Kvarntorp plant of the Swedish Shale Oil Company. But although the annual oil production was approximately 110,000 metric tons, the plant should be considered only as a large pilot plant.

Mr. Richter outlined the four different pyrolysis methods in operation at the Kvarntorp works, pointing out that the oil produced by the Ljungström method, whereby the oil shale was not mined but heated *in situ* by electric energy, was quite different from that produced by the other methods. The Ljungström method produced less olefins and correspondingly more paraffins.

The gas given off by pyrolysis contained appreciable amounts of shortchain olefins and paraffins, and the possibility of extracting those hydrocarbons had been studied. An absorption plant was under construction which would produce some 7,000 to 8,000 tons annually from the retort systems only.

Greater mechanization and the development of by-products were required if extraction of oil from Swedish oil shale were to give an adequate economic return.

Mr. CATTELL presented his paper on production of "Oil from Oil Shale — Experience in the United States". He pointed out that the Bureau of Mines, in complete co-operation with other government agencies, private industry and educational institutions, was conducting an oil-shale research and demonstration plant programme. The results of those studies showed that oil shale has promise as a source of liquid fuels to supplement those from petroleum. An example of the rapid progress made was afforded by a test made near Rifle, Colorado, since Mr. Cattell had prepared his paper in March 1949; that test showed that the output was 110 (instead of 100) tons of shale per man-shift of underground labour, and that the net cost was 52 (instead of 58) cents per ton.

Mr. ABREU presented Mr. Bastos' paper on "Oil Shale in Brazil". Research in that field was at its inception in Brazil, and large funds were required to conduct adequate investigation and to establish a basis for the future utilization of the enormous shale deposits which existed in various regions of the country. The Brazilian *Instituto de Biologia e Pesquisas Tecnológicas* was anxious to receive reports and experience papers on oil shale production from countries where such production was at a more advanced stage.

Mr. JACQUÉ recalled that the shale industry had been in existence in France since 1830, the first retorts having been constructed for gas production. After the development of petroleum products, the use of oil shale had continued on a very limited scale and only then because of measures protecting national products. At the same time it also continued to be a subject of experimental research.

During the Second World War, France, lacking oil supplies, undertook new oil shale research and industrial development efforts.

Since the war, the Government has limited its help to the Autun plant and a new plant at Severac (Aveyron) primarily to experimental work. The first plant worked permian shale of medium oil content (7 per cent), extracted from the underground at medium costs; it developed the mechanization of the mine, the utilization of shale fines for heating its steam generating station, and the making of building materials with the spent shale. The second plant worked liassic shale of low oil content, extracted in surface pits at low cost, in modern retorts; it studied the transformation of spent shale into hydraulic binding material.

Studies are now being carried out on shale carbonization. In one of these studies a pilot retort with complete energetic autonomy has been perfected by the French Petroleum Institute.

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29 August 1949

Chairman:

W. A. MACFARLANE, Director, United Kingdom Scientific Mission, Washington, D.C.

Contributed Papers:

Review of Present Status and Trends of Oil Chemistry
GUSTAV EGLOFF, Director of Research, Universal Oil Products Company, Chicago, Illinois, U.S.A.

Petroleum Refining in the United Kingdom
F. MACKLEY, General Manager, Shell Refinery and Marketing Company Ltd., Stanlow Refinery, Cheshire, England

Some Aspects of the Development of the Petroleum Chemical Industry in the Netherlands
J.W. H. UYTENBOGAART, Chief, Chemical Industries Department, Bataafsche Petroleum Maatschappij, Carel Van Bylandtlaan 30, The Hague

Study of the Present Position and Trend of Oil Chemistry
LÉON JACQUÉ, Lecturer at the Ecole Polytechnique, President and Director-General of the French Petroleum Institute, Paris, France

Synthetic Fuel Production
W. C. SCHROEDER, Chief, Office of Synthetic Liquid Fuels, Bureau of Mines, United States Department of the Interior, Washington, D.C.

Synthetic Fuel Production
S. LANDA, Professor, Czech Institute of High Learning, Prague, Czechoslovakia

The Flexibility of the High Pressure Hydrogenation Process for Liquid Fuel Production
R. HOLROYD, Research Director, Imperial Chemical Industries, Ltd., Billingham, England

Summary of Discussion:

Discussants:

Messrs. EGLOFF, MACKLEY, UYTENBOGAART, JACQUÉ, ERRERA, ARIES, SACHANEN, C. L. BROWN, SCHROEDER, SIR HAROLD HARTLEY, KEMP, ROBERTS, UREN

Programme Officer:

MR. W. A. MACFARLANE

Review of Present Status and Trends oı

GUSTAV EGLOFF

ABSTRACT

Modern petroleum refining is the outgrowth of chemical research. The economic and social effects of diᵼ **in oil chemistry have been far reaching. The developments are critical in the conservation of our petroleum resou**ᵡ **New processes enable the refiner to use every drop of crude oil efficiently. They enable the industry to meet ever i**ᵡ **creasing demands and to adjust operations to changing markets. The superior motor and aviation fuels available today are vital to modern, high-speed transportation which not only makes life more convenient and comfortable but also provides for better distribution of food and other materials. Tailor-made lubricants, which have resulted from improved refining processes and chemical additives, are another essential in modern transportation. Chemicals now being produced from petroleum and natural gas include entirely new compounds as well as those formerly produced from coal tar, carbohydrate materials and fats. Over 5,000 commercial products are now derived from crude oils.**

Emphasis on research is consistent with the forward-looking attitude of the oil industry, and research in all branches is being constantly expanded. About $ 112 million, which is 25 per cent of all industrial expenditures for research, are spent by the oil industry every year in the United States.

Over a period of years, research men have determined the chemical compositions of crude oils and studied the performance of refined products. These studies have promoted further research which has resulted in processes for making products of desired properties and chemicals which improve these products as well as techniques applicable to other industries. Recent developments have initiated whole new industries based on the manufacture of chemicals from petroleum and natural gas.

PETROLEUM COMPOSITION

Petroleum consists primarily of paraffin, cycloparaffin, and aromatic hydrocarbons with small amounts of olefins. It also contains small percentages of sulphur, nitrogen, and oxygen compounds with traces of inorganic materials which appear as ash when the oils are burned. Olefin hydrocarbons are produced by cracking so that all of the four major hydrocarbon groups are available for the manufacture of fuels, lubricants and chemicals. Analyses have shown that individual hydrocarbons are only present in petroleum in small percentages. However, improved methods of separation have made available many lower-boiling compounds in pure form, and synthetic processes now produce many hydrocarbons not present either in the original oils or their cracked products. Chemical studies have shown the types of hydrocarbons most suitable for different uses so that crude oils of different composition have been segregated for special product manufacture.

Natural gas consists principally of the lower-boiling gaseous and liquid paraffin hydrocarbons. The chief component of most natural gas is methane. Some natural gas contains hydrogen sulphide, mercaptans, carbon dioxide, helium, and nitrogen. Many natural gases contain sufficient amounts of gasoline to permit its recovery by cooling, compression or absorption processes. These natural gasolines consist mainly of paraffin hydrocarbons which are blended with other gasolines or converted to high anti-knock gasoline.

GASOLINES

Fuels for internal combustion engines amount to over 50 per cent of all petroleum products. The most important of these fuels is gasoline. Crude oil, however, averages about 20 per cent gasoline. As the popularity of the automobile increased, methods for producing more gasoline from crude oil become imperative. Through chemical research, cracking and other processes have been developed so that present production is about 45 per cent gasoline from every barrel of crude. There are processes which permit the refiner to produce an even higher percentage of gasoline but 45 per cent is consistent with present demands for other products. If it becomes necessary, gasoline production can be increased to over 100 per cent by the hydrogenation of heavy oils, a process which has been developed but is not in use at present in the United States.

Cracking more than doubles the yield of gasoline from crude oil. It conserves gasoline in that the cracked product gives increased power and mileage. During the thirty-six years that cracking has been in operation, the increased yield and improved quality of gasoline has made unnecessary the production of 30,000 million barrels[1] of crude oil in the United States alone. The United States oil production in 1948 was 2,051 million barrels from which 922 million barrels of gasoline were produced. Over 60 per cent was cracked gasoline. The increased volume and quality of gasoline resulting from cracking processes make unnecessary the production of an additional 2,500 million barrels a year of petroleum which would be needed if dependence were placed entirely on the gasoline naturally present in crude oil. The greater anti-knock quality and the greater mileage obtained from cracked gasoline saves the motoring public $ 1,000 million yearly in gasoline bills.

The first commercial cracking process was thermal. It has been continuously improved through the years and now processes 2,225,000 barrels of heavy oil daily. About 60 per cent of the United States cracked gasoline is thermally produced at present. This gasoline averages about 68 motor octane.[2]

The thermal cracking process is being supplanted by catalytic cracking which produces both higher yields and better quality gasolines averaging 80 motor octane. Spurred by increasing demands for high octane gasoline, the charging capacity of

[1] 1 barrel equals 42 U.S. gallons.

[2] One of the most widely used criteria in the oil industry is octane number which is a measure of the anti-knock properties of gasoline. "Motor" method octane numbers are determined by tests which impose relatively severe operating conditions corresponding to high-speed driving, while "research" method octane numbers are determined under conditions corresponding to low driving speed in city traffic.

OIL CHEMISTRY

...; increased in only ten years from ...aily. In 1940, only 2 per cent of the ... United States was catalytically cracked, ... cent will be thus derived.

catalytic cracking pl... zero to 1,500,000 ... gasoline prod... out in 194...

In ... king, special clays or silica-alumina oxides ...s. In the first commercial process, catalysts ...onary beds, while in today's plants, catalysts ...on. The newer processes permit continuous re... catalysts, better heat distribution, better distribu... ...sts through the reaction chamber and continuous ... The process which has the most rapidly growing commerci... importance is called the "Fluid Flow". Units of this type ...re now processing over 1 million barrels of gas-oil a day. A ... ant of this type producing 20,000 barrels per day was operated for 611 days without a shut-down.

Catalytic cracking is extremely important because of its flexibility. Yields can be varied according to product demand. For example, gasoline demand is higher in the summer and yield is therefore increased while heating oil yield is decreased, and the converse is ...e in the winter. The components and volume of cracked ... ...lso be varied to meet requirements.

Other p... ...forming", have been developed to improve ... ...es of gasoline recovered by primary ... ...m natural gas. Heavier portions ... either thermally or with cata... ...ne are thermally reformed ... yields and better pro... s, a molybdenum ... ...d with oil vapors ... eloped process cal... results. A highly se... ...multaneous conversions ... ...ane hydrocarbons into high-oc... ... The process yields 90 to 95 per cent gasoline whereas thermal reforming yields 60 to 75 per cent.

Processes auxiliary to cracking make increased quantities of gasoline still higher in anti-knock rating than the cracked gasoline itself. Both thermal and catalytic cracking produce gases containing olefins which are catalytically converted into 82 motor octane gasoline by polymerization, using catalysts prepared from diatomaceous earth and phosphoric acid. Polymerization increases the yield of gasoline from cracking by 2 to 10 per cent. By selectively polymerizing butylenes from cracked gases, polymers are obtained which on hydrogenation yield gasoline of over 90 motor octane number.

Alkylation produces gasoline of over 90 motor octane rating by reacting the isobutane and olefins from cracked gases. The alkylation products are among the most powerful components of aviation gasoline and, after adding tetraethyl lead, have ratings above 100 on the octane scale. In alkylation processes, sulphuric acid, hydrogen fluoride or aluminium chloride is used as catalyst. The use of hydrogen fluoride, a corrosive and violently reactive compound which prior to its use in alkylation plants was employed in only relatively small quantities, has necessitated modifications in plant design. By careful choice of steels for construction, use of monel metal in valves, and other developments, hydrogen fluoride is now handled on a tonnage basis in oil refineries. In a plant producing 8,000 barrels of alkylate a day, 175 tons[3] of hydrogen fluoride are in use.

[3] 1 ton equals 2,000 lb.

The search for hydrocarbons of especially high anti-knock properties has led to the production of a hydrocarbon known as triptane on a semi-commercial scale. This compound has the highest engine-performance rating of any hydrocarbon known and also the highest susceptibility to improvement by tetraethyl lead addition. In specially designed engines the use of triptane has enabled the development of three times the power obtainable from 100 octane gasoline. At present this hydrocarbon can only be produced by costly synthetic processes.

Chemical additives are another factor in the production of high quality gasoline. The most important of these is tetraethyl lead which improves octane rating. A large-scale chemical industry has been developed to meet requirements for this product which is used in about 90 per cent of all gasoline. Eighty thousand tons of lead were used in its manufacture in the United States during 1948. Other necessary materials are ethylene from cracked gases, sodium, chlorine and bromine. Other chemical additives used include inhibitors for the prevention of gum formation during storage and dyes for identification purposes.

Present trends in automotive and aviation engines are motivating an intensified search for processes to make even higher octane gasolines at lower prices. Of great importance is the fact that compression ratios of automobiles are being increased to improve fuel efficiency. As compression ratios increase, higher octane is required to prevent knocking. Compression ratios of present American automobiles are in the range of 6.5 : 1 to 7.5 : 1. Octane numbers of United States regular gasoline average 80 research, and premium grade, 86 research, while in some localities 93 research octane gasoline is marketed. It is estimated that 30 to 45 per cent of cars on the road require premium gasoline for elimination of knock.

The trend towards higher octane motor fuel is apparent from the experimental engines which have been built. With compression ratios of 8 : 1, 10 : 1 and 12 : 1, gasolines of 93, 98 and 100 research octane, respectively, are required. The 12 : 1 compression ratio engine shows a 35 per cent increase in mileage over that obtained with a 6.5 : 1 engine. Fuels have already been developed by the oil industry to meet these requirements.

Airplanes require even higher qualities of gasoline. The increase in air transportation and the constant improvement of aircraft engines have been a great incentive to the oil industry. Consumption has increased from 70,000 barrels per day in 1946 to 128,000 in 1948. The performance ratings of some gasoline blends are as high as 145, compared with 100 octane fuels. The fighting grade fuel is a blend of alkylate and isopentane with an addition of 4.6 ml. tetraethyl lead per gallon.

JET FUELS

Jet propulsion of aircraft has created new fuel problems. The requirements for jet fuels are not completely known and a large amount of experimentation is in progress to develop appropriate fuels. One of the greatest problems is the high fuel consumption of jet planes. A jet plane uses five times as much fuel as its reciprocating engine counterpart. An early solution to this problem is imperative inasmuch as the range of operation is limited by high consumption and operation is very costly. A satisfactory fuel must burn rapidly and completely, have a very high heating value per unit weight, and a low freezing point because of the low temperatures at extremely high altitudes. Kerosene has been and still is used to some extent but is being replaced by low octane gasoline which is available in larger quantities. The gasoline gives improved performance and facilitates starting in cold weather. Out of the present welter of research will come tailor-made hydrocarbons for jet fuels and new processes for making them, just as special products and processes were found for making high quality aviation gasolines.

DIESEL FUELS

Intensive reseach is being carried on to develop improved diesel fuels. The petroleum industry is confronted with steadily rising demands for these fuels, particularly for use in locomotives, buses and trucks. The use of diesel engines in locomotives is increasing rapidly; 90 per cent of present orders in the United States are for this type of engine. In 1939, consumption of fuel oil by diesel locomotives was 1 million barrels while in 1948, consumption had risen to 30 million barrels. This shift is an economy measure because the efficiency of diesel engines is over 30 per cent while that of coal or oil-burning steam locomotives rarely exceeds five per cent. The complete replacement of all steam locomotives by diesels would actually lower railroad fuel consumption. The resulting requirements for oil would be only 110 million barrels and coal consumption would be zero. The savings would amount to 40 million barrels of oil and 150 million tons of coal annually.

HEATING OILS

Without catalytic cracking, the oil industry could not meet rapidly increasing demands for heating oil. Catalytic cracking, as compared to thermal cracking, produces higher yields of distillate suitable for heating oil and relatively small amounts of residual oil of which there is over-production at the present time. Production of distillate fuel oils rose over 100 per cent from 1941 to 1948 as compared to 44 per cent for all petroleum products. Inasmuch as oil heating requires less manual labour, is cleaner and more easily regulated than coal heating, it has become popular both for homes and industrial buildings. Estimates are that oil burners have been installed in over 4 million American homes.

LIQUEFIED PETROLEUM GAS

Liquefied petroleum gas, consisting of propane and butane, is one of the most rapidly growing industries in the United States. Sales increased about threefold in the four years from 1944 to 1948. They are now 2,600 million gallons per year. Some years ago propane and butane were burned under boilers and distillation units, but research and developments have shown the way to much more advantageous use. At present about 59 per cent is used for domestic purposes such as cooking and heating, 11 per cent in industry, 11 per cent in enrichment of city gas, and 19 per cent for chemical manufacture. The industrial figure includes some use as motor fuel for locomotives, buses, and trucks on the West Coast of the United States. Demands are being met by augmenting supplies through greater recovery from gases accompanying petroleum production, natural gas, and refinery gas.

LUBRICATING OILS

Lubricating oils are a $ 2,000 million-a-year business. Quality of these oils has been constantly improved through the development of chemical processes for their manufacture and through the development of chemical additives to improve their properties. In the refining of lubricants, selective solvents are used to remove asphalt, wax, and oils with poor lubricating properties. The solvents include furfural, [illegible] zene, phenol, propane with a mixtu[illegible] chlorex (bis-[2-chloroethyl]ether), and nit[illegible]ide with ben- [illegible] ing operations, propane or methyl ethyl ke[illegible] propane is also employed in de-asphalting. To [illegible] cresols, lubricating properties and adapt oils to special se[illegible] cals are added. These include compounds which [illegible] freezing point, oxidation inhibitors, synthetic deterg[illegible] preventing deposits on rings and cylinder walls, and v[illegible] stabilizers. In the United States, 500,000 lb. of these chem[illegible] additives are used daily. Some of these additives are petroleum-based products. For example, polymers of ethylene and butylene from cracked gases are used as viscosity stabilizers.

The new lubricants are tailor-made for specialized services varying from the lubrication of fine instruments such as watches to use in heavy machinery. Different types of oils are prepared for the many types of transportation vehicles and for climatic differences. A development of particular importance is the production of lubricants which permit aircraft operation at both desert temperature of 60 degrees C and stratospheric temperatures of 40 degrees C below zero.

High-melting microcrystalline waxes are obtained as by-products of the solvent refining of lubricants. They have a variety of special uses which include waterproofing, leather, paper containers and textiles; insulating electrical and radio equipment and furnishing ingredients for ointments and cosmetics.

Synthetic lubricants are of high potential interest. Some of them are being produced commercially but are at present too costly to warrant extensive use. One class includes members of the silicone group which are synthesized from sand, hydrocarbon oils and water. They are particularly valuable because their viscosity shows little change between 0 degrees and 200 degrees C. Another type, derived from the cracked gases, ethylene and butylene, also shows excellent viscosity stability. Water soluble lubricants useful in textile machinery and tire molds are derived from ethylene which is in turn converted to glycol and polymerized.

CHEMICALS

An entirely new industry has recently come into being as a result of the development of processes for deriving chemicals from petroleum and natural gas. Plants costing over $ 1,000 million are being built in the United States. In 1925, total production was less than 150,000 lb., whereas in 1948, over 3,000 million lb. of raw materials for chemicals were produced. This huge quantity, however, represents less than 0.5 per cent of the annual petroleum production and has a negligible effect on the supply. It is also estimated that less than 10 per cent of the 5,600 thousand million cub. ft. of natural gas produced annually is being used in chemical and carbon black manufacture.

The materials used for chemicals are principally natural gas and gases from petroleum cracking. Utilization of these products for chemicals is a conservation measure as they were formerly burned under boilers and stills. The petro-chemical industry is also of economic importance because present chemical demands are much higher than the amount which can be supplied from coal, carbohydrate materials and fats, which were formerly the only sources.

Many chemicals can be directly recovered from petroleum and natural gas. Naphthenic acids which are present in some petroleums are useful in making soaps, paint driers, and fungicides. Cresols, also present in petroleum, are used as disinfectants, in impregnating railroad ties, and in the manufacture of resins. Nitrogen compounds, mostly of quinoline structure, have potential use but have not been commercialized.

Natural gas contains recoverable amounts of hydrogen sulphide, carbon dioxide, and helium. The hydrogen sulphide is used for manufacture of elemental sulphur and sulphuric acid. Similar products are made from recovery of hydrogen sulphide in refinery gases. Carbon dioxide is extracted from natural gas for the manufacture of dry ice. Helium is an inert gas and is used for a variety of purposes in which non-combustibility is an important property. Mixtures of helium and oxygen are supplied to deep-sea divers and caisson workers in place of air. Since helium, in contrast to the nitrogen in air, is not adsorbed by the blood stream, such workers suffer no discomfort during decompression periods. Similarly helium-oxygen mixtures are used in tents for respiratory patients and with anesthetics to eliminate post-operation nausea.

In manufacturing chemical derivatives from petroleum hydrocarbons, the original materials are usually oxidized, halogenated, sulphonated or nitrated. Many of the products are used as solvents or intermediates and others are used as finished products.

Many of the oxygenated derivatives are produced on a high tonnage basis. These include alcohols, acids, aldehydes, and ketones. It is of particular interest that petroleum is now a major source of alcohols. Methanol is an excellent example of the shift from coal to petroleum and natural gas for raw materials. Two years ago, over 70 per cent of the United States synthetic methanol production was derived from coal-carbonization products. Since then, production has been doubled to over 1,000 million pounds and natural gas is furnishing over 70 per cent of the raw material.

The trend is similar for ethyl alcohol. From ethylene, a constituent of cracked petroleum gas, ethyl alcohol is made for a cost considerably less than alcohol from fermentation of grain. Of the 160 million gallons of ethyl alcohol produced in 1948, 70 per cent was derived from petroleum. If this 112 million gallons of alcohol had been made from corn, it would have involved the use of 1,600 square miles of farm land.

Petroleum is the only source of isopropyl alcohol. This product is made from propylene, another constituent of cracked gases. The annual production is around 75 million gallons. It is used principally as a denaturant and a rubbing alcohol. Alcohols containing seven, eight, and nine carbon atoms are made from olefins in narrow fractions of cracked gasoline by reacting them with carbon monoxide and hydrogen by the Oxo process. This process is significant because it represents the use of liquid hydrocarbons in chemical manufacture. These higher alcohols are now important in the manufacture of plastics and plasticizers formerly obtained only from vegetable oils such as castor oils.

Ethylene glycol is a dialcohol made from the ethylene in cracked gases. The production of this compound in 1948 was 370 million lb., 70 per cent of which was used as an anti-freeze in automobile radiators.

The commercial manufacture of glycerin, a trialcohol, from propylene in cracked gases is the result of years of chemical research. The annual production of this compound in the United States is 35 million lb. This process has far-reaching significance as a food-conserving measure. Prior to its manufacture from petroleum, all glycerin was made from fats as a by-product of soap manufacture. Fats yield about 10 per cent glycerin, and thus commercial production of glycerin from petroleum will conserve 350 million lb. of fat every year. Reaction of glycerin with acids made by oxidizing petroleum wax yields edible fats which can further contribute to our food supplies. The synthetic glycerin process yields a number of important by-products including allyl alcohol, acrolein and other chemicals.

Other oxidized products made in large quantities from petroleum and natural gas include formaldehyde, acetaldehyde, acetone, and formic and acetic acids. The oxidation of petroleum wax yields high molecular weight acids which may either be reacted with glycerin to synthesize fats, or used as additives in lubricating oils. By oxidation, ortho-xylene derived from catalytic cracking or hydroforming is converted to phthalic anhydride which finds use in manufacturing plasticizers and alkyd resins. Heretofore, the entire phthalic anhydride production was derived from naphthalene. In 1948, the production from naphthalene was about 150 millions lb. and that from ortho-xylene about 8 million lb.

CHEMICALS FOR AGRICULTURE

The agricultural industry of today is highly dependent upon petroleum products. It is one of the largest users of motor fuels, lubricants, heating oils, liquefied petroleum gas and chemicals. In recognition of the interrelation of the two industries, petroleum companies are devoting great effort to research on agricultural problems. Large experimental farms are a part of the vast outlay of petroleum research laboratories.

The oil industry is producing insecticides, weed killers, fertilizers and many other products which increase food production. If world food supplies are to be raised substantially, the control of harmful insects, fungus growths and plant diseases is essential. For example, many tropical areas of potential food-producing value are malaria-ridden, and thus the elimination of mosquitoes by insecticides can open up enormous tracts to cultivation.

Petroleum oils have been used in insecticidal work for a long time. Kerosene and lubricating oils have been employed as carriers for nicotine, pyrethrum, derris and lead arsenate. More recently, petroleum hydrocarbons have been used in the manufacture of insecticides themselves. Except for chlorine, all of the basic materials for DDT and Gammexane can be obtained from petroleum.

The soil fumigant D-D, a by-product of the synthetic glycerine process, has restored many blighted agricultural areas to productivity by destroying wire worms and nematodes. After soil fumigation, the bodies of the worms become fertilizer. Treatment of infested soil with this petroleum product has increased crop yields over 100 per cent. In southern United States, 3,000 square miles of land can be restored to productivity by the use of this chemical.

Oils and synthetic chemicals from petroleum have been successfully employed as weed killers. In the cultivation of carrots and other root crops, weeds are selectively destroyed, without damage to vegetable foliage, by spraying with aromatic petroleum oil. Petroleum laboratories are also active in developing plant hormones for stimulating and regulating growth. One such product is a weed-killer similar to the popular 2,4-D. Another is spray, popularly called "endrop", which prevents premature fall of fruits such as apples.

Ammonia derived from natural gas and liquid air greatly augment our fertilizer supplies. About 620,000 tons of ammonia is produced from these sources annually. It is now used as fertilizer by direct injection into the soil or irrigation waters, as well as in the form of ammonium nitrate or ammonium sulphate produced through reaction with acid sludges from oil treatment.

SYNTHETIC RUBBERS

The development of synthetic rubbers is a large factor in world economy. Pressure of war demands brought about a totally new industry which produced 1 million tons a year. Synthetic rubbers occupy an assured position because they are produced at a price competitive with natural rubber and because synthetics are better suited to many purposes than natural rubber.

The synthetic rubber produced in greatest tonnage for tires is GR-S from the copolymerization of butadiene and styrene, both of which are petroleum products. Since the inception of synthetic rubber manufacture on a commercial scale in the United States, about 2 million tons of butadiene have been made from petroleum. Recently developed "cold rubber", made at temperatures around 0 degrees C gives about 30 per cent greater tire mileage than natural rubber. Because of the superior quality of cold rubber in tire treads, manufacturing units are being rapidly converted to low temperature operation.

Butyl rubber, derived from petroleum, is a unique product. Inner tubes of butyl rubber maintain air pressure ten times longer than those made of natural rubber. Driving safety is increased because of less wear on tire cords, and greater resistance to aging, tear and abrasion. Research is indicating that different types of synthetic rubbers are needed for casings, rims and treads of tires so that the future tire will be a composite of several kinds of rubber. Extensive research is in progress on synthetic rubber and more and better types are being developed.

RESINS AND PLASTICS

The resins and plastics industry is one of the largest consumers of chemicals derived from petroleum and natural gas. Many types such as polystyrene, vinyl resins and polyethylene are produced either wholly or in part from petroleum sources. Ethylene, isobutylene and other constituents of cracked gases are among the basic materials used. The present trend indicates that many of the aromatic-based resins and plastics will be produced from petroleum inasmuch as demand is exceeding the quantities which can be derived from coal sources.

The large variety of resin and plastic products range in physical characteristics from liquids for treating textiles to radio cabinets. They make possible such interesting materials as water-shedding felt for hats, glass that sheds ice and moisture and unbreakable phonograph records. Special resins have been made which are particularly resistant to electrical stresses and are therefore suitable for such uses as radar equipment. The horizons are broad in the resins and plastics field, and new marvels are being invented continuously.

DETERGENTS

Synthetic detergents, the so-called "soapless soaps", comprise a large industry which is approaching 1,000 million lb. annual production. Petroleum is the source of a major portion of the 400 million lb. of active ingredients which are required. In this way the petroleum industry is contributing to fat-conservation on a large scale. The savings are on the order of 1,000 million lb. of fats per year inasmuch as one pound of commercial detergent replaces a quantity of soap which would require one pound of fat for production.

The principal types derived from petroleum are alkyl and aryl sulphonates. Some of the detergents are superior to soap for certain purposes and other have uses in addition to cleansing. In textile finishing, they have a wide variety of application. They are more effective in hard or salt water, can be used in acid solutions and do not form curd which leaves a gray film on lavatories, bath tubs, and dark fabrics. It has also been discovered that these compounds can be used to settle dust on city streets.

The new developments in chemicals and their applications are symbolic of the progressive trend of the oil industry. Practically all oil companies are expanding their research laboratories to house the most modern facilities and are likewise increasing their staffs to include thousands of highly trained chemists, physicists, and engineers. The whole industry stands as a direct outgrowth of research and bases its future on the continued development of new processes and products.

Bibliography

Petroleum composition

C. M. McKinney and O. C. Blade, "Analyses of Crude Oils from 283 Important Oil Fields in the United States", Report of Investigations 4289, U.S. Dept. of the Interior, Bureau of Mines, May 1948.

Frederick D. Rossini, Beveridge J. Mair and Augustus R. Glasgow Jr., "Report on Summary of the Hydrocarbons Isolated from One Representative Petroleum", American Petroleum Institute Research Project 6 at the National Bureau of Standards, 28 February 1949.

Petroleum refining

F. S. Lott, "Petroleum Refineries, Including Cracking Plants in the United States", January 1, 1948, Information Circular 7483, U.S. Dept. of the Interior, Bureau of Mines, August 1948.

Anon., "Modern Refining Processes", *Oil and Gas Journal*, vol. 46, no. 48 (1 April 1948), page 118.

Gustav Egloff, "Oil Refining from the Modern Viewpoint", *Mining & Metallurgy*, vol. 28, no. 49 (November 1947), pages 550–5.

Gustav Egloff, "Expansion and Modernization in Petroleum Refining", *Oil and Gas Journal*, vol. 47, no. 47 (March 1949), page 152.

Gustav Egloff and R. F. Davis, "Refinery Process Developments", *Reviews of Petroleum Technology*, vol. 7 (covering 1941–1945), page 99. Published by the Institute of Petroleum, Manson House, 26 Portland Place, London, W. 1.

T. B. Kimball and J. A. Scott, "Refinery Tools for Producing High-Octane Gasoline", *Petroleum Refiner*, vol. 27, no. 6 (June 1948), page 116 (326).

Anon., "Expansion of Refining", *Petroleum*, vol. 12, no. 3 (March 1949), page 52.

Walter Miller, "Petroleum Refining", *Mining & Metallurgy*, vol. 28, no. 48 (February 1947), page 101.

Davis Read, "Processes for Octane Improvement", *The Petroleum Times*, vol. 50, no. 1, 278 (20 July 1946), page 757.

Davis Read, "Factors in Evaluating Small Refiner's Position", *Petroleum Refiner*, vol. 26, no. 10 (October 1947), page 111.

Davis Read and Gustav Egloff, "Refining South American Crudes", *Journal of The Institute of Petroleum*, vol. 33, no. 286 (October 1947), page 621.

Davis Read, "Refinery Planning", *Petroleum Refiner*, vol. 26, no. 8 (August 1947), page 73.

Davis Read, "Improving Yields of Gasoline, Distillates from Pa. Grade Crude Oil", *Petroleum Processing*, vol. 3, no. 4 (April 1948), page 329.

Davis Read, "Processing Pennsylvania Crude", *Petroleum Engineer*, vol. 20, no. 6 (June 1948), page 122.

Hugh W. Field, "New Products of the Petroleum Industry", *Journal of the Franklin Institute*, vol. 243, no. 2 (February 1947), page 95.

C. J. BAUER, "Foreign Petroleum Refining", Address delivered at the 44th Semi-Annual Meeting, National Petroleum Association, Cleveland, Ohio, 18 April 1947.

Catalytic cracking

ANON., "Fluid Catalytic Cracker Record", *Petroleum Times*, vol. 52, no. 1333 (10 September 1948), page 859.

EDWIN F. NELSON, "Trends in Cat Crackers, Catalysts, and Product Treating", *Oil and Gas Journal*, vol. 47, no. 50 (14 April 1949), page 108.

C. WEIZMANN, E. BERGMANN, H. STEINER and M. SULZBACHER, "Production of Aromatic Hydrocarbons from Petroleum", *Journal of the Society of the Chemical Industry*, vol. 67, no. 6 (1948), pages 114–118.

VLADIMIR HAENSEL and MELVIN J. STERBA, "Pyrolytic and Catalytic Decomposition of Hydrocarbons", *Industrial & Engineering Chemistry*, vol. 40, no. 9 (September 1948), page 1660.

DAVIS READ, "Stopgap Processes vs. Catalytic Cracking", *Petroleum Refiner*, vol. 26, no. 5 (May 1947), page 99.

DAVIS READ, "Application of Fluid Catalytic Cracking in Present Refinery Operations", *Oil and Gas Journal*, vol. 44, no. 47 (30 March 1946), page 243.

DAVIS READ, "A Fluid Catalytic Cracking Unit for the Smaller Refiner", *Petroleum Engineer*, Reference Annual, 1946, page 256 (P. 721.3).

MARSHALL SITTIG, "Catalytic Cracking in 1948", *Petroleum Processing*, vol. 4, no. 3 (March 1949), page 274.

WILLIAM F. BLAND, "Cut Costs on New 3000 b/d Fluid 'Cracker' by using unified reactor-regenerator", *op. cit.*, vol. 2, no. 9 (September 1947), page 670.

E. VAN DORNICK, "Modern Fluid Catalytic Cracking", *Petroleum Engineer*, vol. 18, no. 7 (April 1947), page 149.

ANON., "Standard of Jersey Plans 41,000 b/d Fluid Cracker", *National Petroleum News*, vol. 39, no. 25 (18 June 1947), page 15.

ANON., "Spent Catalyst Stripper Separate from Reactor in New Fluid Cracker", *Petroleum Processing*, vol. 2, no. 12 (December 1947), page 921.

R. T. ARMSTRONG and B. L. DENKER, "Microspheroidal Catalyst used in Shell's New 'Cat' Cracker", *World Petroleum*, vol. 18, no. 8 (15 July 1947), page 69.

WALTER MILLER, "Catalytic Cracking Still Held Way to Meet Higher Octane Numbers", *National Petroleum News*, vol. 39, no. 9 (26 February 1947), page 40.

GUSTAV EGLOFF, "Catalytic Cracking", *Chemical Abstracts*, vol. 42, no. 10 (10 May 1948), page 3555; *Chimie & Industrie*, vol. 59 (1948), pages 121–7.

ROBERT E. WILSON, "Research on a Single Reaction and Its Social Effects", Third Annual Arthur Dehon Memorial Lecture at the Massachusetts Institute of Technology.

E. V. MURPHREE, H. G. M. FISCHER, E. J. GOHR, W. J. SWEENEY, and C. L. BROWN, "Fluid Catalyst Cracking for Premium Fuels", *The Petroleum Engineer*, Reference Annual (1944), page 230 (P. 721.33).

E. V. MURPHREE, E. J. GOHR, H. Z. MARTIN H. J. OGORZALY and C. W. TYSON, "High-Capacity Operations on Fluid Cracking Units", *Petroleum Refiner*, vol. 24, no. 11 (November 1945), page 97; *Petroleum Engineer*, vol. 17, no. 3 (December 1945), page 136.

N. K. ANDERSON and J. STERBA, "Simplified Catalytic Cracking Unit Meets Requirements of Smaller Refiners", *Oil and Gas Journal*, vol. 44, no. 33 (22 December 1945), page 77.

H. MCREYNOLDS and J. M. BARRON, "Thermal Cracking of Fluid Catalytic Cycle Gas Oils", *Petroleum Refiner*, vol. 28, no. 4 (April 1949), page 111.

GUSTAV EGLOFF, "Use of 'Cat' Cracking Rising Sharply Here and Abroad", *Journal of Commerce*, N.Y. (5 November 1948), page 21.

ANON., "Fluid Cat Cracker Run Establishes New Record", *Petroleum Refiner*, vol. 27, no. 8 (August 1948), page 160–2.

ARCH L. FOSTER, "Small Fluid Cat Cracker Handles High-Sulfur Charge Efficiently", *Oil and Gas Journal*, vol. 46, no. 31 (6 December 1947), page 74.

JAMES SETH, "Record Run Made by Avon Cracking Unit", *Petroleum Engineer*, vol. 18, no. 11 (November 1946), page 170 (P. 721.2).

D. P. THORNTON Jr., "Fluid 'Cat Cracker' Designed to Use New MS Catalyst", *Petroleum Processing*, vol. 2, no. 3 (March 1947), page 173.

Alkylation, polymerization and isomerization

FRANK C. WHITMORE, "Alkylation and Related Processes of Modern Petroleum Practice", *Chemical & Engineering News*, vol. 26, no. 10 (8 March 1948), page 668.

M. H. GORIN, C. S. KUHN Jr. and C. B. MILES, "Mechanism of Catalyzed Alkylation of Isobutane with Olefins", *Industrial & Engineering Chemistry*, vol. 38, no. 8 (August 1946), page 795.

J. L. BLACK, "Alkylation and Isomerization", *Modern Petroleum Technology*, 1946, page 173, published by the Institute of Petroleum, Manson House, 26 Portland Place, London, W. 1.

ANON., "HF Alkylation", *Oil and Gas Journal*, vol. 44, no. 47 (30 March 1946), page 153.

ANON., "Sulfuric Acid Alkylation", *ibid.* (30 March 1946), page 156.

LOUIS SCHMERLING, "The Mechanism of the Alkylation of Paraffins, II. Alkylation of Isobutane with Propene, 1-Butene and 2-Butene". *Journal of the American Chemical Society*, vol. 68, no. 2 (February 1946), page 275.

JOHN A. SCOTT and ROBERT M. COOPER, "Economic and Successful Operation Obtained at HF Alkylation Plant", *Oil and Gas Journal*, vol. 44, no. 47 (30 March 1946), page 206.

C. A. REHBEIN, "Alquilación, Isomerización y Polimerización", *Petroleo Interamericano*, vol. 5, no. 12 (December 1947), page 92.

P. C. WEINERT and G. EGLOFF, "Catalytic Polymerization and its commercial application", *Petroleum Processing*, vol. 3, no. 6 (June 1948), page 585.

GEORGE ARMISTEAD Jr., "Nonselective Catalytic Polymerization has important postwar utility", *Oil and Gas Journal*, vol. 44, no. 48 (6 April 1946), page 131.

B. L. EVERING, G. S. WEEMS and N. FRAGEN, "Commercial isomerization of light paraffins", *National Petroleum News*, vol. 361, no. 44 (1 November 1944), page R-737.

J. A. CHENICEK, C. G. DRYER, R. E. SUTHERLAND and J. O. IVERSON, "Butane Isomerization", *ibid.* (4 October 1944), page R-678.

J. E. SWEARINGEN, R. D. GECKLER and C. W. NYSEWANDER, "The Isomate Process", American Institute of Chemical Engineers, *Transactions*, vol. 42, 1946, page 573.

J. A. CHENICEK, J. O. IVERSON, R. E. SUTHERLAND and P. C. WEINERT, "Butane Isomerization, UOP Process", *Chemical Engineering Progress*, vol. 43, no. 5 (May 1947), page 210.

J. L. BLACK, "Isomerization", *Institute of Petroleum Review*, vol. 1, no. 10 (October 1947), page 323.

Gasoline

ANON., "Ever-Increasing Use of Premium Quality Gasoline Indicated by Surveys, Frey Says", *Chicago Journal of Commerce*, 12 May 1949.

ANON., "National Motor-Gasoline Surveys", U. S. Dept. of the Interior, Bureau of Mines, Reports of Investigations.

ERROL J. GAY, "Gasoline Quality Abroad", *Ethyl News* (September 1948), page 15.

DANIEL P. BARNARD, "Oil Research Man Views the Octane Trend in Meeting Requirements of Future Autos", *National Petroleum News*, vol. 41, no. 8 (23 February 1949), page 38.

G. H. SCHOENBAUM, "European Motor Fuel Demand and Octane Improvement", *Oil and Gas Journal*, vol. 47, no. 5 (24 June 1948), pages 142–3.

WHEELER G. LOVELL, "Knocking Characteristics of Hydrocarbons", *Industrial & Engineering Chemistry*, vol. 40, no. 12 (December 1948), page 2388.

Diesel fuel:

ANON., "Fuel Oil for Diesel Locomotives in Relation to the Supply of Petroleum", *The Petroleum Engineer*, vol. 20, no. 1 (October 1948), page 105.

ANON., "Railroads to use less oil by shift to Diesels", *World Oil*, vol. 128, no. 9 (January 1949), page 23.

ANON., "Wide-cut Diesel Fuel for Railroads", *Petroleum Processing*, vol. 4, no. 2 (February 1949), pages 131–3.

M. SMOLAK and F. L. NELSON, "Diesel Fuel Additives", *Petroleum Refiner*, vol. 27, no. 8 (August 1948), page 75 (405).

Heating oil:

ROBERT GRAY, "Oilburners, and Distillate Demand", *Fuel Oil & Oil Heat*, New York, National Petroleum Association, Cleveland, 22 April 1948.

Lubricating oils:

A. T. COLWELL and A. L. POMEROY, "Lubricant Requirements for the Automobile Engine of the Future", Paper for presentation to a Group Session on "Lubricant Requirements, Additives, and Brand Names", under the auspices of the Division of Marketing, during the 28th annual meeting of the American Petroleum Institute in the Stevens Hotel, Chicago, Ill., 10 November 1948.

A. BRUCE BOEHM, "Lubricating Oil Improvers", *Petroleum Refiner*, vol. 27, no. 12 (December 1948), page 131.

A. BRUCE BOEHM, "Methods of Improving Lubricating Oil with Use of Additives", *National Petroleum News*, vol. 40, no. 46 (17 November 1948), page 21.
H. L. WEST, "Synthetic Lubricants and Additives in Germany", *Journal of The Institute of Petroleum*, vol. 34 (1948), pages 774–820, B.I.O.S. Final Report, no. 1611; *Chemical Abstracts*, vol. 43, no. 6 (25 March 1949), page 2417.
E. R. SMOLEY and D. FULTON, "Modern Manufacture of Lubricating Oils", *Petroleum Processing*, vol. 2, no. 8 (August 1947), page 594.
C. J. LIVINGSTONE and W. A. HOWE, "Improving Engine Lubricating Oils through the Use of Additives", An address presented at the 36th annual meeting of The Western Petroleum Refiners Association, Galveston, Texas, 5–7 April 1948.

Rubber:
L. R. SPERBERG, L. A. BLISS and C. C. BIARD, "New Synthetic Rubber and Oil-Type Carbon Black make the best Tires", *Oil and Gas Journal*, vol. 47, no. 32 (9 December 1948), page 70.
CLAYTON R. SUTTON, "Chemists foresee host of Synthetic Rubbers made for special jobs", *Wall Street Journal*, 14 March 1949.

Chemicals:
LEIGH S. MCCASLIN Jr., "World's First Synthetic Glycerine Plant opens at Houston", *Oil and Gas Journal*, vol. 47, no. 20 (16 September 1948), page 86.
GUSTAV EGLOFF, "Petrochemicals", *Oil and Gas Journal*, vol. 46, no. 48 (1 April 1948), page 179.
F. G. WATSON, "Shell Succeeds in Producing Acrolein", *Chemical Engineering*, vol. 54, no. 12 (December 1947), page 107.
GEORGE WEBER, "Sulfur from Sour Gas... an Added Income", *Oil and Gas Journal*, vol. 45, no. 44 (8 March 1947), page 58.
W. L. NELSON, "Progress in Petrochemical Manufacture", *ibid.*, no. 49 (9 December 1948), page 100.
ANON., "Esso Makes Synthetic Alcohol Commercially", *ibid.*, vol. 47, no. 32 (9 December 1948), page 125.
R. J. S. PIGOTT, "Fuels & Lubricants for the Modern Engine", prepared for presentation at National Petroleum Association, Atlantic City, N.J., 16 September 1948, Research Report AN 12, Gulf Research & Development Co., Pittsburgh, Pa., 10 August 1948.
ANON., "Union Oil extracts carbon dioxide from natural gas", *Chemical Engineering*, vol. 55, no. 11 (November 1948), page 217.
ANON., "'Oxo' Process Chemicals", *Petroleum*, vol. 12, no. 4, April 1949, page 98.
R. F. GOLDSTEIN, "Petroleum-Chemicals Reviewed", *Petroleum Times*, vol. 53, no. 1347 (25 March 1949), page 199.
BRUCE K. BROWN, "The inter-relationship of the petroleum industry and the organic chemical industry", Meeting of Chicago Chamber of Comm., the Illinois Mfrs. Assn. and the American Chemical Society, 12 October 1949.
M. SITTENFIELD, "Petroleum Chemical Detergents", *Chemical Engineering*, vol. 55, no. 6 (June 1948), pages 120–2.
GUSTAV EGLOFF, "Chemicals from Petroleum and Natural Gas", *Chemical and Engineering News*, vol. 25 (8 December 1947), page 3634.
ANON., "Chemicals from Petroleum", *Petroleum*, vol. 10, no. 5 (May 1947), page 102.
A. E. GRIFFITHS, "Petroleum Products in Agriculture", *Chemurgic Digest*, vol. 7 (June 1948), pages 14–16.
HAROLD M. SMITH and W. C. HOLLIMAN, "Utilization of Natural Gas for Chemical Products", Information Circular 7347, U. S. Dept. of the Interior, Bureau of Mines, March 1947.
GUSTAV EGLOFF, "Huge Expansion predicted for petroleum-derived chemicals", *Journal of Commerce*, New York, 30 August 1948.

Research:
ROBERT PRICE RUSSEL, "Progress in Petroleum Research", *Petroleum Times*, vol. 5, July and August 1947, page 706.
ROBERT E. WILSON, "Technology as a Multiplier of our Natural Resources", *Chemical & Engineering News*, vol. 22, March 1944, pages 784–7.
MONROE E. SPAGHT, "Future Research in Hydrocarbons", *Chemical & Engineering News*, vol. 25, no. 16 (21 April 1947), page 1122.
E. V. MURPHREE, "Research and Development in the Oil Industry", presented at the Manufactured Gas Dept. of the American Gas Association at Atlantic City, New Jersey, 7 October 1946.
ROBERT E. WILSON and J. K. ROBERTS, "Petroleum and Natural Gas—Uses and Possible Replacements", *Mining and Metallurgy*, vol. 29, no. 504 (December 1948), page 817.

Petroleum Refining in the United Kingdom

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ABSTRACT

This report deals with the pre-war status of the petroleum refining industry in the United Kingdom, showing the predominance of specialized refining for lubricating oils and bitumens as end products.

An account is given of war-time developments particularly in respect of the development and operation of the Heysham plant for aviation fuels, and also the utilization of the small amount of indigenous (Eakring) crude. Reference is made to the late war-time development of the synthetic detergent industry.

The status of the industry in 1948–1949 is discussed, emphasis being placed on the development of large-scale crude oil refineries, the development of petroleum chemicals, and the expansion of activity in synthetic detergents.

The report is concluded with an account of trends in the refining industry, largely conditioned by the establishment of a sufficiency of crude oil refining to meet home requirements.

This report deals with the subject matter under the following headings:
1. **Status of the United Kingdom petroleum refining industry at 1939.**
2. **War-time developments.**
3. **Present status (1948–1949)**
4. **Future trends.**

STATUS OF THE UNITED KINGDOM PETROLEUM REFINING INDUSTRY AS AT 1939

Before the war no substantial attempt was made by the refining industry in the United Kingdom to meet the needs of the country for a full range of fuels derived from petroleum. By far the greatest proportions of such fuels of all types were readily available from refineries located near producing areas.

In general, therefore, the United Kingdom refining industry had developed on specialized lines to meet the specific requirement of the home market for certain types of petroleum products, notably asphaltic bitumens, lubricating oils and petroleum solvents of narrow boiling range, although exceptionally, a few refineries imported crude oil and manufactured a full range of fuels and lubricants on a limited scale.

Development in high-grade lubricating oil manufacture had resulted in the establishment of several types of solvent extraction plants, and in total a considerable proportion of the home requirements was being manufactured in United Kingdom refineries, from selected imported feedstock. Associated with lubricating oil manufacture was the production of substantial amounts of wax, and the production of large quantities of extract of aromatic and naphthenic character.

One of the preoccupations of the industry at this time was the upgrading of by-products from refining operations to products of higher market value, a trend to be accelerated by the shortages and other circumstances of the impending war.

WAR-TIME DEVELOPMENTS

Although the war did not cause any great increase in the volume of United Kingdom refining, a great impetus was given to the maximum utilization of facilities, and to the best utilization of all products of the refining processes. Research facilities were established or augmented and some new processes were put into operation.

The pooling of resources on the distributing side of the industry was accompanied by a simplification and reduction in the number of grade products required, and this led to the more economic use of refinery equipment.

On the lubricating oil side of the refining industry there was considerable emphasis on the manufacture of grades to Air Ministry specification, and also on the refining of used aviation oils for reuse.

The recovery of napththenic acids from certain refinery distillates was developed toward maximum yield of high acid material.

New uses were found for the aromatic extracts from the solvent refining of lubricating oils, and, notably, certain fractions of these extracts were found to be very valuable as rubber extenders.

The shortage of vegetable and animal fats accelerated the usage of slack wax from the solvent dewaxing of lubricating oils as a source of olefines which could be converted into sodium alkyl sulphates having excellent properties of wetting power and detergency. (1) [1]

The process consists essentially of the vapour-phase cracking of slack wax to give the optimum yield of the desired olefines which are fractionated from the pressure distillate. The olefines are treated with strong sulphuric acid to form alkyl-sulphuric acids. Caustic soda is used as the neutralizing base, and the resultant solution of sodium alkyl-sulphate is extracted with a light petroleum fraction to remove unreacted hydrocarbons.

The most important war-time addition to United Kingdom refining capacity and experience was the erection and operation of plant and equipment at Heysham for the purpose of producing aviation gasoline. (2)

Considerable experience of hydrogenation was already available from the hydrogenation of coal and creosote at Billingham and the knowledge available was freely drawn upon in developing a process for production of high octane gasoline using a suitable imported naphthenic gas oil as feedstock for processing to butane and 100 O.N. base gasoline. The butane was used for the production of iso-octane.

The freshly distilled gas oil was saturated with hydrogen at high pressure for removal of nitrogen and then hydrogenated in the vapour stage for conversion to lighter hydrocarbons which were subsequently fractioned to separate butane and blending base gasoline.

[1] Numbers in parentheses refer to items in the bibliography.

The heavier fractions were recycled to the hydrogenation stage and fractions lighter than butane were used for the production of supplementary hydrogen required in the primary process.

Over-all yields of butane and 100 O.N. base gasoline were about 20 per cent and 74 per cent respectively and small quantities of pentane and propane were also produced.

The butane was converted to iso-octane in three vapour-phase stages using suitable catalysts.

Dehydrogenation at 560 degrees C and normal pressure converted the butanes to butylenes which were then polymerized to octylenes at 150 degrees C and 900 lb. per sq. in. pressure. After distillation to remove higher polymers the octylenes were hydrogenated at 176 degrees C and 95 lb. per sq. in. to yield iso-octane.

Hydrogen obtained from the dehydrogenation of butane was used for hydrogenating the octylenes.

The entire plant was capable of processing 1,400 tons per day of raw gas oil and producing 1,200 tons per day of high octane fuel.

A similar process to that used at Heysham was employed at Billingham for the production of high octane fuel from creosote derived from coal, and iso-octane was also produced at Stanlow by hydrogenation of suitable polymers which were imported for the purpose. (2)

These products were used as concentrates and, together with tetra-ethyl-lead, were blended with imported fuels of lower octane value to meet aviation requirements.

Exploration for crude oil in Britain resulted in the development of the Eakring field which reached a production of some 70,000 tons per annum. This crude yielded high quality lubricating oil and wax distillates which were solvent extracted and dewaxed on an Edeleanu plant with subsequent acid and earth treatment. (3)

The heavy residues were used to augment the feedstock requirements of a duosol solvent extraction plant and an M.E.K. solvent dewaxing plant which were operating on imported residue for the production of high-grade aviation lubricating oil. The lubricating oils produced by Duosol extraction received final treatment with activated earth on a contact filter plant and were subsequently blended to meet aviation requirements.

PRESENT STATUS (1948-1949)

Although there has been marked development of the refining industry since the end of the war, particularly in the direction of developing chemicals from petroleum, the industry is currently dominated by the very considerable expansion of general refining facilities which is now taking place. This expansion has been activated by British Government policy regarding United Kingdom refining (4) and springs from a number of factors which are peculiar to the oil industry in the United Kingdom.

The programme envisaged entails construction of new refineries, extension of existing refineries, and adaptation of existing plant, and the general intention is that the capacity thus available will operate on crude from the Middle East.

Activity has firstly been directed towards adapting and expanding plant but some new construction is already well under way or is shortly expected to commence.

The Heysham plant which was shut down in 1946 has been modified and is processing Middle East Crude at 4,500 tons per day for the production of gasoline, gas oil and fuel oil.

The Llandarcy refinery has been stepped up from 360,000 tons per annum to 850,000 tons per annum and should reach a capacity of 3 million tons by end 1949 and the Grangemouth refinery is being similarly increased from 360,000 tons to 1,500,000 tons per annum.

Concurrently there is considerably development in production of petroleum chemicals and at least two of four plants under development are expected to be in production by mid-1949.

These plants will use imported gas oil as basic feed for cracking to olefines for subsequent processing to the objective end products.

The products from the various chemical plants will include aliphatic alcohols and ketones, acetone (from which more complex alcohols and ketones will also be manufactured), glycols, aromatic hydrocarbons, high boiling point aromatic solvents and plastics. (5)

The production of detergents is being considerably increased. The Shell plant at Stanlow has already been expanded to produce 50,000 tons per annum while plants for the production of other types of detergents have been developed by I.C.I., Monsanto and Anglo-Iranian.

On the lubricating oil side of the refining industry maximum production of a full range of oils is being maintained. Plant capacities are progressively being improved by cutting maintenance and off-stream times and by removal of bottle-necks. New uses have been found for by-products of the refining processes, such as the naphta-sulphonic soaps derived from clean sludges resulting from the refining of certain white oils.

All well-established processes have been thoroughly looked over to ensure maximum efficiency in the production of an ever-growing variety of primary and secondary grades, and there is a continuous review of operations in an endeavour to satisfy each new need.

FUTURE TRENDS

So far as refinery capacity is concerned the future trends of the United Kingdom refining industry are fairly clearly indicated. It appears quite definite that projected expansion will lift capacity from the pre-war level of about 4.5 million tons to approximately 20 million tons by about 1953. In any case it appears that the crude oil refineries now under construction will be capable of easy expansion should the need arise. It is estimated that United Kingdom requirements of petroleum products for 1948-1949 will be in the region of 18 million tons, and it may well be that home demand will rise to about 22 million tons by 1953. (6)

There seems to be no doubt that by implementation of the current programme, the United Kingdom will be substantially self-supporting in petroleum refinery capacity.

It seems clear also that the new crude oil refinery development is to be of the most flexible character possible and that the proposed plants will be able to meet all commercial and military needs, with freedom to switch in quantity and quality of products.

Arising from the operation of these crude oil refineries, there will be available a large potential of refinery gas with appreciable olefine content and in at least one case it is proposed to feed high olefine content gas to an adjacent plant for the manufacture of aliphatic alcohols and ketones. It seems likely that availability of such gas at other locations will encourage the further development of petroleum chemicals, for the production of which pyrolysis of suitable distillates must be the starting point for the time being.

It is also probable that there will be a corresponding development towards the sale of the saturated hydrocarbons, propane and butane, as "liquid gas", and in certain instances it may prove profitable to pipe methane for admixture with town gas.

A probable alternative outlet for some of the low molecular weight saturated hydrocarbons is the production of carbon black.

The necessity to remove sulphur from certain of the fractions resulting from refining of Middle East Crude is likely to result in the production of elemental sulphur or sulphur compounds.

On the petroleum chemical side of refining operations indications are that there is likely to be great activity during the next few years, both as regards erection of new plant, and the development of new processes. It is likely that there will be early development towards halogenated hydrocarbons, in which case it is probable that there will be concurrent development of tetra-ethyl lead manufacture. So far as detergents are concerned, it is certain that there will be continuance of intense study and development for several years, and that the results of these efforts will progressively provide relief in the world shortage of vegetable and animal fats. The use of synthetic detergents from petroleum is firmly established in the textile and other industries, and a substantial entry has already been made into the domestic market.

In agricultural and horticultural matters, there is an increasing interest in the use of sprays to combat various pests, and also in soil fumigants. These are largely derived from petroleum, and although total sales are small in volume, their anticipated more extensive use is likely to show significant results in increased productivity of the land.

Research, which is now a weighty item in petroleum expenditure, is being extended into all new fields of operation, aircraft fuels including jet fuels, motor and diesel fuels, petroleum chemicals, lubricants and bitumens. There can be no doubt that within the next ten years, probably within five years, the United Kingdom refining industry will be very firmly established on the basis of supplying all home requirements, and of exploring all possible outlets for new products from petroleum. Though the creation of the refining industry in the United Kingdom is basically for the supply of the home market, it is possible that an export trade will be developed in specialized types of products such as lubricants and chemicals.

Bibliography

1. Stedehouder, Wijga and Dammers, "Synthetic Detergents with Special Reference to Those Derived from Petroleum Products", *I. P. Review*, May 1948, 2 (17), 149.
2. K. Gordon, "Hydrocarbons in the Fuel and Chemical Industries" (Melchett Lecture 1947), *Petroleum*, Jan. 1948, 11 and 16, Feb. 1948, 11, 35.
3. J. S. Parker, "The Crude Oil of England", *Jour. Inst. Pet.*, vol. 33 (1947), 280, 230.
4. J. S. Parker, British Government White Paper, Cmd. 7268, 1947, *Capital Investment in 1948.*
5. R. F. Goldstein, "Petroleum Chemicals Reviewed", *Petroleum Times*, June 18, 1948.
6. Anon., "European Co-operation, United Kingdom Refining and Overseas Oil", *Petroleum Times*, May 11, 1948.

Some Aspects of the Development of the Petroleum Chemical Industry in the Netherlands

J. W. H. UYTENBOGAART

ABSTRACT

In this paper a survey is given of the development of the petroleum chemical industry in the Netherlands; some particulars are discussed in connexion with the manufacture of *sodium alkyl sulphates, polyvinyl chloride* and *sulphur.*

Possibilities of processing the wax present in crude oil is dealt with. By cracking this petroleum wax and treating the olefines obtained with sulphuric acid, the higher secondary alkyl sulphates are produced, which have excellent detergent properties.

The disadvantages of soap are mentioned, after which the general trend in the development of synthetic detergents is indicated.

Further, the preparation of these sodium alkyl sulphates is briefly described and the considerations which have led to the erection of an installation for the manufacture of these products in the Netherlands. In the light of the present world fat shortage, which will continue for several years, the importance is shown of manufacturing synthetic detergents in order to save fat.

Finally, reference is made to the manufacture of polyvinyl chloride and sulphur from refinery gases which were burnt till a short time ago.

This experience paper does not aim at giving a general survey of the chemical industry based on petroleum as initial material, but purports to throw a special light on the aspects of the petroleum chemical industry as it has developed and is still developing in the Netherlands.

The petroleum chemical industry in the Netherlands is comparatively young and dates from the first year after the war. Consequently, the number of chemical products is not large, but as a result of research work done before and during the war it was possible to start or complete the erection of installations for the manufacture of *sodium alkyl sulphates, polyvinyl chloride* and *sulphur* immediately after the war.

The production of sulphur was started some time ago, while the factories for sodium alkyl sulphates and polyvinyl chloride will be in production by the time this Conference is held. For this reason, this exposition will be restricted to the discussion of some particulars which are connected with the manufacture of the three products mentioned above.

SODIUM ALKYL SULPHATES

Before the war, when in the whole world a liberal use was made of raw materials, which were available everywhere in comparative abundance, there was little reason for the Netherlands, which was very prosperous at the time, to pay special attention to the conservation and utilization of the available resources.

Important sources of prosperity were agriculture, cattle-breeding, shipping, etc., while the industries, with the exception of the agricultural industries, were, as regards their raw materials, largely dependent on supplies from abroad. This was true particularly of oil, which was obtained from various parts of the world.

As some of the oils contain wax the question arose for what purpose this wax could be used.

The wax-containing oil could be cracked, with or without previous distillation of the light fractions, after which the cracked products could be further processed in the usual manner.

Another method would be to distil the crude oil and to dewax selected distillate cuts after which the dewaxed fractions could be processed to lubricating oil. The wax could either be sold as such or processed further.

Before the war a process had been developed in the Research Laboratory of the Royal Dutch Shell Group at Amsterdam, in which unsaturated compounds, mainly consisting of straight chain α-olefines, were obtained by cracking wax from mineral oil in the gas phase. By treating these olefines with sulphuric acid and neutralization with caustic soda, the higher secondary alkyl sulphates were obtained, which proved to possess excellent detergent properties.

A great disadvantage of the fatty acid soap, which for a long time was considered to be the only detergent, emulsifier and foaming agent, is the formation of insoluble calcium and magnesium salts. The deposit formed in hard water attaches itself to the fibre, which has a detrimental influence on the appearance, feel and mechanical strength of the fabrics made from these fibres. At the same time the alkaline reaction of the soap solution is unfavourable to the treatment of wool and silk, while soap, because of the separation of the free fatty acid, cannot be used at all in an acid medium.

Washing with fatty acid soap in hard water causes a large annual waste of fatty acids from fat, while at the same time such an important and expensive textile material as wool gradually deteriorates in quality with continued washing with fatty acid soap, which means a great loss of consumer goods.

Therefore, the general aim of the development of synthetic detergent has been either to block the carboxyl group of the fatty acid molecule by reduction to alcohol, esterification or amidation, or to replace this group by the sulphonate group (SO_3Na) or by the sulphate group (OSO_3Na), which groups do not possess the disadvantages of the carboxyl group mentioned above.

In Germany the trend in the development of synthetic detergents was principally towards:

(*a*) Processing natural fats (Turkey red oil, fatty alcohol-sulphates, etc.);

(*b*) Processing synthetic fatty acids, obtained by oxidation of certain fractions originating from the Fischer-Tropsch process; and (*c*) The manufacture of sodium alkyl sulphonates, the so-called mersolates, made by sulphochlorination of Fischer-Tropsch paraffin waxes.

In the United States, however, more emphasis was laid on the development of synthetic detergents of the sodium alkyl aryl sulphonate type.

On the other hand, the main object of the investigations in the Netherlands was the synthetic detergents of the sodium alkyl sulphate type, the manufacture of which is briefly described below.

From the unsaturated compounds obtained by vapour-phase cracking of wax a certain fraction (C_{10}-C_{18}) is distilled off. This fraction is treated with concentrated sulphuric acid at a low temperature, and the alkyl sulphuric acid is formed by addition:

$$RCH{=}CH_2 + H_2SO_4 \rightarrow \begin{array}{l} RCHCH_3 \\ \;\;| \\ \;OSO_2OH \end{array}$$

At the same time dialkyl sulphuric acid is formed:

$$\begin{array}{ccccc} CH_3 & & & & CH_3 \\ | & & & & | \\ CH & -O- & SO_2 & -O- & CH \\ | & & & & | \\ R & & & & R \end{array}$$

while polymerization of olefines also occurs.

The next step consists in neutralization and hydrolysis of the acid reaction product with caustic soda, during which the sodium alkyl sulphate is formed and the dialkyl sulphuric acid is saponified, while one molecule of sodium alkyl sulphate and one molecule of secondary alcohol are formed.

After this the reaction product must be freed of the unconverted olefines, polymers and alcohols, which is done by means of extraction with a special gasoline fraction after addition of a de-emulsifier to check foam formation as much as possible. The thus purified product is for the greater part marketed as a solution, containing 21 per cent active material and 6 to 7 per cent sodium sulphate. Dry products can be obtained from this solution by spray-drying or drum-drying, with or without the addition of various builders such as sodium sulphate, silicates, phosphates, etc.

In Great Britain, where the first installation for the manufacture of these products in accordance with the process developed in the Netherlands was erected, these sodium alkyl sulphates enjoy great popularity, which is partly caused by the rationing of soap, but is mainly due to their good qualities, in which these synthetic detergents distinguish themselves from soap. This enabled them to capture a firm market during the war.

The ever-increasing demand for these products and the availability of the required wax in the Netherlands, further the great amounts of fat to be saved, were the reasons for building a similar installation in the Netherlands.

When considering the influence of the manufacture of these synthetic detergents in the Netherlands on the economy of the country, it can be stated that it means a saving in foreign currency on the import of oils and fats.

For a production of 25,000 tons per year and assuming that one ton of synthetic detergent (21 per cent active material) is equivalent to one ton of 50 per cent fatty acid soap, a quantity of 12,500 tons of oils and fats is saved, which at the present world prices represents an amount of about $ 6 million per year.

Apart from this saving in foreign currency, which from an economic standpoint is of course very important, it is of still greater importance that in this period of great fat scarcity this quantity of fats is saved and becomes available for human consumption. (It may be remarked in this connexion, that by improving the refining methods and the processing of oils and fats, the difference between edible and industrial fats has become of less and less importance.)

The quantities of edible fats gained in this way are of all the more importance as because of the continuously growing population in the whole world and the rising standard of living (particularly in Asia) the demand for oils and fats will steadily increase.

This can be illustrated by the following example: the export of oils and fats from India amounted to 470,000 tons per year in 1937-1939, as compared with a production of 1,800,000 metric tons. A a result of the increase in population and the higher consumption per head this export had decreased by 400,000 tons to 80,000 tons in 1947, notwithstanding the fact that the production was maintained at almost the same level.

According to fairly reliable estimates the present fat shortage will certainly continue for another ten years and as the allocations of fats for human consumption naturally have priority over those for the manufacture of soap, it is obvious that for the time being there will remain a shortage of soap throughout the world.

Although everywhere in the world and more specially in the tropical countries great areas are being brought into cultivation to grow oil-containing products (the East African Groundnut Scheme), the yield of these plantations alone will not be sufficient to do away with the world fat shortage.

This will only be possible if synthetic detergents can be made on a larger and larger scale, which at the same time would diminish the influences of vagaries of climate and plant diseases, on which the crops of oil-containing products are partly dependent.

The other component originating from the decomposition of oils and fats in order to obtain fatty acids for the manufacture of soap, viz. glycerine, can also be prepared in accordance with a recently developed process on the basis of the gases obtained in the cracking of oil. In applying chemistry based on petroleum as raw material to this field the world has become independent of the oils and fats available for human consumption.

POLYVINYL CHLORIDE

Another example of the application of chemistry based on petroleum in the Netherlands and of the most effective use of base materials is the manufacture of polyvinyl chloride.

Whereas in Europe acetylene is generally taken as base material for the manufacture of this product, it was decided in the Netherlands to use ethylene instead, and more especially the ethylene produced from the gases originating from the modern refining and conversion of petroleum.

Up to now this ethylene was not removed from these gases but was burnt with the fuel gas. By separating the ethylene from the gases mentioned above a more efficient use is made of an important base material for the petroleum chemical industry.

As is generally known, polyvinyl chloride has found many applications, e.g., in the clothing industry, for cable insulation, floor-covering, etc.

SULPHUR

Finally, sulphur is produced from petroleum in the Netherlands.

The hydrogen sulphide, either present as such in the oil or formed in the cracking process, was formerly burnt as a component of the fuel gas, owing to which the SO_2 formed occasionally gave rise to complaints from those living in the neighbourhood.

Nowadays the hydrogen sulphide is removed from these gases by absorption and thereupon burnt with the theoretical quantity of air to water and sulphur, in accordance with the Claus process.

The sulphur produced in this way is very pure and may be used for various purposes, such as the manufacture of sulphuric acid, in the rubber industry, etc.

It will be clear from the above that by processing this sulphur to sulphuric acid, the other component for the manufacture of the sodium alkyl sulphates discussed under sulphuric acid, can also be made from the by by-products in the processing of petroleum.

By the development of the processes described above and their application on a commercial scale, in which a rational use is made of certain petroleum fractions which were burnt till a short time ago, the Netherlands has contributed in the field of the petroleum chemical industry towards the conservation and utilization of resources, while many further possibilities will be realized in future developments.

Bibliography

F. H. Braybrook, "The Development of Synthetic Detergents and Future Trends", Contribution to the Symposium on detergents, wetting and emulsifying agents held by the London Section of the Society of Chemical Industry on 5 and 6 April 1948. 5 pp.

P. L. Stedehouder, P. W. O. Wijga and H. F. Dammers, "Synthetic Detergents with Special Reference to Those Derived from Petroleum Products". *The Inst. of Petr. Rev.*, *2*, 1948, pages 149–58.

British Intelligence Objectives Sub-Committee, B.I.O.S. Final report No. 445., Item Nos. 9 and 22. "Investigation of German plastics plants". Part III, Processing of P.V.C. 15 Sept.–23 Oct. 1945.

do., B.I.O.S. Final report No. 999., Item No. 22. "Manufacture and Fabrication of Polyvinyl Chloride", Bitterfeld area. London, March 1946.

do., B.I.O.S. Final report No. 1509, Item No. 22. "Polyvinyl Chloride Manufacture and Testing in Germany".

Combined Intelligence Objectives Sub-Committee, C.I.O.S. File XXXIII-23. Item Nos. 9 and 22. "Investigation of German Plastics Plants". Part II, 12–28, June 1945.

J. M. DeBell, W. C. Goggin and W. E. Gloor, *German Plastics Practice*, DeBell and Richardson, Springfield, Massachusetts: 1946, 554 pages.

Field Information Agency Technical, F.I.A.T. Final report No. 862, "Polyvinyl Chloride Production at Burghausen and Ludwigshafen", July 1946.

do., F.I.A.T. Final report No. 30 (PB 14, 506), "Polyvinyl Chloride Manufacture—Vinol HH at Alexander Wacker Ges. Burghausen", 7 Sept. 1945.

H. Gibello, *Résines vinyliques*, 2nd edition, Dunod, Paris, 1947, 315 pages.

H. Bähr, "Gas Purification by the I. G. Alkazid Process and Sulphur Recovery by the I. G. Claus Process", *Refiner Natural Gasoline M.*, *17*, 1938, pages 237–44.

G. Weber, "Sulfur from Sour Gas", *Oil Gas Jour.* No 45, March 8, 1947, pp. 58-9, 84, 87.

Study of the Present Position and Trend of Oil Chemistry[1]

LEON JACQUE

ABSTRACT

Although rapidly increasing, particularly in the last ten years, the consumption of petroleum as a chemical raw material remains small in proportion to its use as a source of power and does not threaten the conservation of resources. On the contrary, selective fractionations and reactions of the basic carbon structures of petroleum relieve industry of more expensive processes.

A few sectors of the field will be considered:

Increasing quantities of methane or liquid fractions are being converted into hydrogen and carbon monoxide. Twenty per cent of French natural gas will contribute to the nitrogen industry, and this is likely to increase.

In regard to light olefines—the principal object of petroleum chemistry—future development lies along selective preparation and more direct passage to commercial derivatives. The following are obtained:

From ethylene: ethanol, glycol, ethylene oxide and derivatives (solvents, plastics, insecticides...). By 1953 French consumption would apparently be 35,000 tons of ethylene, 15,000 tons of which would come from petroleum.

From propylene: acetone, acetic products, glycols, glycerine; estimated production: 35,000 tons of propylene:

From butylenes and butadiene: solvents, plastics and elastomers.

Ethylene, propane and propylene, by reducing the demand for acetylene, will promote the development of our industry. The higher olefines will give high-grade detergents (60,000 tons of active matter).

The programmes which have been started would consume scarcely 2 per cent of the petroleum treated in France and represent a saving of power.

In the past twenty-five years, and the last ten in particular, there has been an increased development in the use of petroleum fractions as chemical raw materials.

This development appears to hold no threat for the conservation of natural resources, as the resulting consumption is very small in proportion to the other uses of petroleum; it is in conformity with the criteria of abundance, facility and specificity which govern the improvement of man's standard of living and, as regards power and carbon consumption, corresponds in general to an economy which should be included in a coherent international programme for the utilization of carbon resources from both the vegetable and animal kingdoms and from fossilized organic matter.

After relating the position of petroleum to that of the other chemical raw materials, I shall consider a number of individual aspects and their relations with connected fields and, in regard

[1] Original text: French.

to the French aspects of these problems, I shall express my personal opinion formed in the course of collective studies undertaken in France and of contacts with our foreign colleagues.

GENERAL POSITION IN REGARD TO OIL, AS A CHEMICAL RAW MATERIAL

The world consumes annually, in amounts intentionally given in round figures:

(*a*) One thousand five hundred million tons of solid mineral fuels, containing in round figures 1,300 million tons of carbon and 80 million tons of hydrogen combined in complex and thermally fragile structures with large quantities of oxygen and, to a lesser extent, with sulphur and nitrogen. Being combined with mineral substances, these compounds can hardly, if at all, be "fractionated" into simple carbon elements.

(*b*) Nearly 500 million tons of liquid petroleum and 100 million tons of natural gases, together comprising 500 million tons of carbon combined with 80 million tons of hydrogen, a much higher proportion than in the preceding case. On the whole the components are simpler and, to a considerable extent, are easily fractionable either into pure compounds or into groups of compounds which are fairly homogeneous in dimensions and molecular structure. A few million tons of sulphur and a small quantity of oxygen sometimes provide complications.

(*c*) Animal or vegetable tissue or reserve matter, less easy to assess as regards over-all quantity, most of which serves as food for other living creatures but other categories of which, because of their ease of procurement or structural qualities, constitute sources of energy, carbon and hydrogen.

Carbon from fossilized fuel is mostly used today for the production of thermic, mechanical and electrical energy. A considerable proportion, perhaps one-tenth, is used as a reducing and thermic agent in various metallurgical processes.

The chemical industries also consume energizing carbon and reactive carbon; the latter constitutes only a small fraction of the former, a rational use of which will effect a greater saving than a reduction in the use of reactive carbon.

In regard to the latter much energy may be saved by a careful choice of the starting basis. There should be increased and more wide-spread study of individual analyses in order to evolve rules for economy.

Oil chemistry, as it happens, often presents greater possibilities in this regard than coal chemistry.

In the case of coal, non-oxidizing thermic treatment releases a small percentage of condensable by-products (benzols and tars) chiefly cyclic in structure, which, together with alcohol from fermentation, were the main object of organic synthesis at the beginning of the century. It also releases gases rich in hydrogen and methane, on which Continental Europe and France in particular have built up large synthetic ammonia plants and a small ethylene industry.

The reduction of water by coal or coke has also contributed to the manufacture of ammonia and has been the basis for the synthesis of alcohols and of the oxygenated, halogenated or "sulphonated" derivatives of synthetic waxes and olefines.

The electro-chemical reduction of lime by coke, which accumulates considerable quantities of surplus electrical energy, has founded the widely ramified acetylene family.

With the exception of the production of aromatics and gases, which is limited by the manufacture of coke or the direct use of gas, the other processes for the manufacture of basic products, gaseous or liquid hydrocarbon mixtures, often require a considerable supply of power.

The structural features of petroleum have special advantages in regard to chemical operations.

(1) "Oil chemistry" proper consists in the production from petroleum, by cracking, slight structural modification and synthesis, of organic compounds, pure or in simple mixture, or of the products of polymerization or condensation of hydrocarbons.

Although petroleum accounts for perhaps one-half of the world organic synthesis industry computable at less than 12 million tons, its corresponding consumption is little more than 1 per cent of the total production.

Many of the products manufactured by petroleum synthesis contribute to economies in the power and equipment used in other manufactures, improved use of thermal or electrical energy (insulators) or reductions in the deterioration or exhaustion of materials.

The utilization by chemistry of 1 per cent of the petroleum carbon, which can often be achieved rationally in large continuous units, results in a reduction in the world balance which is definite although hard to compute and which reasonable developments in this field will increase appreciably.

(2) The conversion of natural gas or the gasification of liquid fractions also serves to produce reducing gases — carbon monoxide and hydrogen, with an exceptionally favourable thermic balance; these gases may be used in metallurgy and in organic or mineral synthesis (ammonia); developments along these lines are taking place in the United States and in several industrial European countries.

SPECIAL FIELDS

While avoiding technological details and a long enumeration, we shall now indicate the particular features of a number of fields and their interconnexion with related sectors which may suggest subjects for more detailed study in preparation for the future.

Modern processes, which were often foreseen or begun by gifted chemists and engineers in the past hundred years or so, have more recently been able to develop rapidly owing to the improvement of the cracking and selection processes and to the development of selective catalytic reactions.

METHANE

The annual world supply of natural methane is more than 150,000 million cubic metres, most of it concentrated and often very pure, contrary to the very unequal refinery gases or coking gas (20 to 25 per cent). Although it contains 25 per cent by weight of hydrogen combined with 75 per cent of carbon by symmetrical combination forces relatively difficult to activate, methane is nevertheless one of the best starting points for the manufacture of hydrogen (3 to 4 volumes for 1 volume) and nitrogenous fertilizers or combinations of carbon monoxide and hydrogen and their derivates.

In France, where the first natural gas developments in the south-west do not yet produce 500 million cubic metres annually, the trend has been rather towards the profitable use of gas as a source of power within a reasonable radius of action, reducing coal and petroleum imports or the heavy sums required for the reconstruction of gas works.

Prospecting, however, holds out great hopes and suggests that the use already made in France of natural methane as a source of hydrogen (20 to 30 per cent) will soon increase, side by side with the production of hydrogen separated from coking gases by liquefaction, which will rise from 300 to 400 million cubic metres per annum.

The future will tell whether the reserves, production and cost of our new methane resources will permit the development of organic syntheses based on this gas, using mixtures of carbon monoxide and hydrogen, and standard or modernized (fluid catalyst) syntheses.

Great efforts should, I consider, be made to improve the specificity of carbon monoxide synthesis reactions so as to simplify later fractionations.

Another method consists in the direct oxidation of methane, particularly into formaldehyde, which seems to have been achieved by an American company; it would be interesting to learn its efficiency and the prospects before it.

On the other hand, in a country anxious to economize on power, serious attention should be given to the improvement of the manufacture of carbon black; this is foreshadowed by recent advances.

Lastly, plans may be made in France for the manufacture of acetylene by pyrolysis or incomplete combustion of methane if there is an abundant supply of the latter and particularly if the process is coupled with the manufacture of hydrogen. Halogenation is only mentioned incidentally.

SIMPLE SATURATED HYDROCARBONS: ETHANE, PROPANE, BUTANE, PENTANE

To a certain extent the arguments put forward in regard to methane continue to hold good, but in the case of simple saturated hydrocarbons the main stages of chemical evolution are as follows:

Dehydrogenation with or without rupture of the carbon chain;

Halogenation;

To a lesser extent, nitration.

Of these methods, the selective creation of unsaturated linkages will gain in importance, as it gives ethylene, propylene, butylenes and butadiene, the derivatives of which already represent the finest products of oil chemistry.

The tendency should be for halogenation to be used only where the chlorinated derivatives themselves are required and in all other cases the olefines should be the objective.

Lastly, there is the importance of simple saturated hydrocarbons, together with certain higher homologues, as solvents whose properties are the more specific the more they are purified.

The use of propane in oxy-acetylene cutting and welding will furthermore make acetylene available for other purposes.

LIGHT NON-SATURATED HYDROCARBONS

Ethylene

Long derived from alcohol produced by fermentation, ethylene is now itself becoming a starting basis which is lessening the direct chemical importance of alcohol.

We shall confine ourselves to a few brief observations:

Production and separation. Ethylene may be obtained from complex gaseous mixtures produced in cracking, by absorption, selective solution or fractional liquefaction.

Although still discussed, preference seems to be towards liquefaction, particularly to obtain pure ethylene for the manufacture of polythene. Some chemists recommend the production of ethylene from propane, which would reduce separation costs.

Transformation methods. The recently announced catalytic hydration of ethylene directly into alcohol constitutes a noteworthy advance in ethylene chemistry and this technique will undoubtedly be still further improved.

For my part I shall be glad if a development of French policy in regard to alcohol enables this method to be introduced into France, as it provides a source of industrial progress and can be made to restore sugars for the food supply.

For the moment the use of chlorine, difficult though it is, still appears to be the method preferred in the chemistry of glycols, ethylene oxide and derivatives. It is much to be desired that the new industrial process of oxidation directly into the oxide should find, in improved catalysis, the confirmation which at present is in doubt.

The manufacture of vinyl chloride using dichlorethane may be advantageously combined with the fixation of hydrochloric acid on acetylene. I recently estimated that a judicious combination of these two processes is capable of reducing the consumption of electric power required for this plastic material by at least 30 per cent.

Situation in France. The situation is somewhat peculiar: the synthetic ammonia industry, more than 50 per cent of which is based on the liquefaction of coke-oven gas, is capable of producing 10,000 to 15,000 tons per annum of a 30 per cent concentrate of ethylene in the next few years and 25,000 tons per annum thereafter. It seems desirable, in the first stage, to restrict our production of ethylene from petroleum to some 15,000 tons per annum.

The development of ethylene chemistry will reduce the consumption of acetylene, the potential demand for which exceeds our possible supply of calcium carbide and would handicap our synthetic textile and plastic industries.

Propylene

Propylene has the advantage over ethylene in being easily obtainable from petroleum gases.

The three principal modes of derivation, in order of importance, are as follows:

Isopropanol and acetone;

Chlorhydrine-oxide-glycols;

Halogen derivatives, glycerine, alkyl derivatives.

Propylene projects in France are focussed on the production of 20,000 to 25,000 tons of acetone; the total consumption of propylene would amount to 30,000 to 35,000 tons obtained by treating refinery gas or by a special naphtha cracking process.

This manufacture would also help to ease the position in regard to calcium carbide; it may even be hoped that, if propylene and acetone are produced at sufficiently low prices, acetic products will be manufactured, in part, by the acetone-ketone process.

Butylenes and butadiene

Butylene chemistry is primarily concerned with the manufacture of alcohols and ketones, the development of which as solvents and sources of plastics is of great importance. Methyl-ethyl-ketone may be used with particular advantage as a solvent or precipitant (dewaxing) and for various syntheses.

Moreover, butadiene and iso-butylene are the principal key-materials of various elastomers and the butane chain can be used for the synthesis of adipic acid and polyamides.

French industry has not yet taken a decision in regard to the production of synthetic elastomers on a commercial scale, but a reasonable output of butyl rubber would seem to deserve favourable consideration.

For the present, serious attention is being given to small-scale projects for the manufacture of chemical derivatives of the butylenes to a total of a few thousand tons.

HIGHER OLEFINES AND NAPHTHENIC ACIDS

The French chemical industry is studying the manufacture of detergents, wetting agents and insecticides by treating higher olefines or aryl olefines derived from selective extracts of refined gas-oil fractions, specially prepared, or imported. The now standard sulphating or sulphochlorinating methods are still in use. Including the naphthenates left over from refining, the present programme can be computed at some 60,000 tons of active products. This should release a larger quantity of soaps, leaving fats to be refined, if necessary, for use as food.

The use of these products as industrial or household detergents has the further advantage of not harming the structure of the fibres treated with them.

There is also the use of various olefine or aryl-olefine extracts of petroleum or shale oils as sources of plastics.

AROMATICS DERIVED FROM PETROLEUM

In 1914-1918 France was one of the first to use toluene extracted from Borneo petroleum for the manufacture of tolite, which it supplied to the French and allied armies.

Successful research also makes it possible to improve the octane number of fuels by catalytic aromatization. In view, however, of the future level of benzol and tar production in France (100,000 and 800,000 tons per annum respectively) it seems unlikely that, in the hoped for absence of war, France will in the future, develop a large-scale manufacture of pure aromatics from petroleum.

The situation in France appears to be different from that in other countries, including Great Britain, possibly because of coal carbonization methods.

It is not impossible, however, that the manufacture of ortho-xylene from octane will have to compensate for a slight shortage of naphthalene for the manufacture of phthalic anhydride.

CONCLUSIONS

This brief review of oil chemistry shows that the separation of the simple carbon structures of petroleum fractions makes the synthesis of an increasing number of organic or even mineral bodies extremely simple and profitable. The raw materials required represent scarcely 1 to 2 per cent of the world petroleum output.

In the case of France, 300,000 to 350,000 tons of petroleum products, or 2 per cent of our refining programme, will be sufficient to produce 150,000 to 200,000 tons of chemical products, while considerably relieving other sections of our industries and effecting a considerable saving in materials and power.

Synthetic Fuel Production[1]

W. C. SCHROEDER

ABSTRACT

The need for synthetic liquid fuels in the United States arises from increased use of gasoline and oil for a great variety of industrial and domestic purposes coupled with increased difficulty and cost in finding petroleum. Raw materials available in abundant quantities for synthetic fuels are coal and oil shale, which are sufficient to meet all foreseeable demands for hundreds of years.

During the past decade great progress has been made in developing plants and processes for the production of synthetic fuels. New mining methods make possible the production of as much as 80 tons of oil shale per man-day under ground. Three new retorts are under test that promise continuous low-cost methods of making oil from shale. In the Fischer-Tropsch process of converting coal to oil the required gasification methods now are available to produce synthesis gas in a single step from a wide variety of coals, either coking or non-coking. Fischer-Tropsch synthesis chambers now can be designed with capacities up to 1,000 barrels per day of either a good motor gasoline or a good diesel oil. For the hydrogenation process cheaper methods of generating hydrogen have been developed which, coupled with the conservation of heat throughout the process, are expected to yield an over-all heat efficiency of about 45 to 50 per cent.

This progress, plus the increased cost of discovering and producing petroleum, has narrowed the price differential between synthetic products and those from petroleum. When coupled with considerations of national defence, these factors provide strong impetus for the development of a synthetic fuel industry in the United States.

The dominant position of petroleum in the industrial economy of many nations has centred attention and effort on the provision of an adequate supply of this fuel. In virtually all cases, this has involved intensive exploration to discover oil not only within domestic borders but also in some foreign areas where the prospects were thought to be exceptionally good.

Since the start of this century when the automobile came into use, the consumption of petroleum has grown at an ever-increasing rate and world demand now is approaching 10 million barrels a day. In spite of the great magnitude of this demand, it still can be met for a number of years from known and prospective petroleum reserves providing that oil flows freely from the point of discovery to the point of need.

The major oil-producing areas of the world are limited and localized, whereas the need for petroleum is essentially world-wide. During the early days of the oil industry the United States supplied oil to a great proportion of the world. With discoveries now more difficult in the United States and a sharp increase in demand, exportation of oil products in large

[1] Work completed on manuscript 1 January 1949.

quantities no longer is possible. Instead, the United States is importing oil, particularly from the Caribbean area which is assuming increasing importance as a source of world oil supply. Fortunately, at this time of need, the apparently enormous reserves of oil in the Middle East are being developed to help meet world requirements, particularly those of Europe.

In the past, one of the strong factors inducing the development of synthetic liquid fuels has been this limited geographical area of oil supply. Industrialized nations that did not have an adequate petroleum reserve within or close to their borders tried to develop processes that could supply liquid fuels from the raw materials they possessed. The oil shale industries in England, France, Sweden, Estonia, South Africa, and other countries evolved from this desire to have an indigenous oil supply. In Germany the same factor led to the development of a large industry making oil from coal.

Until the beginning of the last war, it is doubtful that fuels were manufactured synthetically as cheaply as oil could be supplied in any country, assuming the absence of specific taxes on oil and the need of a sufficient supply to justify economic transportation such as by pipeline or tanker. Development of synthetic fuel processes since the war indicates that in some cases synthetic fuels are about ready to compete with petroleum and its products on a price basis.

SYNTHETIC FUELS IN THE UNITED STATES

The economic well-being, security and progress of the United States is linked directly to an adequate supply of oil. Here, there is roughly one automobile for every family. These, of course, are used for pleasure, but more often they take the family head to his daily work over distances that may exceed 10 or 20 miles. Public transportation cannot satisfy this need, particularly in areas of scattered suburban dwellings that are becoming increasingly popular. In addition, the family car makes it possible to reach shopping districts or other facilities that may be some distance from the home.

There has been a great increase in the use of oil for home heating. Obviously more convenient than a solid fuel, it eliminates the irksome task of hand-shovelling coal and ashes.

The American farm is being mechanized with power from oil. Gasoline and diesel-driven machinery have become indispensable aids to food production. In 1800 three out of four individuals in the working population were required to provide food. Now only one in seven is needed, and a single farm worker supplies food for himself and 13 other people. Much of this improvement is directly attributable to the use of machinery driven with oil and gasoline. The tractor, combine, cotton picker, and other large equipment are only a part of this story. Equally important are those much smaller machines that speed up and lighten the burden of the farm family's numerous daily chores. An oil-driven electric generator often provides light for the house and barn, power for the milking machines, cream separator, and water pump, and for all the labour-saving household equipment. In addition, the farmer can cut wood with a gasoline-driven saw or spray paint on his buildings with a gasoline-driven air compressor. While the oil-propelled revolution in farming during and since the last war has been extensive, it is far from complete, in fact, it is only beginning, and an increased fuel demand for such equipment is certain.

American railroads traditionally have used steam locomotives burning coal. Since 1940, however, there has been an increasingly rapid conversion to diesel engines, first for switching purposes in the yards and then for general use. Now 98 per cent of the new locomotives on order are of the diesel type, which indicates that before many years the entire land, air, and water transportation system of the United States will be based on oil.

Industrial applications of oil are growing as well. It serves for power generation, especially in the south-west and west; it fires metallurgical furnaces; it drives ships; it supplies a large chemical industry; and it lubricates the machines of all industries.

From these and countless other applications, it may readily be seen not only that the economy of the United States is dependent upon oil but that this dependence is growing broader and greater. This country, therefore, must have assured oil supplies not for just a few years in the immediate future but for an indefinite period.

In contrast with this increasing demand, it has become more and more difficult to discover new oil in the United States. This situation has led to the active interest in synthetic fuels.

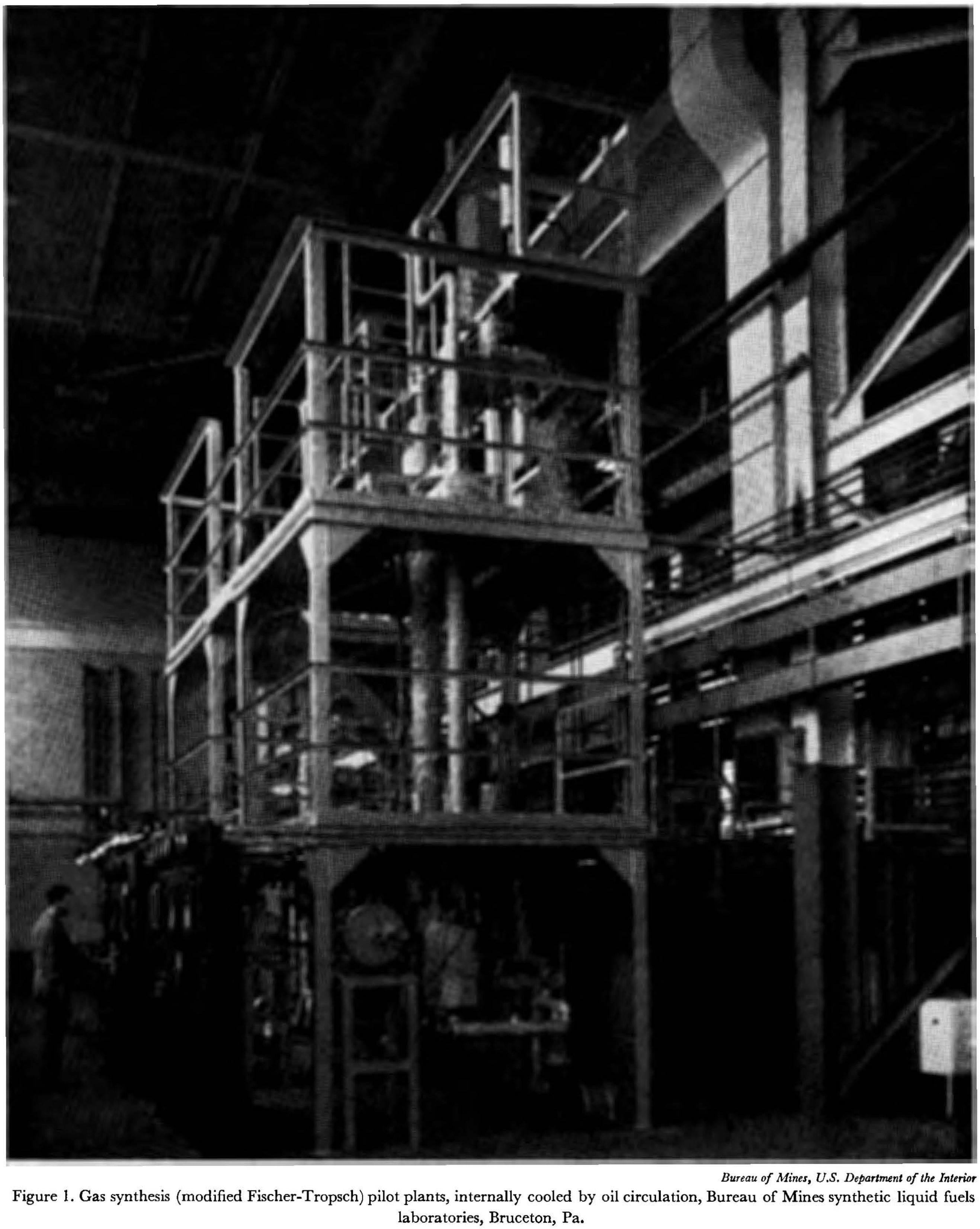
RAW MATERIALS FOR SYNTHETIC FUELS

The United States possesses three important raw materials from which oil can be made in quantity. There are natural gas, coal, and oil shale. It is interesting to compare briefly the potential oil available from these sources with the present known reserves of petroleum, which exceed 20,000 million barrels. Known reserves of natural gas are estimated at 170 trillion cub. ft., much of which is needed for pipelines serving industrial or domestic users. It now appears that some 25 or 35 trillion cub. ft. could be dedicated to oil production which would amount to 2½ or 3 billion barrels. This estimate can be altered greatly by future demands for gas on one hand and future discoveries on the other. At this time it does not appear that there is enough uncommitted natural gas to make a major addition to oil reserves.

Coal reserves in the United States are estimated at 3 trillion[2] tons, which is roughly half the known reserves of the world. However, this includes coal in seams down to 14 in. thick and at depths of 3,000 ft. The thin seams at great depths certainly would not be considered mineable for synthetic fuel purposes under present-day conditions. Nevertheless, the reserves are so great that supplies of mineable coal are sufficient to meet all needs, including the production of the total oil demand from coal, for many hundreds of years. A relatively detailed survey of only a part of one coal producing state recently revealed suitable sites (including water and other facilities) for 60 synthetic fuels plants. Over their life these plants would produce about 25 billion barrels of oil. A similar survey will be conducted in the remainder of this state and in other coal producing states.

Reserves of oil shale are large, but are not yet well explored and they range widely in oil content. The largest and richest are in Colorado, Utah, and Wyoming, and the recoverable oil is estimated to be in excess of 300 billion barrels, or about ten times the known petroleum reserves. Production of oil from this source will not be controlled by the magnitude of the reserves, but rather by the water avail-

[1] One billion equals 1,000 million; one trillion equals 1,000,000 million.



Bureau of Mines, U.S. Department of the Interior

Figure 1. Gas synthesis (modified Fischer-Tropsch) pilot plants, internally cooled by oil circulation, Bureau of Mines synthetic liquid fuels laboratories, Bruceton, Pa.

Table I. Summary of Requirements for a 2-Million-Barrel-a-Day Synthetic Liquid Fuels Industry Geared to Peacetime Fuel Demands but readily convertible to Military Products in Event of Emergency

							Products (Thousands of barrels per day)			Total products	Cost
Process	*Raw material (Thousands of tons or cubic feet per day)*	*Capital investment in millions of dollars*	*Capital investment in dollars per barrel per day*	*Steel (Thousands of tons)*	*Steel (Tons per barrel per day)*	*Operating force (Thousands)*	*Gasoline & petroleum gases*	*Distillate*	*Fuel Oil*	*Thousands of barrels per day*	*Cents per gal. of total products*
Oil Shale	1,500	2,600	3,100	3,000	3.5	60	116	215	519	850	5.5
Fischer-Tropsch											
Natural Gas	1,600,000	800	5,300	700	4.7	7.5	133	17	—	150	7.2
Coal	350	4,300	8,600	3,300	6.6	60	441	59	—	500	12.1
Coal Hydrogenation	250	4,500	9,000	3,200	6.4	68	293	207	—	500	12.6
Total		12,200		10,200		195				2,000	

Figure 2. Large-scale equipment used underground keeps mining costs low at the experimental oil-shale mine operated by the Bureau of Mines near Rifle, Colo. Here an electric shovel with a 3-cubic-yard dipper loads a 15-ton diesel truck while holes for the next round of shots are sunk by multiple drills mounted on the truck at left.

able in the area for plant and community use. Information now available does not allow a prediction of the number of plants that might be operated to make oil from shale.

SYNTHETIC FUEL PROCESSES

Oil can be produced from natural gas, coal, and oil shale by one or more of three known processes — Fischer-Tropsch, coal hydrogenation, or retorting. Each has been investigated abroad and in the United States, and great progress has been made, particularly since the end of the war.

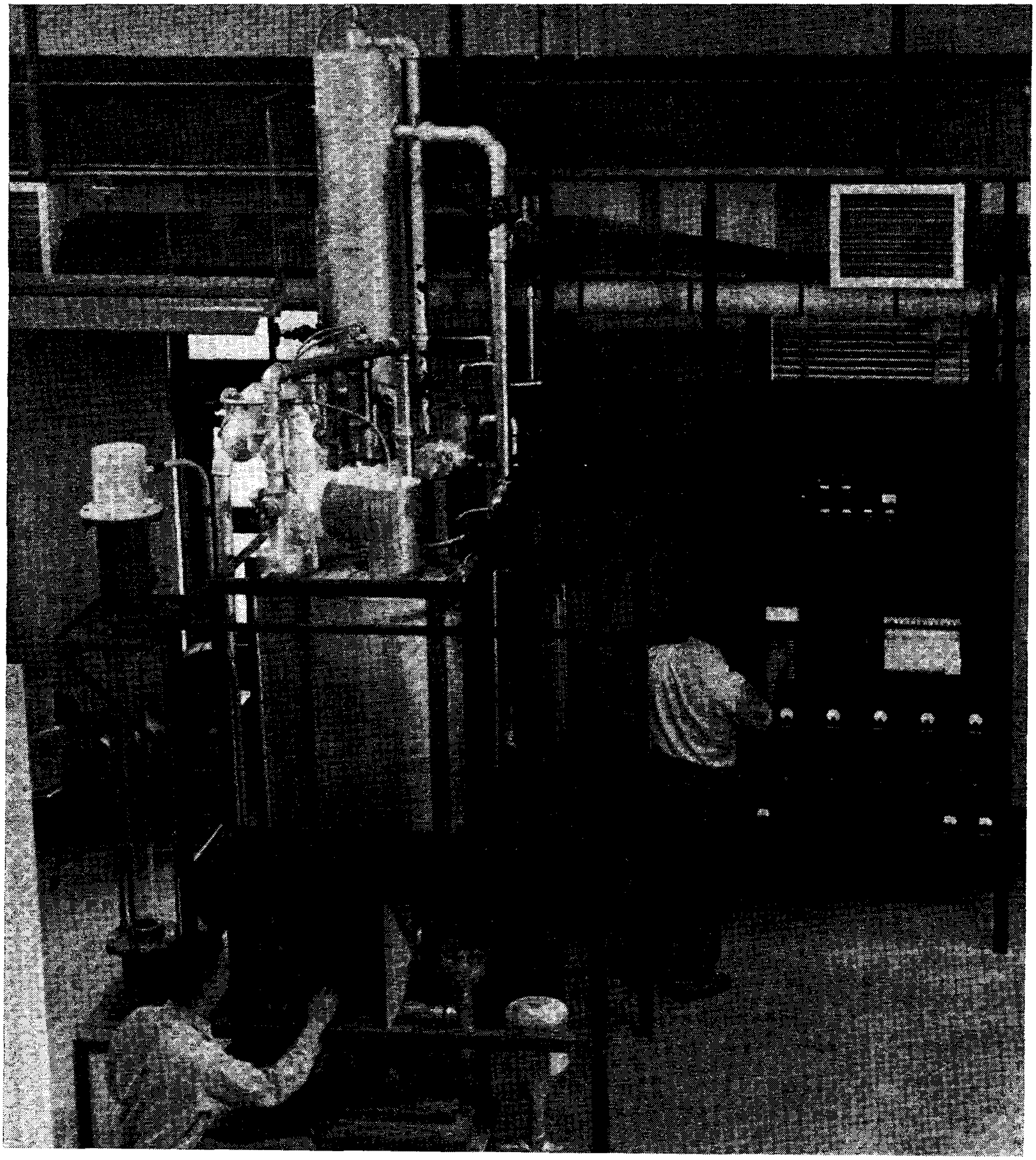
Fischer-Tropsch process.

In general the Fischer-Tropsch process as practised commercially has involved: (1) coking bituminous coal, (2) production of water gas from the coke, including purification and adjustment of proportions for use as synthesis gas, (3) catalytic combination of the components of the synthesis gas to make hydrocarbons, and (4) separation of the products.

For the production of large amounts of liquid products this process had several serious faults. It required coking coals which are available only in limited areas and which often are costly to mine. Coke ovens and water gas machines are expensive to install and operate. The Fischer-Tropsch catalytic conversion chambers were small, usually producing only about 15 to 20 barrels of oil a day. A plant making 10,000 barrels of oil a day would need 500 or more converters. Servicing this large number of converters is not practical under American conditions. And finally, the yield of motor gasoline was relatively poor (25 per cent) and its octane number was low.

Many of these faults are now on the way to correction. Where natural gas is cheap it can be burned with oxygen and steam[3] to supply a low-cost synthesis gas. Carthage Hydrocol, Incorporated, is building a plant of about 7,000 barrels a day capacity that will use natural gas in this manner at Brownsville, Texas. The oxygen will be obtained from air by liquefi-

[3] Natural gas also can be cracked catalytically with steam to furnish synthesis gas.



Bureau of Mines, U.S. Department of the Interior

Figure 3. Heat of retorting apparatus, Petroleum and Oil-Shale Experiment Station of the Bureau of Mines at Laramie, Wyo.

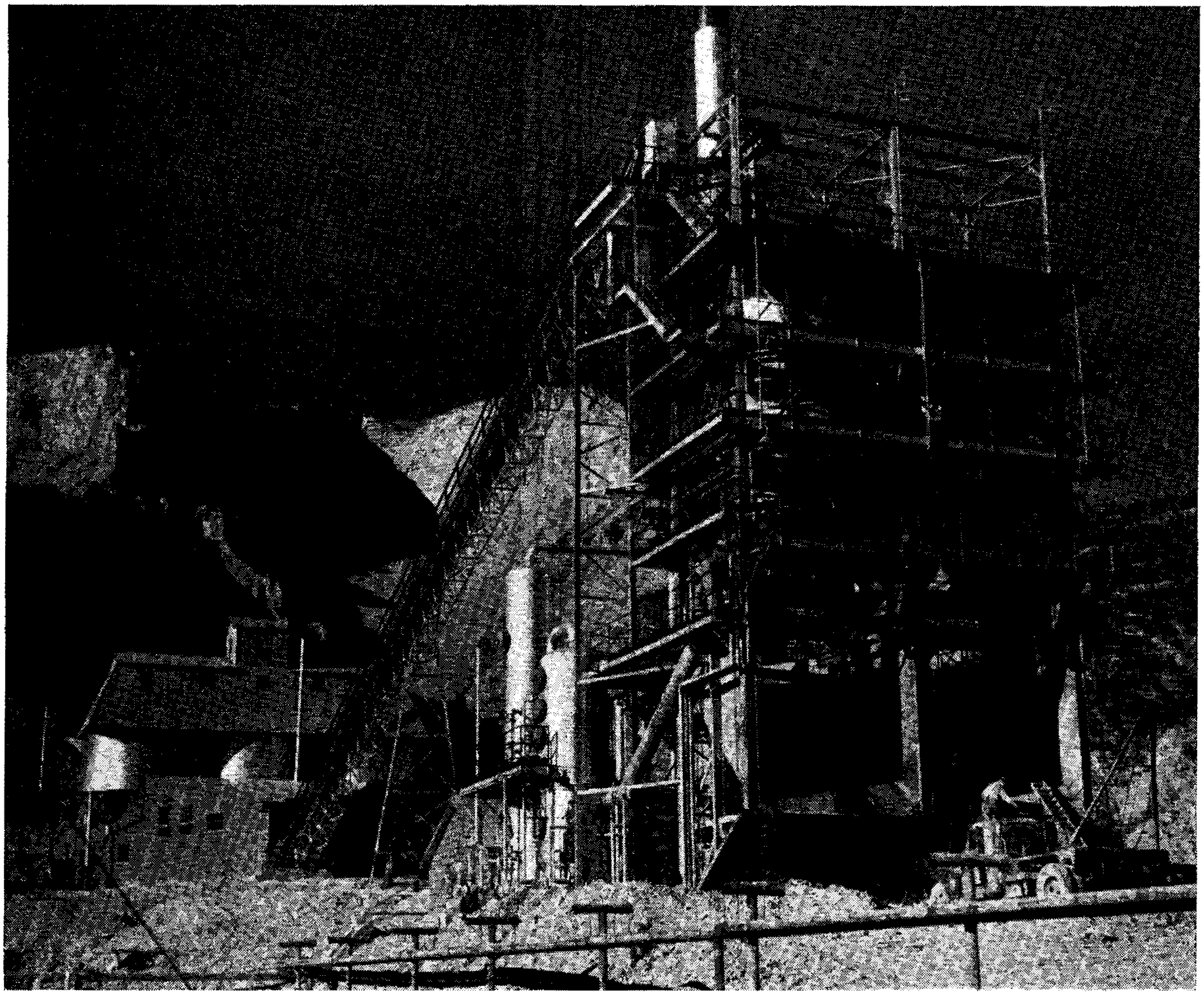


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Figure 4. A conveyor links the N-T-U retorts (foreground) and the shale-storage bins (background) at the Oil Shale Demonstration Plant of the Bureau of Mines near Rifle, Colo. Sheer cliffs of oil shale in the far background form a part of the Naval oil shale reserves.

cation processes. Coal also can be burned directly with oxygen and steam to provide synthesis gas. The Bureau of Mines now is testing three separate experimental units designed to do this. Rated capacity varies from about 200 to 2,000 lb. of coal an hour. Test results indicate that almost any coal can be used with the possible exception of strongly coking coal. Reaction rates are high with large throughput for relatively small units of equipment. The steam used in the reaction is superheated as much as possible to decrease oxygen consumption. In continuous pebble heaters, steam can be heated to about 2,600 degrees to 2,800 degrees F. (1,430 degrees to 1,540 degrees C.). In intermittent heaters it is believed that temperatures up to 3,800 degrees F. (2,090 degrees C.) can be reached.

Three types of Fischer-Tropsch synthesis chambers have been developed with capacities of more than 500 barrels of primary product a day. The first of these uses a fluidized catalyst, and heat is removed by tubes carrying cooling water through the reaction space. Development work on this unit was carried out by several oil companies, and it is being installed in the Carthage Hydrocol plant in Texas.

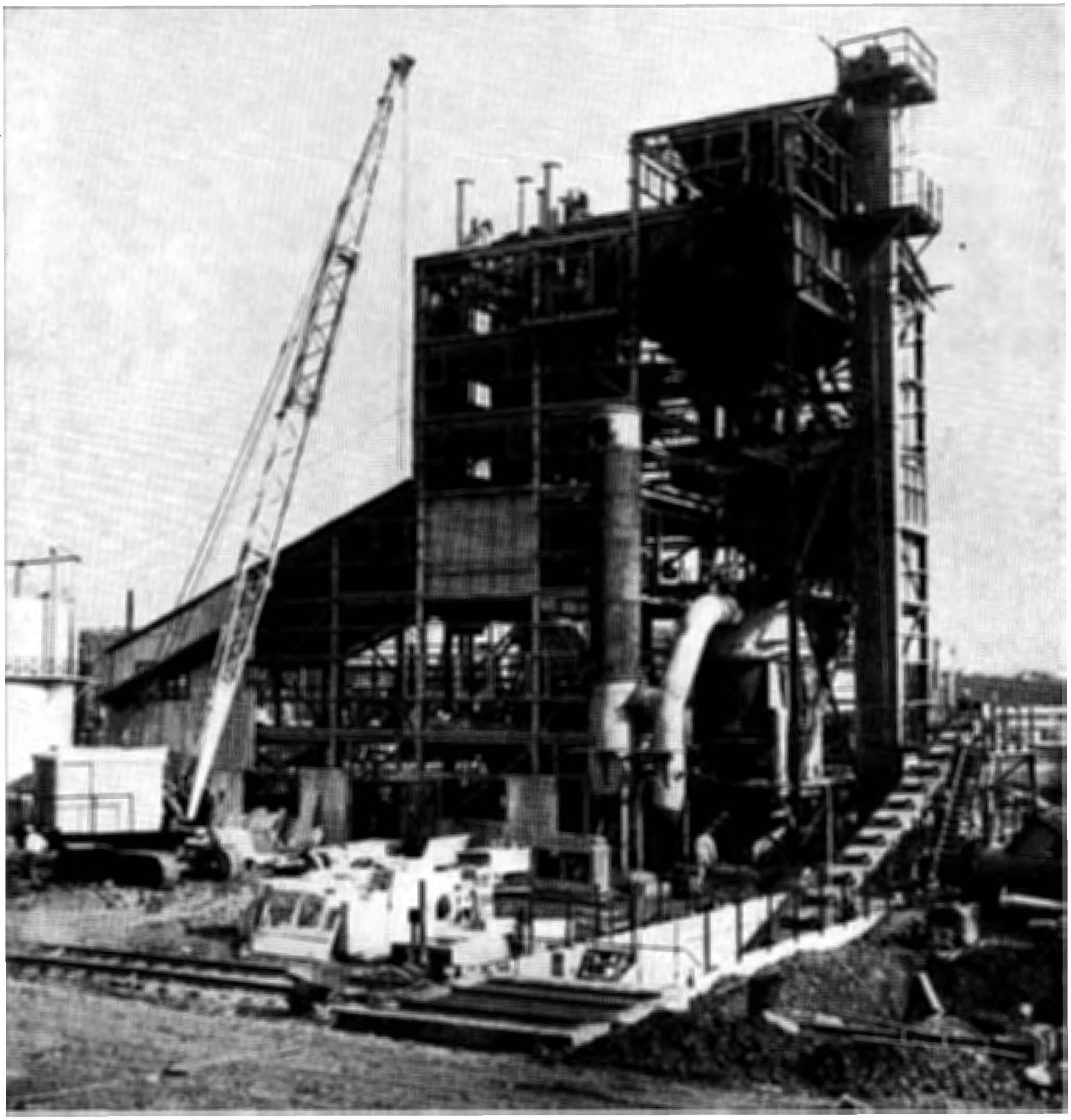
The Bureau of Mines has developed one converter using a fixed bed catalyst, either pelleted or granulated. This catalyst is immersed in oil (a fraction of the product) to control the temperature. Synthesis gas is bubbled through the oil, and heat is removed by external heat exchangers. This unit has high capacity and can be used with either cobalt or iron catalysts.

A second converter unit is under development in which finely powdered catalyst is suspended in an oil bath, forming a slurry, through which the gas is blown. This unit offers excellent temperature control with high throughput. Heat is removed by circulating the slurry through an external heat exchanger, or by extending bayonets carrying cooling water into the reaction space.

The improvements in gasification and synthesis will have considerable effect in reducing both investment and operating costs in the Fischer-Tropsch synthesis.

Hydrogenation process.

A study of the thermal efficiency (ratio of heat in the in-



Bureau of Mines, U.S. Department of the Interior

Figure 5. Coal gasification unit under construction for the Bureau of Mines at Louisiana, Mo. This will be a part of the Gas Synthesis (Fischer-Tropsch) Demonstration Plant.

coming coal for all purposes to heat in the outgoing products) of some of the European hydrogenation plants indicates an over-all efficiency of about 30 per cent. If a major improvement in this figure can be obtained it would lower both plant investment and plant operating costs.

The hydrogenation operations are essentially as follows:

1. Coal preparation and paste making;
2. Hydrogen production and compression;
3. Liquid phase conversion;
4. Vapour phase conversion;
5. Separation of the products.

Step 2, hydrogen production and compression, accounts for about 50 per cent of the operating cost and at the same time offers material opportunities for increased plant efficiencies. The major proportion of the required hydrogen can be made by cracking the non-liquefiable hydrocarbon gases produced in the process and making up any further needs by the direct gasification of coal with oxygen. This avoids the wasteful burning of hydrocarbon gases and eliminates installation of large coke oven and water gas machines.

Substantial improvements can be made in the liquid and vapour phase conversions by more effective use of the exo-

Figure 6. Rear side of converter stalls, Bureau of Mines Coal Hydrogenation Demonstration Plant at Louisiana, Mo. Buildings, left to right, are the high-pressure pump house, instrument house, and heavy-oil pump house.

thermic heat of the hydrogenation reactions; full heat exchange between the outgoing hot gaseous and liquid products and the incoming cold paste; and finally by letting down the very high pressures through power recovery units.

By taking full advantage of all available methods of saving heat it is estimated that a thermal efficiency of nearly 55 per cent can be obtained, compared with an actual efficiency of about 30 per cent in Germany. In practical application an efficiency of 45 to 50 per cent is probably the best that can be expected at present.

The Bureau of Mines now is operating a hydrogenation demonstration plant in the State of Missouri to test means for attaining the improvements that have been outlined. This plant will produce about 200 barrels of oil or gasoline a day and has been in operation since the early part of 1949. Significant results will be available about the end of this year.

The approach which has been described for improvement of the hydrogenation processes is largely an engineering attempt to carry out a certain chemical process more efficiently. It is equally necessary to consider major process modifications.

One of the more promising of these on which the Bureau of Mines has done a great deal of development work is the dry hydrogenation of coal. Hydrogen and dry coal are fed directly to a converter where they react to produce gaseous, liquid, and solid hydrocarbons. This eliminates paste making, paste pumping and preheating and, under some conditions, greatly decreases the amount of hydrogen needed. This process, however, is in only a laboratory stage.

Shale oil.

Producing oil from shale involves the following major steps:

1. Mining;
2. Retorting;
3. Refining.

Situated in Colorado, most of the richest shale beds are about 500 ft. under ground, and strip mining is possible only in very limited areas. In general, the shale outcrops and drift mining is practical. Mining can be carried out in a 70-ft. section that will average 30 gallons of oil per ton. Under present conditions oil from shale might be worth \$2.90 a barrel. As 1½ tons of shale are required to produce a barrel of oil, it is apparent that mining costs must be low to make the use of oil shale at all attractive.

At the Oil Shale Demonstration Plant operated by the Bureau of Mines near Rifle, Colorado, mining methods and equipment have been developed to assure low-cost production. A room and pillar system of mining is used, and no roof support is needed in rooms as wide as 60 ft. The 70-ft. section is mined in three benches of about equal height. In the first bench, horizontal drilling is required to open the rooms, but the next two benches then can be drilled vertically. A multiple drill has been developed which drills four horizontal holes simultaneously. Average drilling rate is about 90 ft. of 2-in. hole per man hour. Special research finally has culminated in a hard-surfaced bit that will drill from 1,000 to 2,000 ft. of shale before it is dull. Holes now are drilled to a depth of 10 ft., but this depth may be increased to 15 ft. Approximately one ton of shale is obtained for each foot of drilling. Powder consumption is less than ½ lb. per ton of shale.

Large diesel trucks are driven directly into the mine and loaded with shale by an electric shovel having a 3-yard dipper. This shovel, operated by a single man, can load as high as 300 tons of shale an hour.

Operation of the demonstration mine has shown that production rates as high as 80 tons per man-day (underground workers) can be achieved. Total cost for mining shale is estimated at 60 cents per ton.

Under American conditions, with high labour costs and the need for very large commercial plants, it is probable that the only successful retorting methods will be those that are continuous and have high throughput. Although hundreds of methods have been suggested and used for retorting shale, three now under test appear to offer the greatest promise for meeting these conditions. These are the gas flow retort of the Bureau of Mines, the fluid flow retort of Standard Oil Development Company, and an internally-fired underfeed retort developed by the Union Oil Company of California.

In the gas flow retort shale passes downward and hot gases flow across the retort. Operation is continuous and the throughput is high. Heat for operation is obtained by burning waste gas and spent shale in a space separated from the retorting area. This unit is being tested by the Bureau at Rifle, Colorado.

The fluid flow unit consists of two vessels, one for retorting the shale and the other for burning the spent shale. Hot spent shale is blown from the combustion zone to the retorting zone to provide heat to drive the oil from the raw shale. This process now is being tested on a pilot plant scale by the Standard Oil Development Company at Baton Rouge, Louisiana. The Bureau of Mines is supplying the shale and co-operating in conducting these tests.

The retort developed by the Union Oil Company forces a column of shale upward through a vertical cylinder by means of a piston arrangement at the bottom. Spent shale is burned in the upper part of the retort, and the hot gases flow downward to remove the oil from the raw shale. The retort is high enough to use the incoming shale to condense the oil from the outgoing vapours. In addition to high throughput and continuous operation, this retort also offers the advantage of relatively low water consumption. This is important in the arid regions in which the best American shales are located.

From the test programme on these three types of retorts, it is believed that one or more will be found suitable for economical retorting of American shales.

Crude oil from American shale runs from about 18 to 25 A.P.I. gravity depending on the method of retorting and recovery of light ends. Its character is different from petroleum and many foreign shale oils. It is generally waxy and contains a considerable amount of nitrogen compounds which occur rarely in petroleum. Sulphur content is about 1 per cent and nitrogen about 2 per cent. On distillation it yields about 5 to 10 per cent of gasoline, 15 to 20 per cent heating oil, about 25 per cent gas oil, and the remainder residual oil. The gasoline yield can be increased by cracking, but it still has a low octane value and there is a considerable loss of oil through coke formation. Extensive research now is in progress both in industrial laboratories and in the Bureau of Mines to develop improved methods for refining shale oil.

PLANTS FOR THE PRODUCTION OF SYNTHETIC FUELS

Plants for the production of synthetic fuels from coal would cost more now than equivalent capacity in oil wells and refineries. This differential is rapidly narrowing, however, as further improvements are made in synthetic fuel processes and as the costs of finding and developing new petroleum advance. On the other hand, shale oil plants are less expensive.

A recent estimate from industry shows that the capital investment required for each barrel-day of new petroleum capacity is about $5,000 to $6,000, including expenditures for exploration, field development, transportation and refining.

Comparable estimates for synthetics, based on a detailed analysis by the Bureau of Mines in the early part of 1948, are $3,100 per barrel-day for shale oil, $5,300 for synthetic oil from natural gas, $8,600 for synthetic oil from coal using the gas synthesis or modified Fischer-Tropsch process, and $9,000 for synthetic oil produced by direct coal hydrogenation. These estimates include the investment required for coal and shale mining.

Moreover, the steel requirements for synthetic fuels plants, long thought to be excessive, under some conditions may actually be less than those for an equivalent new capacity of petroleum.

Including drilling operations, pipelines to refineries, and the refineries themselves, 6 tons of steel now are required for each barrel day of new petroleum capacity. On the other hand, steel requirements for oil shale plants would average 3.5 tons, for synthetics plants using natural gas 4.7 tons, for gas synthesis plants using coal 6.6 tons, and for coal hydrogenation plants 6.4 tons per barrel day of new capacity. Once synthetic fuels plants were built, no additional steel would be required other than for maintenance and normal equipment replacement for some 20 to 25 years, the life of the plant.

Table I presents the material and man-power requirements and the salient cost figures for a hypothetical industry adequate to produce 2 million barrels a day of synthetic fuel products. For convenience, it also shows the amount of products from each source material and the average cost per gallon of total synthetic liquid fuel product. The capital investment required under conditions existing during the first half of 1948 was about 12 billion dollars, the steel requirements 10 million tons, and the total operating force nearly 200,000 men. The estimated average cost of the full range of products, which includes fuel oil and gasoline, is 9 cents per gallon. This figure includes all costs except interest on investment and profit.

CONCLUSIONS

I have tried to indicate briefly the work that is going on and the progress that has been made in the United States in the development of synthetic liquid fuels. The effort by both government and industry is of considerable magnitude, but the problem of meeting increased oil requirements to ensure economic and military security is being thrust upon the country at a much faster rate than was anticipated in 1944 and 1945 when the present programmes were planned.

Fortunately, owing largely to process improvements, the cost factors upon which any large-scale synthetic fuel production will depend are becoming increasingly favourable in the United States. However, the improved relative cost position of the synthetic products also is attributable in part to sharply increasing costs of finding new petroleum. If this trend continues, it is probable that a large synthetic fuel industry based on coal and oil shale will develop in the United States. Known reserves of these raw materials are so large that they can meet all our needs for centuries, a comforting and reassuring fact. But it is well to remember that we still have far to go, not only in research and development but in plant construction as well, before liquid products are available in quantity from coal and oil shale to fuel the engines of America.

Synthetic Fuel Production

S. LANDA

ABSTRACT

The manufacture of synthetic fuels is indispensable for countries which possess no crude oil reserves, but also for those which up to now are thus supplied. The price differential hitherto obtaining between the products from crude oil and those from coal is gradually disappearing. It is essential above all to reduce investment outlay by simplifying installations. Automatic working, improvement of thermal efficiency and the exploitation of all by-products accruing in the processing by combining certain species of production: these are further steps towards lowering the price of synthetic fuels.

The consumption of fuel oils after the Second World War has not only not declined but on the contrary has increased. This increase was to be expected in countries where motorization was less developed, but it was surprising in the case of the United States. The rise in consumption of fuels is in excess of the new sources that have been discovered, or of the improvements made in processing crude oil whether by direct distillation, by cracking and in particular by alkylation through the use of the gases produced in cracking, or by polymerization. In these modern methods we even make use of gases which formerly served only for heating purposes, and in a very advantageous manner, too, for we convert them into gasoline of high octane number, the consumption of which per kilowatt is substantially smaller. In spite of these developments even the largest producers of crude oil are compelled to give the most serious consideration to the question of natural gas and bituminous shale.

Theoretically every material containing carbon may be a source for the production of synthetic fuel. In practice, however, we have only a few kinds of raw material, notably coal, natural gas and bituminous shale.

Very few countries are in the happy situation of having at their disposal adequate quantities of methane gas for the production of synthetic fuels, a relatively simple matter in the case of methane which, because of its low cost, permits the production of synthetic fuels that can compete with those produced from crude oil. Among such countries is the United States, where the methane gas resources are estimated at 45,000 million cub. metres, while the consumption is 140 million cub. metres *per annum*. For the United States methane gas represents about the same supply of fuel as the ascertained crude oil resources in that country.

Methane gas, too, represents a raw material from which synthetic fuel may be very easily produced, while bituminous shale is a material from which synthetic fuels are produced with the greatest difficulty, not only because of the relatively small content of combustible matter but also because of the disproportionately high costs of bringing the shale to the surface and its usually high content of sulphur and nitrogen. By carbonization at low temperature, bituminous shale is processed in Scotland, Esthonia, France and Sweden where it ranks among the shales that are richest in oils. The shales with less oil content will probably have to be directly distilled underground, as is being done already by way of experiment in Sweden with the aid of electric current or by gasification underground, or by combined carbonization and gasification, in order to economize on mining costs. It is probable that in many cases the method of distillation with simultaneous cracking of the heavier oils can be employed, a method in which the technique of a fluid catalyser is used and a mineral constituent of shale acts as catalyser. There is no doubt that the world resources of bituminous shale are enormous. In the United States alone the oil resources contained in bituminous shale are estimated at not less than four times the crude oil resources. Nevertheless, the exploitation of these resources is probably reserved for a later date.

For the majority of countries it is coal that is given chief consideration as the raw material for the production of synthetic fuels. Coal offers a basis on which long-term planning is possible, for the proved and probable reserves of coal and lignite throughout the world total 7.4 million million tons, of which coal reserves are estimated at 4,579,975 million tons and lignite reserves[1] at 2,881,870 million tons. The consumption of coal is small in comparison with the reserves and is rising only slowly. In the year 1927 consumption amounted to 1,481 million tons, and in the year 1937 was no more than 1,549 million tons.

If we calculate on the basis of an average consumption of 5 kg. of coal per 1 kg. of fuel and a total consumption of crude oil in 1947 of 409.6 million tons, the proved reserves of coal would last for at least 200 years, and the proved and probable reserves for 2,100 years.

To-day there are in fact two general methods of obtaining synthetic fuels. These are by hydrogenation, and by complete

[1] Including brown coal.

synthesis of carbon monoxide and hydrogen, and even the second method consists essentially of the hydrogenation of carbon monoxide. Both brown and black coal, as well as pitch and tar, naphtha and heavy oils, can be hydrogenated, gasoline of at least 80 per cent yield being produced from naphtha and heavy oils. Anthracite is not a particularly good material for hydrogenation. For the synthesis, any kind of fuel may be gasified. It is only natural that the less valuable fuels are the first choice.

The synthetic fuels contain, per 1 kg. of carbon content, 0.166 kg. of hydrogen, that is, about 1.86 cub. metres, whereas coal contains only some 0.05 to 0.1 kg. of hydrogen. In hydrogenation, therefore, hydrogen must be added in elementary form, not only in the case of the CH_2 group but also in the case of coal, tar and pitch in order to eliminate oxygen, nitrogen, sulphur or arsenic compounds. The actual consumption of hydrogen is about 0.236 kg. per kg. of coal. Coal contains from 8 to 28 per cent of oxygen in pure combustible form in addition to ash and water which cannot be separated mechanically as in the case of naphtha, but must be condensed. It is also necessary to break up complicated molecules. For all these operations considerable power is essential.

Therefore, although only about 1.6 kg. of coal is necessary for the actual conversion of coal into gasoline, some 4.1 kg. of coal are required for the production of hydrogen and for the necessary power therefore, or in all some 5.7 kg. There is no doubt that this consumption can in the future be reduced substantially, but it is already clear from this calculation that synthetic fuels cannot be so cheap as fuel produced from crude oil where hydrocarbon-forming fuels are already in existence or converted.

At the end of the Second World War there were in Germany and in the territories occupied by the Germans twelve plants turning out gasoline by the hydrogenation of coal or tars, with an annual capacity of 4 million tons, and nine factories for synthesis on the Fischer-Tropsch system with an annual capacity of 740,000 tons. Although we have to-day plenty of data from the majority of the plants set up by the Germans, it is still not easy to decide whether to erect hydrogenation or synthesis plants. That the synthesis factories using the Fischer-Tropsch system turned out only a fraction of the fuels that could have been produced, and that the gasoline produced was of poor quality, of octane number about 45, cannot have any great influence upon a decision, for we know to-day that it is possible to produce, with an installation differing but little from that referred to, predominantly gasoline and very good gasoline, too, of octane number about 80. In view of this consideration, we may fairly easily compare production costs on the basis of the figures available to us.

We see that installations turning out synthetic fuels are too complicated and therefore costly. Where the raw material is cheap, as in the case of natural gas, the capital outlay represents half of all costs. The investment outlay per ton of annual output in the case of older plants for atmospheric synthesis under the Fischer-Tropsch system, amounted to RM. 800, or $320 and for mean pressure to $360. In the case of the latest installation, that of the *Hoesch Benzin Gesellschaft*, the figure dropped to $260 and in the case of the *Essener Steinkohle* concern even to $160. Under the Hydrocol system for production from coal the investment outlay per ton of annual output is to amount to $150.

The amount of investment outlay for the production of synthetic fuel by the hydrogenation of black coal (capacity 200,000 tons) is given as RM. 728 per ton, that is, $291, including the outlay for a hydrogen department. For the production of the same quantity of synthetic fuel per annum from black coal tar, the amount of investment is stated to be RM. 780 or $312 per annual ton. This figure would seem to be somewhat low, since in other plants where double the amount of brown coal tar is processed, including carbonization, the investment outlay works out at RM. 1125, that is $450 per annual ton.

Comparison of Production Costs in Per Cent of Production Price

Process	Distillation of naphtha	Hydrocol	Fischer-Tropsch		Hydrogenation		Hydrogenation of black coal tar
			Atmos here	Mean pressure	Black coa	Brown coal	
Size of installation in thousands of tons per annum	160	300	80	50	200	580	200
Price of products–benzine in RM per ton			237.10	258.10	234.70	190.00	205.65
Price of products in dollars per ton	17.42	18.29					
Capital involved in per cent of production cost	5	50	31	32	37	12	27.4
Cost of raw material in per cent of production cost	80	20	34	31	40[1]	38[2]	48[3]
Outlay on wages in per cent of production cost	2	—	4.6	4.6	7.3	9.3	5.6
	Per cent		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Catalyzer and chemicals	5.3	—	10.2	11.9	2.1	3.3	3.5
Other outlay	2.7	—	12.6	13.8	8.6	—	10.8
General overhead costs	5	—	7.5	7.6	5.0	8.8	4.7

[1] Price of 1 ton of black coal, RM. 21.50. [2] Price of 1 ton of brown coal, RM. 3.00. [3] Price of 1 ton of tar, RM. 40.00.

Labour costs, too, are fairly high and vary considerably. While in the case of the distillation of crude oil less than one working hour is needed for the production of a ton of gasoline, in the case of Fischer-Tropsch synthesis 5.2 working hours are required per ton of products in a plant with a capacity of 150,000 tons per annum, not including the labour required for the preparation of the synthetic gas. To the 325 persons occupied only with the syntheses there must be added another 400 who are required at present for the preparation of the gas; thus there is a further increase of 4.8 hours, bringing the total up to 10.9 hours. The production of synthetic fuel by hydrogenation requires 11 hours in the case of a plant producing 200,000 tons per annum from black coal. A plant with an annual capacity of 580,000 tons of gasoline produced from brown coal requires only 6.1 working hours per ton of gasoline produced, to which in both cases there must be added approximately 5 working hours for the production of hydrogen.

There are relatively few precise data available as to the thermal efficiency of individual plants engaged in the production of synthetic fuels. Comparison of the figures for hydrogenation and for Fischer-Tropsch synthesis shows that the thermal efficiency is approximately the same and moves between 50 and 60 per cent.

What are the possibilities for the future, and what is the probability of a reduction in the price of synthetic fuels?

In view of the declining stocks of crude oil it is improbable that it will fall in price, and this is the major item in the cost of producing gasoline from crude oil. Meanwhile prices tend to rise, as is only natural when the search for crude oil has to explore greater depths, and the labour and the outlay connected therewith must be greater.

Nor would it seem that there will be any discovery that could cause an abandonment of the paths hitherto pursued. No other course remains, therefore, but to improve the present known methods with respect both to favourable reactions in the preparation of gas and synthesis, and to the efficiency of the equipment, its suitability and durability. It is manifest that little has so far been accomplished with respect to the technical thermal aspect.

From an analysis of production costs we see that, apart from raw materials, the heaviest burden is the high cost of the plant. A large share in the high investment outlay is represented by the preparation of synthesization gas and hydrogen. The investment outlay on a ton of hydrogen per annum amounted to RM. 850 to 900, that is $340 to $360. It is probable that the underground gasification of coal which, it is true, does not yet show any great success, may bring a substantial reduction both in the investment item as well as in the cost of raw material. The price of coal is mainly a matter of wages and timber, and the outlay on these could be reduced to a minimum in the case of underground gasification. The attempts already made in the Soviet Union for a number of years, and those quite recently commenced with underground gasification in Belgium and in the United States under the ægis of the Bureau of Mines and in co-operation with the Alabama Power Company, indicate that this path will lead to the desired goal, not generally, perhaps, but in cases of thin beds with impermeable upper strata. It is probable that we still have long to wait for the carrying out of underground gasification suitable for the synthesis of fuels.

For the very near future we have, however, several possibilities of reducing the production cost of gasification by pressure for the production of synthetic gas. Such gasification has been employed for the production of gas for lighting purposes in Lurgi generators, and considerable economies have been achieved in handling gas under high pressure for long-distance distribution. For synthesis, which in the future will be carried out solely under pressure, this fact has no small significance when we remember that for 1 kg. of products we need 6.3 cub. metres of pure synthetic gas, or about 9 cub. metres of crude gas, and that for 1 cub. metre of gas we require about 0.2 cub. metres of oxygen. It is necessary here to point out that pressure generators in their present form are unsuitable for gasifying coal with a moisture content over 25 per cent. Although brown-coal coke is highly reactive, it is, even so, unsuitable for pressure gasification. Nor is it possible to gasify all bituminous coal in the existing generators, which will have to be adjusted, at least with regard to their proportions.

Gasifying by oxygen has great advantages, but up to now generators which run intermittently and without the use of oxygen give a cheaper synthetic gas, even though the gas is produced from expensive foundry coke. Gasifying with oxygen permits the use of the less valuable fuels which are in ample supply, as they lie at little depth below the surface and the costs of raising them are low. The cost of oxygen represents the greater part of the outlay on current. The efficiency of the compressors hitherto employed is not entirely satisfactory, and much work still needs to be done by engineers in this connexion. The main consumption of current occurs in compressing a volume of nitrogen 3.78 times larger than is the volume of oxygen. Ten per cent of air is compressed to nearly 200 atm., and 90 per cent to 4.6 atm. Four-fifths of the total volume, after cooling to —196 degrees, has been, or still is, discharged into the air in the majority of factories turning out synthetic fuels. For the future it is necessary that the synthetic fuel factories be combined with the production of ammonia and fertilizers, in which case a portion of the outlay on oyxgen would be transferred to nitrogen.

In the transferring of a portion of the costs to other types of production, especially the cast-iron turned out in blast-furnaces by aid of oxygen, the synthetic fuel concerns have great possibilities. Synthesis under the Fischer-Tropsch system provides an ample basis for products of an aliphatic nature, and hydrogenation for cyclic products. It may to-day be stated with certainty that the majority of organic chemicals will be manufactured on these bases. In the case of the synthetic fuel factories it will be necessary to set up chemical sections for the exploitation of all the by-products accruing from production, including all slag or ash.

It will be possible in the future to effect great economies in operation. In this respect the German technique lagged far behind the mechanization achieved in the United States. None of the installations for the production of synthetic fuel by hydrogenation was equipped with automatic temperature and pressure regulators. The introduction of automatic service will not only bring about a reduction of labour costs, but will mainly ensure safer operation and reduce the damage resulting from shortcomings in service.

Bibliography

1. P. C. Keith, "Progress in Transformation of Basic Fuels", *Combustion*, December 1946, pages 55–57.
2. Ministry of Fuel and Power, *Report on the Petroleum and Synthetic Oil Industry of Germany*, London, 1947.
3. *Ibid.* and S. Landa, "Ovýrobě pohonných látek hydrogenací" (Production of Fuels by Hydrogenation), *Chemický Obzor*, 1947, pages 154–162.
4. H. Rose, "Underground Gasification of Coal", *Gas World*, 1943, pages 109–110; *Power*, 1947, page 106.

The Flexibility of the High Pressure Hydrogenation Process for Liquid Fuel Production

R. HOLROYD

ABSTRACT

Processes for the production of synthetic fuels vary considerably in the choice of starting materials which they allow and in the control of the type and quality of fuels which they produce. The flexibility of the hydrogenation process in these two respects is here considered.

Large-scale experience of the hydrogenation process has shown that the range of raw materials which can be successfully treated includes bituminous and brown coals, tars, pitch, petroleum residues, gas oils, naphthas etc.

The control of products which hydrogenation allows is twofold. Firstly, it is possible to obtain a desired product in high yield with an absence of material of higher molecular weight than the feed stock and a comparatively small yield of by-products. Thus the hydrogenation of coal can give fuel oil as one of its main products, or the stages of hydrogenation can be carried so far as to give a high volatility petrol as the only liquid product. The ability to recycle unconverted material is an important feature. Secondly, the choice of conditions of temperature, pressure and catalyst affords an important means of controlling the nature of the hydrocarbons which are found in the final product. Thus by hydrogenation of coal or coal products, highly aromatic petrols can be made or, alternatively, petrols with very low aromatics but richer in naphthenes and paraffins.

All processes which have as a primary object the production of petrol or other fuels from materials of different molecular weight fall naturally into two main groups.

1. Processes which build up the required product from lower molecular weight materials, i.e., polymerization processes of various sorts, alkylation, Fischer, Tropsch, etc.
2. Processes which obtain the required product by breaking down larger molecules, i.e., cracking and destructive hydrogenation.

In the first group the flexibility arises mainly in the process of building up since there is not much room for variation in the low boiling olefines and isoparaffins, $CO + H_2$ mixtures etc., which are used.

In the second group, however, there is a wider choice of both starting materials and of products and it is proposed to set out in this paper some of the features of the hydrogenation process which emphasize its flexibility in both of these respects.

RANGE OF FEED STOCKS

Some examples are given to show the range of materials which have been successfully hydrogenated.

COAL

Brown coal was first hydrogenated commercially in 1927. The older coals were, however, more difficult to treat and it was not until 1935 that the first plant to hydrogenate bituminous coal was in operation. Carbonaceous materials still lower in hydrogen content, such as anthracite, offer still greater difficulties but there has not been, up to the present, any practical necessity to consider their use. The nearest alternative to hydrogenation is here, as elsewhere, a cracking process, carbonization. The name itself emphasizes that the main product is carbon. Liquid fuels arise as by-products, whereas with hydrogenation there is only a minor residue of ash and unconverted oil. Thus the liquid yield of 68 per cent obtained in the hydrogenation of bituminous coal at Blechhammer (1)[1] may be compared with the 5 to 10 per cent yields of total liquids obtained in carbonization processes. The yield of unconverted coal (excluding ash) at Blechhammer was only 4 per cent as against the 67 to 77 per cent obtained in carbonization at various temperatures.

TARS AND TAR FRACTIONS

Since these are products of carbonization they are not suitable materials for the further application of cracking or carbonization processes with a view to obtaining more valuable liquid fuels. Hydrogenation, however, can deal with all fractions of tars from even the most severe carbonization processes. For example, pitch from bituminous coal tar was hydrogenated successfully at Welheim during the war with a high yield of liquid products and only 15 per cent of unconverted pitch + solids (2). Where distillate fractions are used as feed stocks, the conversion to lighter products is 100 per cent.

PETROLEUM OILS

Petroleum residues and heavy fuel oils can be very readily treated by hydrogenation. Gas oils and similar cracker feed stocks are excellent raw materials, and even naphthas which are unsuitable for catalytic cracking can give a high yield of petrol by hydrogenation. Although outside this field, it may also be observed that, if required, high yields of low boiling paraffins rich in C_3, C_4 and C_5 can be obtained by the complete hydrogenation of petrols and light oils. These paraffins are mainly branched in structure. These considerations show the flexibility of the hydrogenation process in dealing with a

[1]Numbers in parentheses refer to items in the bibliography.

very wide range of raw materials. The chemistry of all processes for synthetic fuels turns upon the distribution of hydrogen. Carbonization and cracking processes generally can be looked upon as disproportionation reactions producing some free hydrogen at one end of the scale and at the other end material of higher molecular weight and lower hydrogen content than the feed. Hydrogenation avoids the polymerization reactions which lead to high molecular weight products by adding hydrogen at the point where a carbon — carbon bond is broken, so preventing the formation of unsaturated groupings which can polymerize. It also is more selective than cracking processes in its ability to break down preferentially the higher molecular weight components of the feed, and, in so doing, to avoid production of extensive amounts of gas, especially methane and ethane, which are undesirable.

RANGE OF LIQUID FUEL PRODUCTS

A survey of large-scale hydrogenation operations reveals a great variety of products obtained by high pressure hydrogenation. It is, however, important to observe that the nature of the feed stock used has considerable effect on the properties of the product (3). This follows from the fact that in hydrogenation the original molecules are dismembered until the desired molecular weight is obtained and in this dismemberment there is no ring closure and only a limited conversion of cyclic structures to paraffin until the molecular weight is low. There is, however, a certain amount of isomerization with the production of five-membered rings and some branching of paraffins to form 2- and 3-methyl alkanes. As a result it is not possible to make diesel fuels of high octane number from highly aromatic feed stocks such as bituminous coal tars and creosotes, nor can highly paraffinic gas oils be hydrogenated to aviation petrols with good rich mixture rating.

It is possible, however, to adjust the hydrogenation process very extensively and so to modify the nature of the resulting fuels. The control which can be obtained in hydrogenation is outlined here, first with regard to molecule size distribution and secondly with regard to the nature of the molecules themselves.

CONTROL OF MOLECULE SIZE DISTRIBUTION

In hydrogenation processes the pass conversion has an important effect on the distribution of the molecule sizes in the product. Thus it has been shown (4) that in coal hydrogenation increased time of reaction increases the middle oil and petrol yields at the expense of the heavy oil. This control of heavy oil make has been used to give a variety of methods of operating the coal stage of hydrogenation. In a rather similar manner the pass conversion in vapour phase hydrogenation of a middle oil can be used to modify the characteristics of the petrol cut to a given end point. Its volatility can be increased by working to a higher conversion.

The possibility of producing large yields of fuel oil from coal and heavy residues has engaged attention in Germany and the U.S.A. At Welheim, pitch was hydrogenated to give 45 per cent yield of fuel oil and 28 per cent of middle oil + petrol, (2) while at Blechhammer, bituminous coal was hydrogenated to give an excess of heavy oil which was blended with some of the middle oil to give fuel oil (1). It has been suggested (5) that an early application of hydrogenation in the U.S.A. might be the production of fuel oil from coal to make up for the reduced quantities which are available with present refinery practice.

Turning to the other extreme in liquid fuels, aviation base petrol can be produced from any of the various feed stocks discussed above; thus in England aviation petrol has been made from coal, tar, creosote, petroleum gas oil and naphthas. It is an important feature of the hydrogenation process that complete conversion of liquid feeds can be obtained by the recycle of unconverted material. The ability to operate with recycle means that petrol volatility can be increased and the end point lowered with only a small loss in yield, and this loss appears as hydrocarbon gas, the greater part of which is butane — a valuable starting point for production of blending agents.

Between these two extremes of fuel oil and aviation petrol lie a range of oils, most of which have been produced by hydrogenation at one time or another. Diesel oils were made in Germany during the war by the hydrogenation of brown coal tar: Yields of 50 per cent or more of diesel oil were obtained at Zeitz by the TTH and MTH processes (low and medium temperature hydrogenation) while at Böhlen a lower yield (40 per cent) of diesel oil and an increased yield of motor spirit were obtained by the use of the more usual 5058 catalyst (1). In this same range lie the fuels now required for jet engines. Experimental batches have been made by hydrogenation but the production of these fuels may be a development in which the flexibility of the process has to be proved in the future.

CONTROL OF TYPE OF HYDROCARBON IN PRODUCT

Aviation petrol has received more attention than any other fuel in its properties and specifications, and the changes which have been called for in the last fifteen years have been a severe test of the flexibility of the hydrogenation process. Although aviation fuels are no longer cuts of selected boiling range, but contain added hydrocarbons such as iso-octane, nevertheless, the quality of the base petrol is still of the greatest importance since upon it turns the economic use of blending agents.

The changes made in the hydrogenation process have concerned the temperature and pressure of operation and also the type of catalyst used. These variables are not generally independent except over narrow ranges of conditions and hence the examples considered, while they show the net results obtained, do not show the effect of an isolated variable.

CONTROL OF AROMATIC/NAPHTHENE RATIO

In the hydrogenation of an aromatic type of feed stock, the saturation of aromatics to naphthenes can be limited either by working at high temperatures where the equilibrium lies nearer the aromatic side, or by using catalysts which are designed to achieve the minimum of saturation necessary for catalyst life.

An early I.G. process using catalyst 64 is an example of operation at high temperature. This catalyst, consisting of molybdenum, zinc and magnesium oxides, was used at temperatures of over 500 degrees C. to give a highly aromatic petrol which was, however, deficient in light ends.

The next development made use of tungsten disulphide (5058) which was active at a much lower temperature, but gave a very naphthenic product as will be seen from table 1. A further increase in activity was obtained with catalyst 6434, and at the same time some restriction of saturation with an increase in the aromatic content and knock rating of the petrol. A still further development in this range of medium temperature catalyst was made by I.C.I. This catalyst (231) gave a considerable increase in aromatics with no loss of activity, and motor spirits were produced with clear motor method ratings of 77 to 78 (6). This catalyst probably represents a limit in the restriction of saturation capacity which can be achieved with medium temperature operation; any further restriction would have brought with it a marked shortening of the extended life obtained with this and previous catalysts.

For oils which contain nitrogen or oxygen in more than trace amounts, it is very desirable to apply a presaturation process before treating with the more active catalysts 6434 and 231. This presaturation eliminates the deleterious elements and affords another opportunity for control of product quality. 5058 was first used at a temperature where its splitting activity was negligible, but during the war both in Germany and in England improved saturation catalysts were obtained which gave less conversion of aromatics to naphthenes. The best known of these developments is catalyst 8376 used in Germany in place of 5058 (1).

Table 1. Motor Petrols by Hydrogenation over Various Catalysts

Catalyst	*64*	*5058*	*6434*[1]	*231*	*Welheim catalyst*
Feed oil	Creosote middle oil				Middle oil from pitch hydrogenation
Temp. degrees C.	490–520	420	400	380	480–500
Press. atms.	250	250	250	250	700
Petrol					
Percentage aromatics	43	3	7	15	50–60
C.F.R. (motor-method) rating	80	68	75	77	82–85

[1] With presaturation over catalyst 5058.

The next marked development affecting petrol properties was the use of a high temperature splitting catalyst with restricted saturation capacity developed at Welheim for use at 700 atms (2). This raised the aromatic content to 50 to 60 per cent and although the petrol leistung (0.4—0.7 kg./litre/hr.) is less than that obtained with 6434 or 231, this is partly counterbalanced by the ability of the catalyst to deal with feeds which have had no presaturation. The Welheim type of catalyst is to be used in the demonstration plant built in Louisiana and is expected to produce a petrol with a clear motor method rating of 82 to 85 (8).

Control of paraffin structure: This is a much less marked feature than the control of aromatic/naphthene ratio, but it has contributed significantly to the improvement in weak rating of petrols. Thus the more active catalysts 6434 and 231 not only increased aromatic contents of petrol, but also reduced the concentration of straight chain paraffins (9), as is seen in table 2.

Table 2. Compositions of Petrols Produced Over Different Catalysts

(Percent)

	5058	*6434*	*231*
Aromatics	3	7	15
Naphthenes	50	54	48
Branched paraffins	31	33	32
Straight chain	—	—	—
Paraffins	16	6	5

These changes were also reflected in the iso content of the butane produced.

This review indicates the measure of the changes it has been possible to make in the boiling range and quality of fuels by hydrogenation without marked loss of yield. However, in the process, and especially when producing aviation petrol some hydrocarbon gases are formed as by-products. The gas produced in coal stage hydrogenation is richer in methane and ethane than that made in medium temperature vapour phase operation, but in general hydrogenation gases are richer in C_3 and C_4 than cracker gases.

PRODUCTIONS OF BLENDING AGENTS

In many moderate temperature splitting stages the gas contains 75 per cent C_4 of which 75 per cent is isobutane. It is then possible to make a virtue of necessity and to produce from this by-product gas in high yield iso-octane or alkylate to improve the weak mixture rating of the petrol. Alternatively butylenes can be used to alkylate benzene and so make a very effective rich mixture blending agent (6). Both of these processes were operated in England during the war. The use of the newer vapour phase catalysts with the production of highly aromatic petrols will probably eliminate the addition of a rich mixture blending agent.

The history of hydrogenation has shown that the process is capable of great flexibility both in its raw materials and in the nature of the products, and even where the selectivity of the process has been incomplete, as in the formation of by-product hydrocarbon gases, these products can be turned to good account.

Bibliography

1. Ministry of Fuel and Power, *Report on the Petroleum and Synthetic Oil Industry of Germany*, H.M.S.O., 1947.
2. C.I.O.S., XXX, 104.
3. K. Gordon, *Jour. Inst. Petrol.*, vol. 33, no. 284 (1947), page 478.
4. K. Gordon, *Jour. Inst. Fuel*, vol. 9 (1935), page 69.
5. L. L. Hirst and C. C. Chaffee, *Indust. Engin. Chem.*, vol. 41 (1949), page 870.
6. K. Gordon, *Jour. Inst. Fuel*, vol. 20 (1946), page 42.
7. C.I.O.S., XXX, 103.
8. L. C. Skinner, R. G. Dressler, C. C. Chaffee, S. G. Miller and L. L. Hirst, *Indust. Engin. Chem.*, vol. 41 (1949), page 87.
9. K. Gordon, *Jour. Inst. Fuel*, vol. 21 (1947), page 53.

Summary of Discussion

The CHAIRMAN said that the meeting would be devoted to two subjects: first, the review of the present status and trends of oil chemistry and, secondly, synthetic fuel production. For the purposes of the first part of the discussion, oil chemistry meant not only the use of chemistry for increasing the amounts of petroleum fractions which could be made available for various purposes, but also the use of petroleum products as raw materials in chemical industry.

Mr. EGLOFF presented the paper he had prepared on the "Review of Present Status and Trends of Oil Chemistry". Modern petroleum refining was the outgrowth of chemical research and recent developments in that field had initiated whole new industries, based on the manufacture of chemicals from petroleum and natural gas, such as gasolines, jet fuels, diesel fuels, heating oils, liquefied petroleum gas, lubricating oils, various chemicals including some for agriculture, synthetic rubbers, resins and plastics and detergents. The economic and social effects of discoveries in oil chemistry had been far-reaching and of great help in the conservation of existing petroleum resources. Indeed, the new processes enabled the refiner to use every drop of crude oil efficiently. The superior motor and aviation fuels were not only vital to modern transportation, but also provided for better distribution of food and other materials. Tailor-made lubricants were another essential in modern transportation. The chemicals produced from petroleum and natural gas included entirely new compounds as well as those formerly produced from coal tar, carbohydrate materials and fats. Over 5,000 commercial products were now derived from crude oils. The whole petroleum industry stood as a direct outgrowth of research and based its future on the continued development of new processes and products.

Mr. MACKLEY presented the paper he had prepared on the development of "Petroleum Refining in the United Kingdom". Before the war, the petroleum industry in the United Kingdom had been confined to the production of a few specialized products for home consumption. The exigencies of war, however, had given a very powerful impetus to that industry and the development had continued after the cessation of hostilities. The projected expansion would increase the refinery capacity of the United Kingdom to approximately 20 million tons in 1953 as compared with the pre-war level of about 4½ million tons. The existing programme would make the United Kingdom substantially self-supporting in the field of petroleum refinery capacity by 1953. Indeed, it was even expected that the country might be able by then to export some of the wide variety of petroleum products it would produce.

Mr. UYTENBOGAART presented the paper he had prepared on "Some Aspects of the Development of the Petroleum Chemical Industry in the Netherlands". Although the industry was comparatively young, and the first oil-wells had come into production as late as 1946, it was already yielding approximately 30 per cent of the country's needs of oil in 1949. The oil produced in the Netherlands contained a high percentage of paraffin wax, which was used as basis for the production of detergents. That was a very important aspect indeed, in view of the world-wide shortage of oils and fats.

Mr. JACQUÉ presented his paper "Study of the Present Position and Trends of Oil Chemistry in France". Having indicated that, despite the extensive destruction and damage caused by the war, the pre-war refinery capacity of 8 million tons had already been exceeded and was now approximately 12 million tons per annum, he said that the aim was to achieve a refinery capacity of 15 to 18 million tons per annum. French research had given particular attention to the treatment of petroleum and its by-products as a raw material for the production of various chemical products. Indeed, the separation of the simple carbon structures of petroleum fractions made the synthesis of an increasing number of organic or even mineral bodies extremely simple and profitable. The raw materials required represented barely 1 to 2 per cent of the world petroleum output, and less power was needed for the treatment of petroleum or its by-products than for the production of the same chemical products by other methods. Consequently, the production of various chemical products from petroleum and its by-products was an extremely economical operation from the conservation point of view. In the case of France, 300,000 to 350,000 tons of petroleum products, or only 2 per cent of the French refining programme, would be sufficient to produce 150,000 to 200,000 tons of chemical products.

The CHAIRMAN congratulated the authors of the papers on oil chemistry on their informative contributions, and opened the subject to discussion.

Mr. ERRERA asked Dr. Egloff whether, in order to ensure maximum production at the lowest cost, ethyl alcohol could be produced from petroleum by-products.

Mr. EGLOFF said the oil industry in the United States is producing at the rate of 110 million gallons of ethyl alcohol a year out of a total production of 160 million gallons. This quantity could be increased to any amount desired whenever the demand is present. So far as he knows, the cost of producing ethyl alcohol from petroleum is highly competitive with any of the fermentation processes used.

Mr. ARIES observed that the reliance of the world chemical industries on petrochemicals would create a revolution in the international situation in respect to the demand for and supply of industrial chemicals. One-third of the chemicals currently produced in the United States was based on petroleum or natural gas, whereas less than 3 per cent of world chemical production was based on such sources. Many countries were installing petroleum chemical units, and some of the latest oil-cracking and conversion improvements were being incorporated in those plants. Large-scale production and exports could be expected from the United Kingdom, Belgium, Canada, France, Italy and Sweden. Other countries, among them Spain, Israel and Mexico, were considering the possibility of establishing petro-chemical installations.

It was anticipated that the United States would continue to import petroleum. But since the United States chemical industry would not obtain the necessary supplies at lower costs than its counterparts in non-importing or oil-producing countries, and since its technology would not long be superior to that of chemical industries in other countries, it was not expected to enjoy such extensive world markets as it did at present. It was even conceivable that, with low tariffs, Europe might export chemicals not only to the rest of the world but even to the United States.

Such a basic economic shift provided an interesting study of the interrelationship of resources and technology being conducted by him.

Mr. Sachanen expressed the view that the production of acetylene from ethylene to be separated from cracked gas was a process too costly to be applied commercially.

Mr. Uytenbogaart pointed out that in the United States large quantities of ethylene were produced from cracked gas, which was itself a by-product. This process was therefore sufficiently cheap to be profitable. The hydrogenation of acetylene was too costly for the commercial production of ethylene.

Mr. C. L. Brown asked Dr. Egloff whether low-grade petroleum products could be put to any other use than the production of coke and other fuels.

Mr. Egloff replied that Standard Oil, New Jersey, had developed processes whereby heavy residuals could be converted into a number of useful products.

The Chairman called for the presentation of the papers on synthetic fuel.

Mr. Schroeder presented his paper on "Synthetic Fuel Production" together with a series of slides demonstrating major aspects of the problem.

It was estimated that by 1975 the total annual oil consumption in the U.S.A. would be between 4,700 million and 6,000 million barrels. Those figures were based on an estimated population of 185 million, and an annual *per capita* consumption of between 25 and 33 barrels. Known and inferred reserves of petroleum and natural gas in the United States were very high, but in view of the growing demand for liquid fuel, a growing shortage was anticipated, starting after 1955. It was therefore necessary to develop synthetic fuels.

One of the most important raw materials for the preparation of synthetic fuel was coal. Experiments in hydrogenation were being conducted by the Bureau of Mines at Louisiana, Missouri, and favourable results were expected. The cost of coal was a major factor in the cost of hydrogenation, but in view of improvements in mechanized mining, it was hoped that the cost of one ton of coal would be below 2 dollars.

Another raw material from which synthetic fuel could be produced was natural gas. A plant was being built at Brownsville, Texas, which would produce 7,000 to 8,000 barrels of gasoline per day from natural gas.

Synthesis gas could be produced by the gasification of coal with oxygen. Oxygen plants could operate at low cost, and the process appeared promising.

It had been found that by the use of iron catalysts rather than cobalt, a higher octane number of gasoline could be obtained.

Synthetic fuel could also be produced from oil shale, of which enormous deposits existed in the United States. In view of the fact, however, that one and a half tons of shale were required to produce one barrel of oil, it was essential that the mining costs should be low. A special mining method had been developed to that end, which required less manpower and thereby reduced production costs. With the existing equipment, 111 tons of shale could be mined per man-shift underground, at a cost of 55 cents per ton; oil could thus be produced at less than 2 dollars per barrel.

Experiments were being conducted into the best methods of retorting. It had been found that United States oil shale did not yield good quality products on a straightforward refining operation; a low pressure hydrogenation process had therefore been developed. It was estimated that good quality cracking stock, gasoline and diesel oil could be produced by that process for 8.4 cents per gallon.

In conclusion, Mr. Schroeder stated that the production of synthetic fuel was already reaching a stage where it could satisfactorily compete with natural fuels.

The Chairman noted with regret that Professor Landa was not present to introduce his paper on "Synthetic Fuel Production", which would therefore have to be taken as read. He drew attention to the table of the paper which gave an interesting analysis of the costs of producing synthetic fuel by different processes, in comparison with those of petroleum refining. Professor Landa had pointed out that, by comparison, labor costs of synthesis were high and had suggested that major economies might also be sought in cheaper methods of gasification.

Sir Harold Hartley introduced Dr. Holroyd's paper on "The Flexibility of the High Pressure Hydrogenation Process for Liquid Fuel Production" which embodied the results of many years' work in the United Kingdom on the hydrogenation of coal, tar and petroleum products. Investigation of the possibilities of hydrogenating coal and tar productions had been begun in 1929 by Imperial Chemical Industries.

Sir Harold Hartley then reviewed the history of the synthetic oil industry in the United Kingdom leading to the establishment of the plan at Heysham for the hydrogenation of gas oil to make aviation spirit. The process developed at Heysham was particularly important because of its flexibility which allowed changes in the nature of the product to be made to suit varying demands. Sir Harold then pointed to Dr. Holroyd's list of raw materials which had been successfully hydrogenated as further evidence of the flexibility of the hydrogenation process. Among them were brown and bituminous coals, tars, pitch, petroleum residues, gas oils and naphthas. As indicated in the paper, the hydrogenation process had been used successfully by the Germans during the Second World War. Dr. Holroyd had drawn particular attention to control of the type of hydrocarbon in the product and had shown how the aromatic naphthene ratio could be altered through varying conditions. He had also given examples of the use of different catalysts to achieve flexibility. With regard to control of paraffin structure, the author had shown that the more active catalysts, 6434 and 231, not only increased the aromatic contents of petrol, but also reduced the concentration of straight chain paraffins, as could be seen from Table 2.

The Chairman called for general discussion of the papers which had been presented.

Mr. Kemp stated, with reference to Mr. Schroeder's paper, that it was desirable that research on the production of synthetic fuel should be continued. Synthetic fuel production had great possibilities if the cost of production could be progressively lowered, especially as the costs of production and distribution of oil from natural resources were rising steadily. Substantial progress had already been achieved in the generation of synthetic gas from coal, and that fact should be stressed.

He noted in passing that the process currently used was very different from the original Fischer-Tropsch method and should therefore not be identified by that name.

As regards the practicability of the process, he thought that from a general point of view its use would be economically profitable in the parts of the world where no oil was available. In conclusion he expressed agreement with Dr. Holroyd's paper regarding the flexibility of the hydrogenation process.

Mr. ROBERTS stated, with reference to Mr. Schroeder's remarks, that the cost estimates recently prepared by the Standard Oil Company of Indiana for the synthetic production of fuel were far less optimistic than those presented by Mr. Schroeder. He quoted figures showing the impracticability of such an undertaking.

Mr. SCHROEDER pointed out that the company's estimates included such factors as housing for workers and transportation of product, which were not properly chargeable to the plant. Shale mining would involve less risk than costly oil prospecting since the oil-shale deposits were well known in the United States; consequently the return on investment in the synthetic fuel industry would be correspondingly less.

Mr. UREN wished to know whether any study had been undertaken on the underground gasification of shale.

Mr. SCHROEDER answered that the possibility had not been considered in view of the relatively low cost of mining shale, approximately 50 to 60 cents per ton.

Coal Mining

19 August 1949

Chairman:

Arno C. Fieldner, Chief, Fuels and Explosives Division, United States Department of the Interior, Washington, D.C.

Contributed Papers:

Underground Mining and the Problem of Coal Resources Conservation
B. Krupinski, Chief Technical Director, Central Coal Board, Katowice, Poland

Longwall Mechanization in Britain and the Development of Machines for "Continuous Mining"
H. H. Wilson, National Coal Board, London, England

Strip Mining in India
H. S. Frost, Resident Director, Sir Lindsay Parkinson (India) Ltd., Calcutta, India

New Techniques for Increasing Coal Production
Henry F. Hebley, Pittsburgh Consolidation Coal Company, Pittsburgh, Pennsylvania, U.S.A.

Summary of Discussion:

Discussants:

Messrs. Nighman, Dixey, Barraclough, Hebley, Cheradame, Ignatieff, Ashley, Bayless, C. J. Potter

Programme Officer:

Mr. J. H. Angus

Underground Mining and the Problem of Coal Resources Conservation

B. KRUPINSKI

ABSTRACT

The paper deals with systems of coal extraction practised in the Polish coal mining industry from the point of view of the best utilization of coal deposits. This is justified by the variety of conditions prevailing in the Polish Silesian coal basin and accordingly by the various methods of coal extraction used there.

After enumerating the different sources of losses in coal mining, the author describes in detail longwall systems with complete caving and partial packing in thin seams, longwall and wing and pocket systems in medium-thick seams and hydraulic stowage systems in seams over 3.5 metres in thickness. With the introduction of more modern mining methods adapted to local conditions, it was possible to reduce the coal loss to 5 per cent and to open to extraction the safety pillars and barriers that had been left to secure the surface and underground galleries.

Systems of mining with hydraulic stowage have made it possible to fight efficiently the danger of underground fires as well as to open to full recovery very high seams reaching a thickness of 22 metres.

As yet it has not been possible to estimate the influence of mechanization on the degree of recovery of coal. The more rapid advance of a coal-face by full mechanization has a positive influence on roof control, permits higher concentration of working places and should result in better recovery.

The high costs of shaftsinking, tunnelling and development are spread over the tonnage of coal extracted from the producing horizons opened by those works. Any loss of coal automatically increases the production costs, forcing earlier resort to new development works, usually in more difficult conditions.

With the rapidly growing consumption of coal it has been generally realized that resources of the fuel are limited and that the aim of mining should be limited to the exploitation of deposits of useful minerals with the least possible expense. The importance of full recovery of mineral reserves has stimulated the mining art to consideration of means which will give the highest degree of recovery.

The economic value of a deposit depends on its degree of accessibility to centres of consumption as well as on the cost of opening works on the deposit. The cost of opening works and the cost of development are spread over the tonnage of coal effectively mined. The difference between the total reserves and the recovered coal represents a loss of capital and of potential energy resource left behind in unrecovered seams or their parts.

We include as "marketable reserves" the total amount of coal that can be economically produced and marketed by modern mining, distribution and utilization methods, and those coal deposits which are likely to be recovered in the future with the advance of mining technique and knowledge of coal preparation. New techniques and more knowledge may open to mining the thinner and lower quality coal deposits now abandoned.

There is also a great possibility of higher recovery in a further development of underground gasification of coal seams.

The factors determining the amount of "industrial reserves" of coal are (1) geological and mining conditions of deposits; (2) degree of deposit exhaustion; (3) mining and coal utilization methods; (4) economic conditions; and (5) transport facilities.

The reserves of coal can be only partially recovered, due to losses which are always connected with underground mining. These fall into the following categories:

1. Coal lost in seams too thin to be mined with methods known today;
2. Coal lost in poor quality deposits;
3. Coal lost in safety pillars under important objects on the surface;
4. Coal lost in barriers for underground galleries, in boundary pillars and near faults;
5. Coal lost in unmined parts of seams because of local difficulties (faulty mining of lower situated seams, local pressure conditions and the like);
6. Coal lost because of mining methods;
7. Coal lost because of underground fires;
8. Coal lost as result of sudden roof-breaking, flooding with water, and other catastrophic events; and
9. Coal lost in handling and mechanical preparations.

Analysing means aimed to reduce losses in coal-mining, we shall consider only those methods which are applied in the Polish coal-mining. In order to guard against losses in mining and to attain the highest possible recovery of coal, special and varying means and methods of working are called for by the great variety of mining conditions found in Poland, such as:

Thickness of coal beds varying from 0.5 to 22 metres,
Dips of beds from level up to 90 degrees,
Depth of mining from 200 to 800 metres,
Variety of roof and floor pressure,
Heavy water inflow reaching in some mines to as much as 25 cubic metres per minute,
Danger of spontaneous combustion,
Methane and coal dust problems,
Necessity of avoiding damage to the objects on the surface in a very densely populated, highly industrialized area.

Since the nationalization of the coal industry in Poland it has been possible:

1. To reduce the boundary losses by fixing new boundaries of mines and areas according to the natural, geological divisions (faults).
2. To limit the erection of new industrial plants and other buildings inside the coal area and to plan a later removal of existing plants to other parts of Poland.

3. To develop the main entries in rock under the thick seam thus avoiding barriers for important galleries in the mines.

4. To start the mining of seams with higher ash-content by increasing the capacity of existing coal preparation plants.

SYSTEMS OF MINING

Some thirty years ago the most used system of mining was the so-called Silesian room and pillar with complete caving. The method, which was good enough in seams of medium thickness, proved to be very wasteful in thick seams, the more so as the average thickness of coal beds in Poland is above 3.5 metres. The mining of less than 1 metre thick steam coal seams was uneconomic. On the other hand, seams over 6 to 8 metres thick presented a difficult problem of roof support with ordinary timbering. It was often necessary to leave behind a coal layer on the roof and a great amount of coal in irrecoverable pillars. Gob fires resulted, very often increasing the coal loss above 50 per cent in some cases.

In the eastern part of the coal basin where the main seam reaches a thickness of 22 metres (66 ft.), it was necessary, to make mining possible at all, to introduce full backfilling with hydraulic stowing, i.e., filling of empty spaces with sand from the surface. This latter method will be dealt with in more detail later in the paper.

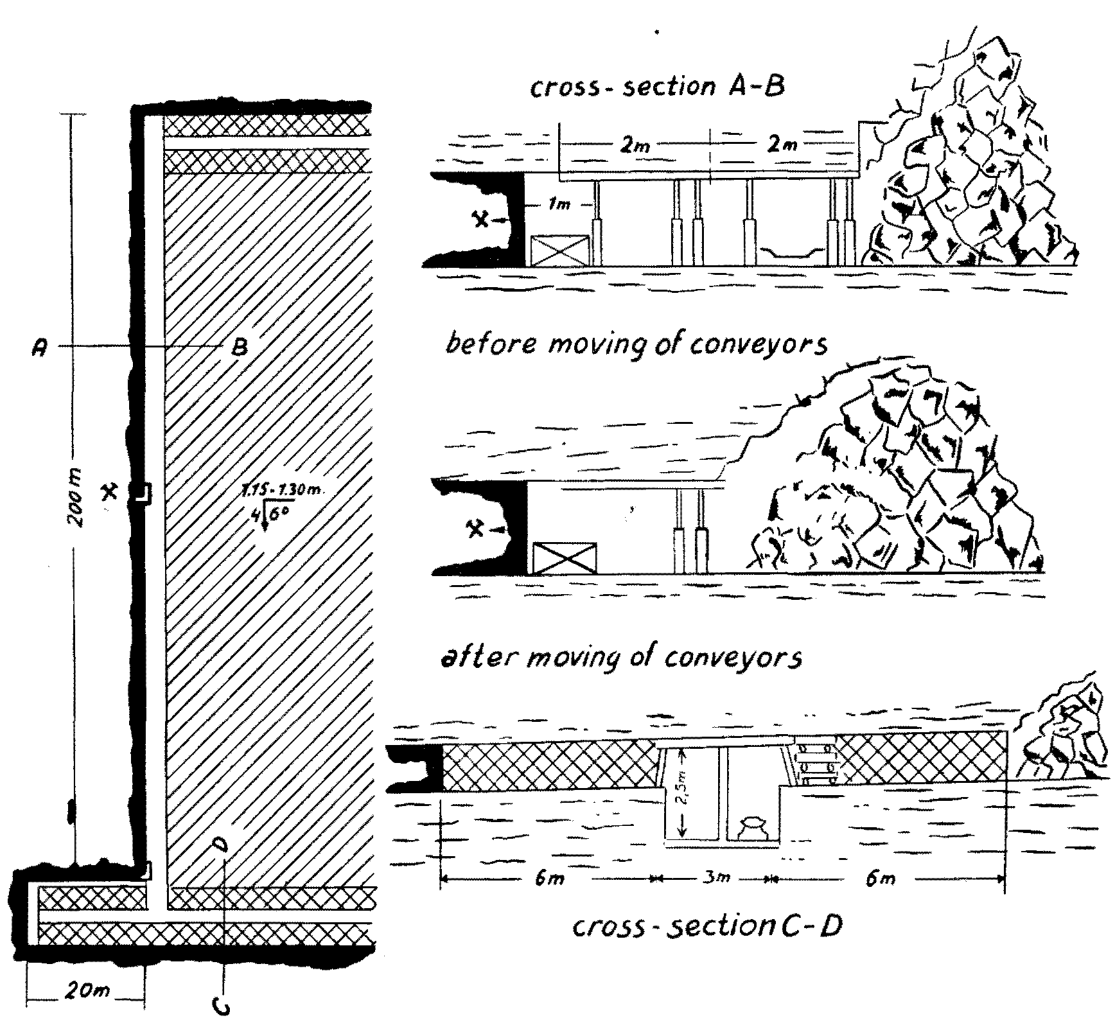
The situation has been much improved by the general introduction of longwall methods in thin coal beds and the gradual introduction of obligatory hydraulic stowing in coal beds over 3.5 metres thick.

LONGWALL METHODS

The principle of longwall mining is well known. We are going to analyse it only from the point of view of its possibilities for increasing coal recovery.

The most important advantage of this method has been the possibility it presents of economical mining of thin seams down to 0.5 metres. It has increased the marketable reserves that can be recovered with up-to-date technical means. It also gives better possibilities for using roof pressure to break the coal, thus increasing the concentration of output and safety. It eliminates completely the danger of spontaneous combustion by leaving very small amounts of coal unrecov-

Fig. I Longitudinal longwall system with complete caving



ered. The coal loss does not extend beyond 5 to 8 per cent in the workings.

The methods of longwall working depend on the composition of roof strata. There are three basic systems of operation:

1. Complete caving,
2. Dry packing:
   (a) Partial packing with roof or floor rippings,
   (b) Full packing.

The most popular method is that of longwall with complete caving. It is used in coal beds up to 35 degrees of dip. The thickness of breaking layers in the roof should be at least three times that of the coal bed. The roof support must consist of rigid steel props. Where pit-props are used, the working face must be secured by a row of steel cribs which are moved with the advance of the face. The cribs are built of anneated steel rails (figure 1).

The semi-caving longwall system with strip packing has its application in coal beds with too thin breaking layers in the roof or with a very strong roof (figure 2). Fully packed longwall is used only in exceptional cases where it is important to prevent any excessive subsidence of the surface or to create room for packing with stone from tunnelling works.

The usual length of the wall is 200 metres, although in some cases longwalls of 400 and even of 600 metres in length have been operated.

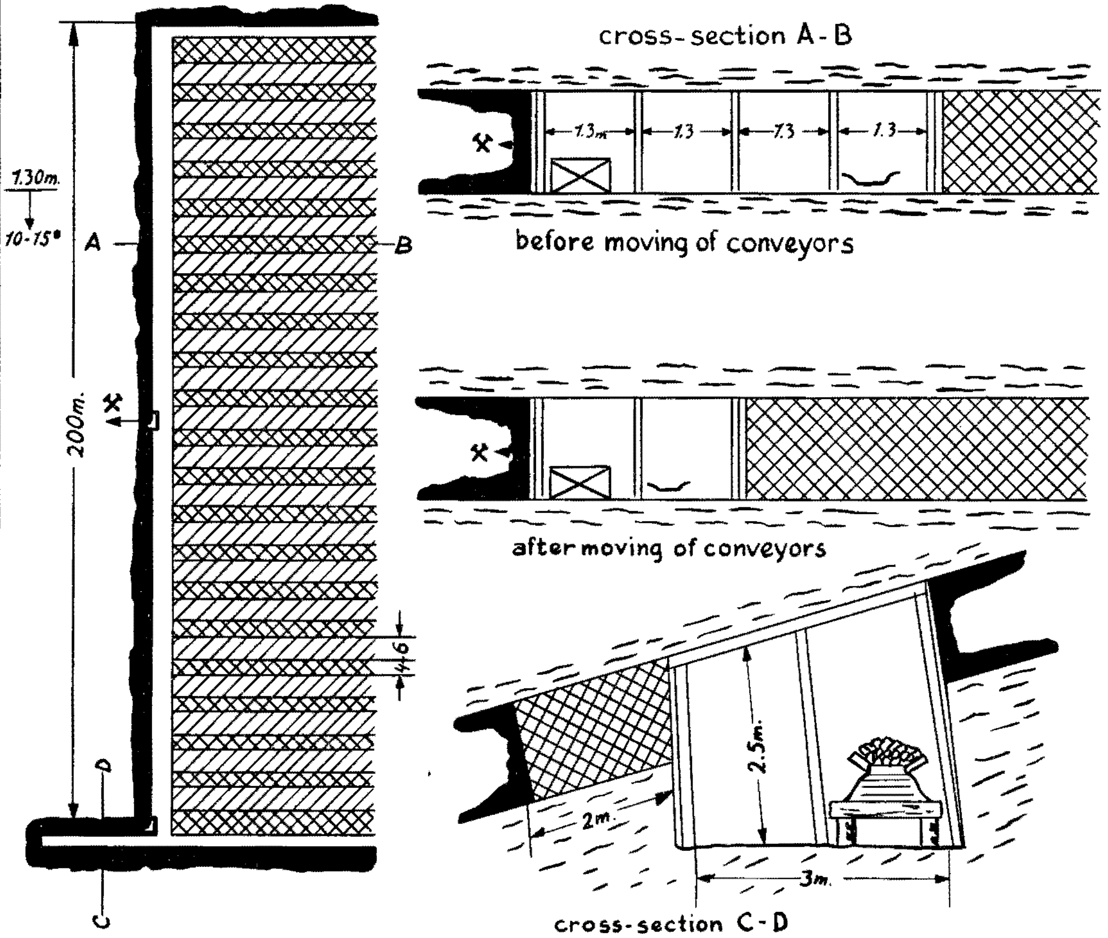
THE DEGREE OF RECOVERY AND MECHANIZATION

A comparison has been made between the room and pillar method used previously and the longwall introduced later in the same coal bed. By going over to the longwall system, coal losses which had ranged from 15 to 25 per cent were reduced to 5 per cent. Owing to lack of longwall loading machines, the mechanization consists of fully mechanized getting and conveying of coal with coalcutters, electric or pneumatic drills, and shaker-scraper or belt-conveyors.

The coal in beds up to 32 degrees of dip is mechanically undercut. Where the coal beds are steeper pickhammers are used. The consumption of explosives is very low. Below, a comparison of costs is given of two longwall operations, the first equipped with 2 electric coalcutters, 2 pneumatic drills, 10 pickhammers and 2 blasting machines. The second, in

Fig. 2

Longitudinal longwall system with strip packing



which there was no undercutting, was equipped with 5 pneumatic drills, 21 pickhammers and 8 blasting machines. The rest of the equipment, i.e., transport and roof support, was identical for both longwalls. Explosives used amounted to 0.05 kg. per ton in the first longwall and to 0.10 kg. in the second.

Costs	*Longwall I (per cent)*	*Longwall II (per cent)*
Labour	77.6	81.1
Mining machines	5.7	1.5
Coal conveying	3.7	3.4
Roof support	9.8	8.8
Explosives	3.2	5.2
	100.0	100.0

The costs per ton of coal in longwall II are higher by 13 per cent than those in longwall I with mechanical undercutting.

Of great importance in addition to the high degree of mechanization is the organization of work in longwalls in cycles completely closed in 24 hours. Only those faces that serve as reserves are not operated in cycles. The sequence of operations is shown in figure 3 for a longwall with complete caving. The first-shift crew has to work coal and undercut the bed for the second shift, during which the mining is continued and the coalcutters are transported down the face. The crew of the third shift moves the shakers, motors and roof support and provides partial undercut for the first shift. Each group of two men operates in a 6-metre-long part of the face, getting coal, loading it and providing necessary roof support. The importance of the cyclic operation on the roof control is expressed also in a bonus for the crew, which earns 1 per cent of its total monthly wages for each cycle. The described longwall is 200 metres long in a 1.25 metre seam with an undercut of 2 metres which gives a daily output of 650 tons.

The whole crew in the longwall face is 137 men, production per man-shift being 4.75 tons.

Figure 4 shows a diagram of operations in a longwall with strip packing. The daily advance of the face is 2.6 metres, i.e., the withdrawing of shaker conveyors and strip packing take places every two undercuts.

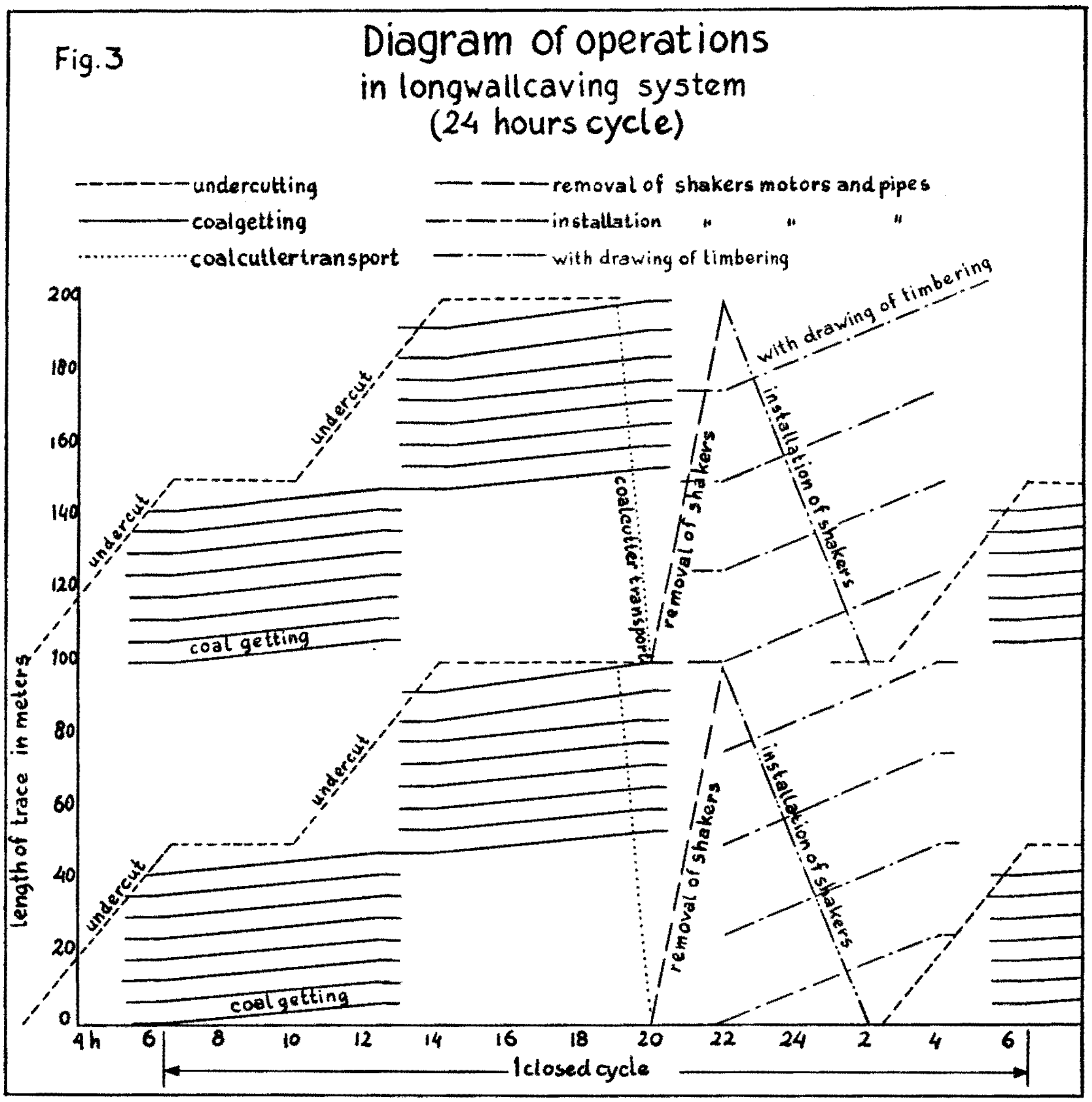


Fig. 3
Diagram of operations in longwallcaving system (24 hours cycle)

The coalcutters are operated twice daily along the whole length of the face. To make this possible the mining crew in groups of two men work during one shift in two different spots on the face. The various operations are shown in the diagram. The total output of the longwall is 850 tons in 24 hours. With a crew of 218 men, production per man-shift is 3.71 tons.

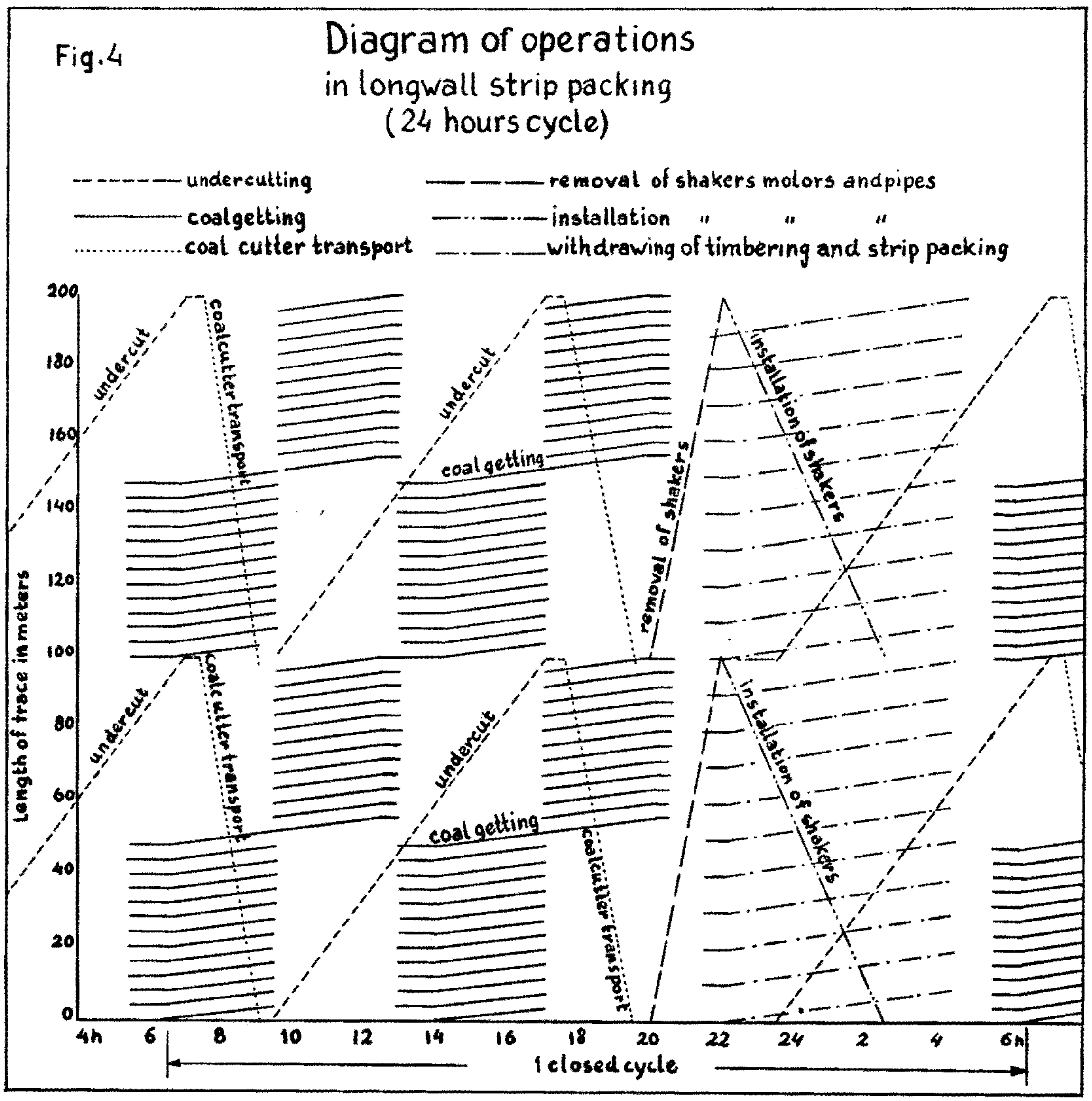
MINING METHODS IN THICK AND MEDIUM-THICK COAL

As mentioned before, coal seams thicker than 2.20 metres had been mined previously by the room and pillar method with caving. The system of working differs from the American room and pillar. The seam is divided into sections by double main entries and butt entries driven at right angles to the main entries. The sections thus obtained are again divided into smaller rectangular blocks in which coal is extracted by the wing and pocket method. The pocket is only 5 to 6 metres wide with a 4 metre wide wing between the pocket and the gob. The length of the pockets depends on the strength of the roof but usually it is about 10 metres long. The coal is blasted with permissible explosives, usually without undercut. Portable-type electric or pneumatic drills are used. Depending on the thickness of the coal bed and local geological conditions, the height of the pockets is up to 7 metres. A sequence of panel extraction is maintained to obtain a straight rib line.

Owing to the great amount of development work required and poor recovery of pillars (under best conditions up to 70 per cent) the method is completely out of date. It was necessary to find other more efficient methods apart from the previously mentioned hydraulic stowing for very thick seams. There are two possible alternatives: (1) American room and pillar system, and (2) Further development of the longwall system.

Both systems effectively reduce the development work from 25 to 12 per cent of the total output. The recovery of coal is also higher, being about 85 per cent for room and pillar and 92 to 95 per cent for longwall. By going over to the American room and pillar system without its full mechanization it was possible to improve the output per man-shift and lower the costs per ton of mined coal. The results were still better by the introduction of cutting and loading machines.

There is also an increase of safety, due to quicker advance of the face, better coal recovery and nearly doubled output



per man-shift. The experience proves that in Polish coal mines the American room and pillar system can be successfully adopted in good roof and floor conditions. At a dip up to 8 to 10 degrees the mechanical loaders are very satisfactory. At a steeper dip duckbills should be used. A combination of fully mechanized room and pillar system without pillar extraction and hydraulic sand stowing, can be successfully applied in mining safety pillars under cities and industrial plants.

Figure 5 shows an example of application of the room and pillar system in a 2.5 metre seam, with 360 metres over-burden, which proved to be very satisfactory. The roof control is very easy because of thick shale strata over the coal seam.

The development consists of double section entries from which rooms are driven with a dip up to 13 degrees. The length of a room is 100 metres, the width 6 metres. Between rooms 14-metre-wide pillars are left. They are extracted by the wing and pocket method, the 2-metre-wide wing being taken if possible after the pocket has been mined. The method reduced the quantity of development work from 25 to 12 per cent, and the quantity of mechanical equipment is as follows:

	Old system	*New system*
Shaker pans	1987 metres	803 metres
Shaker drives	65	27
Ventilating fans	30	16
Portable electric drills	35	20

The tonnage of coal increased per unit as follows:

	Old system	*New system*
Shakers	175 tons	408 tons
Ventilating fans	380	690
Portable drills	326	550

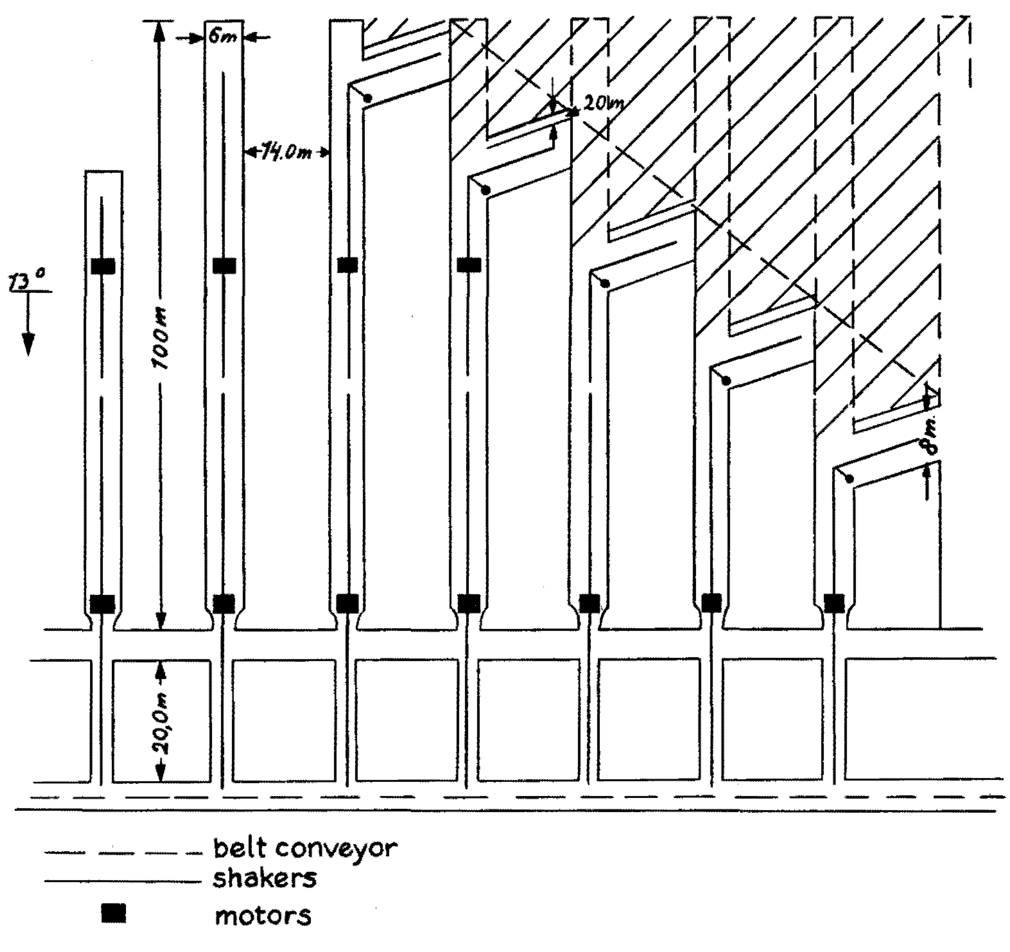
The output of one section in the new system is 1,100 tons per day, equivalent to a total output of 1,140 tons of three sections in the old systems. It is intended to mechanize this system by the introduction of duckbills.

Aiming at the best recovery with the least possible development works, one mine started to operate longwall systems with caving in high coal. The seam has a thickness of 3.2 metres. The coal bed is overlaid with sandy shale which breaks in large blocks. Geological conditions permit a face 110 to 140 metres long.

The face is supported by movable steel props. The steel crossbars 2.25 metres long are set on three props at right angles to the coal face. The distance between crossbars is 0.9 metres. On the line of gobbing, additional props are set. An average of 1.73 props is used for one square metre of roof. Timbering is done with pneumatic and hydraulic lifting jacks. The face is cut by a longwall cutting machine with a 2.20 metre jib. The coal is blasted into a longwall scraper conveyor with a capacity of 150 tons per hour. A small amount of coal is hand-

Fig.5

Room and pillar system with pillars extraction



loaded. The conveyor pans are used as a track for the cutter. Now tests are being started with a longwall loader in one set-up with a cutter. In the longwall entry there is a gathering belt conveyor as in the room and pillar system. The face output is 1,200 tons in two days' cycle. This output is smaller than in case of a one day cycle, but the safety of operation and the possibility of increasing output are better.

Figures 6 and 7 show this system and working schedule. In high coal the longwall system gives the best recovery, estimated at 95 per cent. In mining in two layers the recovery is reduced, because it is necessary to leave a parting of coal between. In 6 metre seams the estimated recovery is about 88 per cent. The mechanization equipment in longwall consists of large-capacity scraper conveyors, longwall cutters and various additional machines. In comparison with room and pillar the longwall system has the following advantages:

1. Reducing of development works down to 6 per cent.
2. Reducing of materials, especially timbering.
3. Very high recovery, reducing the danger of underground fires.
4. Better sizing of coal.
5. Very good concentration of work and mechanization.
6. Better and less expensive ventilation.

The following table presents the comparison of costs of producing one ton of coal by the room and pillar and the longwall system.

Costs	*Room and pillar*	*Longwall*
(a) Labour	53.2	63
(b) Timbering	16.1	4.3
(c) Blasting materials	8.4	6.6
(d) Steel Timbering	—	7.6
(e) Power and maintenance	7.2	8.7
(f) Development works ..	34.6	9.8
Totals	119.5 per cent	100.0 per cent

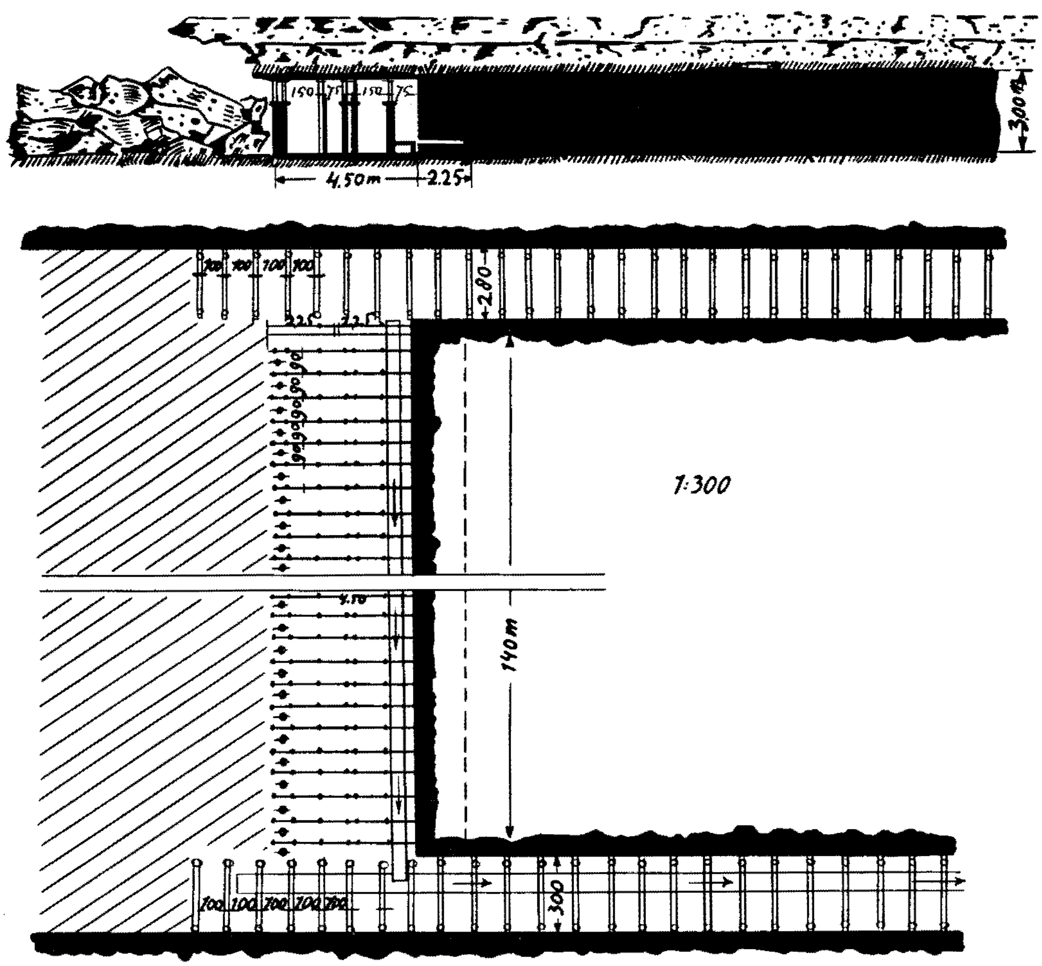
The cost per ton of coal is lower by 19.5 per cent in the longwall system, the determining factor being the low cost of development. With mechanization of timbering, the cost of labour in the longwall system can be reduced.

THE PROBLEM OF MINING COAL SEAMS OVER 3.5 METRES IN THICKNESS

The coal seams of a greater thickness than 3.5 metres are considered as thick seams, and local safety regulations calling

Fig. 6

Longwall system in 3 meter high seam



for their special treatment have to be taken into account. In order to avoid losses in coal recovery, to secure a higher degree of safety in working and to avoid damage to the surface the regulations demand the application of back-filling with sand in those seams. Keeping in mind the fact that 50 per cent of the total Polish coal output is obtained from seams thicker than 3.5 metres, we find that the mining conditions in Poland are basically different from those in other European countries. Any losses in recovery in thick seams, as was mentioned in the beginning of this paper, are proportionally higher in comparison with losses in thin seams.

This feature of Polish coal mining led as early as 1901 to the introduction of systems of working with complete or partial back-filling of mined-out spaces with hydraulic sand stowage. The principle of this system is to bring water with sand into the gob; after the water is drained off, sand fills up the mined space. In this way a higher degree of coal recovery is attained as well as increased safety in mining, easier fighting of fires because of the clean working and the prevention of air currents through old workings, and finally any dangerous surface subsidence is avoided.

The compressibility of sand stowing with fine sand is only 10 per cent of the height. In thicker seams mined in layers this percentage is even lower, thus giving further possibilities of coal recovery through partial or complete extraction under objects on the surface which are protected by this system. If we consider that 14 per cent of total coal reserves is contained in safety pillars, i.e., an estimated 10,000 million tons to the depth of 1,000 metres, we can appreciate the enormous importance of this system in the geological conditions of the Polish coal basin. It also provides the possibility of working without any fenders by mining along the sand. Moreover, it permits later working of seams situated above, which were left because of impure coal or underground fires. In one case it was possible to extract 50 per cent of the coal under a city without any damage to the surface.

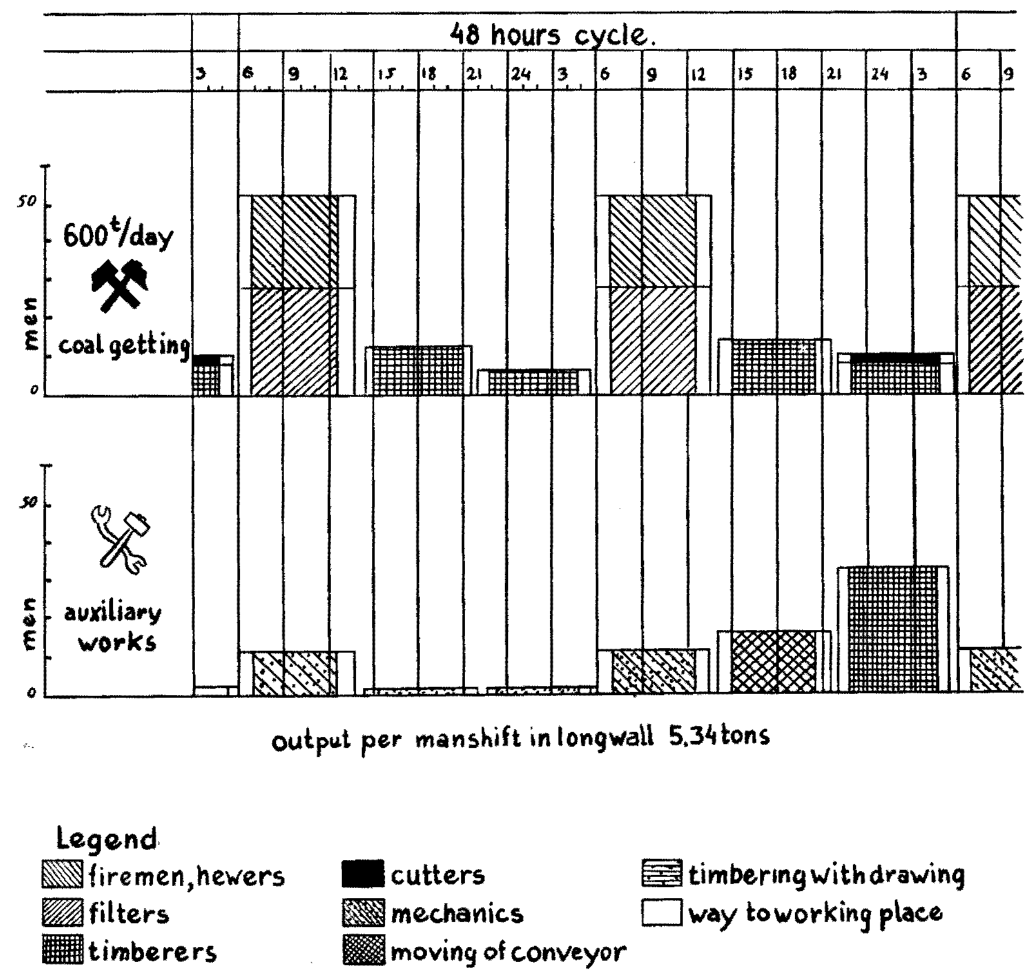
By a full realization of the planned extension of sand stowage, about 20 per cent of the total coal reserves in Poland will be opened to mining. This means an amount of 15,000 million tons of coal to the depth of 1,000 metres. Today, for a yearly output of 70 million tons of coal, 11 million cubic metres of sand are being brought to the mines. Starting in 1955, when the highest percentage of thick seams in the total output will be worked, the quantity of sand will increase to 27 million tons per year.

In order to present the working systems with hydraulic stowing in more detail, the three systems most in use are described below.

Fig 7

Diagram of operations

Longwall system in 3 meter high seam



output per manshift in longwall 5.34 tons

Fig. 8

Longitudinal room and pillar system with hydraulic stowage
(rooms driven upwards)

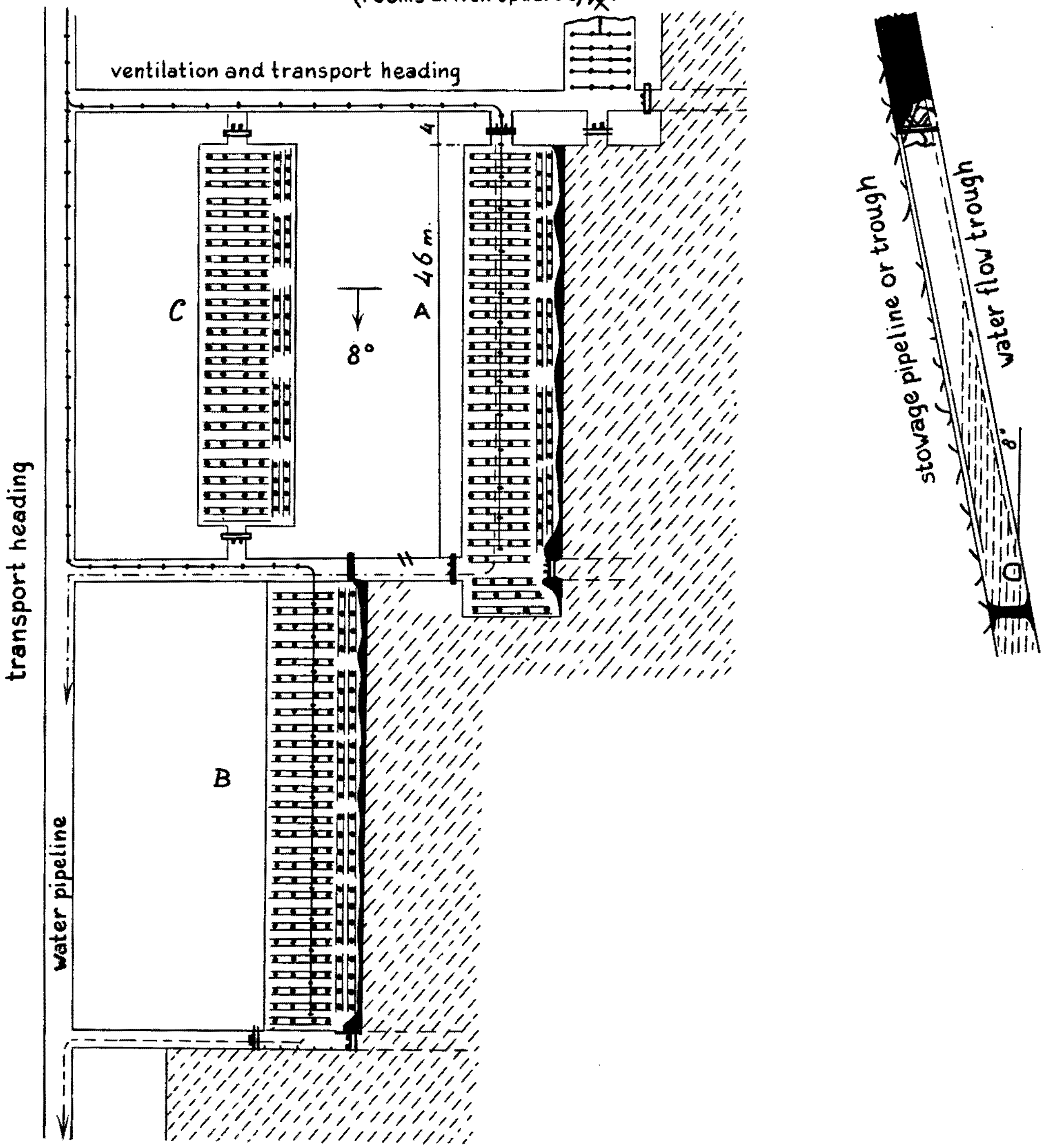
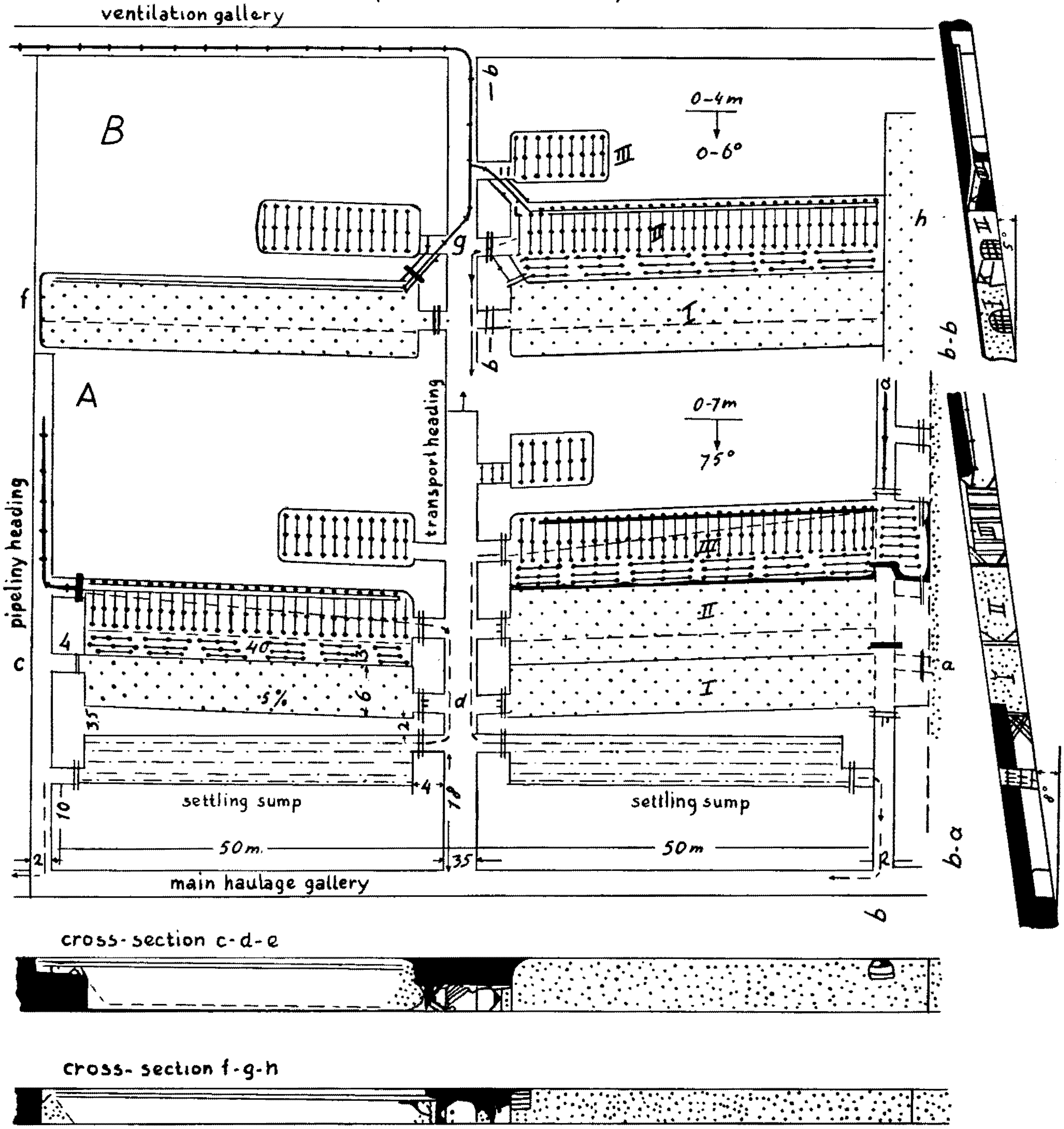


Fig. 9 Longitudinal room and pillar system with hydraulic stowage (rooms driven on strike)



(1) In figure 8 a very popular system of mining is shown. This is longitudinal pillar and room system with the coal face moving upwards. From each butt-entry coal is mined in single or double panels, the panels being cut by horizontal galleries at distances of 50 metres. Beginning from the lowest gallery a 6-metre-wide room is driven up the dip leaving a 3-metre-wide fender from the old workings. The room is not cut through to the upper gallery with its full width but only at a length of 2 metres, where a wooden partition is built and through which the stowage pipes are introduced. The remaining pillar around the partition is taken later from the upper part.

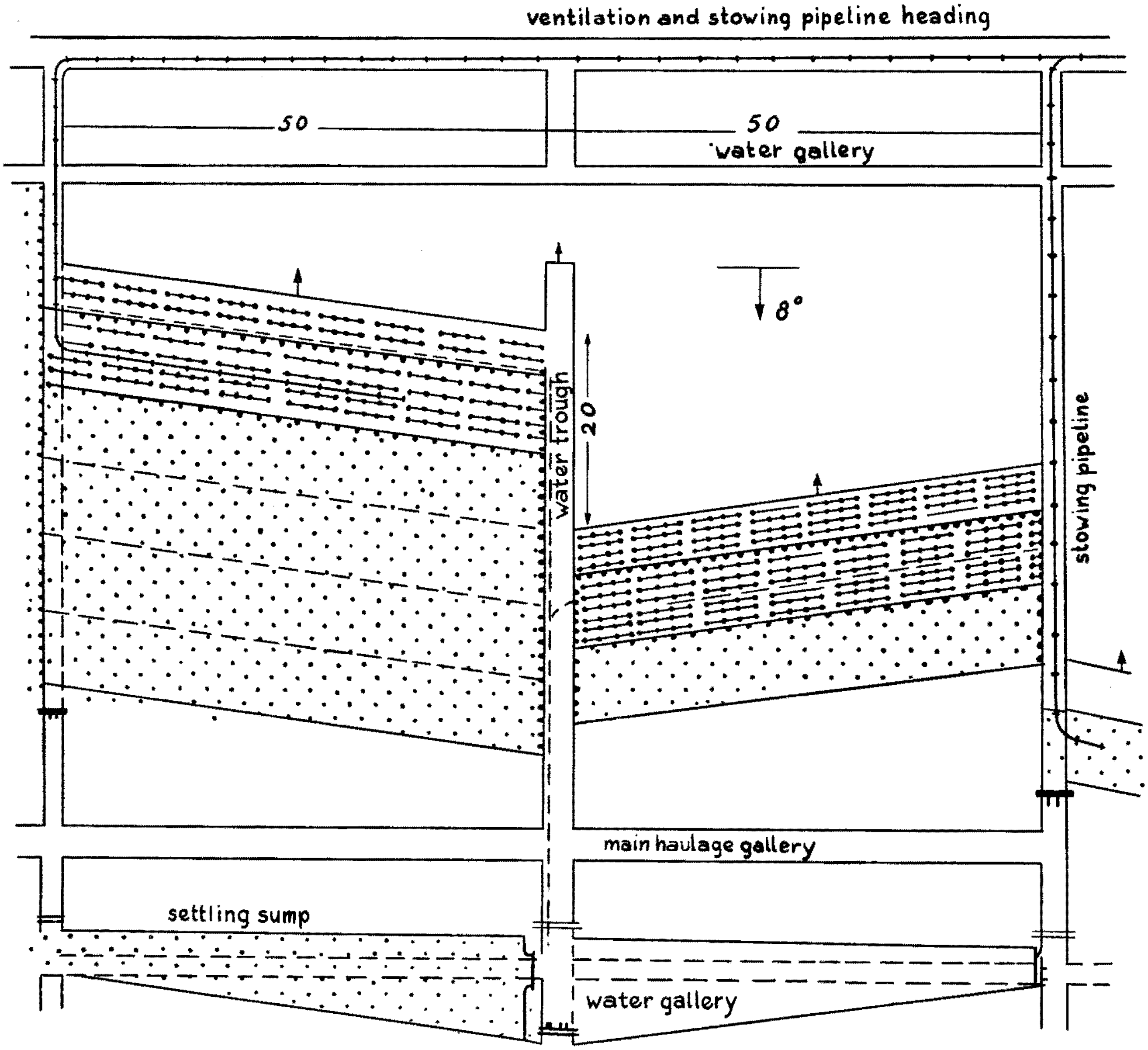
For the drainage of water a stowing partition is also built in the lower gallery. From the latter a small wooden trough is set to the top of the upper dam. The trough is covered with short planes as the stowing advances. The trough serves as water drainage. In order to make possible a simultaneous driving of two rooms from one gallery, they are started as narrow openings 4 metres long.

The stowing pipeline is installed only in the upper gallery. The drainage water after leaving the wooden trough is carried in steel pipes or covered wooden troughs to the settling sump under the main entry. After clearing it flows to the main pumping system.

(2) In less inclined seams mined in layers another system is applied, as shown in figure 9, which allows a reduction of development work to transport and stowage pipeline headings. From the transport heading on its two sides two narrow rooms are started which then broaden to 6 metres, leaving a 3-metre pillar from the old workings. The room cuts to the upper gallery with a small opening sufficient for the pipes. The stowage pipeline connected with the stowage shaft carries

Fig. 10

Shortwall system with hydraulic stowage



the sand and water along an incline. The drainage water is carried to clarifying sumps above the main entry.

The pillar along the pipeline heading is mined by driving rooms towards the back-filled part. The upper stowing partition is then set above the room in the heading. The heading is usually driven under the rock-roof or in the higher layer. At a steeper dip the transport headings are used for the pipeline.

(3) The shortwall system with sand stowing is shown in figure 10. It is similar in development to the system described under 2 above. The coal face moves from the bottom upwards. The stowing partition is set up along the coal face at a distance of at least 2.5 metres from the face and a side partition is set up along the transport heading. The stowage water is carried below the main haulage road where it is clarified and then flows to the pumping system.

This system gives a clean recovery of coal, good back-filling and continuous coal-getting. To reduce the costs of wooden partitions the surface of which is seven times larger than those used in the room system, strong deal board brattices are used which are moved with the advance of the face.

The upper layers of the coal seams are developed independently from the lower ones. The coal face advances on the sand in the floor. By washing sand at the side and in the floor an undercut is obtained which results in reduction in explosives consumption and an increase in the coarser sizes of coal.

The number of the labour force employed at sand-filling depends on the coal output of the mine and varies from 20 to 300 men divided into surface and underground crew. The output of sand per man-shift on the surface (sand mining, transport, workshops) is 30 cubic metres. Sand is mined with shovel excavators with a capacity of 220 cubic metres per hour and continuous bucket excavators with a capacity of 800 cubic metres per hour. The total output of the hydraulic stowage section of the Polish coal industry together with setting of partitions averages 15 cubic metres per man-shift.

The capacity of the stowage pipelines, depending on the distances and the depths of stowage, ranges from 150 to 400 cubic metres per hour; 1.4 cubic metres of water are used per cubic metre of sand. The costs of stowage amount to 13.9 per cent of the total costs of production of one ton of coal with hydraulic stowage.

MECHANIZATION AND COAL RECOVERY

Since the First World War there has been a trend towards mechanization of underground mining. Coal-getting, loading and transport have been mechanized according to the conditions in the various coal-producing countries. The results have not always been satisfactory. Although a higher output per man-shift has been reached, the investment costs have also increased, threatening the balance between production costs and sales prices. The problem of full mechanization is related to the degree of industrialization of the coal-producing country, for the difficulties in post-war trade relations often make it impossible to import the most modern equipment.

The more rapid advance of the coal face with mechanized means gives a better opportunity for adequate roof control and often permits maximum extraction of pillars before the weight of overburden acts upon the immediate roof. Unfortunately there are not enough data available to express the obtained results in figures. The most important aspect of full recovery for the national economy is the increase in extracted tonnage which reduces the unit costs for shaft-sinking, tunnelling and development work, a decisive factor especially in deep-horizon mining in Europe. The life of each level opened to production depends on the daily attention which the management gives to the problem of preventing any loss of extractable coal. The too early exhaustion of one developed level makes it necessary to go deeper where extraction will take place in more difficult conditions that will increase the production costs of mined coal.

Longwall Mechanization in Britain and the Development of Machines for "Continuous Mining"

H. H. WILSON

ABSTRACT

This paper deals with the application of machinery to the mining of coal, particularly in respect to the longwall system. The historical background leading to the design of existing machines for use under conventional methods are discussed and it is suggested that the results obtained have not been as satisfactory as first anticipated.

It is pointed out that the application of machinery to the longwall system of working had certain disadvantages. In particular it involved the use of relatively large teams of men operating under a cyclic system of work. The implications of these features on the mental reaction of the men are reviewed and their importance stressed.

The paper further points out that unless the technique of roof control improves in respect to the maintenance of narrow roadways at depth, the mechanized room and pillar system of mining, so successful in the United States, is unlikely to have a wide application in Britain and the majority of British output will continue to be produced by the longwall method.

Finally, the possibility of the application of a continuous system of mining, whereby cyclic working could be eliminated with the provision of greater scope for individual skill and initiative, is discussed, along with the trends in design of machines for such an application.

The application of machinery to underground mining has probably been less rapid than in other industries and mining technology has often been accused of not keeping abreast of the times. In some quarters this has been attributed to a traditional conservatism amongst both management and men, but more probably it arises from the fact that mining, being a continual struggle against the forces of nature, has to make use of such fundamental methods that major changes in technique are not to be so readily expected. In this respect mining is different from any other industry and the mechanization of a mine is much more involved than in the case, say, of a factory. Dangers inherent with underground operations, lack of space, and the use of artificial light impose serious restriction on the designers of mining machinery and development of suitable types of equipment is generally a slow process.

Nevertheless, progress has been steady, if not spectacular, and the machine in some form is now established as the chief means of coal getting. Developments continue, both in respect of improvements in existing machines and in the design of new types, with the purposes of reducing production costs, promoting greater safety, and eliminating arduous physical toil.

In the United States where the coal is got by the room and pillar method of mining, mechanization has made rapid strides during the past decade and the excellent results now being achieved can be attributed to the application of cutting and loading machines developed for this class of work.

On the other hand in Britain where, for various physical reasons, room and pillar mining has only a limited application, the major percentage of the coal is produced by the Longwall method. The application of machinery, particularly for loading, has proved much more difficult with this system and has not been accompanied by such phenomenal results.

Mechanization of Longwall coal faces in Britain has been based on the use of a coal cutting machine. This eliminated the slow and laborious work of undercutting by hand and was followed by the adoption of suitable conveyors to facilitate loading and concentration of increased output at one point. The coal continued to be loaded on to the conveyor by hand and it was not until the beginning of the war that attention was directed to the use of a suitable loading machine. Several machines were designed and installed with the object of replacing hand-filling, but probably the most notable development was that of the A. B. Meco Moore cutter-loader which was capable of both getting and loading the coal. This machine uses the principle of the cutter in that the coal is got by high speed rotating picks before being picked up by a specially designed conveyor incorporated in the machine and loaded on to the normal face conveyor. Where conditions are suitable excellent results and a substantial increase in the O.M.S. can be obtained with this machine, but it cannot yet be regarded as suitable for universal introduction. Experience has shown that conditions have not only to be good, but consistently good for successful application. The output obtained from an average of 38 machines in use during 1948 amounted to 3,007,325 tons, representing an O.M.S. to the loading point of 7.01 tons.

It is of importance to note that these machines were installed on traditional Longwall mechanization principles. This involves taking a relatively deep cut (4½ ft. to 6 ft.) from off the coal face with the cutting or cutting/loading medium in a separate track or lane, formed by the supports, from the conveyor.

The coal has therefore to be loaded, whether by hand or by power, through and between adjacent supports in a row, and for each consecutive web the conveyor has to be broken and moved by hand into a new track. Since coal filling is stopped when the conveyor is being advanced, a cyclic system of work is therefore unavoidable.

Extensive Longwall mechanization on these lines occurred from 1927 onwards when the coal cut and conveyed increased from about 20 per cent to 75 per cent of the total output. Despite progressive improvements in equipment and skill in application, enabling longer faces to be worked with greater depths of cut, it cannot be said that the hopes of appreciable improvement in production entertained by most mining engineers in Britain have been fulfilled. There is little doubt that mechanization of the system on these lines involved a complete change of technique and it may well be that some fundamental issues arose that were not fully appreciated.

For instance, it gave rise to the introduction of large teams of men with loss of individuality resulting in the rate of production becoming based on that of the poorest workman. The work tended to become more repetitive and of such a nature that craftmanship was at a discount. It also tended to become more monotonous, leading to diminished interest and incipient labour difficulties.

These factors were aggravated by the development of interdependent cycles of work extending over 24 or 48 hours. During this period the work automatically separated into a series of separate operations, coal cutting and preparation, loading, conveyor moving, and ripping. Each operation was to a large extent dependent on the work done on the preceding one, making successful co-ordination difficult, especially where attendance was irregular.

In addition the advancement of faces at greater speed with more rapid removal of support, introduced more difficult roof control problems and increased the number of men employed on non-productive work at the coal face.

The repercussion of these factors on the workmen cannot be ignored, particularly as the change from hand getting methods occurred at a time when the miner's mental reaction to his industrial environment was embittered by strife and the fear of unemployment. Mental attitudes are probably more important in mining than any other industry and may account to some extent for results accruing from orthodox mechanization not being so good as anticipated.

Unless the technique of roof control improves to such an extent that narrow roads with soft floors can be maintained at depth, an essential for room and pillar mining, the bulk of British coal output will continue to be won by the Longwall method of working, and any improvement in productive efficiency can only be expected within the framework of this system. The objective appears to be the elimination of as many individual operations as possible so that mining can be carried on continuously, and engineers have for some time been reflecting on the possibility of machines suitable for this purpose.

Probably the most notable advance in this direction was the development in Germany during the war of the "Kohlenhobel" or coal plough. This consists of a specially designed plough, with a cutting edge and share which, when pulled along by means of a rope, shears or planes a narrow strip (11 in.) of coal off the face and loads it on to a conveyor. This development represents two significant alterations in existing Longwall mining practice in that the use of high speed picks is dispensed with, being replaced by a shearing or wedging action, and a shallow cut enables a conveyor to be used in the same track as the getting unit. The conveyor is of the chain type and is of heavy construction capable of withstanding the outward thrust of the plough. In addition it can be "snaked" and advanced mechanically.

Simultaneous with these developments in Germany the thoughts of British engineers were being directed towards the design of a machine for coal getting on somewhat similar principles, but whereas the German engineers were concentrating on the use of rope-pulled equipment, British designers were investigating the possibility of a machine incorporating a power-driven wedge. This approach was fundamentally sound as it is now realized that with harder British seams considerably more force is required to dislodge the coal from the solid than is necessary with the softer German seams, and that the rope-pulled equipment will only have a limited application in this country.

As a result of intensive experimental work a power-driven British machine has been developed. This machine, called the "Samson stripping machine", utilizes hydraulic power for driving a wedge into the coal and also for propulsion to and fro along the face. It consists of two wedge heads connected by two circular guide bars on which a propulsion unit is mounted. The propulsion unit comprises a vertical hydraulic jack, which engages between roof and floor and a horizontal cylinder and piston rod. The latter can either exert a force on the wedge head, in which case the propulsion unit is anchored by the vertical jack, or it can move forward the propulsion unit which is free to slide on the guide bars when the vertical jack is not in action. Hydraulic power is developed by means of an oil pump driven from a 20 h.p. electric motor which is carried and moves forward with the propulsion unit.

The machine is 13 ft. 7 in. long, 25 in. in width, and can operate on a coal buttock up to 2 ft. 3 in. wide in seams 4 ft. thick and over. The length of stroke is 2 ft. 9 in. and a speed of 4 ft. per minute can be achieved where the necessary forward thrust is under 20 tons. With thrusts in excess of this and up to the maximum of 40 tons the speed is reduced to about 3 ft. per minute.

In action the vertical jack is extended to anchor the propelling unit between roof and floor and provides the necessary reaction when the wedge head is forced into the buttock of coal. The coal, on being dislodged, is ploughed up a ramp onto the conveyor. The pressure on the vertical jack is then released bringing it clear of the roof and floor, following which the propulsion unit is drawn up to the wedge head ready for repeating the stroke. Movement along the face is therefore by a series of steps corresponding to the length of stroke. All movements are hydraulically controlled through special valve gear operated by one man.

The machine works alongside, but is not guided by, a scraper chain conveyor. This is of much lighter construction than that used with the German-type plough as it has not to withstand a heavy outward thrust from the machine, which is designed to give a permanent inward bias. It can, nevertheless, be advanced mechanically without dismantling, and is installed in the same track as the machine, i.e., with no props between it and the coal face.

With machines of this type there is no cycle of operations, each shift following on where the preceding one stopped. Continuous mining of coal is thus possible, the only limitations being the rate at which roads can be made and/or the roof controlled behind the advancing face. The importance of the latter cannot be over-stressed as apart from its significance in respect to safety, and its influence on the work of the coal, the majority of the men are engaged on the erection and withdrawal of supports. The number required is, to some extent, determined by the convenience with which this work can be done and attention is being directed to the design of more suitable props and bars, allied with power stowing of wastes where some form of packing is necessary. The ideal would be some form of mechanized roof support, combined with continuous power loading, and with these operations now independent (no cessation of the work being necessary to move the conveyor) this is a possibility that cannot be ignored.

From the labour aspect the implications of such a system are considerable. Elimination of cyclic operations with replacement of the monotony and drudgery of hand filling by more interesting work that provides greater scope for personal skill and initiative may completely alter the outlook of the miner and lead to better co-operation and improved labour relations.

The goal is a simplified sequence of mechanized work with the elimination of as many operations as possible. A machine suitable for universal application may not yet be available but much thought is being given to the subject and several are being developed.[1] The prospect is improved production efficiency, mechanization of thinner seams and greater safety.

[1] In addition to the machines with a wedging action, such equipment as the "Logan Slabber" and the "Gloster Getter" which, whilst retaining the principle of cutting by picks, operate with a reduced depth of cut and can be used in the same track as the conveyor, thus making continuous mining possible.

Strip Mining in India

H. S. FROST

This method of stripping the overburden which covers the coal deposits by means of heavy mechanical plant, and leaving the latter to be removed by hand labour at a subsequent and convenient date is not entirely new to India, but has only been attempted on a large scale at Bermo in Bihar.

The contractors have, however, considerable experience in this class of work in England, and it is upon this and their experience at Bermo that the following conclusions have been reached.

Methods of working. On sites where the overburden is of a soft nature, and free from stones, and where the site is of sufficient area to permit of easy gradients, and where the excavated material can be tipped within an economic distance of approximately 1,000 ft., the cheapest method to employ would be the tractor and scraper.

The top soil is taken off the land by high-powered caterpillar tractors and scrapers, which peel the turf and soil from the surface, at the same time loading it into self-contained boxes and transporting it clear of the working area, where it is mechanically unloaded on the spoil banks.

Alternatively, a mechanical loader of the Euclid type could be used in conjunction with the Euclid tipping lorries if the haul was of greater distance than that stated.

Neither of these methods however appears to be economical or generally practical owing to the layer of stone between the soft overburden and the coal-face.

On sites where both soft overburden and rock have to be removed, and where it is possible to discharge the excavated material in spoil banks within the operating circle of the boom without any further handling or removing; the mechanical dragline excavator should be used. These machines should have a bucket capacity of not less than three and one-half or more, preferably five cubic yards, with a boom of not less than 150 to 180 ft.

The method of working is simple. The machine stands over its work and digs below the level of its platform, the limit of its range, both as to depth of dig and area of discharge, being the working limit of the boom. A machine of this type is capable of performing a complete cycle of operations of digging, slewing and discharging in less than one minute, an average output of 200 cubic yards per hour or 1,500 cubic yards per single shift of eight hours.

The dragline excavator is, in fact, a combination of excavator and conveyor, the length of the boom which can turn with the machine in any direction determining the distance each excavation can be disposed.

In cases where the overburden is too deep to be handled to a sufficient distance by one dragline, a second dragline may be employed to rehandle the material cast over from the first, but this of course, while giving greater working scope, increases the cost of production.

If however the excavated material has to be removed to a permanent spoil bank, as is the case at Bermo, this method is not recommended.

On sites where both soft overburden and rock have to be removed and where the excavated material has to be carried away to a permanent tip, the best and most economical method to be used is the mechanical shovel, working in conjunction with a fleet of tipping wagons of the Euclid type. The shovel is the more positive type of excavator best able to excavate hard material and blasted rock and load it direct into the wagons for disposal. In direct contrast to the dragline excavator the shovel must work from a cut and dig from a face which is above its tracks.

This method is undoubtedly the best for the general conditions likely to be encountered in strip mining in India.

There are of course many varying factors which determine the detailed method and the type of machinery to be employed— the dip of the coal seam which has to be bared, the depth and class of the substrata and, above all, the disposal of the excavated material.

Nevertheless the work can be roughly divided into the following operations:

1. The removal of the soft overburden.
2. The drilling and blasting of the underlying rock to such dimensions that it can be easily handled by the shovel.
3. The loading of the blasted rock into wagons.
4. Removal of the excavated material to the tip.

Plant repairs, maintenance and general overhaul. It must be stressed that mechanical methods of strip mining should only be undertaken on large sites where a number of machines can be economically employed, and where it is possible to install and maintain proper work shops and the necessary facilities for overhaul and repair of the machines and particularly the mechanical transport with its attendant difficulties of petrol, oiling and greasing, and the wear and tear of the tyres which is very considerable in this class of vehicle.

Any breakdown either of the shovel at the face or the transport attending upon it means loss of output and the consequent increase in cost.

To reduce this to a minimum, the various classes of plant to be used should be reduced to as few makes as possible, e.g., the shovels to be only from one maker and the wagons only of one type. If this is possible the following advantages will be gained:

1. The stock of spares without which no contract can be carried on would be reduced and would be used for any machine.
2. The training of Indian personnel would be made so very much easier and quicker in the repair shops and maintenance depots.
3. The training of the drivers and crews of the shovels and of the tipping wagons would be simplified.
4. The general efficiency and maintenance of the output would be more easily attained with the resulting saving in costs.
5. Within the period of a few years there should be sufficient number of trained Indian staff capable of undertaking the supervision on the various large constructional schemes such as dams, etc., on which this type of machinery is used.

As it appears probable that strip mining contracts will be carried out in areas where there is or will be an adequate supply of electric power, it would be desirable if all machines were electrically operated. This is a cheaper method of power and also saves the costs of expensive petrol tank installations and the delays which sometimes occur owing to difficulties of transport of petrol tankers to isolated sites.

Economic factors and costs. Basing these costs on the present price of mined coal at the pit head on Rs. 15/- per ton, it would appear that, assuming that coal can be actually dug by hand labour at the approximate cost of Rs. 3/- per ton, it would be within the economic limits to carry out strip mining operations on sites where it would be necessary to remove two tons of overburden to obtain one ton of coal.

It is estimated that the present cost of removing which is likely to be fairly constant upon an ordinary site, including the cost of explosives and of all the various operations and cost, is between Rs. 135/- to Rs. 150/- per 1,000 cub. ft., or Rs. 3/10/- to Rs. 4/1/- per ton.

Taking the highest figure, the estimated cost of a ton of coal would therefore be the cost of two tons of overburden, Rs.8/2/-, plus the cost of obtaining the coal Rs. c/- = Rs. 11/2/- per ton.

The difference between this and the Rs. 15/- already quoted was assumed to be required for the overhead charges etc., in respect of the various services required in carrying out the work.

These estimated figures however, do not take into account the particularly large capital commitment which would have to be made in the purchase of the new plant, but it does include rather large repair and maintenance costs which would not have to be faced if the plant was new.

It is impossible to assume what this capital outlay on new plant would be, as this can only be ascertained after consultation with Government economic and financial advisers, and would be based primarily on the output of coal required per year.

Basing the written down value of the plant however on the Indian Income Tax scale, the capital value of the plant would be wiped off in a period of approximately six years, in which it might reasonably be assumed that repairs and maintenance charges would under normal conditions be reasonably small.

After the capital value of the plant has been written off, it is suggested that the costs of major repairs and overhaul would approximately equal this amount, and it is on this basis that the costs of Rs. 135/- to Rs. 150/- per 1,000 cub. ft. are based.

It should be borne in mind that on several sites the ratio of overburden would be less than two to one, and that costs therefore would be correspondingly less, or conversely the profits would be higher.

There does not appear to be any reason why the production of coal should not be increased to 3 million or 5 million tons per year in the course of the next five years, if the economy of the country needs it, and the capital expenditure is provided for the purchase of the plant. The large initial capital outlay would immediately become revenue producing and the production of coal could be adjusted to meet the demands of industry.

It might well be considered that it would be more advisable to start the scheme on a much smaller scale, in which case it is possible that some small sum might have to be set aside to adjust the economic working of the plant.

A further point to be considered is the advantage of opening up new sites more quickly and easily, as mechanical plant is able to start operations directly it is erected on the site and the necessary power, either electric or diesel or oil, is available.

With regard to sites operated by hand labour, dowhras must be built, grain shops installed, water supplies and sewage lines laid and the attendant services which are required for a large community, the costs of which in these days of high building costs is a very serious factor in opening up any project of this nature.

A serious note of warning must however be sounded. It is of no use producing coal in large quantities at the quarry face, if the transport system of the country is incapable of conveying it to the industrial sites where it is required.

Mining of stripped coal. In the present operations, the actual getting of the coal itself is done by hand labour, the work being of such a nature that it is easy and economical to do so by this method.

This hand labour can easily be displaced by small coal machines, but it would appear that the cost would be slightly higher. There is no need therefore for suggesting that hand labour should be substituted by machines, especially as this might complicate the already serious labour problem which is facing the country.

The only thing to be said in favour of substituting hand labour by machine is the fact that more coal should be obtained in the same comparative time, but this could be easily compensated for by the fact that more areas of coal can be bared by the large excavating machines, so that more hand labour can be employed if it is so desired.

New Techniques for Increasing Coal Production

HENRY F. HEBLEY

ABSTRACT

The text has been confined to treating the mining methods employing the room and pillar system in seams varying in thickness from 36 to 120 inches.

Attention is drawn to the difference in definition between the use of the word "mechanization" in the United States and in Europe.

The mechanized mining cycle as practised in the United States is described and stress is placed on the use in the mining operations of heavy-duty, high-speed machines for cutting, drilling, loading and transportation.

Attention is drawn to the use of both track-mounted and trackless machines and the paramount importance of keeping the machines in active operation a maximum percentage of the cycle time.

The early developments of the continuous mining machine are touched upon and attention is drawn to the potential advantages that may accrue. Mention is also made of some of the problems that will have to be solved if the maximum benefit is to be derived from this revolutionary method of mining. It calls for original thought and bold pioneering experimentation.

The conservation of fuel resources and the possible difference in mining and safety laws existing in other countries may modify the adoption of this high-speed method that yields such large tonnages per man.

INTRODUCTION

During the last decade, the underground mining techniques for the extraction of coal as practised in the United States of America have received increasing attention by mining officials and engineers in coal-producing countries abroad. During that time there has been a steadily increasing stream of visitors and observers from foreign lands seeking to learn some of the methods employed in coal-mining in the United States that yield such great production per man employed.

In this text an effort wil be made to bring to the attention of those interested some of the methods employed that yield the high tonnages produced at present and also indicate some of the modern trends toward greatly increased production that are at present in the experimental stage and show bright hopes for the future.

Because of the restricted length of the text of this manuscript, most of the comments will concern the extraction of coal from the bituminous fields in the Appalachian and the Illinois-Indiana areas.

In both of these areas, the seams lie for the most part in the horizontal plane and the seams worked are comparatively thick (say from 36 to 120 in. in height).

1. The various states have their own laws governing the methods of coal mining, especially in regard to safety in mines.

The system of mining adopted in these areas is generally the room (Bord) and pillar system, with pillar extraction practised in most of the Appalachian area.

In the Illinois-Indiana fields most of the operations abandon the pillars, and depend on the coal extracted on the first mining for their production.

MECHANIZATION OF COAL MINING OPERATIONS

The meaning of the word "mechanization" needs clarification. In foreign countries (Great Britain, the Netherlands, Belgium, France etc.) most of the coal was loaded manually and transported by cars, tubs, or skips through the use of rope haulage, to the shaft bottom. Here multiple deck cages raised the loaded cars to the surface for treatment and disposal. When mechanical equipment began to replace manual operations and rope haulage, the change was considered "mechanization". It included such operations as cutting, shearing (if employed), drilling and transporting from the face through the use of belt or flight conveyors to the main haulage loading-point. The type of power employed was in most cases compressed air. From this point to the surface, tubs were still employed.

In the United States, cutting machines, electric drills and haulage by trolley or battery locomotive have been employed so long that their use in the mining system has been taken for granted. Thus "mechanized" mining in American mines came to mean a machine that loaded coal at the face into mine cars or shuttle cars for transportation to the surface. This difference in terminology must be borne in mind.

THE MINING CYCLE

The cycle of preparation of coal at the face ready for its removal to the surface is generally carried out in the following steps:

1. The face is cleaned up and the room timbered ready for the cutting operation.

2. The cutting operation, dependent on the practice which may employ under-cutting, over-cutting, shearing or a combination of these cuts. Most of these machines are electrically operated, using direct current. Such units may be track-mounted machines or placed on caterpillar treads for mobile operation.

3. The necessary holes are drilled for the insertion of the explosive charges required to bring down the coal. Such electrically operated drills may be track-mounted and arranged to drill all the holes from one position of the carriage. Also, the drills may be mounted on posts clamped between the roof and the floor. In such cases the auger is fed into the coal face through operation of an appropriately threaded feeder shaft. In more modest coal mining operations, portable hand-held electric drills are used and appreciated because of their flexibility and ease of handling.

4. The holes are charged either with permissible explosives or cartridges employing CO_2 or air as the explosive.

5. The coal is then shot down and placed in a suitable position for its convenient loading into mine cars or shuttle cars, ready for transportation to the surface.

6. The loading machine is then "trammed" (flitted) into position and placed at the task of loading out the coal into mine cars, shuttle cars or onto shaking conveyors, and thence to the main haulage and to the surface. All of these machines are electrically operated. They vary in the "gathering" principle adopted, but yield a reasonably satisfactory performance.

7. The final step in the cycle consists of cleaning up the loose coal, the ribs and roof preparatory for the next cycle.

The foregoing mining cycle is typical of the methods employed in many of the coal mining operations in the United States. By its adoption it has brought about a greater concentration of the active operations, thus permitting closer supervision. The amount of track work is greatly reduced compared to hand loading operations, and delays caused by the failure of car supply to the face are far less prevalent.

However, inherent in this cyclic method of coal production, there are a number of factors that tend to reduce the efficiency of the equipment employed.

In the first place, there is a multiplicity of machines that have to be used in sequence at the coal face. Dependent on the required time for each phase of the cycle, the actual time during which each machine is in use may only be a fraction of the time required by the total cycle. In order to reduce these periods of inaction, the equipment is moved from working place to working place in an orderly manner. However, the period of travel is itself a non-productive one.

A second factor lies in the great loading capacity of the loading machine. Where mine cars are supplied directly to the machine in order to be loaded, there are the inevitable delays caused by the removal of the filled car and its replacement by an empty one. In order to overcome this drawback, the capacity of the mine car has been increased, reducing the number of car changes required. However, this increase in car capacity cannot be pressed with impunity. Such governing factors as height of seam, width of entry, track gauge, radius of curvature of track, weight of rail, type of roof and floor, width of room necks etc., will modify the mine car design and the layout of any mine being planned for fully mechanized exploitation.

In the case of existing mines, the size of the mine car adopted will be greatly restricted by the foregoing factors, as it is generally impractical and uneconomical to carry out great changes in the mine layout and equipment, just to permit a large mine car to be used.

Such cases are essentially ones of compromise after careful consideration of all the factors involved.

An alternative solution to the problem of sustained operation of the loading machine is to be found in the use of the shuttle car. Its service is just what its name implies. It acts as a storage for retaining the discharge from the mechanical loader and then shuttles between the loader and the surge bin at the main haulage. As soon as the loaded shuttle car moves away from the loader, a second shuttle car moves in to take its place.

Provided there is room for manœuvring and the floor over which the shuttle cars travel is not too soft and muddy, this method provides the flexibility and continuity of operation that results in increased coal production. The absence of track-laying from the main haulage to the face is also a distinct advantage both in cost, loss of time due to derails and in case of retreat with all equipment if a "squeeze" develops.

The main transportation system from the surge bin to the shaft bottom may become the point of congestion, causing delays because of lack of cars. The methods adopted to alleviate this condition tend toward large-capacity mine cars, and wide-gauge track employing heavy rail on substantial ties that have been carefully laid and well ballasted. Heavy-duty tandem electric trolley locomotives, with ample capacity to move many cars at high speed, are employed. Such trips are delivered to the shaft bottom and discharged through a rotary dump into a skip storage hopper with sufficient capacity to permit the hoisting cycle to be somewhat independent of the arrival of the loaded trips at the mine shaft bottom. The system also insures a rapid "turn around" of the cars as they do not leave the shaft bottom level but are returned to the working face comparatively rapidly.

Where the position of the seam in relation to the surface and other local conditions is favourable, it may be an advantage to adopt the use of high-speed belt conveyors for the main haulage from the surge storage bin underground to the surge bin at the surface. Such systems permit the continuous flow of coal to the surface coal-preparation plant.

The type of mechanized mining which has just been described has been responsible for the remarkable production tonnages that have been associated with coal-mining in the United States. The foregoing cycle presupposes, however, that certain favourable conditions are present or available, namely:

1. The room-and-pillar system of mining in which some recovery of the pillars may or may not be practised;
2. A fairly level seam of convenient height;
3. A freedom of decision regarding the amount of coal that may be left for roof or floor protection;
4. The freedom to use explosives on the operating shift;
5. The freedom to decide on the amount of coal that may be won on the first working; and
6. The freedom to use electricity, both direct and alternating current, for the various electrically operated machines employed in the extraction of coal.

It may well be that in other countries the desire for the conservation of fuel resources and safety and mining laws may preclude the use of some of the methods that result in such high production. However, the mining systems in use in the United States of America have yielded high production with a remarkable degree of safety.

THE CONTINUOUS MINING SYSTEM

Everyone employing the methods just described has been well aware of the poor efficiency of the system. For years considerable thought has been given to the development of a mining method that would approach continuous operation. In the last three years, these thoughts have been incorporated in at least two types of machines that have been placed in more or less experimental operation. Both of these units have been fully described in the technical literature so the discussion in this paper will be confined to the potentialities of this method of mining. Such a system of mining requires the discard of all concepts previously held that were based on past experience.

Recalling the cyclic method of mining, it is interesting to note the steps that have been eliminated, namely:

1. Under-cutting and shearing of the seam;
2. Drilling preparatory to receiving explosives;
3. Explosives and shot firing; and
4. Clean-up of loose coal at the face.

As the continuous mining machine does not have to "tram" from room to room during the working shift, a great deal of inoperative time is avoided. The machine is always working in the coal. With a machine advancing two to four ft. per minute, the problem of removing the coal produced is a formidable one. It is this phase of the operation that must be satisfactorily met. To date, this requirement has only been partially fulfilled. From a strictly mining point of view, there are both advantages and disadvantages associated with the principle of continuous mining.

The system permits a closer concentration of the working faces than is possible with the mechanized cyclic methods. Because the shattering disturbing effects in the roof structure by explosives has been eliminated, it is hoped that stronger roof conditions may result. Also because of the rapid advance of the machine into the face and the necessity of maintaining adequate roof support at a pace approximately equal to the rate of advance of the machine, it is hoped that supports may be placed before the tectonic stresses released by the removal of the coal seam exert their full force. It is in this experimental field that studies must be carried out. It is most important that knowledge be gathered regarding the stresses that are set up in the roof, not only above the room where the coal support has been extracted, but also in the strata ahead of the face and also along the ribs. Investigations similar to those of van Iterson (1)[1] in the Netherlands, and also to those of Phillips (2) and Winstanley (3) in Great Britain, could be carried out with profit in the United States. It is fortunate that the designers of "continuous" mining machines are cognizant of the roof-control problem and can conveniently trim the roof to present a smooth face that will permit continuous distribution of the load along the supporting member.

From a safety view point, there is great promise that the "continuous" mining machine will insure safer working conditions. As pointed out by Forester (4) the elimination of a number of electrically operated machines by their replacement with one unit has obviated the confusion of numerous traffic congestions of men, machines and materials with their attendant noises as they move in and out of position.

No doubt there will be a smaller number of men in the crew required to operate the continuous mining machine, thus helping to reduce the number of "man-hours of exposure". The machine operator himself is back from the face a distance of at least 15 ft., yielding a considerable measure of protection.

Because of the speed with which the coal is mined and the concentration of the operations in very narrow limits, the hazards from dust and the release of methane from the workings are increased. Water sprays or fogs are being tested for efficiency in depressing the dust and some consideration is being given to the design of special dust-collection equipment.

The problem of ventilation must be considered in order to render any heavy release of methane harmless.

With the rapid advance of the face that is being carried out, it is imperative that illumination at the face and around the machine should be adequate. This phase needs intensive study. Probably the vital problem of continuous mining is to devise a method whereby the coal mined can be continuously transported from the machine to the surface. The closer the solution approaches a theoretically continuous transportation system,

[1] Numbers within parentheses refer to items in the bibliography.

the closer will the "continuous" mining machine approach in practice the duties for which it was designed.

In conclusion, it may be said that the adoption of fully mechanized methods of mining as practised in the United States, and employing the latest heavy-duty machines of the high-speed type, will yield a high production of coal. The cycle method as used in the United States has yielded gratifying results.

The future methods of mining, employing "continuous" mining machines, show every promise of still further increases in production. Some of the attendant problems pose some difficulties and it may require a distinct departure from the orthodox methods of mining. There is little doubt, however, that these difficulties will be overcome.

Such ancillary problems as the size consist of the coal produced, the difficulties of coal cleaning and preparation, and the waste disposal of greatly increased quantities of refuse are beyond the scope of this paper and will not be discussed. The problem of subsidence, if pillar extraction is practised, is another phase that must be taken into account especially in mines that have shallow cover or have other seams lying above or below the seam being worked.

Mention has been made of these other important factors, which, while not strictly classed with increased output, nevertheless exert great influence. In the adoption of any of these systems, it is imperative that all phases receive due consideration. Only in that manner will the fullest results be achieved.

Bibliography

1. Prof. TH. VAN ITERSON, "The Theory of Rock Pressure on Coal Mining", *Geologie en Mijnbouw*, October 1948.
2. D. W. PHILLIPS, "Strata Control in Great Britain", AIME Technical Publication No. 2062; "Tectonics in Mining", *Colliery Engineering*, June, August, September, October and November 1948.
3. A. WINSTANLEY, "Mechanization and Falls of Ground Accidents", *Transactions* of Institute of Mining Engineers, July 1942; "Roof Control Aspects of American Mechanized Systems of Mining" (Co-author D. W. Phillips), *Transactions* of Institute of Mining Engineers, February 1944.
4. M. H. FORESTER, "Advantages and Disadvantages of Continuous Mining Machines from a Safety Standpoint", the Mine Inspectors' Institute of America, June 1949.

Summary of Discussion

The CHAIRMAN stated that the various papers which would be read at the meeting would deal with new techniques for increasing coal production. The question was more complicated than might appear at first glance, as it included both methods of increasing production in a given coal-bed and methods of increasing the rate of coal recovery. Methods for reducing loss should therefore be studied first.

Endowed with rich coal deposits, the United States of America was only now beginning to envisage the possibility of their exhaustion and to be concerned over the ratio of coal recovery to the total resources of coal in mines. The ratio was not yet fully known, but it was certain that it was lower than in the United Kingdom. There were consequently differences in production on which it would be useful to have an exchange of views.

Mr. NIGHMAN, in the absence of its author, introduced the paper prepared by Mr. Boleslaw Krupinski on "Underground Mining and the Problem of Coal Resources Conservation". The paper dealt with the methods of coal extraction applied in the Polish coal industry from the point of view of the best utilization of coal deposits. It drew attention to the variety of conditions prevailing in the Polish Silesian coal-basin and the various methods of coal extraction consequently used in that region.

The coal resources could only be partially recovered, in view of the inevitable losses incurred in underground mining; those losses could be classified as follows:

Coal lost in seams too thin to be mined with methods known at present;

Coal lost in poor quality deposits;

Coal lost in safety pillars under important objects on the surface;

Coal lost in barriers for underground galleries, in boundary pillars and near the faults;

Coal lost in unmined parts of seams because of local difficulties (faulty mining of lower situated seams, local pressure and similar conditions);

Coal lost due to methods of mining;

Coal lost due to underground fires;

Coal lost as a result of sudden roof breaking, flooding with water and other catastrophic events, and in addition,

Coal lost in handling and mechanical preparations.

In his paper, Mr. Krupinski described in detail longwall systems with complete caving and partial packing in thin seams. He also gave an explanation of the wing and pocket systems used in medium-thick seams and of the hydraulic stowage systems used in seams over 3.5 metres thick. By adopting more modern mining methods, which were better adapted to the conditions, it had been possible to ensure the best recovery of coal, estimated at 95 per cent; in seams 6 metres thick it amounted to 88 per cent.

By using mining systems with hydraulic stowage it had been possible to fight efficiently the danger of underground fires and to achieve full recovery of very high seams reaching a thickness up to 22 metres.

It had not been possible as yet to estimate the influence of mechanization on the degree of recovery of coal. A quicker advance of fully mechanized coal face operations had a positive influence on roof control and higher concentration of working places, and should result in better recovery.

Mr. DIXEY presented an experience paper which had been prepared by H. H. Wilson on "Longwall Mechanization in Britain and the Development of Machines for 'Continuous

Mining'." According to that paper, the application of machinery to the Longwall system of coal mining had certain disadvantages; in particular, it involved the use of large teams of men, with a consequent loss of individuality, which led to a decrease in production. Furthermore, it was necessary to develop interdependent cycles of work extending over twenty-four or forty-eight hours. During that period, the work automatically separated into a series of separate operations: coal cutting and preparation, loading, conveyor moving, and ripping. Each operation was to a large extent dependent on the work done on the preceding one, making successful co-ordination difficult, especially where attendance was irregular. The author examined the repercussion of those factors on the workman and stressed their importance.

He then pointed out that the objective should be the elimination of as many individual operations as possible, so that mining could be carried on continuously. Probably the most notable advance in that direction had been the development in Germany during the war of the "Kohlenhobel" or coal plough. That consisted of a specially designed plough with a cutting edge and share which, when pulled along by means of a rope, sheared or planed a narrow strip of 11 in. of coal off the face and loaded it onto a conveyor. Simultaneously with those developments in Germany, the thoughts of British engineers had been directed towards the design of a machine on somewhat similar principles; but whereas the German engineers had concentrated on the use of rope-pulling equipment, British designers had investigated the possibility of a machine incorporating a power-driven wedge. Rope-pulled equipment could only have a limited application in Great Britain.

As a result of intense experimental work, a power-driven machine, "the Samson stripping machine", had been developed in Britain. The author described its main characteristics. With machines of that type, there was no cycle of operations, each shift following on where the preceding one stopped. Continuous mining of coal was thus possible. Elimination of cyclic operations together with replacement of the monotony and drudgery of hand filling by more interesting work that provided greater scope for personal skill and iniative, might improve the outlook of the miner and lead to better co-operation and improved relations between employer and worker.

Mr. Barraclough introduced the communication prepared by Mr. H. S. Frost on "Strip Mining in India". According to that paper, the method of stripping the overburden which covered the coal deposits by means of heavy mechanical plant and leaving the coal to be removed by hand labour was not entirely new in India, but had only been attempted on a large scale at Bermo in Bihar.

On sites where the overburden was of a soft nature and free from stones, and where the site was of a sufficient area to permit of easy gradients and where the excavated material could be tipped within an economic distance of approximately 1,000 ft., the cheapest method to employ would be the tractor and scraper.

The top soil was taken off the land by high-powered caterpillar tractors and scrapers, which peeled the turf and soil from the surface, at the same time loading it into self-contained boxes and transporting it clear of the working area, where it was mechanically unloaded on the spoil banks.

Alternatively, a mechanical loader of the Euclid type could be used in conjunction with the Euclid tipping lorries if the haul was of greater distance than that stated.

Neither of the methods, however, appeared to be economical or generally practical, owing to the layer of stone between the soft overburden and the coal face.

On sites where both soft overburden and rock had to be removed, and where it was possible to discharge the excavated material in spoil banks within the operating circle of the boom without any further handling or removing, the mechanical Dragline Excavator should be used. Those machines should have a bucket capacity of not less than three and one-half or more, preferably five cub. yards, with a boom of not less than 150 to 180 ft.

Mr. Hebley summarized his experience paper on the mining methods employing the room and pillar system in seams varying in thickness from 36 to 120 in. Attention was drawn to the difference in definition between the use of the word "mechanization" in the United States and in Europe. In the United States, stress was placed on the use of heavy-duty, high-speed machines for cutting, drilling, loading and transportation of coal. It was important to keep the machines in active operation a maximum percentage of the cycle time. The paper described what had been achieved in the field of continuous coal mining and the advantages of that kind of operation.

The Chairman opened the discussion on the communications which had been submitted and called on Mr. Cheradame to address the meeting.

Mr. Cheradame gave a brief survey of the development of coal-mining methods in France.

At present the main objective was not to increase the total production of the country or even to increase the proportion of seams that could be worked as compared with those that could not, but rather, in view of the importance of economic and social factors in the mining industry, to lower the production cost per ton of coal and to increase the productivity of man-power.

France had first tried to solve the problem by developing mechanization. As early as 1944, it had endeavoured to benefit by the methods used in the United States and the United Kingdom, and some mines had been supplied with the most up-to-date equipment. Success, however, had not been as marked as in American mines, because mining conditions were much more difficult in France.

The best results had been achieved in France by the utilization of the type of machine described by Mr. Hebley, though smaller in size.

The desire to reduce the cost of production and the necessary amount of man-power had led to priority being given to research on the use of new explosives. Mr. Cheradame laid particular stress on that development. No explosive was completely safe; on the other hand, it was obvious that the objective could not be attained by means of ordinary explosives. Another solution, therefore, had to be sought. Efforts had been made in the manufacture of explosives to increase their safety at the expense of their power, so that they should be less dangerous when fire-damp was present. France had followed with great interest the use of *cardox* in the mines of the Saar.

Moreover, the solution adopted in any country should meet the conditions prevailing there. Present mining conditions should take into consideration to a greater extent the importance of psychological factors. Machinery, for example, reduced fatigue among the men, and a worker would be more proud of operating a complicated machine than of doing simple and tiring manual work. That was the principal advantage.

Mr. IGNATIEFF said how interested he had been in the papers read to the section. He made it clear that the constant increase in American production was due not only to advanced mechanization and an extremely good transportation system but also, and above all, to excellent organization.

It had been proved that high output depended to a great extent on the presence of favourable mining conditions. In Canada favourable conditions were very rare. The seams were not horizontal; they most closely resembled the deposits in the Western states of the United States of America or the anthracite deposits in Pennsylvania. For that reason the use of large machinery did not give such good results in Canada as in the United States; it was better to employ lighter machinery. That was why the Canadian Department of Mines had followed with great interest the studies carried out by the U.S. Bureau of Mines with a view to evolving lighter machinery suitable for mining coal-seams with an acute angle of dip. It was hoped to diminish the coal lost in working such seams.

Mr. Ignatieff emphasized that he had been very interested in that part of the paper prepared by Mr. Krupinski which dealt with the mining of thick seams and described the mining methods in use in Canada.

Mr. ASHLEY drew attention to the fact that the increase in output per man in the American mines was due to competition from other energy-producing sources such as petroleum, gas and hydro-electric power, so that increased output was a vital question for the American coal industry. At the beginning of the century coal had constituted 92 per cent of resources in energy, whereas it did not now constitute more than 46 per cent. In order to compete with other sources of energy, the coal industry was obliged to reduce working costs, which accounted for the use of machinery.

The question arose as to how the use of machinery affected the percentage of coal mined. The most optimistic forecasts of potential coal resources in both Canada and the United States had been made about thirty years ago, but revised estimates had been made now that showed it was possible to foresee the exhaustion of the deposits currently being mined. It had been found that in the United States potential resources constituted barely one-seventh, and in Canada one-tenth, of those previously estimated.

Mr. HEBLEY underlined the difference between mines worked by the State and those worked by private companies. In the latter the main object was to reduce the production costs per ton. In the former the Government tried to adopt a policy the primary object of which was to conserve the country's resources. In certain American mines, in the Appalachian mountains for example, 85 per cent was considered a high rate of recovery for coal, where in Indiana and Illinois the average rate was 50 per cent. Consequently, the advantages of mechanized mining were costly from the point of view of conserving resources. The current tendency was to encourage mining companies to use methods which would enable a higher rate of recovery in the United States.

Mr. BARRACLOUGH emphasized that in view of the mining conditions prevailing in India, the social welfare measures which employers were legally obliged to take imposed such a financial burden on the companies that it was impossible, for example, for them to build up reserves against times of crisis. The State alone could do that in view of the enormous expense involved.

Mr. BAYLESS supported Mr. Ashley's statement that one of the main objectives of the coal industry in the United States was to reduce production costs, and explaining that mining methods necessarily varied with the quality of the seams which were being mined. In Wyoming, for example, the dip of the seams varied between 4 degrees and 47 degrees.

He stressed that speedy results must not be expected from complete mechanization. It should be noted that apart from the time necessary for training miners in new methods of mechanized mining, the economic possibilities of complete mechanization were dependent to a large extent on the quality of the seam, the situation of the mine and other similar factors. The so-called "room and pillar system" to which Mr. Krupinski referred in his paper was already in use in Wyoming.

With regard to recovery, Mr. Bayless stated that it was greater when mining was carried on towards the bottom rather than towards the top of the seam. In Wyoming that method had made it possible to recover from 50 to 92 per cent.

Mr. DIXEY pointed out that the difficulties which lay in the way of complete mechanization in Canada, and which arose from the quality of the seams, also existed in the United Kingdom.

On account of the existence of large or small faults and the hardness, depth and dip of the beds, mechanization could only be applied to a very restricted extent. Special machinery had to be built to meet the particular nature of the beds worked. Furthermore, mechanization involved re-adaptation of the miners and that was a question of time. Nevertheless it was reasonable to predict an increase in coal production in the United Kingdom.

He was surprised that the ratio between the "overburdens" and the beds worked was only two to one in India. In the United Kingdom and the United States the ratio was ten to one.

Mr. BARRACLOUGH recalled that the Conference was called upon to study the problem of the conservation of resources and stated that the three factors governing coal production, namely, maximum output per shift, low cost of production and maximum recovery, were conflicting. For example, low production costs were incompatible with maximum recovery.

He explained that in India the output was very low: one-third of a ton per man-day. An increase in production would therefore necessitate a considerable labour force, which in turn would result in high expenditure of a general nature on social services etc. Since the coal industry in India was not in a position to meet those general expenses, it was faced with the necessity of applying mechanization while utilizing an untrained labour force. In view, however, of the danger of explosions and underground fires involved in mechanization on account of the great depth and thickness of the seams, hydraulic sand stowing had been employed. That involved a twenty per cent increase in production costs.

Lastly, Mr. Barraclough stated that, in his opinion and contrary to what Mr. Krupinski had said in his paper, the "pillar" method was less expensive than the "Longwall" method.

Mr. NIGHMAN stated that in Poland hydraulic sand stowing had led to a ten per cent increase in production costs for a seam at a depth of 360 metres with a dip of 36 degrees. The sand had been brought from a place 15 km. away from the mine.

Mr. HEBLEY recalled that sand stowing had originally been used in anthracite mines. In Poland a new and ingenious method had been found for using materials existing near the mines.

Mr. C. J. Potter stated that the exchange of views among people from countries where different mining methods were in use was extremely valuable. He warned Canada and other countries not to be deluded by an increase in production due to mechanization alone. The real problem was how to remove the coal which had been mined. In the United Kingdom, for example, two out of every three men were employed on removing the coal. If the methods of removing the coal were revised, output per man employed in removing the coal would increase by 250 per cent in the United Kingdom and 500 per cent in Poland.

Mr. Potter suggested that all those interested in the mechanization methods in use in America should study how the coal was removed rather than how to increase by mechanical means the actual amount of coal mined.

He concluded by recalling that in the United States production costs rather than conservation were the primary preoccupation. Conservation, however, was a problem which could not fail to arise in the United States, and the methods employed in that connexion by other countries would be of great use.

The CHAIRMAN thanked all the speakers who had taken part in the discussion and stated that the problem of conservation which the Conference was called upon to study could only be solved by taking into account the conditions peculiar to each country or to each region.

Coal Preparation

24 August 1949

Chairman:

P. E. Cavanagh, Assistant Director, Department of Metallurgy, Ontario Research Foundation, Toronto, Canada

Contributed Papers:

Preparation of Coal in America
Thomas Fraser, Supervising Engineer, Coal Preparation Section, United States Bureau of Mines, and
H. F. Yancey, Supervising Engineer, Northwest Experiment Station, United States Bureau of Mines, Seattle, Washington, U.S.A.

Studies on Coal-Washing in France
R. Cheradame, *Directeur adjoint*, and
R. Saint-Guilhem, *Directeur technique*, Centre de recherches des charbonnages de France

The Conservation of Fuel in Britain by Improved Coal Preparation
Arthur Grounds, Chief Coal Preparation Engineer, and
L. W. Needham, Divisional Coal Preparation Engineer, National Coal Board, London, England

Mechanical Preparation of Coal and its Utilization
Tadeusz Laskowski, General Director of Polish Institute of Fuel, Katowice, Poland

Summary of Discussion:

Discussants:

Messrs. Yancey, Cheradame, Lee, Driessen, Bird, McCulloch, C. J. Potter, Newman, Ignatieff

Programme Officer:

Mr. J. H. Angus

Preparation of Coal in America

THOMAS FRASER

ABSTRACT

It is a major function of coal preparation to free the production branch of the industry from serious concern about the quality of the raw product. With preparation facilities to condition the coal for market, the mechanization of production may proceed without restraint toward the goal of economical and complete extraction.

Another great service that may be contributed to our economy is the expansion of coking coal reserves. Much may be accomplished by the application of improved cleaning methods to the large reserves of potential coking coal heretofore considered unsuitable because of impurities.

Both of these functions represent important contributions to the economy of the coal industry and the nation.

Preparation, functionally, occupies the strategic middle position in the series of consecutive operational steps that constitute the coal industry — production, preparation, and utilization. With the production and utilization branches of the industry pressing ahead independently on such revolutionary developments as "full-seam recovery" and "continuous mining", on the one hand, and on complete gasification and liquefaction, on the other, the task of preparation is to co-ordinate the activities of these two other main branches of the industry toward the common objective of employing our fuel resources with maximum economic effectiveness. It is this strategic functional position of coal preparation that offers the greatest opportunity for service; moreover, such opportunity will multiply as new techniques of production and utilization evolve and diversify.

ELIMINATION OF COAL LOSSES

In current American experience, direct savings of fuel creditable to coal preparation are mainly in the field of fine coal recovery. In early coal-production practice, only the lump coal was utilized. Correction of such wasteful practice has been an evolutionary development of a hundred years or more and it is still in progress. The Water Resources Board of the State of Pennsylvania reports that this year will see the end of discharge of fine coal to the streams of the Anthracite Region. In 1927 the loss in that item alone was estimated at 1 million tons a year. (1) [1]

Similar savings are being made in the bituminous fields by application of more effective water-clarification and coal-recovery equipment in the preparation plants. Improvements in progress will facilitate recovery of large tonnages of coal in washing sludges formerly wasted at many preparation plants. Throughout the industry there is a widespread movement toward recovering all fine coal by closing the water circuit. This general movement has been brought about by a combination of the pressure of higher coal prices, public consciousness of stream and air pollution, and technical improvements in coal preparation. For example, the cyclone developed in the Netherlands to thicken heavy medium has been adapted in the United States as a device for recovering fine coal from washery water. (2)

Another important opportunity for economy is the direct saving of fuel by tightening controls on washery rejects. From the conservation viewpoint, this is an attractive feature of the new heavy-medium washing processes. Although a small improvement in the average percentage of coal in the refuse may appear trivial in the individual case, the total national saving becomes important when we think of the 600 million tons of coal, more or less, consumed each year. (3)

RELATION OF PREPARATION TO NEW MINING METHODS

Probably the most important duty of preparation is to support the production branch in pushing ahead with the application of large-scale, mechanical, material-handling techniques to the mining of coal. While the record is not entirely clear as yet with respect to the effect of mechanical mining development on the percentage of extraction, it hardly seems possible that the facility for extremely rapid extraction and for complete recovery, regardless of the effect on raw-coal quality, will not ultimately be reflected in a greater percentage of extraction of available reserves.

In the pioneer period of mechanical mining, not so long ago, progress was hampered by problems in co-ordination of haulage and of preparation as well as in the direct development of the mining equipment and techniques. Today, mechanization of production can proceed with confidence that we have the preparation plants, or if not the plants the knowledge to build the plants, to handle whatever is delivered to them.

Some measure of the importance of this service is indicated by the record of washery operations at mechanized mines and full-seam mining operations. Typical data on four such operations reported by Anderson are shown in table 1. (4)

Table 1. Increase in Refuse Loaded with Raw Coal after Mechanization of Mining Operation, as Indicated by the Preparation Loss

Mine and location	*Preparation loss, per cent* *Before mechanization*	*After mechanization*
A. Illinois	10.8	11.4
B. West Virginia	10.0	31.7
C. Pennsylvania	15.0	27.6
D. Ohio	21.8	35.9

PREPARATION OF COKING COAL

It is only natural that the major concern in conservation of reserves is focused on coking-coal supply, for our reserves of this class of coal are vastly less than our reserves of fuel coal, and it is in this special field that preparation practice has rendered great service.

Coke ash bears a definite relationship to coke consumption and the rate of pig-iron production in the blast furnace. A

[1] Numerals within parentheses refer to items in the bibliography.

clear-cut example of the economy of washing metallurgical coal and the interrelationship between mechanical mining and mechanical preparation is afforded by the experience of a blast-furnace plant in the Chicago area in changing from raw to washed-coal supply. Over a period of some ten years operation with raw coal, the coke ash gradually increased from 8.0 to slightly over 12.0 per cent and the resulting coke consumption increased from 1,550 to about 1,925 lb. per ton of pig iron. Following the change to washed coal, the coke ash decreased to an average of about 9.5 per cent and the coke consumption fell to 1,775 lb. per ton of pig iron.

Such improvement in blast-furnace practice creditable to coal preparation has the effect of increasing the reserves of coking coal through more efficient use. However, the major future role of preparation in increasing our reserves of metallurgical coal, and a spectacular role it promises to be, lies in applying the new heavy-medium processes to low-gravity separations of coals heretofore considered unamenable to beneficiation. Large-scale developments in this direction are now under way to bring into the metallurgical-coal classification the tremendous reserves of Pittsburgh-bed coal in Greene and Washington Counties in Pennsylvania that formerly were barred from metallurgical use by their high sulphur content. Only the comparatively recent advent of heavy-medium cleaning in America, coupled with improved table practice provided by classification of the feed, has made such a venture possible.

Most critical of all, the low-volatile coals adapted to two-way and three-way blending to obtain the most effective coking mixtures, merit the most intensive preparatory treatment. Investigations have demonstrated that some deposits not now used for coking can be improved sufficiently for metallurgical use by skilful preparation. (5)

DECENTRALIZATION OF COAL INDUSTRY

Every national emergency emphasizes the need for wider geographical dispersion of coal production and forces some progress in this direction. In war time, overloading of the transportation system renders shortening of the coal haul a vital necessity. Moreover, current planning features decentralization to render each locality as nearly self-sufficient industrially as possible.

In areas where competing fuels are costly, preparation can play a major role in adapting local coals to industrial use by applying specialized cleaning treatment that otherwise might not be economically justifiable. Substantial developments of this kind have been made in the use of the cretaceous and tertiary coals of western United States and Alaska. In the past decade there has been a notable expansion in the use of local coals throughout the hemisphere.

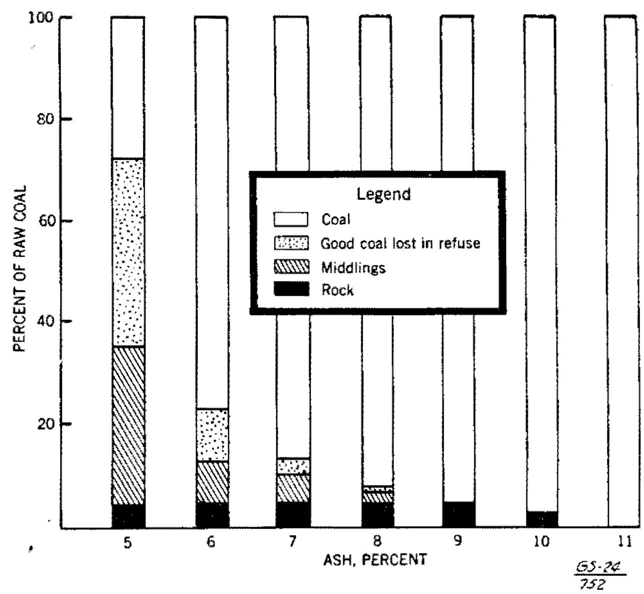
A spectacular example of such accomplishments is represented by the wartime development of a coking-coal field in southern Brazil. (6) By a very difficult washing operation, the high-ash coal of the Barro Branco bed in Santa Catarina is separated into two market grades; the cleanest of these, of very strong coking power and ranging from 17 to 19 per cent in ash content, has proved suitable for blast-furnace use when charged with the low-silica Minas Geraes ores readily available to the National Steel Plant at Volta Redonda.

The variety of ranks and grades of coal reserves widely scattered throughout the hemisphere offers a challenge to the coal industry of the future to develop adequate sources of fuel. There is hardly an important area even in Latin America, once considered deficient in fuel reserves, that is not supplied by nature with adequate deposits of coal of one kind or another. (7)

TRENDS IN PREPARATION OF FUEL COAL

Currently, the authors believe there is a discernible divergence in practice between the preparation of process coal (coking coal and the like) and the preparation of fuel coal.

With the wide diversity of ranks and qualities of coal abundantly available on a very competitive basis, no general conception of a standard of fuel-coal quality could have been expected to develop here during the period when coal was used in the unwashed state; but now, with the rapid rate of mechanization of coal preparation, attention is shifting to uniformity of coal quality. In the interest of conservation it might appear justifiable to try to establish standards for fuel-coal quality now, but probably it will be more effective in the end to rely upon the general evolution of the situation to bring about a more rational criterion of fuel value. In the future, with the changing relation of reserves to fuel demand reflected in the price structure, and a rapid expansion of national coal-preparation facilities to the saturation point, it is to be expected that standards of fuel quality will crystallize around the concept of uniformity at a fairly high-ash content consistent with complete recovery of combustible matter. In view of the long-term advancing price trend, it is to be expected that America will follow the pattern of European development in this regard. The economic loss entailed in progressive ash reduction by washing increases very rapidly in the range below the optimum point; for industrial fuel use, the range of economic washing is rather sharply defined. The importance of this factor in the cost of overpreparation is illustrated by the graphical presentation of the conversion losses to be expected in washing a typical Pittsburgh fuel coal.



Bureau of Mines, U. S. Department of the Interior

Figure 1. An example of the economic aspects of over-cleaning, showing the preparation loss for successive increments of ash reduction

SUMMARY

The obvious summarizing statement is that, while the aggregate value of direct fuel saving such as salvage of fine coal and refuse recleaning is recognized, the major role of coal preparation is in its function as an integral part of a constructive program of effective production and utilization of remaining reserves.

The most important duty of preparation is to support the production branch of the coal industry in pushing ahead with the application of large-scale, mechanical, material-handling techniques in the mining of coal. Today mechanization of production can proceed with the confidence that available preparation technique is adequate to treat effectively whatever is produced by the mine.

Our reserves of metallurgical coal can be increased by applying the improved preparation methods now available to bring into the coking-coal classification the vast reserves of coal heretofore considered unamenable to beneficiation.

In areas where competing fuels are costly, preparation is a factor of importance in adapting local coals to industrial use by applying specialized cleaning treatment that elsewhere might not be economically justifiable.

Preparation of fuel coal should emphasize complete recovery of combustible matter.

Bibliography

1. J. D. Sisler, T. Fraser and D. C. Ashmead, *Anthracite Culm and Silt*, Pennsylvania Geological Survey 4th Series, Bulletin M-12, 1928, 268 pages.
2. H. F. Yancey and M. R. Geer, "The Cyclone as a Thickener of Coal Slurry", American Institute of Mining and Met. Engrs., Technical Publication 2351, 1948, 16 pages.
T. Fraser, R. L. Sutherland and F. F. Giese, *Performance Tests of an Experimental Installation of Cyclone Thickeners*, presented at the annual meeting of the American Institute of Metallurgical Engineers, February 1949.
D. A. Dahlstrom, *Cyclone Operating Factors and Capacities on Coal and Refuse Slurries*, presented at the annual meeting of the American Institute of Mining and Metallurgical Engineers, February 1949.
3. J. D. Martin, "Coal Losses in Washery Rejects", *Mining Congress Journal*, vol. 33, November 1947, pages 44–46.
4. R. L. Anderson, "Full Seam Mining with Mechanical Loading", *Mining Congress Journal*, vol. 33, May 1947, pages 41–44.
5. W. L. Crentz and Thomas Fraser, *Preparation Characteristics of Maryland Coals*, U.S. Bureau of Mines Bulletin 701, 1947, 65 pages.
6. J. A. Good, A. P. Abreu and T. Fraser, *The Coal Industry of Brazil*, U.S. Bureau of Mines Technical Paper 713, 1949, 38 pages.
7. T. Fraser, *Coal in South America*, Pan American Institute of Mining Engineering and Geology, Technical Paper 6, 1948, 16 pages.

Studies on Coal-Washing in France[1]

R. CHERADAME and R. SAINT-GUILHEM

ABSTRACT

Accurate knowledge of the operation of washeries is essential in France, because of the very high ash content of the raw coal, and the extensive programmes for modernization of equipment.

A study has been made of the numerical data (curves and coefficients) that would contribute most to such knowledge, stress being laid on the relationships between them, in accordance with the laws of granular dispersion.

Complete measurements for thirteen machines washing fines by various methods showed what these laws are in practice. They also show that, on the average, these methods may be classified as follows in descending order of washing efficiency: plunger-jig, rhéolaveur washer, pneumatic tables. Further measurements which are being made will make it possible to confirm this result, and to compare several machines of the same type.

New techniques are also being studied. It has already been established that centrifuging in a dense liquid, especially in a cyclone, may give far greater accuracy and stability than previous techniques.

French coal has a very high ash content, owing both to the nature of the deposits and to the mining methods developed: the average ash content of raw coal from the mines is of the order of 30 per cent. The importance of washing[2] is increasing in our country, and extensive projects for the development and modernization of washing equipment are under consideration. Important researches have been undertaken in this connexion, which should lead to a considerable improvement in the useful output.

The nature of our coal and our small reserves demand maximum utilization of waste constituents. Consequently, French mines generally separate raw coal, in the various sizes, into three products: washed coal, mixed coal, and a residue called shale.

Since the average and maximum ash contents are, for every consumer, economic factors depending on the intended utilization and existing prices, the commercial service, by its appraisal of available markets, imposes these factors on the washeries. This information and the composition of the raw coal determine the choice of types: mixed-washed and mixed-shale.

But the greater the flexibility and accuracy of the washing process, the greater is the yield in quality and quantity of commercial products. The more economical it is, the more certain commercial products can be reduced in price and made acceptable, other things being equal, to a purchaser, with a resulting increase of saleable products from a given output.

The researches of the French coal-mines have the following three objectives:

(1) *Accuracy:* In a lot leaving the washing plant, the theoretical ash content of which is between C_1 and C_2, there are a certain number of pieces with a content of less than C_1 or more than C_2.

The number of these "strays" must be reduced: the former are not properly utilized, or are even lost if the lot is sent to the spoil-heap. The latter are costly for the user, either because he has made a more liberal allowance of plant in order to take them into account, or because he suffers a loss of output through their use.

(2) *Flexibility:* In practice, the same washing machine

[1] Original text: French.

[2] The term washing is used in the widest sense to mean mechanical preparation of coal, whether by air, water or dense liquids etc.

should both absorb varied types of raw coal and produce commercial coal of varying specification. The accuracy of the machine must therefore be considered, not for a standard type of raw or commercial coal, but as a whole.

(3) *Economy:* The main economic considerations in France are reduction of the capital expenditure per ton processed, reduction of operating personnel and use of improved plants which are easier to supervise and maintain. The consumption of power, dense liquids etc. are further factors which vary according to the coal-field.

The problem thus stated leads us to consider the following problems:

1. *Choice of a scientific method of washing control:* Replacement of the rough and deceptive control system by a few sample measurements of the ash content of the products obtained, which were until recently considered adequate by most plants.

2. *Determination of the efficiency of washeries:* Determination of the results of various washing operations by as many measurements as may be required. Deduction from these data of the importance of each factor in efficiency: intrinsic suitability of the process and suitability to the coal treated, according to its characteristics at a given moment and their variations, influence of wear and tear and imperfect adjustment.

3. *Research on improvements in efficiency:* Leaving each mine to choose the process best adapted to its particular needs, study and promotion of methods to improve equipment, and estimation of the advantages and disadvantages of new washing methods devised by others or by ourselves.

This is a very extensive programme. Some results have recently been achieved: there is still much to be done.

METHOD OF WASHING CONTROL

We consider here the density of the elements, a factor which is involved in nearly all the present separation methods. Adaptation to other cases presents no difficulty. What are the quantities to be measured?

After a theoretical examination of all those proposed by the experts, we decided on the following:

1. Raw coal of a given size to be processed in a machine is defined by the law of its composition in relation to its density, — elementary composition by elementary interval of density — or by over-all composition, i.e., weight as a function of the density d of the fraction of density less than d; this integral of the elementary composition is the conventional washability curve.

2. The products obtained by washing the raw coal can be completely defined by the curves corresponding to the same definitions. If washing were perfect, these would be portions of the curves for the rough coal merely transposed by changing the unit. As this is not the case, they are new curves showing the efficiency of the operation.

Another presentation is the "separation curve", which gives the proportion of each rough lot emerging as an end product.

3. When it is sought to define the result of washing by a single quantity, the following are the most important:

(*a*) Equivalent cutting density: this defines complete separation, giving the same proportions of the two end products as the incomplete separation considered;

(*b*) Separation density: when the lot is equally divided between the two end products. This is also the value for which the total of strays in the two end products is smallest (it is the abscissa of the ordinate point which is ½ of the separation standard);

(*c*) Probable variation: half the difference of the densities of the raw pieces of which 25 per cent and 75 per cent respectively emerge in the two products;

(*d*) Area of error: measures the total difference between theoretical separation and that achieved by the machine; it is proportional to the probable variation in most cases;

(*e*) Calorific yield: ratio of calorific value of the products obtained (washed + mixed) to that of the raw coal;

(*f*) Organic yield: ratio of the weight of washed coal obtained to the weight, of the same average ash content, that would be obtained by complete washing;

(*g*) Error due to strays: number of strays (equal by definition) produced in each of the two products by the lot corresponding to the equivalent cutting density.

From these definitions we have deduced methods of determining each of these curves and coefficients, all of which have their own particular interest.

But there are relationships between them which are dependent on the law of separation, hence on the machine, and on the composition of the raw coal. A knowledge of these thus makes it possible to simplify control. Consequently, such knowledge has been the main objective of the first series of experiments.

STUDY OF WASHERS IN OPERATION

This is to be the subject of several series of experiments. The first, which is the only one completed, had the following limited objectives: to reduce the scope of the problem, to perfect methods of control and, as already stated, to study their simplification. The series of experiments was conducted on 13 washers of fines (usually 0 to 10 mm. screened coal), consisting of 8 plunger jigs, 2 rhéolaveur washers, 2 pneumatic tables and 1 flotation tank.

This work led to the following conclusions:

(1) The separation curves closely follow Gauss' law, provided that the following are taken as variables:

For dense liquid machines: the density of the products;
For plunger-jigs and rhéolaveur washers: Log (d-1);
For pneumatic machines: Log d.

In the last two cases, this result seems to indicate that the difficulty of separating two particles varies as their relative difference of apparent density at the centre.

These curves do not appear to depend much on the washability curve of the raw coal when the machine is well adjusted.

(2) Accuracy varies considerably from one machine to another, even when they are of the same type:

Pneumatic tables: probable variations 0.15 to 0.50;
Rhéolaveur washers: probable variations 0.10 to 0.30;
Plunger-jigs: probable variations 0.07 to 0.30.

(3) If the probable variations V are graphically represented as a function of $s_d - 1$ (s_d being the separation density) for all tests on machines using water, it will first be observed that the points roughly correspond to a straight line proportional to $s_d - 1$.

Thus it appears that comparison of the efficiency of two machines may be based on the values of $\frac{V}{s_d - 1}$.

The variations in this ratio, including those for constant value of V, are due, in our opinion, first to the process used and then to the operating conditions. In particular, adjustment is inadequate and causes wide probable variations in machines that are overloaded or are processing irregular coal.

(4) In plunger-jigs the probable variation is generally much greater for small pieces than for large.

(5) In calculating the losses in organic yield, which depend on the washability curve, the cutting density and the probable variations, wide differences are to be found:

In wash-mixed coal separations, which in practice correspond to cutting densities of 1.5 to 1.7, they differ considerably and sometimes exceed 10 per cent.

In mixed-shale separations, corresponding to cutting densities of 1.9 to 2.2, they are usually less than 2 per cent.

To these losses correspond calorific losses which are partial in the first case, when the greater part of the stray washed coal will be burnt with the mixed; total in the second case; and always involve a loss in earnings for the undertaking.

A second series of 20 to 30 experiments will begin about April 1949.

CENTRIFUGING IN DENSE LIQUID

Several techniques based on this principle are being studied in our laboratories. Valuable results have already been obtained on cyclones of the type mentioned in various Dutch and American works; they may be summarized as follows:

(1) The general configuration of the cyclone and the injection pressure have little influence on the efficiency of separation. On the other hand, the shape of the shale outlet diaphragm plays an important part: there must be a tubular part projecting into the cylindrical part of the cyclone.

(2) The largest size of raw coal that can be processed is not technically limited, and it will increase with the dimensions of industrial machines. A lower limit does exist, but it is very small: in a large diameter cyclone of 150 mm. we were able to process fines of 0.30 to 0.45 mm. with a probable variation in density of only 0.1 (baryte medium).

The raw coal washability curve has practically no influence on the law of separation as a function of density. This closely follows Gauss' law.

(3) The cyclone is capable of a considerable output in proportion to its size: with a cyclone of 150 mm. diameter we treated as much as 2 tons per hour of raw coal for 6.5 cub. metres per hour of medium.

(4) The three essential constants governing the operation of a cyclone are the density of the inflowing medium and the diameters of the two outlets: jet and diaphragm.

From the curves giving the density of the media flowing out at the jet and at the diaphragm and the separation density as a function of that of the inflowing medium, and from graphs of the probable variation values as a function of the separation density and of that of the medium, very clear conclusions can be drawn: to obtain good separation, the cyclone must be prevented from thickening the medium; this can be accomplished by feeding in a medium of density slightly lower than the separation density required (0.1 to 0.2) and by suitably adjusting the outlet orifices (diameter of the jet slightly less than that of the diaphragm). In these conditions, the influence of the various constants is slight and operation is stable.

FIGURE 1

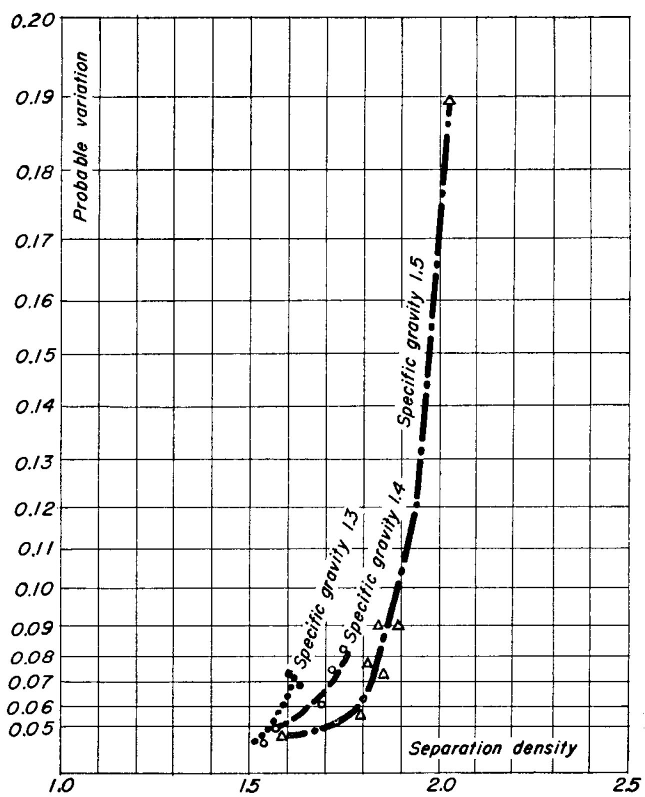
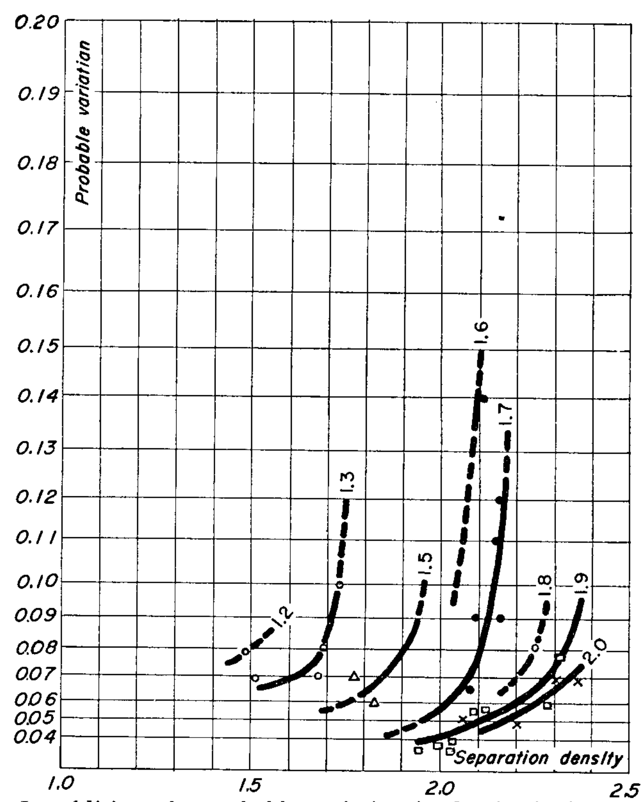


FIGURE 2



In addition, the probable variation in density is then excellent: with the shale and baryte media it does not exceed 0.06 for separation densities less than 1.75 and 2.25 respectively (see figures 1 and 2). In other words, the cyclone makes it possible to process coal of 0.5 to 10 mm. with probable variations two or four times less than those resulting from other fine-washing methods, which is equivalent to calorific losses that are four to sixteen times lower.

The programme for the coming months includes the continuation and confirmation of studies on mine washeries and centrifuging and a new method of adjusting plunger-jigs. We are also working on a system of continuous ash regulation.

But advantage is already being taken of the partial results obtained in the negotiations for new washeries to be constructed and the yields to be obtained therefrom.

The Conservation of Fuel in Britain by Improved Coal Preparation

ARTHUR GROUNDS and L. W. NEEDHAM

ABSTRACT

Losses occasioned in former times by the inefficient hand-cleaning of large coal and consequent loss of coal in the dirt are now being avoided by the use of dense-medium systems of mechanical cleaning. Useful "middlings" fractions are being separated which can be crushed and used direct as boiler fuel or rewashed for the release of a further quantity of coal. For coals of easy washability characteristics, existing washers are being adjusted to deal with larger sizes than formerly, again saving loss of coal in the dirt.

The number of sizes of coal marketed is being reduced to seven basic sizes, with tolerances to allow of variation in breakage characteristics. The very fine coal, previously lost as effluent from washeries or because of its high ash content, is now being treated by froth flotation to give a high-quality clean coal which can be blended or dried separately for use as pulverized fuel. Short-term measures include alteration of washing plants to cope with increasing dirt content and to allow larger sizes to be washed. Improved lighting leads to greater efficiency in hand-cleaning of coal. A probable saving of 2 to 4 per cent of our coal resources will follow adoption of these measures.

The methods in use at most British collieries for preparing market products from the raw coal brought to the surface, namely, cleaning by hand-sorting for the sizes over about 3 in. and simple mechanical washing (with dry cleaning in a minority of cases) for the under 3 in. coal, were chosen when clean seams were being mined by hand-getting methods and when labour was cheaper and easily available, and also when the value of coal, especially of small coal, was much lower.

The situation is now very different. Many of the seams being worked contain bands of shale and inferior coal; mechanized mining, easily justified on general grounds, nevertheless results in less discrimination underground and in a larger proportion of shale and of small coal in the run-of-mine product; labour is more costly and less easily obtained. Moreover, the general decline in output has emphasized the importance of the utmost possible recovery of useful coal from the raw material delivered to the preparation plant.

As a result of these changes the equipment — screens, picking belts and washers — originally provided and still, perforce, in use, is working under very disadvantageous conditions at many collieries and considerable losses of coal occur in consequence. Some of the coals contain too much shale and particularly too much inferior coal or "middlings" for hand-picking to be really satisfactory, even if adequate labour were available, and many washers are overloaded with shale and cannot be relied on to give clean coal products of the right quality or of uniform quality. In addition, most of the cleaning plants were installed without proper equipment for dealing with the finest sizes and a serious loss of fine coal occurs in them. When the plants were built, this loss was much smaller and the fine coal also had a very low value.

In the past, also, in an effort to satisfy customers' demands, a very great variety of sizes and grades of coal has been prepared and too little effort has been made to utilize the combustible material in inferior middlings products. Thus market requirements have been met only at the cost of a considerable, and, from the national point of view, a very serious waste of heat units in coal. It is now widely recognized that such a state of affairs cannot be allowed to continue and that changing it will involve the closest co-operation between coal producers and users. The attitude of those responsible for coal production and preparation can only be that all useful combustible matter should be recovered. If this should result in changes in the market products available, the technique of coal utilization, and chiefly that of combustion should be changed accordingly. No other attitude seems possible: first, because coal is a natural product, unalterable in its fundamental characteristics; and second, because it is a wasting asset. Users of coal, on the other hand, are showing more appreciation of the fact that coal is a naturally occurring material and that not only the most conveniently used grades can be produced, and have to be sold. They stress, quite reasonably, that the coals available should be prepared for the market so as to give the maximum possible uniformity of quality so that consumers know what to expect and adapt their apparatus and processes accordingly.

The above paragraphs provide the background to the present situation. What is being done in coal preparation to meet the difficulties mentioned? The efforts being made can be described under three headings:

(*a*) Mechanical treatment of large coal.
(*b*) Proper treatment of fine coal.
(*c*) "First-aid" measures until much new equipment is available.

MECHANICAL TREATMENT OF LARGE COAL

The advent, in recent years, of the "dense medium" or "float and sink" processes for coal cleaning has made it possible to extend mechanical treatment of the coal, previously common for 3 in. to 0 sizes, to the large coal as well and to visualize "run-of-mine" coal washers treating the coal as it comes out of the pit. There are several of these processes but only their common features are of interest for the present purpose. They all employ a suspension of a finely ground mineral in water in such a way that it acts as a heavy liquid in which coal will float and shale sink. By a suitable choice of suspensions and apparatus, the raw coal can be subjected to a "three-product" separation, giving clean coal, "middlings", and shale. The middlings product can be used as an inferior fuel, or crushed and re-treated if doing so will liberate good coal from it.

The effect of these processes is that a large labour force for hand-picking the big coal is no longer necessary and that inferior coal is dealt with properly and only clean shale is discarded. Experience has shown that the products from a "float and sink" separation are of very uniform quality and customers appreciate them. The processes make extremely accurate separations and the percentage recovery of coal is very high. About 10 per cent of all the coal which is mechanically cleaned in Britain is now cleaned by the use of dense medium plants, and the amount so treated is steadily growing.

Some of the plants already at work employ a combination of the newer float and sink method for the larger coal with one of the older methods (a jig or trough washer, employing water as the separating medium) for the smaller coal; the combined plant thus constituting a "run-of-mine washer" in which the whole output is treated. In some cases, plants have been built to serve more than one pit and are thus described as "central washers".

Enough experience has been gained to enable more, and larger, combined plants of this kind to be planned, and schemes involving a large proportion of the total output are under consideration.

Owing to the fact that mechanical treatment of the larger coal is greatly facilitated if the very largest pieces are broken, and also because all users of coal break the largest pieces in any case, there is a tendency for the top size of market products to be limited to about 8 inches and to include suitable screening and breaking equipment in the run-of-mine coal washers.

The possibility of cleaning larger sizes mechanically is not limited to the use of float-and-sink processes since in certain cases, where the coals concerned are not too high in middlings content, the well-known "jig" washers, using pulsating water currents, can be used.

In the design of new preparation plants (and in altering and improving existing installations) every effort is being made to implement the recommendations of the Grading Committee of the British Colliery Owners Research Association, which suggest seven basic sizes of coal, with tolerances in size to suit breakage characteristics of the various coals. This should lead to simpler plants which are cheaper to operate, and to a welcome decrease of the confusion which now exists regarding the sizing and naming of coal grades.

PROPER TREATMENT OF FINE COAL

Reference has been made to the loss of fine coal involved in many of the existing washing plants. This arises from the means adopted for recovering the clean coal from the water used in the washing process. In all cleaning processes there are two fundamental steps: (1) the actual separation of coal and shale, or of coal, middlings and shale, and (2) the recovery or collection of the products from the separating medium used. In the case of the finest sizes, the second step is frequently more difficult than the first.

The traditional method is to recover as much as possible of the clean coal from the water by means of a series of screens with decreasing size of opening, fractions of the coal being collected in turn as the mesh size is reduced. Generally, some intermediate operations are necessary to thicken the coal and water mixture to an extent suitable for feeding to screens.

The smallest screens in common use have openings of 0.25 mm. and a loss of fine coal occurs when nothing is done to collect the underflow from these screens. This underflow cannot be returned to the washery circuit as it would accumulate in the system and interfere with the separation process. In the past, it has frequently been passed into settling ponds, "slurry" ponds, and left until the solids have settled out in a form dry enough to be lifted and dumped. Some of this fine slurry has been burned, generally with difficulty and low efficiency, on colliery boilers, but much of it has accumulated as a waste product.

In recent years, many plants have been equipped with filtration plants for collecting the solids in washery effluents, and some of these have been successful in collecting the final particles in a reasonably dry form, and in eliminating troublesome and costly (especially in labour) slurry ponds. Frequently, however, the fine coal bled out of a washery is very dirty, since the usual washers are not at all efficient for such fine material, and the recovered fuel has had a low value, being very difficult to use. It has been too dirty to mix with the larger sizes and its disposal has frequently been a difficult problem.

It is now realized that, in general, such fines should be cleaned by froth flotation and recovered by filtration in a form suitable for mixing with other coal. When this is done the ash content of the fine coal is reduced from, say, 20 to 40 per cent to something nearer 10 per cent, and its physical condition is greatly improved.

Froth flotation is a method of cleaning peculiarly adaptable to the treatment of fines. It depends on the difference between the surface properties of coal and shale and in particular on the fact that coal is less easily wetted than shale. Fine coal particles, up to about 1 mm. in size, can be made to adhere to air bubbles in a froth caused by agitation and aeration of a coal-and-water mixture containing small quantities of suitable oils, and can be concentrated in a mass of froth floating on the surface of the mixture. Shale particles, on the other hand, do not adhere to the bubbles but remain in the bulk of the liquid and so are separated from the coal.

The cleaned coal particles are finally dewatered by filtration and are obtained as a filter cake, reasonably easy to handle but still containing up to 30 per cent of water. Thermal drying of this cake may be undertaken in certain cases prior to its use as pulverized fuel.

The use of froth flotation is extending in Britain. "Frothing plants" are being added to existing washers and most of the new plants being planned will include the proper fine-coal cleaning equipment.

"FIRST-AID" MEASURES

These can only be mentioned very briefly. They can be summarized as follows:

(1) Alteration of existing washers to enable them to deal with bigger shale contents in the raw coal.

(2) Alteration of existing jig washers to enable them to treat larger coal, where circumstances permit and conditions

are suitable. Plants designed for smaller coal cannot readily be altered to give maximum efficiency with bigger coal, but sometimes a performance acceptable until new equipment is available can be obtained.

(3) Alterations to picking belt installations to enable inferior coal to be removed more easily and greater use of crushers for such inferior coal, the crushed material being passed into washers for the smaller coal.

The cumulative effect of measures of this kind is considerable, but the improvement possible by adaptation of existing plants is very limited and the urgent need is for new equipment.

As a final general comment, it may be suggested that, taking a general view, losses amounting to from 2 to 4 per cent of the raw coal will be eliminated by a combination of the methods indicated. This represents a noteworthy conservation of fuel.

Mechanical Preparation of Coal and Its Utilization

TADEUSZ LASKOWSKI

ABSTRACT

Available and easily accessible natural resources are not inexhaustible. In mining, for example, the difficulties increase as one goes further and further below the surface, although they can be overcome by modern and more efficacious methods. These difficulties, and first of all the limited resources of raw material, force us to utilize exploitable sources as fully as possible. It will be by no means easy in the future, and perhaps, impossible, to resume operations on partly exploited deposits. Thus, if we wish to maintain the present rate of development, and at the same time to assure for even the next few generations the maintenance of this same rate of development, we must try to utilize as fully as possible all discovered and exploitable natural resources.

With reference to coal, the most important source on earth of heat and power as well as the source of several other products that are recovered from coal, the resources are enormous, but limited. Because the resources are not inexhaustible, it is the duty of our generation to utilize this raw material to the highest possible degree.

The degree to which coal is utilized depends largely upon its mechanical preparation. This process consists of accommodating coal to suitable uses and to its full utilization in these applications. Coal in seams has different technological and chemical properties. As a raw material, coal in addition to supplying heat and power has a wide application in the chemical field. For each of these applications, there are coals of suitable type, size, ash content, ash composition, etc., which permit the most efficient utilization.

Collieries sustain the greatest losses in exploiting the small sizes of coal, especially the coal fines used for heating and steam-generation. This paper directs particular attention to this problem. In the utilization of fines it is of great importance to classify them further by size, whether they are to be used in the raw state or concentrated. The possibility of segregating fines into suitable size classes depends on the moisture content of the coal. The author presents a formula for determining the so-called critical dedusting moisture, exceeding of which is not desirable in dedusting raw coal fines.

In order to utilize suitable both dry and wet coal fines for steam-generation and low-grade mining products, the author points out that co-operation is necessary between the preparation plant and the place where the fines are utilized. Preparation of coal thus becomes a link between the colliery and the consumer. Experience with mechanical treatment of coal indicates to the colliery the negative influence which impurities and the high yield of fines have on the degree of utilization of raw coal. The preparation plant should work out methods with the consumer of fully utilizing low-grade mining products.

In its trend towards modernization, mining like all other fields of technique is steadily introducing new methods of raw material exploitation.

1. Obtaining all the raw material, i.e., without leaving any remainder in the coal faces.

2. Obtaining the raw material at the lowest possible cost.

3. Obtaining raw material of the maximum cleanliness and in such form as enables it to be used quickly, easily, and entirely. With reference to point 3 it should be stated that:

(*a*) The purity of raw coal is closely connected with its fundamental characteristic, i.e., its heating value;
(*b*) The form of mined coal, i.e., the size of the lumps of raw coal, affects the manner in which coal is utilized and hence its market price, which in turn affects the rate of profit of the colliery;
(*c*) The degree of utilization depends on the choice of coal according to size, technical and chemical properties, coking capacity, content of moisture, ash etc.

The question of purity of coal is therefore closely connected with its utilization and the degree of its utilization depends on the use of the proper kind of coal. Selection of the appropriate kind of coal requires:

1. Segregating into types according to:
(*a*) Flame length;
(*b*) Gas yield;
(*c*) Tar yield;
(*d*) Heating value;
(*e*) Coking capacity etc.

2. Grading the raw coal into the sizes required by the consumer.

3. Concentrating, i.e., removing impurities from the coal. By means of concentration it is possible to prepare for the consumer:
(*a*) Coal having a determined ash content,
(*b*) Coal which upon combustion will leave ashes of suitable chemical composition on which depend:
(i) The consumption of fuel.
(ii) The efficiency of blast furnace processes during the smelting of metal ore,

(iii) The quality of smelted pig-iron,
(iv) The flux consumption.

(*c*) Coal having a determined ash fusibility temperature on which depend:
(i) The degree of coal combustion,
(ii) The durability of grates and furnace rim etc.

The three processes mentioned above by which coal is adapted to its most efficient use and the fullest possible effect is obtained therefrom are carried out by a special category of mining operations. This is mechanical coal preparation, commonly called separation or concentration. As a matter of fact, mechanical coal preparation comprises both separation and concentration and also includes segregation of coal into technologically different types. This operation is today a specialty, recognized in the world as a separate branch of engineering; it is no longer a novelty in mining, as it was a few years ago.

SEGREGATION OF COAL BY TECHNOLOGICAL TYPES

As is well known, coal beds occur in three varieties distinguishable by the naked eye as bright, dull and fibrous coal. Coal is therefore not homogeneous even externally. These varieties do not form any determined crystals, but occur as beddings of different thickness which show further heterogeneous features under microscopic examination. The features are known as the petrographic constituents of coal. Depending on the nature and the constitution of the vegetable matter from which the coal was derived, those constituents in the form of woody tissues of plants, leaves, seeds, resins etc. show by chemical analysis multiple elementary constituents, and what is more, constituents that vary according to different degrees of coalification. Chemically, coal is not a chemical composition, but a most complex aggregate of carbonaceous constituents.

The coalification degree of petrographic constituents and their percentage in coal are determined by such physical, chemical and technological characteristics as hardness, fracturability, specific gravity, wettability, heating value, volatile matter contents, gas yield, tar yield, coking capacity etc. The number of coal varieties is enormous. This is due to the substances from which coal was derived, to the different conditions under which the vegetable matter was deposited and to the many different bio- and geochemical processes which the deposits undergo. For each of these coal varieties there are special applications allowing their most efficient use. Coal utilization has made remarkable progress during the twentieth century, nevertheless the question is still far from complete solution.

According to Hilt's Law the carbon content increases with depth in a series of seams. This means that the fixed carbon and the heating value increase while hygroscopic moisture and volatile matter decline. The coking properties of coking coals and gas coals also change with depth. Semi-bituminous coals, for instance, pass into coking coals, which in their turn pass into lean splint coals.

As mentioned above, the length of flame, heating value, coking capacity, and other technological and chemical coal properties require special methods for their complete utilization. The first consideration is the coking capacity of coals; for example, if the coking capacity is too high, the coal cannot be advantageously used in generators, power production, or domestic heating, but it is indispensable for gas manufacture and coking. While in the first case the coking capacity may cause losses through incomplete burning of the coal substance, in the second case it is possible to obtain hard coke used for smelting metal ores and for their further treatment. Hence it can be concluded that it is essential to separate coking coals from non-coking coals, and for this reason first place is given under modern mining methods to the problem of full segregation of these coals.

Likewise, the gas coals with long flame and the splint coals require furnaces and chimney draughts different from those required by high-grade lean coals with short flame.

On the types of furnace, the distance of the furnace from the boiler, the chimney draught etc., depends the degree of utilization of the different varieties of coal. Maximum utilization requires that each variety be selected and used separately according to purpose.

Collieries generally mine several seams at one time, each bearing different types of coal. Before sizing and concentration there should be adequate segregation of coal qualities into groups having definite properties. This work is done in the pit by purposely marking cars and tubs that haul a certain quality of coal and signalling from the pit-bottom any change of quality that is being brought to the surface; it is also carried on in the washery near the tippler devices and by means of belts and grates. The trend of mechanical preparation is in the direction of complete segregation of coal according to its chemical and technological properties, which involves of necessity the installation of several coal cleaning plants at the same colliery. A preparation plant with several types of equipment is more complicated in design, requires more capital and has higher operational costs than obtain in collieries that do not segregate coals into types. When new plants are to be erected, sizing and concentration of every coal type separately is taken into account.

CLASSIFICATION OF RAW COAL INTO SIZE CLASSES

In order to achieve maximum utilization of coal in technological processes it is essential to classify it by specified grain sizes. As is well known, coal combustion is governed by the supply of oxygen. When run-of-mine coal containing grains from the finest dust to large coal lumps are disposed on grates, with the space between the large lumps filled by small grains and the grate-openings stopped by very fine coal dust, it is difficult and sometimes impossible to supply air to all the grains. Consequently, non-sized coal burns irregularly, and neither the desired combustion temperature nor the desired caloric effect is obtained. The result is that a certain amount of coal remains unburned on the grates or in the ash-pits, i.e., unutilized.

Coarse and medium-sized coal, from which undersized coal has been separated, burns easily and completely on various types of grates, as well on small domestic grates as in large stokers with or without forced draught. The proper utilization of a determined size-class is checked, unfortunately, by the amount of under-size present. The under-size hinders:

1. Combustion of coal on grates, by stopping the air supply;

2. Gas yield in producers, by reducing the air flow through the bed of coal in the chamber;

3. Full combustion of coal on grates adapted for special sizes, because the smaller sizes fall through the grate into the ash-pit.

It can therefore be concluded that the consumer in ordering coal must be careful to specify the admissible content of under-size, which not only does not furnish the calorific effect wanted, but even renders difficult the combustion of the size as such.

The greatest difficulties arise with the combustion of the smallest fines, dust and wet slurry; the degree of utilization of these grain classes is very low. One of the most difficult problems presented to engineers is the construction of grates which have such narrow channels as will hinder the falling through of finer sizes into the ash-pit, and at the same time will allow the access of a suitable quantity of air; in addition, the grates must have the required resistance to high temperatures as well as great durability.

The impossibility of complete utilization of coal fines during their combustion, as well as the other difficulties encountered in the process, result in a weak demand for coal fines, a demand that is lower than the amount of production. Consequently, the collieries, having no assured sale for this product, market the fines at very low prices, in many cases for about 40 per cent of the cost of production. The profits of the collieries, of course, are thereby reduced and they are forced to cover the deficit incurred from the sale of fines by charging higher prices for coarse and medium-size coal. This is an anomaly since the power industry, which burns coal fines on grates adapted for this purpose, obtains a high caloric effect and an economic advantage at the expense of the collieries.

Modern furnaces and mechanical grates make possible the complete combustion of fines with the exception of the very fine 1 to 0 mm. sizes, which are called coal dust. A high percentage of these dust grains fall through, unburned, into the ash-pit and do not furnish any heating effect. In other words, the degree of utilization of dust grains is low.

Only pulverized fuel hearths fed by coal ground to the fineness of flour permits complete utilization of the smallest coal grains. For complete utilization of coal dust, therefore, separation into two classes is essential; 10 to 1 mm. and 1 to 0 mm. sizes. The 10 to 1 mm. size should be burned on grate firings, the 1 to 0 mm. size in pulverized fuel hearths.

For the segregation of raw coal into various classes by size, suitable screens and vibrators are used, but they are not satisfactory for sizing very small grains. Sometimes the small sieve holes do not let through all of the under-size present, and, if the coal grains are wet, they clog the sieves thus making separation impossible.

Recently dedusters have been used to separate dust grains less than 1 mm. in size from fines above the 1 mm. size. Dedusters operate by means of air draught (compressed or vacuum), finally passing the coal grains through dust collectors (of the cyclone type) in which centrifugal force effects separation of the ultra-fine particles carried in the air current. Moreover, appropriate regulation of the equipment enables the separation and drawing off of various sizes of dust grains, such as 1 to 0 mm., 0.2 to 0 mm., 0.3 to 0 mm. sizes etc.

Low moisture content in fines is essential to complete dedusting and deduster efficiency. For every coal there is a certain moisture limit, the so-called critical dedusting moisture. When this is exceeded the dedusting of fines is incomplete and unsatisfactory. For example, brown coals which are externally dry and have a moisture content of over 30 per cent dedust quite well; furnace coals with a volatile matter content of 40 per cent dedust even at 18 per cent of moisture, while coking coals containing 6 per cent of moisture are not dedustible. The moisture content referred to above means the total coal moisture, which consists of transitory moisture, that is, pit moisture or free moisture, and of inherent or hygroscopic moisture.

There is an intimate connexion, in fact, an inverse relationship between moisture content and coking properties; that is, the higher the coking property, the lower the moisture content. The test carried out on the dedusting of Upper Silesian coals proved that coals with weak coking properties and high content of hygroscopic moisture, include in their dry form (i.e., when fresh fines from the pit are thrown into the air, the particles are suspended) almost the same amount of free moisture. The author has devised a formula for critical dedusting moisture. (3)[1] When its limit is surpassed, dedusting of coal fines is incomplete and therefore inadvisable:

$$Wp \max = 0.83 \, Wh + 2.2;$$
$$Wc \max = 1.83 \, Wh + 2.2.$$

where Wc max = total critical dedusting moisture in coal,
Wp max = free critical dedusting moisture in coal,
Wh = hygroscopic moisture in coal.

The formula represents the straightline dependence of free moisture upon hygroscopic moisture. The author explains this fact by the capillarity of coals, i.e., coals with weak coking properties have broad channels or capillaries containing much hygroscopic moisture within. On the outside part of these channels much free moisture is also maintained, but it adheres so tenaciously that it does not hinder dedusting. On the other hand, coals with higher coking properties have narrow capillaries containing little hygroscopic moisture within. The capacity of these narrow capillaries to absorb free moisture is limited, and of course, less than that of broad channels.

The determination of the capacity of coal fines to be dedusted plays an important role in the construction of new preparation plants. The first consideration in their design is to effect the most complete and most economic utilization of run-of-mine coal brought to the surface. If the moisture of raw coal fines exceeds the critical dedusting moisture, the fines should be separated on a wet basis, and the moisture then drawn off in centrifugal apparatus and vacuum filters. This process increases the costs of operation, and what is more, the added water produces losses because the combustion of slurries requires an additional amount of heat to evaporate the water, thus reducing the utilization of wet raw fines.

With steady progress in mechanization of extracting, loading and hauling coal, there is increased breakage of coal grains; as a result, the yield of coal fines increases and the yield of coarse and medium sizes decreases. (11) This involves losses for the colliery. Revenue from the sale of large and medium coal sizes is reduced and is not balanced by revenue from the sale of the increased production of cheaper fines and dusts, since it is difficult to sell these sizes. The degree of utilization of run-of-mine coal thus declines because the fines and dusts are incompletely used.

Exact calculations show that the share of small dust grains (1 to 0 mm.) amounts to 7 to 12 per cent in the total output of raw coal. The position of these small grains is therefore of importance in coal production and demands that close attention be devoted to the problem of utilizing these finer fractions.

[1] Numbers in parentheses refer to items in the bibliography.

CONCENTRATION (REMOVAL OF INORGANIC IMPURITIES) OF COAL

In addition to the segregation of coal by technological types, and its classification by size, the third task of mechanical preparation is the removal of inorganic impurities which leave ash after combustion. This process is one of proper concentration, and has the effect of increasing the percentage of the content of organic substances. After concentration the caloric value of coal and the yield of gas, tar etc., increases. Ash and its chemical compositions have an enormous influence (in major part a negative one!) (4) upon the physical and chemical properties of coals, on technological processes during combustion and distillation of coals, as well as negative influence upon foundry processes.

For the separation of impurities, the mechanical preparation of coal applies different concentration methods:

(*a*) Physical (dry and wet) methods, based on the difference in shape, grain size, friction, specific gravity of coal and dirt admixtures,

(*b*) Physico-chemical methods, based on the difference in wettability of coal and dirt admixtures,

(*c*) Electrical methods, based on the difference of electrostatic attraction of coal and admixture grains.

Only the physical methods, because they are inexpensive, are used for the concentration of all types and sizes of coals. The physico-chemical and electrostatic methods are too expensive to be applied except in the case of the concentration of special coals. The difficulty in removing inorganic admixtures from coal arises from the fact that their specific gravities approach the specific gravity of pure coal. The majority of coal concentration methods, of course, are based on the difference in the specific gravity of coal and inherent admixtures.

When burned, the inorganic admixtures leave ash in two forms: inherent ash and external ash.

Inherent ash is the ash left after combustion of:

(1) The original, vegetable impurities, removal of which from coal is impossible by mechanical preparation,

(2) Inorganic admixtures blended with vegetable substance during deposition in such a way that the separation of coal particles from these admixtures by mechanical preparation is difficult, expensive as well as problematic.

External ash is the ash left after combustion of:

(1) Secondary admixtures set in coal after vegetable matter has been deposited. These admixtures are derived from solution circulating in the crevices of coal and surrounding rocks, and take the form of mineral crystals, grains and slates like pyrites, marcasite, calcite, quartz etc. These substances are separable from coal grains by crushing the coal. Since their specific gravity is different, they may be separated by mechanical preparation; while it is possible and not too difficult, it is expensive and hence not practicable on a large scale. Let us hope, however, that in the future when low-ash content coals have become a raw material for the manufacture of rare and precious products, the expensive processes of mechanical preparation will prove to be economically justified and will to a great extent allow removal of this kind of ash from coal.

(2) Sterile middlings coming from rocks found in coal seams during extracting and loading, or from floor and roof rocks surrounding the seam. The clay and sand shales occurring in floor and roof are more subject to abrasion than the coal grains and produce a very fine dust. (1) Separating the latter from coal presents the greatest difficulties in mechanical preparation. (9) Moreover, these substances when diluted in water render any separation difficult and influence negatively the clarifying of washery water and the water economy of the preparation plants.

The removal of sterile admixtures from the large coal grains does not offer great difficulty. Though gangue grains can be distinguished with the naked eye from coal grains, the separation of gangue grains from medium-sizes by such means is difficult and not often applied to-day. In general, coal grains of less than 80 mm. are mechanically treated.

Methods of coal concentrating that are more and more often introduced for the treatment of heavy medium grains enable almost ideal exclusion of inorganic admixtures from coal under 6 mm. in size. (5) Below this limit Baum washery jigs or Simon Carves or Norton Jigs, modifications of the Baum jig, perform concentration sufficiently well. Unfortunately the lower limit of concentrated grains never equals 0. In theory this limit is 0.2 to 0.3 mm., but in practice it is about 1 mm., the 1 to 0 mm. sizes not being fully concentrated by mechanical treatment. (3) As a result pure coal grains left in half-products and waste are lost.

Only by chemico-physical treatment (flotation) may the 1 to 0 mm. sizes be concentrated exactly because of the wettability of coal grains and gangue admixtures. Flotation of coal fines and coal dust proved to be particularly advantageous for the concentration of fine grains of coking coal, a fact that has led to the development of flotation plants in collieries that exploit coal used for coke production. The rather expensive flotation process, which is justified for the coking and special coals, is not warranted, however, for the concentration of non-coking coals. In view of this fact, the problem of mechanical (physical) concentration of small fines and coal dust for use in heating and steam generation calls for exact investigation and cost-accounting studies, in order to determine the suitability of concentrating these sizes. As a matter of fact, the washery half-products and even refuses containing up to 50 per cent of organic substances are burnt to-day in properly adjusted furnaces. However, thermal losses incurred in heating a great amount of ash and evaporating the water remaining in these products after concentration, raise the question whether it is desirable to concentrate such fine sizes, or whether they should be used directly in the raw state (i.e., without concentration).

Economic considerations indicate that in heating and steam generation it is feasible to separate coal dust of 1 to 0 mm. size from raw coal. The raw coal dust might be used without concentration in appropriate furnaces located as near the mine as possible. In this way it is possible to increase the utilization of coal dust without wasting the heat that is required to evaporate the water added during concentration, and also to avoid the transportation of ash ballast.

Here again, as in segregation by sizes, the problem arises of completely separating the finest grain class (under 1 mm. in size) from dust, inasmuch as it is not feasible to concentrate this size together with larger sizes whose presence in dust renders any concentration difficult. By first removing fines of the 10 to 0 mm. size and then the 6 to 0 mm. sizes, the total content of 1 to 0 mm. size can be advantageously subjected to further cleaning operations, and thus insure complete utilization of fines. Consequently the tendency in modern coal preparation is to dedust raw coal fines to the degree permitted by the moisture content.

This raises still another question. What is to be done when the raw coal moisture exceeds the critical dedusting moisture? Should only the 10 to 0 mm. and the 6 to 0 mm. sizes be concentrated, or should the 1 to 0 mm. size after desludging by means of water be left untreated or be concentrated to a certain degree? The aim in these cases is to achieve maximum utilization of wet coal brought to the surface. With respect to concentration of coking coals, the profitableness of flotation decides whether or not raw fines should be dedusted on a wet basis. It is less profitable, in any case, to dedust wet fines for use in steam generation.

If the demand by near-by furnaces for raw fines is equal to the amount of their production it is better not to concentrate them, but to deliver them in the raw state to these furnaces, which are adapted to their combustion. This refers to pulverized-fuel hearths where there is no waste from unburned small sizes falling through into the ash-pit and eventually hindering combustion by clogging the grates. Such fines, of course, must be previously ground to coal flour of a desired granulation.

The problem is less simple if the market demand does not cover the production of fines. Then the collieries are compelled to sell the raw fines at a lower price or to sell a small amount of concentrated fines at a higher price, in which case there would be some loss of the original production in the form of rejects and half-products, the further utilization of which becomes difficult and uneconomic. (10)

If market prices were based on the proportional value of raw material and concentrates, with account taken of the yield of the market products, half-products and rejects as well as of the cost of concentration and losses occurring in the concentration processes, it would not be difficult to put an equitable price on wet fines used for steam generation. Unfortunately the market price of fines for steam generation is influenced now by insufficient demand. The price is also kept low by the difficulties of stocking these sizes. The result is that the collieries are forced to deliver fines at prices which are out of proportion with their real value. Market needs must be complied with despite the losses. If the raw material is to be utilized completely it must be supplied in the form and quality wanted by the market, whatever may be the products the colliery is prepared to deliver.

Power plants erected recently in coal districts have been designed with the view of utilizing this cheap fuel in power production. It is quite certain that the increasing demand for fines will in time lead to a balance between delivery and demand; it will then be necessary to revise market prices which have to be based upon the value of products and on obtainable effects. The present situation is abnormal, because it forces the producer to cede to the consumer valuable material at prices below production costs. The consumer obtains a high degree of utilization of the product, of course at the expense of efficiency and losses for the producer, i.e., the colliery.

Agglomeration of coal grains permits a remarkable increase in the utilization of coal fines for steam generation. For this reason it is advantageous to concentrate them in advance. Since an organic binder is lacking, the briquetting of heating coal fines depends on the available content of pitch. Invention and adaption of a cheap organic binder, or the briquetting on an industrial scale of coal without a binder, would offer a convenient and complete solution to the problem of utilizing coal fines for steam generation, and would reduce the losses sustained by collieries on these classes. (6, 7, 8)

Every coal-field in the world encounters the same difficulties with the utilization for steam generation of the finest grains of coal. Not only is their removal by mechanical treatment attempted, but there is also a trend toward their utilization, after suitable preparation, in appropriate furnaces which have been erected near collieries producing coal for steam generation. For the full utilization of these coals it is essential that they be segregated into classes by size of grain, and that different coal types be chosen for blending according to their heating value, volatile matter content, length of flame, ash fusibility temperature etc. These operations are necessary in order to prepare the kind of fuel for which a furnace has been designed.

As we have seen, the complete utilization of coal depends to a high degree upon the manner in which it is used. Consequently mechanical preparation becomes a link between the colliery and the consumer. On the one hand, mechanical preparation provides the basis for adapting mining methods to the exploitation of raw coal according to technological types, grain sizes and suitable purity; on the other hand, mechanical preparation helps the consumer to utilize as fully as possible those low-grade products, the stocking and transporting of which are difficult, uneconomic, and often impossible.

The rapid rise in centralization of extracting and transporting as well as in mechanization of coal mining, should lead to increased output and efficiency on the part of collieries. Collieries which aim at the cheapest possible output do not take into consideration that coal utilization is greatly influenced by removal of impurities and segregation by sizes. The task of the mechanical preparation is, however, not only concentration and segregation of raw material. By continuously watching statistics of output, efficiency, sale and economic effects, as influenced by mechanical preparation, the collieries are able to determine the permissible degree of impurity that can be present, thereby achieving maximum utilization of coal and the highest economic returns.

Bibliography

1. R. Lessing, "Natural coal dust", *Fuel*, vol. XXVII, no. 4, (September–October 1948).
2. T. Laskowski and T. Mielecki, "Eksperymentalne i teoretyczne porównanie niektórych metod oznaczania stopnia uweglenia wegla", *Biuletyn Instytutu Naukowo-Badawczego Przemyslu Weglowego*, no. 2, Komunikat no. 16 (Katowice 1947).
3. T. Laskowski, "Zagadnienia przeróbki mialu w polskim przemyśle weglowym", *Biuletyn Instytutu Naukowo-Badawczego Przemyslu Weglowego*, Komunikat no. 23 (Katowice 1948).
4. N. N. Dubinin, *Brygadir sortirowki*, Charkow, 1936.
5. T. Laskowski, "Wzbogacanie wegla kamiennego w cieczach ciezkich", *Przeglad Górniczy*, no. 6 and 7, 1945, no. 1, 1946 (Katowice).
6. W. Swietoslawski, B. Roga and M. Chorazy, "O brykietowaniu mialu weglowego bez uzycia lepiszcza", *Przemysl Chemiczny*, vol. 13 (1929), Warsaw, pages 2 and 40.
7. W. Swietoslawski, B. Roga and M. Chorazy, "Brykietowanie mialu pólkoksowego i koksowego z uzyciem wegla jaki środka wiazacego", *Przemysl Chemiczny*, vol. 13 (1929), Warsaw, page 465.
8. T. Laskowski, "Wegiel koksujacy jako spoiwo do brykietowania mialu", *Przeglad Górniczo-Hutniczy*, no. 7 (1934), Katowice, page 333.
9. E. S. Grumell, "Distribution of Ash in British Coals", *Colliery Guardian*, vol. 174, no. 4489, pages 39–43 and no. 4490 (1947), pages 73–77.
10. E. S. Grumell, "The Price Structure of Coal and its Relationship to Preparation and Utilisation", *Journal of The Institute of Fuel*, vol. XXI, no. 118 (February 1948), pages 109–130.
11. H. G. Hague, "The Influence of Mechanisation on Coal Preparation", *Journal of The Institute of Fuel*, vol. XXI, no. 120,(1948)

Summary of Discussion

Mr. YANCEY presented the experience paper he had prepared together with Mr. Fraser on the "Preparation of Coal in America" and explained that the preparation of coal was the intermediate operation between extraction and utilization. Consequently, it was a very important stage in the coal industry for it made it possible to supply the market with coals of suitable quality. Efficient preparation of coals also led to a direct saving of fuel through the recovery of fine coals, as was the case in the United States.

Furthermore, the mechanization of production had resulted in a considerable increase in the refuse contained in run-of-mine coal and this must be removed during preparation. That trend stressed the importance of washing and sorting operations following the mechanical production of coal. Conversely, efficient operation made it possible to proceed with the mechanization of extraction and the extension of extraction to the full seam, including even related layers of inferior quality. The combination of mechanical extraction and mechanical preparation can thus lead ultimately to complete recovery of reserves.

He emphasized that preparation techniques had led to a more complete utilization of coals and that in turn had increased the reserves of coking-coals. Measures were currently being taken to apply the new heavy medium processes to release the tremendous reserves of the Pittsburgh area coal deposits for metallurgical use. The high-sulphur coals had to undergo the most intensive treatment in that connexion.

In areas where competing fuels were costly, preparation played a major role as it enabled locally mined coals to be applied to industrial use thanks to special cleaning treatments which otherwise might not be economically justifiable. Substantial progress in that field had been made through the use of the cretaceous and tertiary coals of the western United States and Alaska. Another spectacular example of such accomplishments was the war-time development of a coking-coal field in southern Brazil.

The prevailing tendency with fuel coal is to seek a relatively uniform standard quality with a rather high ash content because the major aim of preparation should be the greatest possible, if not total, recovery of combustible matter.

Mr. CHERADAME first emphasized that he uses the expression "washing" applied for any cleaning process other than hand sorting.

Before turning to the discussion of his paper on "Studies on Coal-Washing in France", he wished to explain that coal-washing had always been necessary in France because of the very high ash content of the raw coal which had been increased still further by the mechanization of extraction; the average ash content was about thirty per cent.

There were three conventional types of devices used in French plants until now: rhéolaveurs, jigs and pneumatic tables. Results achieved were very different, even with devices of the same type, for accuracy in separation varied considerably in each, which had a considerable bearing on the yield of coal, middlings, and shale. It had become apparent that washing was not being studied scientifically. Washing engineers merely noted the ash content while machine designers often forgot to provide the equipment with devices which would facilitate control of the operation. A test of the products coming from washing machines had revealed considerable irregularities and defects in the quality of those products. It could be inferred that those defects lead to considerable losses of fuel.

The research carried out in France on coal-washing would make it possible to introduce methods which would result in a greater average accuracy and make it possible to determine more easily the efficiency and to check the working of the machines and to develop new processes.

Research was being carried out to establish curves and coefficients for determining with greater accuracy the characteristics of the machines used and the quality of the washing.

The second part of the research was devoted to a study of the different types of washers in operation. The study had made it possible to determine the mathematical law of dispersion. It had also been possible to assess the merits of the various methods used. In descending order of washing-efficiency, they appear to be classified as follows: plunger jigs, rhéolaveur-washers and pneumatic tables.

Regarding centrifuging in dense liquids, appreciable results had been achieved in the course of laboratory experiments, particularly with cyclones and cylindrical machines. The cyclone was a machine capable of a considerable output in proportion to its size; e.g., a cyclone 350 mm. in diameter could treat at least 18 tons of raw coal per hour. Furthermore, the machine made it possible to treat coal with probable variations two or three times less than those resulting from other washing methods.

The use of cyclones in the Saar basin where it is being investigated will make it possible to eliminate middlings whereas the plunger jig method employed till then had left from 10 to 12 per cent.

He emphasized the particular importance of the information gathered from that study and its usefulness in relation to the results to be achieved.

Mr. LEE presented the paper on "The Conservation of Fuel in Britain by Improved Coal Preparation" prepared by Messrs. Grounds and Needham and explained that the former inefficient hand-cleaning of large coal used to result in the loss of considerable amounts of coal in the dirt. Furthermore, many of the seams being worked contained bands of shale and inferior coal; mechanized mining resulted in less discrimination and in a larger proportion of shale and of small coal in the run-of-mine product. Consequently, the screens, picking belts and washers originally provided and still perforce in use were working under very adverse conditions with considerable losses of coal as a result. In addition, most of the cleaning plants had been installed without adequate equipment for dealing with the finest sizes and a serious loss of fine coal occurred.

Consequently, measures had been taken in the field of coal preparation to solve the above-mentioned difficulties; those measures could be described under three headings: (*a*) mechanical treatment of large coal; (*b*) proper treatment of fine coal; (*c*) emergency measures until new equipment was available.

The emergency measures had become necessary because the installation of new equipment required considerable time in view of the scope of the plan which was being carried out.

With regard to the mechanical treatment of large coal, recent improvement of the "dense medium" or "float and sink" processes for coal cleaning had made it possible to apply mechanical treatment, which had previously been commonly applied in the case of three-inch sizes and less, to the large coal, and to visualize "run of the mine" coal washers treating the coal as it came out of the pit. Some of the plants already in operation for the purpose used a combination of the float and sink method with one of the older methods as, for example, the jig or trough washer which employed water as the separating medium.

With regard to the treatment of fine coal, it should be made clear that cleaning processes involved two fundamental steps: firstly, separation of coal, and shale, and perhaps middlings; and secondly, recovery or collection of the products from the separating medium used. The traditional method was to recover as much of the coal as possible by means of a series of screens with decreasing sizes of opening.

A cleaning process which was particularly adaptable to fine coal was froth flotation. It was based on the difference between the surface properties of coal and shale, and, in particular, on the fact that coal was less easily wetted than shale; fine coal particles which adhered to air bubbles in a froth caused by agitation and aeration of a coal and water mixture could finally be dewatered by filtration and were collected as filter cakes.

The emergency measures had involved alteration of existing washers so as to make them suitable for treating raw coal of greater shale content, or alteration of picking belt installations in order to make it possible to remove inferior coal more easily.

In general, a combination of the different methods outlined would eliminate losses of from 2 to 4 per cent of the raw coal, which meant a considerable saving in fuel.

Mr. Lee expressed the view, with reference to the discussion held at the previous meeting on the advantages of attempting to achieve a coke of consistent standard quality, that this would be difficult to achieve in practice on a nation-wide scale although a measure of consistency in ash and sulphur content could be anticipated. It might be possible by careful selection and washing at low specific gravities to produce a coking mixture of good quality and consistency, but this could only be done at many collieries by sacrificing a substantial tonnage of middlings. The aim of the coal industry must be to realize the maximum yield of useable energy from the run-of-mine coal and this would only be possible so far as coking coals were concerned if the middlings could be used for steam raising purposes.

The Chairman observed that the paper on "Mechanical Preparation of Coal and Its Utilization" prepared by Mr. Laskowski had been distributed to the Conference participants.

Mr. Driessen complimented the authors of the papers just presented which gave all the data of particular interest; he wished to stress certain points and to contribute some additional facts.

With regard to large coal, it was remarkable that in the United Kingdom 10 per cent of all mechanically prepared coal was treated by heavy medium methods, and that the percentage was steadily increasing; in the United States, likewise, particularly in the Pittsburgh region, the heavy medium method of washing had also been adopted. In cases where washing on low specific gravities was required, a distinct and exact separation must be obtained as the amount of coal with a specific gravity only 0.1 different from that of the separating specific gravity was relatively large.

Another advantage of washing by heavy medium methods was that certain middlings with a high ash and low sulphur content could be taken out and crushed in order to free undesirable elements which could subsequently be removed in the fine coal washing plants.

Mr. Driessen pointed out that the only static heavy medium process in the United States used magnetite as a medium, whereas in Europe barytes and froth flotation tailings were used. Some attention should be devoted to such mediums as froth flotation tailings also in this country.

Mr. Driessen felt that the largest possible size which could be treated by the heavy medium process apparently depended on the purity of the coal; in most cases, it should not exceed 8 cm. (3 in.).

With regard to fine coal and coal slurry, all papers stressed the difficulty of cleaning and drying the smaller sizes. The principle most commonly used in cleaning coal was based on the different specific gravities of coal and the impurities; differences of apparent specific gravity were greater in water than in air, which was why wet washing was more effective than dry washing. On the other hand, as the particles grew smaller, more time was required to separate the coal from the impurities. Consequently unless new physical principles were adopted, the smaller sizes would probably continue to require washing equipment with larger surfaces than the coarse sizes.

The physical principles referred to by Mr. Driessen were the following:

(1) Replacing the earth's gravity by centrifugal force, a principle adopted in cyclone washers;

(2) Using the physico-chemical principle of different wettability of the coal and shale surfaces; that principle was one of the most remarkable as it not only decreased the effective specific gravity of the coal particle by attaching an air bubble to it, but also increased the effective size, thus reducing the amount of time required for separation;

(3) Taking into account the differences of adhesion to greased or oiled surfaces;

(4) Taking into account the differences of interfacial resistance to electrostatic charges.

Mr. Driessen pointed out that cyclone washers for bituminous fine coal were in operation in Limburg, in Holland. A cyclone washer using barytes as heavy medium was being tested in the Saar mines. Mr. Driessen then drew attention to the cyclone thickeners mentioned in Mr. Yancey's paper which were in operation in one of the larger Pittsburgh washeries.

Mr. Bird pointed out that washing fine coal should be spoken of in terms not of "tons per hour" but of "particles per hour".

He stressed that the "Baum jig" washer could be used for all sizes, from 200 to 0.1 mm., without any limitation.

He made a few suggestions to those using the "Baum jig" washers: (1) The percentage of open area in the screen plate should be under 30 per cent to build up a slight resistance; (2) pre-sizing of feed is detrimental; (3) as little water as possible should be used, just enough to transport the coal.

Mr. McCulloch emphasized the importance, from the point of view of the conservation of national resources, of a full and rational utilization of coal. He drew attention to the waste which could be observed when thick smoke rose from a chimney as a result of the employment of defective methods of combustion. Similarly, the accumulation of piles of sulphurous refuse in the vicinity of mines, and the existence of deposits of sludge near coal washeries were evidence of a defective use of fuel. Any progress achieved in that direction would be of great importance economically. It could thus be hoped that by-products which were currently considered as waste would be put to some useful purpose. The problem of the utilization of those products was fraught with considerable difficulties, but even if existing equipment were employed for the preparation of coal, it did not seem impossible to arrive at a rational utilization. As examples of a more rational utilization of fuel already practised, Mr. McCulloch mentioned the expansion of briquetting plants and low-temperature carbonization plants, and of thermal power plants which used low-grade coal.

He did not approve of the use of the process of beneficiation in dense liquid. While that method made it possible to improve the quality of premium fuel, its drawback was that it left a considerable proportion of the secondary products unusable without additional processing. It appeared necessary to teach consumers to use lower-grade fuels. At a time when the coal industry had to face competition from other fuels, attempts to eliminate waste by the rational use of fuels and by opening markets for lower-grade fuels seemed well warranted both from the point of view of the remunerative possibilities of the industry itself and from the point of view of the conservation of coal resources.

Mr. Cheradame wished to ask Mr. Driessen a question. Very fine particles of coal could be washed by two methods, namely, floating or centrifuging in dense liquid. The latter process was simpler and would therefore seem preferable. He wished to know what were the minimum dimensions which could, in his opinion, be dealt with by the centrifuging process. It was impossible, formerly, to go below 0.5 mm.; he thought it would be possible on the basis of the French experiments to go as far as 0.3 mm.

In reply, Mr. Driessen referred to a communication submitted by him at the Fuel Economy Conference held at The Hague in 1947. As the size of the particles to be separated became smaller, the probable error increased. It was possible to separate particles in a cyclone washer as small as 0.15 mm. or 100 mesh. The two processes, floating and centrifuging in dense liquid, could be used in dealing with particles of about 0.5 mm.

Mr. C. J. Potter remarked that the problem of separation presented difficulties only in the case of very small coals. In that case it was also very expensive. Thus in modern washing plants, the cost per ton-hour capacity was 4,000 dollars. The efficiency of those plants was very great, however, where productivity of manpower was concerned, the quantity handled by one man being 100 tons per day.

He emphasized the importance of the problem of drying. Coal delivered to the consumer must be dry; one per cent moisture in the coal was a defect even more serious than one per cent ash. Current drying methods in the United States were unsatisfactory. The elimination of moisture appeared to him the most urgent problem to which no solution had yet been found.

Mr. Newman said that in certain special circumstances a high ash content coal could be utilized economically, without cleaning, as in gasification where even the presence of shale was not necessarily a disadvantage. He cited the studies undertaken by Mr. Yancey and himself on Nevada bituminous coal which after washing and screening contained 26 per cent of the original heating value, but which provided 75 per cent of the original heating value to the gas producer when washing was eliminated.

Mr. Ignatieff agreed with Mr. Potter on the importance of drying. The problem of coal preparation in Canada was very complex in view of the fact that Canadian producers had to face the competition of coal imported from the United States which accounted for more than half the coal consumed in Canada. Canadian coal was generally friable and had a high ash content. Producers thus have to overcome great economic difficulties, in order to compete with United States coal. The present general practice is to dry clean the small sizes. High standard washing of fines could only result in substantial rejects. Furthermore beneficiation of fines by wet methods brings up the problem of drying which is serious on account of Canadian climatic conditions. The difficulties facing the coal industry in Canada were thus grave and a whole series of research projects had been undertaken with a view to discovering technical processes whereby those problems could be solved.

Mr. Driessen returned to the question of coal drying raised by Mr. Potter. He pointed out that in Europe the methods adopted to solve the problem differed from those employed in the United States. Mines in European countries usually owned thermal power plants which could be operated on inferior coals and even sludge, products which were thus put to direct use. Thus the Netherlands State mines utilized coal with an ash content as high as 40 per cent and with a volatile substance content of 18 per cent. Such fuel produced good results in steam generators adapted to the use of pulverized coal; moreover, the elimination of that type of coal made it possible to obtain coking coal with a very low ash content. Mr. Driessen stated that a new thermal power plant had been erected in the Netherlands which was capable of using coal with an even higher ash content.

Mr. C. J. Potter pointed out that thermal power plants in the United States also used middlings. There were great difficulties, however, in dealing with extreme fines, particularly in regard to drying.

Mr. Driessen stated that in the Netherlands the finest particles were recovered by means of froth flotation and mixed with the washed fine coal and subsequently employed in the production of metallurgical coke. Middlings, on the other hand, were crushed and utilized in the thermal power plants belonging to the mines.

Mr. C. J. Potter pointed out that coal with a moisture content of 5 per cent or more was liable to freeze in winter.

Underground Gasification of Coal

22 August 1949

Chairman:

RAYMOND CHERADAME, *Director adjoint du Centre de recherches des charbonnages de France*, Paris, France

Contributed Papers:

Laboratory and Field-Scale Experimentation on the Underground Gasification of Coal

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Utilization of Coal at the Mine: Underground Gasification

M. DOUMENC, Professor at the School of Mining, St. Etienne, France

Summary of Discussion:

Discussants:

Messrs. ELDER, BAILEY, IGNATIEFF, ALSPAUGH, C. J. POTTER, HUBBERT

Programme Officer:

MR. W. A. MACFARLANE

Laboratory and Field-Scale Experimentation on the Underground Gasification of Coal[1]

M. H. FIES and JAMES L. ELDER

ABSTRACT

The first experiment to gasify coal in place underground began at Gorgas, Alabama, 21 January 1947, and continued for fifty days. It was conducted co-operatively by the U.S. Bureau of Mines and the Alabama Power Company.

This experiment showed that underground combustion could be maintained. Together with experiments conducted in a laboratory-scale retort built at the U.S. Bureau of Mines Station at Morgantown, West Virginia, it contributed facts which led to the decision to conduct a second and large field-scale experiment. This second experiment, under the direction of the U.S. Bureau of Mines, and in co-operation with the Alabama Power Company, is taking place at Gorgas in an area of about 100 acres. Combustion in the second experiment was begun 18 March 1949.

The objectives of the second experiment are to determine the quantity of coal that can be gasified from a given initial combustion zone and the shape and extent of the burned-out areas formed during this gasification; to test the design and installation of various types of equipment and to determine the operational characteristics of the installation under variations of conditions; to determine the quantity and quality of the air-blow product gas generated; to obtain all possible information regarding the action of heat on the overlying strata and to develop fundamental technical and economic information likely to be helpful in selecting plant sites, plant installation and operating processes.

The Bureau of Mines, United States Department of the Interior, has for years been interested in the possibility of gasifying coal underground and desired to conduct experiments directed toward determining the feasibility of the process. In 1946 the Alabama Power Company became attracted to the possibilities of underground gasification as a means of producing a power gas. The objective of the Bureau of Mines is the production of a low-cost synthesis gas. In view of their mutual interest in the subject, representatives of the two organizations met and planned a series of experiments designed to test the possibilities of this process.

Synthetic liquid fuels can be made from three major raw materials — coal, oil shale, and natural gas. Of the three, coal is by far the largest potential source. Excluding fissionable materials, coal comprises more than 95 per cent of our mineral fuel-energy reserves.

Two basic processes have been developed for converting coal into oil: (1) The direct-hydrogenation or Bergius process; and (2) the gas-synthesis or Fischer-Tropsch process. Both require the production of a gas as a preliminary, and costly, step.

In the first process, a large volume of hydrogen is required for catalytic addition to the coal under high pressure to produce liquid fuels directly. Hydrogen now constitutes 50 per cent of the total cost of the liquid products.

In the second process, synthesis gas — a mixture of carbon monoxide and hydrogen obtained by first gasifying the coal — is required for catalytic conversion into liquid fuels. Synthesis gas now comprises 60 to 70 per cent of the total cost of the products.

It is readily apparent that cheap production of the required hydrogen and synthesis gas is the key to the entire problem of competitive liquid fuels from coal. Pure hydrogen can be obtained from synthesis gas by reacting the carbon monoxide with steam and removing the carbon dioxide formed. Therefore, development of an economical method for producing synthesis gas would help to solve the problem.

At this time, four major processes are in use for manufacturing gas. These are: producer-gas process; cyclic water-gas process; continuous water-gas processes; and carbonization of coal.

As previously applied, all these gas-making processes have entailed the use of mined coal and costly equipment, with the result that the product has been a relatively high-cost gas.

Underground gasification of coal has promising potentialities as a method for obtaining low-cost synthesis gas, for it eliminates two basic costs common to other gas-making processes, the mining of coal and the installation of gas generators. Underground gasification also holds alluring possibilities as a source of cheap fuel for power generation and as a method of utilizing coal veins difficult or uneconomical to mine.

FIRST FIELD-SCALE EXPERIMENT AT GORGAS, ALABAMA

Late in 1946 the Federal Bureau of Mines and the Alabama Power Co. began constructing a field-scale experiment at Gorgas, Alabama.

Briefly, two parallel entries had been driven in a coal seam approximately 150 ft. into a small peninsular hill with a surface area of roughly 3½ acres (Figure 1). This seam was connected with a main body of 19,000 acres of coal in which a large mine was in operation but was isolated by an open-cut through the north end of the peninsula. The parallel entries were connected at their extremity by a crosscut, forming a U-shaped path around a pillar of coal averaging 150 ft. in length and 40 ft. in width. The portals were sealed, and pipes for admitting and taking off air or gas were placed in each seal. Air could be blown through and the flow reversed as desired, the gas being removed from the opposite portal. The installation was completed in January 1947, and at 2.00 p.m. on 21 January the project was fired and experimentation begun. The coal was ignited at the east end of the crosscut by dropping thermite bombs down into the coal area through a vertical test hold. Details and results of this first experiment are to be found in several papers. (1) (2) (3)[2]

This gasification experiment was continued for fifty days. At times, tests were made using a blast medium of oxygen-enriched air, oxygen-steam, or steam in a cyclic operation, as in the production of water gas. The greater part of the first Gorgas experiment was made with simple air blast.

[1] Work on manuscript completed 3 March 1949.

[2] Numbers within parentheses refer to items in the bibliography.

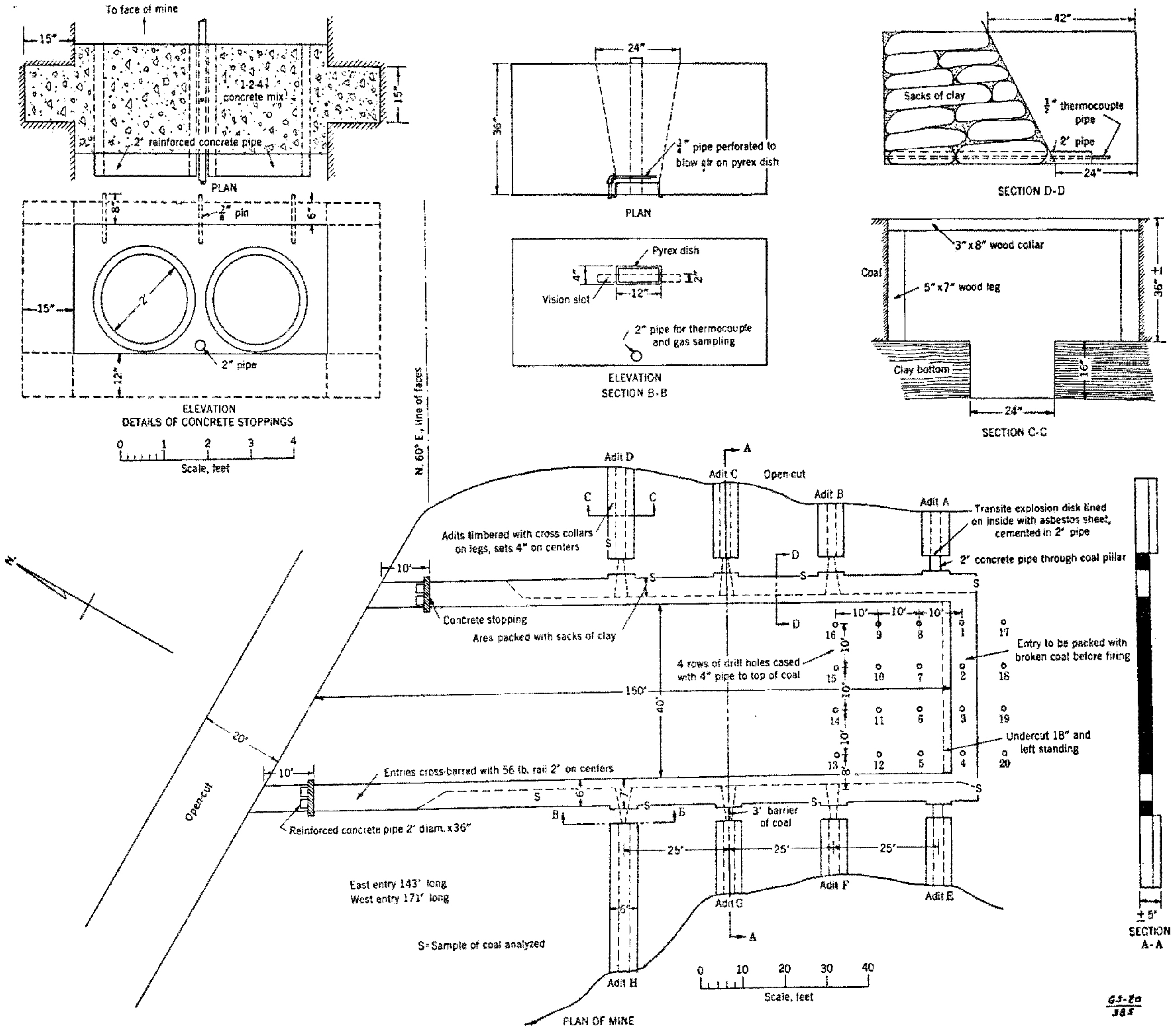

Figure 1. Plan of gasification mine

During one week, gas was taken from several test holes and burned under a small boiler supplying steam for the experiment. A total of 450,000 cub. ft. of gas, with an average heating value of 70 B.T.U. per cub. ft., was burned over this period, and the average composition of the gas was:

	Per cent
CO_2	11.7
O_2	.4
Illuminants	.2
H_2	7.0
CO	9.1
CH_4	1.4
N_2	70.2

This gas taken from the test holes was considerably lower in carbon dioxide and much higher in carbon monoxide and hydrogen than the product gas sampled at the outlets. In addition, the heating value often reached 90 B.T.U. per cub. ft., and the maximum determined value was 108 B.T.U.

From this preliminary experiment, in which approximately 400 tons of coal was coked or burned, these conclusions were drawn:

1. Combustion of coal in a solid stratum underground can be maintained.

2. Coal in place in this instance was gasified completely. Examination of the residue showed that only ash and clinker remained in the combustion zone. No islands of unreacted coal or coke were found.

3. Coking preceded actual combustion.

4. The high temperature developed by the gasification brought about changes in the overlying strata that appeared favourable to the process. Roof rock became plastic, expanded, and settled on the mine floor directly behind the reacting coke face. Settlement of the roof rock forced the air and gas to pass through the narrow openings along the coke-rock interface. However, the formation of these narrow openings increased the pressure drop through the system but did maintain contact between the blast medium and hot carbonaceous surfaces.

5. Volume and velocity of air circulated were not sufficient to give temperatures necessary for optimum results.

6. A product gas of varying quality was produced by the several methods employed. It appeared possible that a power gas could be produced by the use of air, air-steam, or oxygen-enriched air and that a synthesis gas apparently could be made by using an oxygen-steam blast or through a cyclic operation employing a steam run.

LABORATORY EXPERIMENTATION

A horizontal, rectangular, laboratory-scale retort was built at the Bureau of Mines station at Morgantown, West Virginia, to investigate some of the problems and proposed methods of underground gasification of coal at a fraction of the time, labour, and cost required for field-scale operations. The retort (Figure 2) was contained in a steel jacket, open at the top, and was itself constructed of standard refractory materials. It was well-insulated with diatomaceous earth. Inlet and exhaust openings to the retort were provided with regenerators or heat exchangers and suitable equipment for handling air and product gas. The retort was altered repeatedly in size and construction as experimentation progressed, remaining, however, essentially horizontal and rectangular.

During the first test runs, a gas comparable to that in the first field-scale experiment at Gorgas was produced, that is, having a heating value of approximately 50 B.T.U. per cub. ft. A marked improvement in gas quality was noted as experimentation continued. Table 1 gives the results of four

Table 1. Results of Laboratory Experiments

Experiment	*7*	*9*	*10*	*11*
Wt. of charge (in lbs.)	5,180	8,738	8,185	8,030
Wt. of residue (in lbs.)	1,453	4,920	4,717	2,002
Per cent consumed	72	44	43	75
Max. air flow (cu. ft. per hour)	2,350	3,642	4,600	2,940
Analysis of charge (in per cent)				
Hydrogen	4.6	4.2	4.2	4.5
Carbon	75.9	75.6	78.2	76,6
Nitrogen	1.2	1.3	1.3	1.4
Oxygen	6.1	5.6	4.7	6.2
Sulphur	.9	1.3	.9	.9
Ash	11.3	12.0	10.7	10.4
Heating value (B.T.U. per lb.)	13,220	13,010	13,390	13,250
Length of run (in hours)	109.25	83.5	46.3	124.5
Gasification period (in hours)	31.5	52.0	20.3	22.5
Av. gas analysis (in per cent)				
CO_2	8.7	10.2	7.7	7.7
Ill.	.2	.6	.5	.3
O_2	.2	.2	.5	.4
CO	19.9	12.1	14.7	20.9
H_2	4.3	9.5	10.7	4.5
CH_4	1.0	2.4	2.0	2.3
N_2	65.7	65.0	63.9	63.9
Heating value (B.T.U. per cu. ft.)	92.4	106.1	111.6	111.4
Cold-gas efficiency (in per cent)	55.6	75.0	80.9	64.5

of the last runs. The calorific value ranges from 92.4 to 111.6 B.T.U. per cub. ft. These gas qualities given are the average for a large percentage of the test periods involved.

During some of the test runs, the relationship between oxygen, carbon dioxide, and carbon monoxide was determined. This was shown by analysis of gas samples taken after the air gas had traveled 5, 20, 50, 70 and 95 per cent of the length of the channel. These analyses clearly show a decrease in oxygen and an increase in carbon dioxide, then a decrease in carbon dioxide and an increase in carbon monoxide as the percentage of travel through the channel increased. The 5-per cent point was characterized by high oxygen, the 20-per cent point by high carbon dioxide, and the 50-, 70-, and 95-per cent points by increasing percentages of carbon monoxide, with a maximum percentage at the 95-per cent point and in the product gas.

The laboratory tests indicated that it should be possible to use a simple air blast and produce a gas having a heating value of 100 or more B.T.U. per cub. ft. by underground gasification.

SECOND FIELD-SCALE EXPERIMENT AT GORGAS, ALABAMA

The results of the first Gorgas experiment and the laboratory work that followed have led to the construction of a larger-scale underground gasification project at Gorgas, Alabama. This experiment is being conducted in the Pratt coal bed in an area isolated from the main body of coal by nature and consisting of approximately 100 acres. The coal seam is 42 in. thick, and relatively level; it lies under an average overburden of 150 ft.

One of the purposes of the second experiment at Gorgas is to study the characteristics of a unit installation for underground gasification. A "unit" of an underground gasification system consists of: (1) A gasification chamber, which is a passageway in the coal bed; (2) entry and exhaust channels for blast and product gas, respectively; and (3) machinery and piping necessary to operate the system. The installations for the second experiment at Gorgas, Alabama, are shown in the schematic diagram (Figure 3).

The experimental unit consists of a straight-line passage in the coal, with surface connexions at one end through an outcrop seal, and at various points along its length through vertical boreholes. The passage is divided into five sections, each 300 ft. in length. Each section may be used separately as a gasification unit, or several sections may be combined to form a larger unit. The passage in the coal bed consists of two parallel entries 10 ft. wide, separated by a solid pillar of coal 10 ft. thick. The boreholes are drilled into crosscuts connecting the entries. The last 300-ft. section consists of a single 10-ft.-wide entry.

A wide choice of operating methods may be employed during the experiment. Initially, it is planned to use a simple, continuous, unidirectional air blast. If conditions necessitate, a reversing air blast may be used. The use of steam also is possible, either intermittently, as in a cyclic water-gas operation, or continuously with air. Oxygen has been considered for use in underground gasification, but its cost, in large quantities, is prohibitive, at present, so most of the experimental work will be done with air.

The objectives of this second underground gasification experiment are:

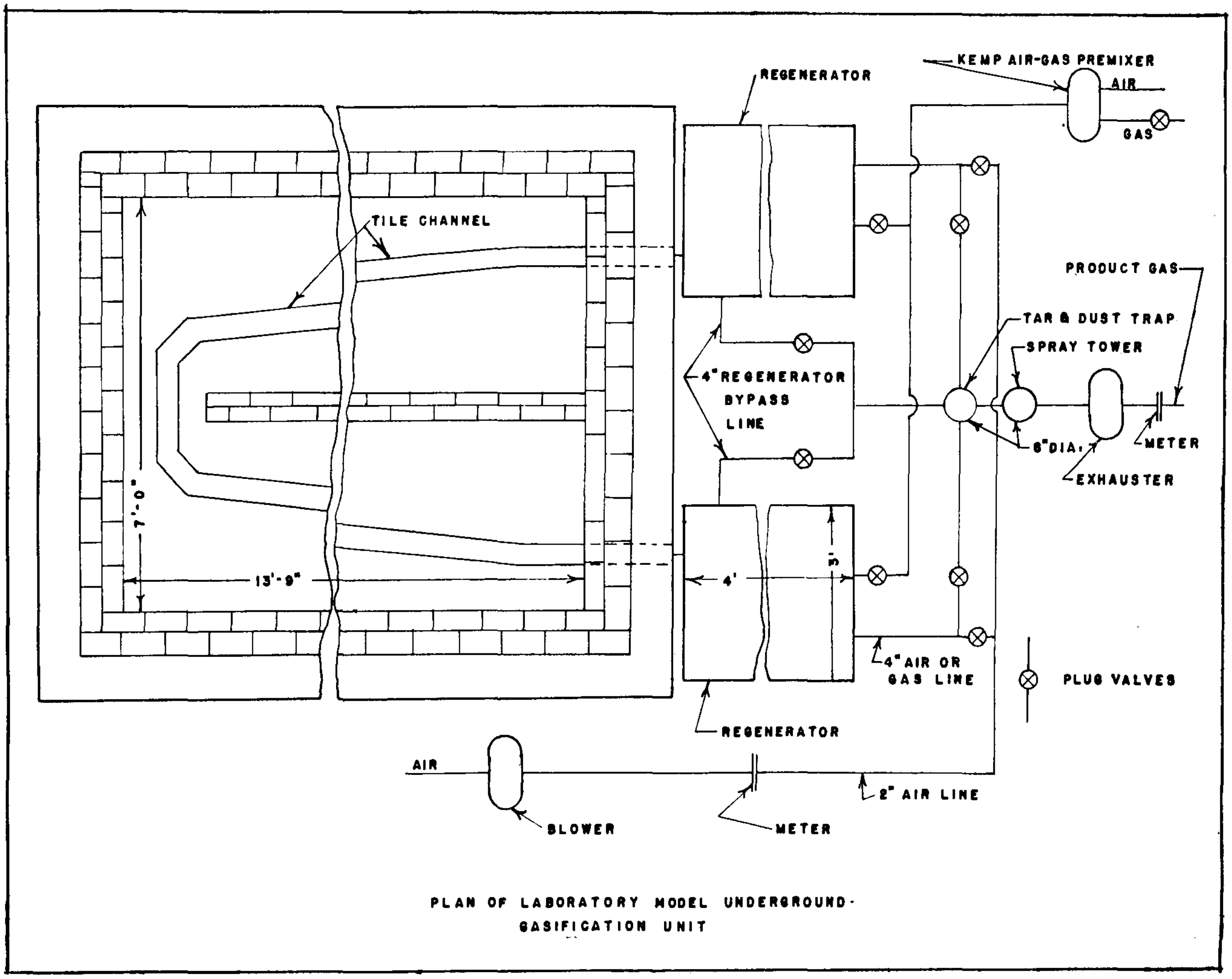

Figure 2

1. To determine the quantity of coal that can be gasified from a given initial combustion zone and the shape and extent of the burned-out areas formed during this gasification.

2. To test the design and installation of types of fixed product-gas outlets, including the seals required.

3. To determine the operational characteristics of the experimental installation under such variation of conditions as the nature of the installation and the progress of the work may indicate to be desirable – for example, the length of passage required; the optimum rate of flow, and the pressure drop.

4. To determine the quality and quantity of the air-blow product gas generated under the experimental conditions. A secondary phase will be determination of the quantity of tar and related products obtained.

5. To obtain all possible information regarding the action of heat on the overlying strata.

6. To develop, without interfering with the foregoing objectives, such fundamental technical and economic information as is likely to be helpful in selecting plant sites, plant installation, and operating processes. Testing of refractory linings and installations designed for handling hot gases will be included.

The construction of the underground gasification unit at Gorgas, designed to operate one year or longer, required equipment and construction work on a magnitude comparable to that of a small industrial plant. A two-cylinder reciprocating compressor, designed to deliver 7,200 cub. ft. of air per minute at 30 pounds per square in. gauge is installed. This source of air is connected to five boreholes by means of a valved 20-in.-diameter manifold.

Entries were driven into the coal bed, and conveyors were used to load out and transport the coal to the surface (Figure 4).

Two 18-in. and three 28-in. churn-drill holes were drilled from the surface to the entry (Figure 5). The strata through which each borehole passes were pressure-grouted by means of four 6-in. churn-drill holes spaced 4 ft. from the centre point of the large hole. Generally, the first two holes took appreciable quantities of cement grout, sometimes requiring 300 bags of cement. At each location, the last two 6-in. holes refused to take grout, indicating that the underground crevices intersected by the holes were securely stopped.

The five large boreholes have been sealed at the surface by lengths of water-jacketed pipe set in concrete (Figure 6). These seals extend approximately 25 ft. below the surface and are seated on hard strata.

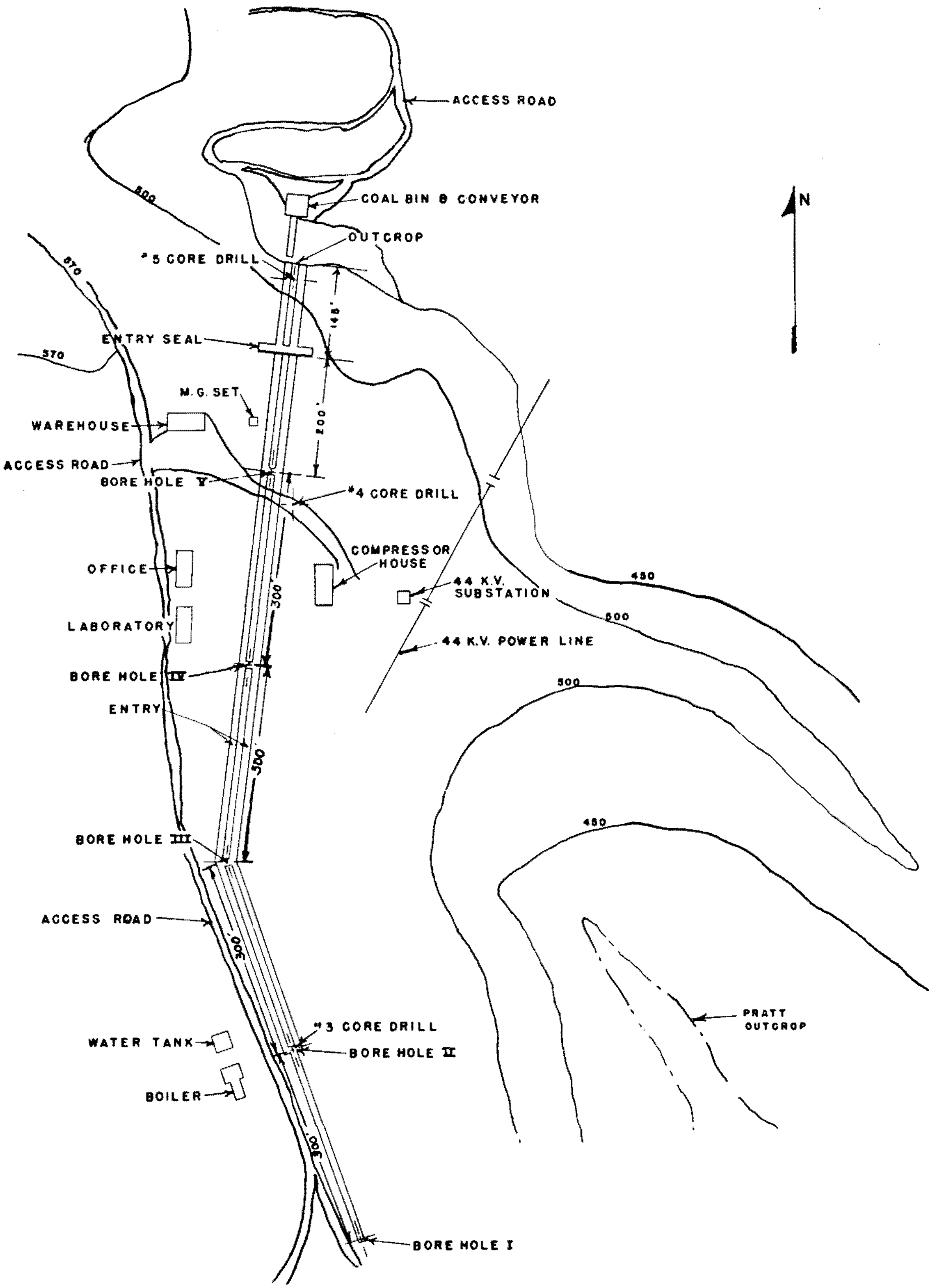

Figure 3. Plant Layout, Plan of Underground Gasification Project.

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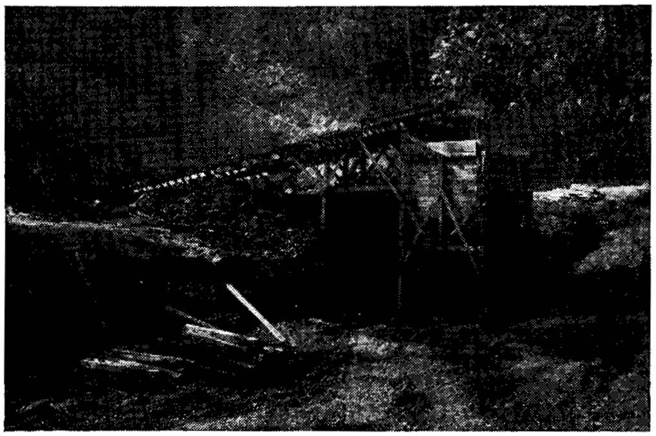

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Figure 4. Mine portal with Conveyor and loading bin

The two 18-in.-diameter boreholes will be unlined below the seal. It is possible that the natural strata will crumble and slag at high temperature, blocking the borehole. To prevent this, a refractory lining has been installed in the 28-in. holes.

Bureau of Mines, U.S. Department of the Interior

Figure 5. Rig used to drill no. 1 churn-drill hole. Note 18-inch bit in foreground and bailer standing upright at left of rig

A 20-in.-diameter pipe casing was set in the hole, and a refractory concrete mix was poured into the 4-in. annulus.

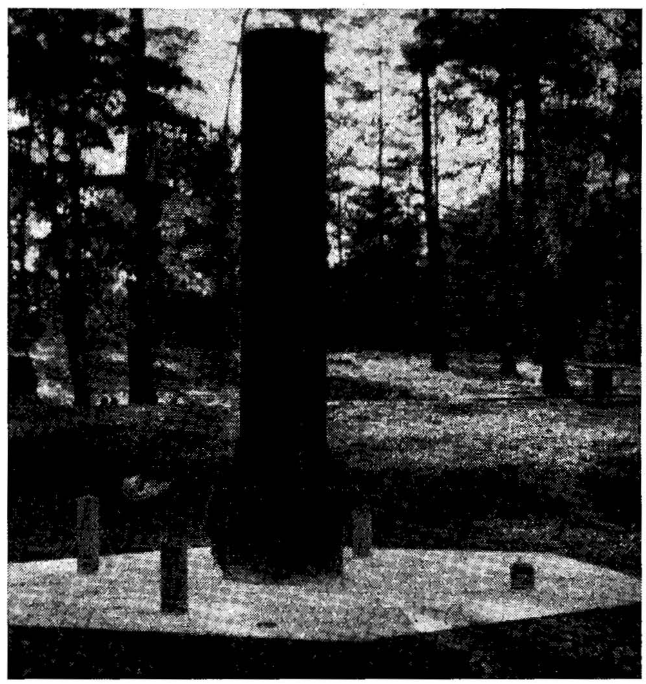
In addition to the large boreholes, a number of 6-in.-diameter holes were drilled to measure the temperature rise in the coal bed. Holes are placed in a pattern so arranged that the progress of the combustion zone may be traced.

The Southern Research Institute of Birmingham, Alabama, is supervising the application of another method of determining the location of the burning face of the coal during various stages of its progress. This consists of the use of volatile materials, used as tracers and placed in capsules in horizontal holes drilled normal to the burning face. The presence of these tracers in the product gas is then indicative of the burning face reaching a definite location.

The entry seal consists of a wall extending across and 25 ft. beyond the outby ribs of the entries. This wall extends 6 ft. into the roof rock and 2 ft. into the bottom. It is constructed of three courses of firebrick, backed and sealed with concrete and cement grout. Outlet pipes have been set in the wall. The design and testing of an entry seal are requisites in underground-gasification experimentation.

Combustion was started near the bottom of No. 1 borehole in the entry and at the end farthest from the outcrop. Air was supplied at borehole 1, and products of combustion were taken off 300 ft. away at borehole 2. A low rate of air blast was used initially, gradually increasing as combustion was established.

When the gasification phase is well-established, air will enter the coal seam in an area where combustion is taking place, and the oxygen will be converted to carbon dioxide as it reaches the reacting coal face. The products of combustion will then leave this area carrying large quantities of sensible heat but no oxygen. These gases will give up this sensible heat to the downstream coal faces and reduce carbon dioxide to



Bureau of Mines, U.S. Department of the Interior

Figure 6. Water-cooled seal installation at borehole 5

carbon monoxide. After leaving this area, these gases will still contain a large quantity of sensible heat, and they will pass down a channel faced with coal distilling off volatile products from the coal. These volatile products will enrich the gases, and the gases will then be drawn from the underground system.

At this time, before the results of the second experiment are fully known, it is not possible to do more than theorize on the economics of underground gasification. If, however, a producer gas having a heating value of 125 B.T.U. per cub. ft. can be developed by methods similar to those used in the experiment, the cost may well be as low as 14 cents per million

B.T.U. produced. This is equivalent to a coal cost of $3.50 per ton f.o.b. mine. Costs might be reduced further with development of machinery for penetrating the coal bed horizontally without the necessity of making the conventional entry.

ADDENDUM ON FURTHER EXPERIENCE

Initial operating period, second underground gasification field-scale experiment at Gorgas, Alabama

On 18 March 1949, the project was fired at borehole 1 with air passing through the workings at an average flow of 2,000 cub. ft. per minute. Before firing, the ribs of the butt entry between boreholes 1 and 2 were undercut to a depth of 12 to 18 in., and the loose coal was piled against the ribs. A pile of broken coal approximately 15 ft. long and 2 ft. deep was placed across the entry and 10 ft. north of the base of borehole 1. Pine wood was stacked on this broken coal and at the base of borehole 1, and the mass of combustible was then saturated with fuel oil by pouring 2 barrels from the surface down borehole 1. A thermite hand grenade was tossed down the borehole to obtain the ignition.

The air flow was continued for 10 days in the same direction, and the rate of flow was varied as the quality of the effluent gas dictated. During this period, the temperature level of the underground passage rose rapidly at first and then fell. Oxygen was always present in the effluent gas, and the indications were that the high-temperature zone was moving toward borehole 2. The flow was reversed after 10 days' operation, and the product gases were removed from borehole 1. The flow was continued in this direction for 6 days, and the high-temperature zone was driven back toward borehole 1. These prolonged periods of flow in one direction tended to waste a large percentage of the sensible heat in the effluent gases, rather than store this heat underground. It was then decided to set a maximum stack temperature of 700 degrees F. and to reserve the flow each time this temperature was reached. This procedure has been followed to date, and the cycle time has reduced from 72 hours to 9 hours, indicating that a higher temperature level has been obtained underground. The oxygen content of effluent gas has been decreasing slowly but steadily during this period, and the resistance to flow has been increasing. The expectations are that continued operations of this nature will continue to raise the effective temperature level between boreholes 1 and 2; and, with subsidence of roof rock into the passageway, the gases will be forced into intimate contact with hot carbonaceous surfaces. This, in turn, will improve the quality of the product gases obtained.

During these initial operations, the test holes adjacent to the ribs of the single entry connecting boreholes 1 and 2 have shown a gradual and steady increase in temperature. Test holes 10 ft. from the ribs of the entry now show temperatures approximately that of the boiling point of water, indicating that the combustion zone has traveled an appreciable distance normal to the entry but has not yet burned away 10 ft. of coal from either rib. One week after operation of the project had started, a mercury capsule 100 ft. north of borehole 1 and 3 ft. off the west rib of the entry burst, and the mercury vapor was detected in the product gas. This indicated that, at this point, at least 3 ft. of coal had been affected.

It was anticipated that a long time would be required to obtain temperature levels underground high enough for gas-making purposes. These expectations have been realized, but with the cyclic-type operating procedure now in effect, a steady increase in temperature underground and the increase in back pressure indicate that the project is approaching the required operating conditions.

Bibliography

1. Milton H. Fies, "The Gorgas, Ala., Experiment in Underground Gasification of Coal", *Transactions*, Canadian Inst. Min. and Met., vol. 51 (1948), pages 234–247.
2. Milton H. Fies and W. C. Schroeder, "Underground Gasification, an Account of Experiments on Coal, Conducted at Gorgas, Ala.", *Mech. Engineering*, February 1948, pages 127–135.
3. James J. Dowd, James L. Elder, J. P. Capp and Paul Cohen, *Experiment in Underground Gasification of Coal at Gorgas, Ala.*, Bureau of Mines, Rep. of Investigations 4164, 1947, 62 pages.

Other references

"Gasification of Coal Underground", *The Fuel Economist*, June 1936, page 331.

"Underground Gasification of Coal in the USSR", *Gas World*, vol. 114 (1941), page 101.

"Underground Gasification of Coal", *Colliery Engineer*, vol. 18 (1941), pages 220–221.

"Arrangement of Shafts for Underground Gasification of Coal. German Patent 725,079", *Chem. Zentralb.*, vol. 2 (1942), page 2965.

R. Foster, "Underground Gasification of Coal", *Min. and Petrol. Technol. Mag.*, Birmingham University Mining Society, 1943.

A. V. Chernyshev, "Russian Gasification Progress", *Gas Times*, vol. 37 (1943), page 39.

"Underground Gasification in Russia", *Chemical Age*, vol. 158 (1943), page 653.

H. J. Rose, "Underground Gasification of Coal, the Gasworks of the Future", *Gas Times*, vol. 35 (1943), pages 26–27.

"Underground Gasification", *Coke and Smokeless Fuel Age*, August 1943, page 144.

G. E. Foxwell, "Underground Gasification of Coal", *Iron and Coal Trades Rev.*, vol. 149 (1944), pages 257–259, 268.

N. Shvernik, A. Gorkin (for the Supreme Soviet of the USSR), N. A. Voznesenskii, A. Pianovoe, G. Kosyachenke, N. Baibakov and Khozaysteo, *Some Data on the Planned Development of the Oil and Chemical Industries of the U.S.S.R. for the period 1946–50*, 1946; no. 2, pages 5–63, 64–68, 100–112, 136–147; no. 3, pages 12–19.

South African Mining and Engineering Journal, January 18, 1947, page 555.

W. C. Schroeder, "Synthetic Liquid Fuels in the United States", Paper 47-A-40, December 1947.

L. J. Jolley and N. Booth, "The Underground Gasification of Coal, Survey of the Literature", *Fuel in Science and Practice*, vol. 24, no. 2, pages 1–14.

Utilization of Coal at the Mine: Underground Gasification[1]

M. DOUMENC

ABSTRACT

French research in the underground gasification field now includes:
An underground experimental plant in Morocco which it is intended to fire in July 1949;
Participation in the Franco-Belgian experiments at Bois-la-Dame (Belgium);
Research conducted at the experimental Station of the *Charbonnages de France* (Montluçon).
For the present the object in view is to generate producer gas.

The present paper discusses three problems on which the success of the process seems to depend: favourable thermo-dynamic balance; full completion of the gasification reactions; behaviour of the terrain.

The research carried out in this connexion has led to the adoption for the experiment in Morocco of the method consisting in the application of a blast to a horizontal stall on the rise in a steep seam, a relatively small flow of air, reheating of the blast and preheating of the shaft.

A preliminary plan of industrial operation makes it possible to define the conditions which must be satisfied in this first experiment if it is to be regarded as economically advantageous. As the initial outlay is relatively high, the industrial experiment must not be embarked upon lightly; but the human value of the process justifies the continuation of research.

RESEARCH

French research into this new technique dates from the latter part of 1946. Previously French technicians had kept abreast of developments abroad by studying published material but no serious scheme had been put forward. The French collieries had a heavy reconstruction programme to carry out; moreover our coal fields at home, most of whose easily accessible deposits, even of low-grade coal, had been wholly or partly worked out during the period of forced autarky, were ill-adapted to the trial of gasification on a limited scale.

French Research (Djerada): In fact the first experimental work took shape outside metropolitan France in North Africa, first in the Tunisian lignite fields at Cap Bon, a scheme which was soon dropped, and later in the Djerada anthracite field in Morocco with the encouragement of Mr. E. Labonne, at that time French Resident General in Morocco. It was decided to set up and equip an experimental plant which it is intended to fire for the first time in July 1949, and our principal efforts have been concentrated on carrying this scheme into effect.

The characteristics of the experiment in Morocco and its object were defined in May-June 1947 by a working party responsible for laying down the general conditions to be satisfied. "It appears", one of the reports states, "that for the most part foreign investigators have obtained combustible gas from the products of coal distillation, mixed with carbon dioxide derived from the total combustion of part of the remaining coke. This easy solution is impossible in the case of anthracite (containing only 5 per cent of volatile matter) and the problem is to achieve, with the help of modern firing techniques, the gasification of the coal into carbon monoxide, which is a much more efficient operation. Exceptionally favourable conditions for the experiment exist at Djerada, namely, the outcropping 'panel', the almost vertical dip of the seam, the absence of water inflow and the distance from any other works, and fully justify its choice . . . ; on the other hand the composition of the coal and the thinness of the seams mean that the scheme will have to be planned with great care . . .".

[1] Original text: French.

Franco-Belgian Research: When the Research and Study Centre of the *Charbonnages de France* decided late in 1947 to engage in its turn in research into underground gasification, put in hand some laboratory experiments and then signed an agreement with the Belgian Socogaz Research Society to organize joint research so as not to disperse European efforts in this field, its directors were careful to maintain very close liaison with the Djerada Gasification Committee. Thus perfect co-ordination is secured between the policies underlying our activities in the three fields, namely: the experiment in Morocco (Djerada, conducted by the *Charbonnages Nord-Africains;* French participation in the Belgian experiments at Bois-la-Dame; and research at the Coal Research Station, the *Charbonnages de France (Montluçon)*.

CONDITIONS FOR THE GENERATION OF PRODUCER GAS IN THE MINE

We set ourselves as a first target the generation of producer gas, "power" gas to use the Russian terminology. For the present it is proposed to feed our plants with ordinary air only. This is not because we fail to recognize the possible advantages of a blast enriched with oxygen or superheated steam in an underground gas generator, where the protection of the walls will doubtless raise fewer problems than on the surface, but for the first experiments, however, we consider that the enrichment of the blast although desirable in so far as it is practicable, is not necessary; we believe that once we have a working knowledge of the phenomena which occur in a fired stall, it still be open to us to incorporate in the basic scheme any modifications which we deem necessary and the advantages of which we shall know in advance.

However, the published data and our initial experimental studies tell us very little about what happens inside an underground gasification shaft. We know that it is easy to fire the seam, even in the case of anthracite, a fact which could indeed be inferred from the frequency of underground fires in normal mining operations. We hope, although on this point experience abroad is less conclusive, that with proper technique we shall succeed in extending the zone of combustion to an entire level and thus arrive at a permanent operating state. The success of the process will then be dependent on three fundamental requirements:

A favourable thermal balance in which the loss through the ground is not too large;

Full completion of the gasification reactions before the gas leaves the working;

Favourable behaviour of the terrain as the face advances.

We hope to obtain information on these three requirements and on the establishment of normal working conditions from our initial experiments, the interpretation of the results being simplified by prior research in the laboratory.

The terrain: The behaviour of the terrain is a mining problem regarding which we can offer no fresh information, as we have not yet completed any underground experiments. For the latter, as has been done in the case of other experiments in the West, we have retained the procedure recommended by the Russians, that of a blast limited to a single burning stall. It would be naive to imagine that the initial state is maintained throughout combustion and that the coal face remains clear and burns on the surface; in practice the problem lies in the size of the falls of coal and the physical characteristics of the walls at the temperature attained. As our information on the Russian experiments mentions very great resistances in the circuit, requiring a high pressure blast, we looked for a steep seam so as to install rise workings; our section may consequently be too open. In any case in Belgium we advocated the continuation of research on stalls on the rise but reversed at the angle of the coal-fall slope. In this way we hope to acquire some data on the mining problem in vertical seams, which will round off the American research on level seams.

Chemical reactions: The kinetics of the chemical reactions vary *a priori* in accordance with the size of the falls of coal, and consequently in accordance with the mining conditions. If the gases were filtered through tightly packed blocks, following a technique analogous to that adopted in gas generators, the contact might be expected to be sufficiently close to ensure proper gasification. But for other reasons, in particular the volume of the unburnt tonnage, this solution is undesirable: the Russian documentation seems conclusive on this point. We therefore chose to furnish a draught with a view to lambent combustion. But we do not expect that the reactions will be sufficiently active to permit of a rapid movement of the burning face; for theoretical reasons, supported by the results of some experiments on a scale model, we believe that the advance would be at the rate of one centimetre an hour. Hence in Morocco where the electric power available is limited, we preferred to reduce the blast (8,000 cub. metres an hour supplied by a volumetric compressor) in order to keep a certain margin of pressure in hand (0.7 atmosphere). In Belgium the fans provided for the second underground experiment normally provide 15,000 cub. metres an hour for a shorter stall; this will give us a somewhat different datum for comparison.

RESEARCH ON A SCALE MODEL

We are also conducting parallel researches on scale models, with the aim of discovering data helpful in the interpretation of the results of the underground experiment, rather than of achieving absolute similarity, which is in any case theoretically impossible because of the number of parameters of different kinds. We first tried to achieve a general but approximate similarity by working on small galleries; but the relative importance of the coal structure plays too great a part in the complete phenomenon to afford any hope of obtaining data valid on another scale; we are now therefore using such test galleries only in order to perfect our methods of measurement. For basic data on lambent combustion we are turning to more theoretical experiments on the reactivity of the surfaces and the diffusion of the gas strata; here we achieve local similarity of the combustion face.

The thermo-dynamic problem: We lay particular stress on the third problem which is thermo-dynamic in character. The transfer of energy in the gasification process is primarily dependent on the equilibrium of the thermal balance which consists of three factors: latent heat (calorific power of the gas); liberated heat (exit temperature of the gas); losses through the ground.

It is of primary importance to know the magnitude of these losses, which will always limit the efficiency of the operation. Some idea of their size may be formed on the basis of a few assumptions regarding the thermal regime established in the deposit, and on this basis a figure of 10 to 15 per cent has been estimated; these figures, however, disregard the phenomena of fusion and chemical reactions (vaporization, decomposition of carbonates etc.), which always occur on a greater or smaller scale and which substantially modify the calorific flux. We are conducting a series of laboratory experiments on this problem, but we are relying on the underground test for definite data regarding the percentage of losses. It is practically impossible to measure them directly. We are therefore anxious that the two other items in the balance should be determined as accurately and with as much cross-checking as possible; we have organized the control of the test in Morocco with this in mind, and measurements not directly affecting the items of the balance are being treated as secondary.

The calories carried by the gas produced are expressed on the one hand by its high temperature and on the other by its calorific value. All are theoretically utilizable; the former directly in an exchanger and the latter by means of burners. But only the latent heat can be easily transmitted to a central station where it can be used, and although it is possible to visualize the installation of boilers at the head of each shaft, the principal objective is combustible gas with a calorific value at least equal to that of blast-furnace gas. This means a close balance, which *a priori* rules out a rate of steaming higher than is unavoidable (humidity of the coal and of the walls) and which has everything to gain from the addition of calories in the form of pre-heating of the airblast. The latter possibility fits in well with the general conditions: the gasification reactions are slowed down at a temperature of about 700 degrees: there is no advantage if the exit temperature of the gases is lower; if the liberated calories are not directly utilized, they must obviously be returned to the shaft by pre-heating the air in order to increase the amount of latent calories.

While we have some reason to hope that the insulation of the shaft under a permanent working state will be sufficiently complete to ensure that the losses are not so large as to prevent proper gasification, it is to be feared that the establishment of permanent working state conditions will be a difficult undertaking. The amount of calories absorbed by the terrain is very important. Local combustion may not extend to the whole circuit: the fire may smoulder. To avoid any incident of this kind and to ensure successful initial operation, we intend, in the experiment in Morocco, to pre-heat the whole coal mass before it is fired by prolonged sweeping of the shaft with hot combustion gases from large oil burners.

TOWARDS A CONCLUSIVE EXPERIMENT

The foregoing observations justify the lines on which we have so far conducted our research and in which scientific and economic considerations have both played their part. We can only judge their merits when we have carried out a conclusive underground experiment. We have shown to what extent the experiment in Morocco, involving pre-heating of the shaft and re-heating of the blast by periodical inversions in regenerators, satisfied our first objective. We hope after this experiment to have enough data to set up a semi-industrial plant in which to investigate the economic efficiency.

We believe indeed that the technical importance of underground gasification depends on the extent to which it can generate cheap producer gas; thus, the economic value of any attempt to improve the quality of the gas, whether for synthesis or for long distance distribution purposes, will reside in the low cost of the basic material. It is therefore essential to determine from the outset the possible costs of producer gas and the conditions which the experiment in Morocco will have to satisfy for justifying its continuation on a semi-industrial scale in a larger plant feeding a small thermal group.

The experiment now being prepared will cost 45 million francs. But this sum to a large extent refers to immobilized material only part of which need be amortized; the expenditure proper may be estimated at 25 million francs, for a panel likely to furnish approximately 25 million cubic metres of producer gas. On the most favourable assumptions, costs cannot be lower than one franc per cubic metre; this figure is double that required if the process is to be an economic one; it is due to the fact that the pilot plant is not on an industrial scale.

FUTURE PROSPECTS

However, assuming a future plan of operations in which four plants each producing some 20,000 cub. metres an hour on a larger scale than that of the experiment (200 metres face; 50 cm. a day advance) are in constant operation providing the heat for a 20,000 kw. station, we cannot reasonably put cost factors per cubic metre lower than the following figures:

Mining works and underground consumable materials (depending on depth: 0 to 300 metres)	0.15 fr. to 0.20 fr.
Surface material, amortizable over 20 years and corresponding capital charges	0.15 fr.
Labour and current operating expenditure	0.05 fr.
Power for transporting gas	0.05 fr.
Power for air blast:	
pressure of 0.2 atmospheres	0.10 fr.
pressure of 0.6 atmospheres	0.20 fr.

These figures presuppose, however, for underground workings a regular bed easy to prepare, and, for the surface plant sufficient concentration (average distance of 2 km. from the power station).

These estimates, compared with the normal prices of power in France at the present time show that we must, if the experiment is to succeed, obtain gas at least equal in quality to blast-furnace gas at a cost for the blast of approximately 0.10 francs a cub. metre; the experiment must therefore prove that falls in the circuit leave the resistance low and that the combustion remains lambent. Otherwise for obvious economic reasons, the whole question will have to be thought out afresh and an entirely different layout will have to be tried.

On the other hand the considerable sum put down for fixed and capital charges should be regarded with some reserve. The installation of an industrial plant of the type indicated would require an outlay of over 1,000 million francs which can only be accepted with satisfactory guarantees. A simple semi-industrial test, which will be essential in any case even after success at the experimental stage, will immobilize almost 300 million francs as regards gasification alone. This means that despite the importance attached to the scientific aspect in this paper, economic considerations will continue to exercise a considerable influence on the continuation of our research.

* * *

We do not wish, however, to give them a predominant place. For one thing, the conditions governing the utilization of producer gas may be modified in such a way that the economic balance of the process is upset. But it is our belief that even if underground gasification does not turn out to be so revolutionary from the point of view of the cost of the energy produced from coal as some people should have liked, it retains its full value on the human plane. The difficulties of recruiting skilled labour prove, if proof is required, that the coal miner's job is still, in spite of the progress made, a hard and difficult one: any method of using coal reserves without having to extract them would undoubtedly be a great step forward.

Summary of Discussion

The Chairman asked Mr. Elder to present the paper prepared jointly by Mr. Fies and himself on "Laboratory and Field-Scale Experiments on the Underground Gasification of Coal".

Mr. Elder pointed out first of all that to convert coal into a low-cost fuel it was essential to be able to produce a low-cost synthesis gas. Reviewing the various processes used for manufacturing gas, he emphasized that the underground gasification of coal had the advantage of eliminating the cost of mining the coal and of installing gas generators.

The first experiment had begun at Gorgas on 21 January 1947 and had continued for fifty days. At times tests had been made using a blast medium of oxygen-enriched air, oxygen-steam, or steam in a cyclic operation, as in the production of water gas. The greater part of the Gorgas experiment, however, had been made with simple air blast. The heating value of the gas taken from test holes over a period of one week had averaged 70 B.T.U. per cub. ft. The average composition of the gas included 11.7 per cent of carbon dioxide, 9.1 per cent of carbon monoxide and 7 per cent of hydrogen.

The experiment had shown, *inter alia*, that underground combustion could be maintained; that coal had been completely gasified and that the residue contained only ash and clinker without any islands of unreacted coal or coke; and that the volume and velocity of air circulated had not been sufficient to give temperatures necessary for optimum results.

That experiment had been followed by laboratory experimentation undertaken by the Bureau of Mines. The laboratory tests had indicated that it should be possible to use a simple air blast and produce a gas having a heating value of 100 B.T.U. per cub. ft. by underground gasification.

The encouraging character of the results thus achieved had led to the decision to carry out a second experiment at Gorgas. That experiment had begun on 18 March 1949 in an area of 100 acres. Its objectives had been to determine the quantity of coal that could be gasified from a given initial combustion zone; to determine the shape and extent of the burned-out areas; to test the equipment manufactured for that purpose; and to study the characteristics of the installation by varying the conditions of the test. One of the main objectives was to obtain more detailed information on the quality and quantity of the gas thus produced and on the action of heat on the overlying strata. It was thus hoped to develop sufficient information for selecting plant sites that would be most favourable for underground gasification installations.

If producer gas having a heating value of 125 B.T.U. per cub. ft. could be developed, the cost might well be as low as 14 cents per million B.T.U. produced. A ton of coal, at a cost of $3.50, would produce heat at the same cost per million B.T.U.

The cost of gasification might be reduced further with the development of machinery for penetrating the coal bed horizontally without the necessity of making the conventional entry.

The CHAIRMAN thanked Mr. Elder for his survey, which he regarded as an example of the successful results achieved by experiments on underground gasification. In the absence of Mr. Doumenc, mining engineer and professor at the School of Mining at Saint Etienne, France, he presented the latter's paper on the "Utilization of Coal at the Mine: Underground Gasification".

To illustrate the spirit in which that problem had been approached in France, the Chairman pointed out that Mr. Doumenc had given a survey of the question at a meeting of mining engineers in Paris during the previous winter. He had recalled that the first research in that field dated back to 1933, when experiments had been carried out in the Soviet Union. At Gorlovka, for instance, it had been possible to obtain 2,000 cub. metres of gas per hour. That gas contained 1,000 calories per cub. metre and was composed of approximately equal amounts of carbon monoxide and carbon dioxide. The results of that experiment were not yet well known and allowance had to be made for possible errors in figures. Another experiment carried out at Gorlovka in 1941 had resulted in the production of 30,000 cub. metres of a similar gas per hour. No further information had been received from the USSR until the establishment in 1946 of a new Five-Year Plan which provided for the production of 920 million cub. metres of gas between 1946 and 1950, corresponding to 250,000 tons of coal, namely one-thousandth of the USSR coal production. In quoting those figures, Mr. Doumenc had pointed out that gasification, therefore, was used on a very small scale only.

He had then given details of French research, with which he had been connected, and which had been carried out in Morocco. For that research, the method adopted had been the blast method, as used by the USSR, as opposed to the method of filtration and boring mentioned by Mr. Elder.

The researches, which had been carried out on scale models, were difficult to transpose to an industrial scale. Indeed, it was theoretically impossible to seek a rule of similarity. Thus, some disappointing results obtained during the experiment were still being attributed by some to the fact that the air blast had been too powerful and by others to the fact that it had been insufficient. Only conclusive underground experiments would determine the behaviour of a section of a stall and the movement of the burning face.

The production of gas was small: a stall 100 metres long in a seam of one metre in width with an advance of 20 centimetres per day could supply 3,000 kw. per hour. That was a ludicrously small amount.

The Chairman considered that the new technique was as yet an unknown quantity and that it was still premature to speculate on the results of the utilization of underground gasification on an industrial scale. He hoped, therefore, that the members of the Conference would understand why the experiments in which France was taking part followed the direction outlined in Mr. Doumenc's document.

The first experiments carried out in Morocco dealt with anthracite, which contained only 5 per cent of volatile matter. It was the gasification of coal into carbon monoxide which would have to be achieved if a combustible gas is the target.

The first objective of the French research is not however to produce a gas with a high calorific value, but to produce an industrial gas of any type.

The firing itself was not difficult, even in the case of anthracite. Furthermore, it was hoped that the zone of combustion could be extended to an entire level. That would presuppose a favourable thermal balance, the full completion of the gasification reactions (carbon dioxide changing into carbon monoxide) and a favourable behaviour of the terrain.

For the research carried out in Djerada, Morocco, the method used had been the application of a blast to a horizontal stall on the rise in a vertical seam. The flow of air had been furnished with a view to lambent combustion and had been reduced to 8,000 cub. metres per hour in order to keep a certain margin of pressure in hand.

The higher the reaction temperature the better the gas and therefore it was necessary to achieve the highest possible temperature. In Morocco the shaft would be pre-heated with hot smoke from an oil burner and afterwards the flow of air would be reversed.

The last part of Mr. Doumenc's paper dealt with questions of price, the conclusion being that underground gasification could become a paying proposition if the gas obtained was at least equal in quality to blast-furnace gas and if air pressure did not exceed 200 grammes per square centimetre.

In 1948 the experimental station of the *Charbonnages de France* had carried out a number of experiments at Montluçon with models several metres long. Those experiments had shown an extension of the zone of combustion downwards; an increase in the air flow beyond the width of a shaft; a lack of homogeneity in the quality of the gas produced, which could be corrected by increasing the length of the shaft.

In 1949 the experimental station had carried out a study of losses in the coal deposit and of the influence of water in neighbouring strata on those losses. The study had shown that the losses ranged from 10 per cent in the case of dry sand to 70 per cent in the case of moist sand.

The Chairman then commented on the work on underground gasification carried on in Belgium. He stated that the Belgian Socogaz Research Society was composed of certain Belgian industrialists who utilized gas. A preliminary experiment carried out near Liège in February 1948 had confirmed the fact that fire could be started and maintained in the shaft. In June 1948 the Research and Study Centre of the *Charbonnages de France* had signed an agreement with the Belgian Research Society to organize joint research, with the provision that costs and results should be shared by both parties. In 1949 the Belgian Research Society had admitted Poland to participation in the work. Thus since 1949 Poland had been taking part in the discussion of the conditions under which a second experiment should be carried out at Bois-la-Dame.

The Franco-Belgian collaboration had tended primarily to reconcile certain differences of view. The Belgian society, composed of private firms which used gas, wanted rapid results, while the Research and Study Centre was in favour of proceeding on a basis of sound scientific research.

The experiment would be conducted on coal containing 11 per cent volatile matter in a seam 1 metre thick and of almost vertical dip. The method of an air blast without inversion would be applied to an oblique seam 80 metres in length. Air, possibly with oxygen, would serve as the combustible. Oxygen, which was an expensive product practically unobtainable in sufficient quantities in Belgium at the existing time, would only be used to fan or move the fire in the stall if the air should prove inadequate. It was not planned to re-heat the air systematically, but it would be possible to add small quantities of water or steam.

There had been long discussions on the question whether, after ignition, the fire would of its own accord move up or down the face of the seam. That fact showed how little was known of the problem.

The Chairman stated that the firing of the shaft, planned for July 1949, had been postponed for three to four months on account of an additional pre-heating device which was to be completed.

Mr. Bailey, who had visited the experimental sites in the United States and in Belgium, stated that in order to secure optimum conditions, account should be taken on the knowledge already acquired both on the coal deposits which would be used for the experiment, and on the behaviour of gas generators and furnaces. The air blast must be directed to the right place, the contract area should be as large as possible, and reaction should be more rapid than during the previous experiments, in order that a more adequate and dependable reaction temperature might be attained.

In the first experiment conducted at Gorgas the walls had given way; in the second experiment it had not been possible to maintain a sufficiently high temperature. Pre-heating of the coal face had been decided upon in Belgium. It could not be expected that contact of oxygen with coal would yield the desired gas. It had become increasingly clear that it was necessary to envisage a chain reaction which, by a reversal of cyclic operations with regenerative heating, would yield the desired product.

In order to obtain results which would be at all conclusive, it was essential, in his opinion, to operate on a much larger scale and over a much longer period of time than had hitherto been done. The gas should be analysed as it emerged, so that its composition might be studied in the light of the conditions of the operation: blast, temperature, etc. It would be essential to provide for a reversing air blast.

In conclusion Mr. Bailey pointed out that in order to provide the best conditions for the experiment it would be necessary not only to gather available information from all countries but to consult geologists, mining engineers, chemical engineers, mechanical engineers and other specialists, in order that all aspects of the problem might be clarified.

Mr. Ignatieff agreed with the Chairman that the work of underground gasification conducted in the USSR was still in the experimental stage and that its results could not be considered conclusive. All that was known was that so far it had been possible to gasify only 50,000 tons of coal.

The agencies which had undertaken underground gasification experiments in face of the scepticism of mining engineers were certainly worthy of praise. Nevertheless, those experiments had been conducted on too small a scale to permit conclusions to be drawn regarding the industrial possibilities of the new process. It was clear from the documents submitted that those agencies were bending their efforts towards maintaining constant combustion or gasification rather than obtaining optimum quality gas.

Mr. Ignatieff drew attention to two points. Firstly, in the stream method, a great proportion of air was lost for gasification, which was not the case with surface gas generators. Secondly, the required underground preparatory work adds to the cost of this method. With regard to the best method, Mr. Ignatieff thought that the use of boreholes in a concentric pattern, current in flat seams in the USSR, might give good results inclined seams. The question was whether propagation could be maintained so that large coal deposits could be gasified. Boring the holes presented no problem; they could be spaced 50 to 100 ft. apart, and could reach a depth of 500 ft.

It was essential to conduct experiments on all qualities of coal, in order to ascertain whether extensive coalbeds could be gasified. Canada was particularly interested in the question of underground gasification, because many of its coal seams were less than 3 ft. thick.

He then asked the Chairman how thick was the seam which it was proposed to gasify in Morocco, and why the volume of blast used in the Moroccan experiment was less than half that used in the second Gorgas experiment in the United States.

The Chairman thanked Mr. Ignatieff for his statement and noted with satisfaction Canada's interest in the problem of underground gasification. In reply to Mr. Ignatieff's questions, he said that the thickness of the seam was 1.20 metres; the face was 100 metres long. The volume of blast was determined by two factors: the anxiety to overcome compression, and the obligation to adopt readily available blowers.

Mr. Alspaugh felt that the problem should be approached from the point of view of both economics and the conservation of resources. Economic exploitation meant a maximum of production with a minimum of effort. When the time factor was injected, the problem of conservation arose.

He thought that the underground gasification method could be used to best advantage in working seams which were too thin or contained too many impurities. If it proved technically possible the underground gasification method might produce good quality gas. It remained to be seen how, in view of the high cost of oxygen, underground gasification could be carried out on a large scale. In his opinion, only small quantities of underground gas could be used for the production of power. Finally, a great many experiments would be required to determine the prospects of underground gasification.

He called attention to the enormous loss of heat caused in wet seams by refluxing, in other words, the cycle of evaporation and condensation of the water. With regard to the use of oxygen, it appeared that the Bureau of Mines of the United States Department of the Interior had postponed experiments until it had obtained conclusive information on the utilization of air.

He noted that European countries were more concerned with the problem than the United States, where mining conditions were still good. Their efforts would undoubtedly produce very interesting results.

Mr. C. J. Potter stated that the problem of underground gasification was of capital interest to the United States, where high quality coal was being rapidly used up and the coal resources were less great than had been thought.

Losses due to extensive exploitation reached 65 per cent. In the State of Illinois, only 3 million tons of coal out of 8 million per square mile had been mined in certain places. Flooding and caving had caused widespread damage. The United States would certainly need those enormous residues, which might best be exploited by the method of underground gasification.

He then remarked that the work on underground gasification was being followed in the United States with great interest.

Mr. Hubbert inquired what percentage of power could be obtained by means of underground gasification.

Mr. Elder replied that, in theory, maximum cold gas efficiency would be approximately 70 per cent. In the first Gorgas experiment a cold gas efficiency of 50 per cent had been at times obtained. He thought that proper temperatures could be maintained on condition that the necessary surface contact was present. The effects of humidity had not been great.

The Chairman thanked the speakers and expressed the hope that experiments would increase in numbers and scope and that positive results would be obtained before the following conference.

Coal Carbonization

23 August 1949

Chairman:

ALEXANDER KING, Chief Scientific Adviser, Office of the Lord President of the Council, United Kingdom

Contributed Papers:

The Coking Industry with Special Reference to Great Britain

D. HICKS, Director of Scientific Control, National Coal Board, London, England, and

G. W. LEE, Director of the British Coke Research Association, London, England

Overcoming Shortages of Metallurgical Coke

A. C. FIELDNER, Chief, Fuels and Explosives Division, Bureau of Mines, United States Department of the Interior, Washington, D.C. and

L. L. NEWMAN, Fuels and Explosives Division, Bureau of Mines, United States Department of the Interior, Washington, D.C.

Production of High-Grade Metallurgical Cokes from Coals of Poor Coking Quality

J. SABATIER, *Directeur aux Charbonnages de France*, Paris, France

A New Electric Process for the Carbonization of Non-Coking Bituminous Coal

OLAF JENSEN, *Norsk Hydro-Elektrisk Kvaelstofaktieselskab*, Oslo, Norway

Possibilities of Reducing Coke Consumption in the Production of Iron and Steel

MAGNUS TIGERSCHIÖLD, Director of Research, The Swedish Iron Master's Association, Stockholm, Sweden

Methods for Reducing the Amount and Quality of Coke Used in Smelting Iron Ore

P. E. CAVANAGH, Assistant Director, Department of Engineering and Metallurgy, Ontario Research Foundation, Toronto, Canada

Summary of Discussion:

Discussants:

Messrs. LEE, NEWMAN, CHERADAME, LOWRY, MULCAHY, C. J. POTTER, CRICHTON, FALKUM, VELANDER, CAVANAGH, JACQUÉ, YANCEY

Programme Officer:

MR. W. A. MACFARLANE

The Coking Industry, with Special Reference to Great Britain

D. HICKS and G. W. LEE

ABSTRACT

The outputs of steel, pig iron and hard coke in Great Britain, the United States of America and Germany in 1943, 1947 and 1948 are tabulated and also the tonnages of coal carbonized in coke ovens and gas-works in Great Britain. The wide range of British coking coals is described and the overlapping demands of the two carbonizing industries for the same types of coal are indicated. Details are given of the reserves and current outputs of the various types of coal in Great Britain and the impact of these data on the future development of the coking industries is considered.

The various factors affecting coke quality are listed, and the desirable properties of a metallurgical coke are discussed. It is emphasized that coke quality is largely determined by coal type but the importance of consistency of coal quality for the preparation of coke for blast furnaces is made clear.

Recent developments in coke oven plant design are described under the headings of plant layout, coal-blending facilities and oven design. It is shown that the same trends occur in the United States of America, Great Britain and Germany. New building in Great Britain is tending towards larger units as in America and the underjet systems of firing are now being freely adopted in all three countries to effect maximum fuel economy. The paper makes brief reference to the advances in by-product recovery practice and emphasizes the importance of dealing with the effluent problem.

INTRODUCTION

The coke oven industry in Great Britain, although primarily designed and operated to make coke suitable for the iron and steel industry, is increasingly being integrated with the demand for gas and solid fuel for domestic and industrial uses. The gas industry, whilst concentrating on meeting the demand for gas, also produces a large tonnage of coke; the coke is unsuitable for the blast furnace and is sold mainly in the domestic market.

In the past, the gas and coking industries have developed on separate and distinct lines but if the resources of coking coal are to be used most economically the needs of the two industries should be considered together since they draw, in the main, on the same types of coal. The relative sizes of the steel, pig iron and coking industries in Great Britain, the United States of America and Germany are shown in Table I.

Table I. Relative Sizes of the Steel, Pig-Iron and Coking Industries in Great Britain, U.S.A. and Germany[1]
(Million tons)

Year	*1943*	*1947*	*1948*
Steel production:			
Great Britain	13.03	12.72	14.88
U.S.A.	88.37	84.78	88.15[2]
Germany	20.76	2.95	5.37[2]
Pig-iron production:			
Great Britain	7.18	7.79	9.28
U.S.A.	56.97	58.51	53.41
Germany	9.28	2.26	4.61
Hard coke production:			
Great Britain	14.08	13.81	15.4[2]
U.S.A.	57.07	73.45	75.00[2]
Germany	39.75	13.24	18.88
Coal carbonized in Great Britain:			
Coke ovens	20.9	19.8	22.3[2]
Gas works	20.8	23.8	24.4[2]

[1] Bizonal area.
[2] Estimated.

THE RANGE OF PROPERTIES OF THE COALS IN GREAT BRITAIN

The British coals cover a very wide range—from the high rank anthracites with a volatile matter content as low as 5 per cent and carbon content of the coal substance as high as 95 per cent—to the low-rank non-caking bituminous coals with volatile matter content as high as approximately 40 per cent and carbon content of the coal substance as low as approximately 80 per cent. The change in rank is gradual and coals of all types from the highest to the lowest occur in substantial quantities.

The onset of caking properties occurs at about 13 to 13.5 per cent of volatile matter; from 13.5 to 20 per cent volatile matter the caking properties increase rapidly and reach a maximum in the range of coals with a volatile matter content of 20 to 30 per cent. Above 30 per cent volatile matter there is a general fall in the caking properties as the volatile matter increases. The relationship is not a close one but most coals of between 30 and 34 per cent volatile matter are strongly caking and most of those above 38 per cent are feebly caking or non-caking.

It is difficult to define the caking property of a coal in a quantitative manner and laboratory tests have so far only provided a basis for a broad classification, the ultimate test being large-scale oven trials. The three most important laboratory tests in use in Great Britain are:

(*a*) The British Standard Swelling Test, with a range of swelling numbers from 1 to 9. (1)[1]

(*b*) The coke type produced in the Gray King Carbonization Assay at 600 degrees (which ranges from Type A (non-caking) through B, C, D, etc. to greater thans G_9 (very strongly caking). (2)

(*c*) The British Standard Agglutinating Value Test which gives a range of indices from zero to 35 and over. (3)

Small scale tests used in the United States include:
(*a*) The United States Steel Corporation Assay Test.
(*b*) The Fischer L. T. Carbonization Assay.
(*c*) The Agglutinating Value Test for Coal.
(*d*) The Free Swelling Index of Coal as specified in B.S. 1016 (originally devised by the Woodall-Duckham Company) and

[1] Numbers in parentheses refer to items in the bibliography.

which has been adapted by the United States Bureau of Mines for routine test purposes.

(*e*) Plastometer tests.

All the British tests are standardized and are in common use, but none is strictly comparable with the other. Increasing use is being made of the small-scale oven tests and latterly the Russell Moving-Wall Oven which was perfected by the Koppers Company of America has been used to test a wide range of British coals. (4)

It is impossible to discuss quantitatively the resources of caking coal and the types of coal now used in coke ovens and gas-making plants without reference to a classification of coals. The Coal Survey organization, whose major task is to carry out a physical and chemical survey of the coal resources of Great Britain has adopted a simple classification which combines volatile matter content and Gray King coke type. For ease of reference a system of code numbers has been adopted. The classification divides British coals into nine main groups:

Description	*Per cent volatile matter (dry ash-free coal) and coke type*	*Code No.*
Anthracites	<9.5 A	100
Low volatile steam coals	9.5–20, A–G_8	200
Coking coals[a]	20–30, G_8 and over	301
Very strongly caking coals	>30, G_9 and over	400
Strongly caking coals	>30, G_5–G_8	500
Medium caking coals	>30, G_1–G_4	600
Weakly caking coals	>30, E–G	700
Very weakly caking coals	>30, C–D	800
Non-caking coals	>30, A–B	900

[a] I.e. coals especially suitable for the manufacture of high-grade furnace and foundry coke.

The classification further provides for subdivisions of the main groups as shown in the appendix.

The main tonnage of coal carbonized either in coke ovens or at gas works in Great Britain falls within the range of types 301 to 700. A relatively small tonnage of coals outside this range is carbonized, mainly as a constituent of blends, in ovens or as doubles or trebles in gas works. The strength and size of the coke made in ovens is mainly determined by the type or rank of the coal (see later). The best metallurgical and foundry coke (1½ in. shatter index greater than 90) is made from the 301 coals (volatile matter 20 to 30 per cent).

Substantial tonnages of metallurgical coke are also made from types 400, 500 and 600 coals either by themselves or blended with each other. The 600 coals give a small coke and a 2 in. shatter index of the order of fifty to sixty. Blends of types 600 and 700 coals are carbonized in ovens and in some cases, type 700 coal is carbonized unblended. These coals give high yields of gas, tar and benzol, and whilst the resulting coke is unacceptable for the blast-furnace it finds a ready market in the domestic field. A marked improvement in the size and hardness of the coke made from types 500, 600 and 700 coals (or mixtures of them) can be obtained by adding some 301 and 400 coals. The limiting factor is the cost of transporting the latter from the distant fields to the localities where the 500 to 700 coals occur. The problems of supply and carbonization practice are, however, complicated by the disposition of the various types of coal. With the exception of Durham and Northumberland none of the British coal-fields produces coals covering the full range used in carbonization, and consequently any consideration of blending types to improve coke quality must include a careful consideration of transport and handling charges.

SURVEY OF RESERVES AND PRODUCTION OF COKING COALS IN GREAT BRITAIN

The most recent appraisal of the reserves of coal in Great Britain was made by the Coal Survey organization in 1945, when an estimate was made of the coal likely to be worked in the next 100 years, with a partial estimate of what would remain after this period. (5) This work is now being carried out in greater detail. The national picture is not likely to be materially altered, although the economics of production might shift the emphasis a little. Tables II and III summarize the reserves likely to be worked in the next 100 years and the total output of the main types of coal in 1947 in the eight National Coal Board Divisions.

Comparison of the two tables shows that the present output of the different types is roughly in the same proportion as the reserves. There are, however, marked differences in the main types of coal in the various Divisions. The coals which produce the best metallurgical coke are found mainly in the Northern (Durham) and South Western (South Wales) Divisions. The coking coal in the North Eastern Division is on the average lower in rank and the coke produced there is smaller and not so hard. In the East Midlands Division, another important cokemaking area, the coal is even lower in rank than in North Eastern Division and the coke produced is generally not hard enough for blast furnaces but finds a ready sale in the domestic market.

Whilst the data on reserves and gross output give a broad picture of availability they are in some respects misleading. Firstly, substantial tonnages are unsuitable on account of high sulphur and high inherent ash contents. For example, if 1.5 per cent of sulphur was a limiting figure, about 30 per cent or even more of the reserves and current production of the appropriate types would have to be discounted, although some could be used if blended with coals of lower sulphur content. Secondly, some collieries have not at present the necessary coal treatment plants to clean the run-of-mine coal free from the extraneous ash and size it in a form suitable for carbonization. This will, in time, be remedied. Thirdly, some of the reserves and output are located too far away from the coke ovens and steel-works, many of the latter being sited partly on account of ease of supply of coke (or coal) and partly on account of ready access to either imported or home ore.

Finally the gross figures for reserves and current output ignore both the important factor of the sizes of the commercial grades and the price structure. Traditionally the coke oven industry in Great Britain has used small coal mostly less than 1 in. in size, the large and graded coal being disposed of in other markets. The size distribution of the present output of coal in Great Britain is approximately as follows:

	Per cent of total
Large	35.1
Unscreened	8.1
Graded	20.1
Washed smalls	15.1
Untreated smalls	18.2
Other sizes	3.4
Total[a]	100.0

[a] Excludes anthracite, miners coal and colliery consumption.

Vertical retort practice in the gas industry has been developed efficiently to use sized coals (mainly doubles and singles) of the medium to feebly coking type (500, 600, 700). The horizontal retorts use the more strongly coking sized and unscreened types, chiefly 401b and 501. It is thus evident that the gas industry demands a large tonnage of sized coal from many of the same sources supplying coke ovens with small coal. There is not at present enough sized coal of suitable quality to meet the demand, and consequently a substantial tonnage of large coal is supplied to the gas works where it is crushed before it is carbonized. The two carbonizing industries are to some extent complementary and they both demand a high standard of coal preparation.

In addition to the problem of supplying the right type, size and quality, geography and transport costs also play an important part in determining the pattern of the market. The coke oven industry is concentrated and its location is determined largely by the location of the steel industry which is not entirely determined by accessibility of coking coal. The gas industry is widely dispersed almost in direct proportion to the distribution of the population and consequently the flow of gas coals is over a very much wider area.

The total coal requirements of the coke oven and gas industries in Great Britain are at present approximately forty-five million tons per annum representing about 50 per cent of the gross output of the caking types. The remainder of the caking coal is either unsuitable on account of high ash and high sulphur or at present uneconomic to dispose of to the coke oven and gas industries on account of price and transport costs. There is, in addition, a big demand for sized medium to feebly caking coals for use in producers.

A first appraisal of the resources of coal suitable for coke ovens and gas works (types 301 to 700 inclusive) suggests that the foreseeable demand can be met although if the consumption of coal in these industries increases it may mean restricting supplies of these types of coal to other classes of consumers. Table II shows that the reserves of the best coking coals (type 301) in Great Britain are a small proportion of the total (5.8 per cent) amounting to about 1,200 million tons. It would be extremely difficult to provide the steel industry of Great Britain with only the very best coking coal; neither the reserves nor output are sufficient for this purpose. At present also many of the best coking coal seams are mined at a loss. This may be partly rectified by the reorganization of the industry but, even so, the future disposition of coke production in Great Britain and the economics of the process will require detailed study. Before the problems of the most economic development of the caking coal resources of the country can finally be decided it will be necessary to have a rational and stable price structure and in the long term the over-all economy of the coal, gas and steel industries together will determine the best way to use the resources of caking coal.

Much the same problem concerning the quality of coking coal applies in America, where the best coking coals are becoming exhausted. A recent paper placed the life of the Pittsburgh bed at a hundred years and the Connellsville coking coal of this bed is said to be sufficient for only twenty to thirty years. It is likely, so far as America, Great Britain and Germany are concerned, that larger tonnages of lower-rank coking coals will have to be used for the manufacture of metallurgical coke which will continue to be required in large quantities. It is unlikely that blast-furnace technique will alter in any major respect for many year although there will be changes in emphasis in relation to the process, particularly in the blending techniques and in the sizing and grading of the ores charged to the blast-furnace. The process as carried out in modern steel-works is highly efficient and its replacement by other methods is improbable.

FACTORS AFFECTING COKE QUALITY

With a possible decline in the availability of the very best coking coals increasing attention will have to be given to the manufacture of coke of consistent quality from poorer coking coal. This will involve improvements in blending practice and a closer attention to the carbonizing practice. A Sub-Committee of the British Coke Research Association (Panel No. 4) (6) has studied coke oven dimensions in relation to coal and coke quality and has reached the following conclusions:

(1) The quality of any given coke is determined principally by the characteristics of the coal from which it is produced.

(2) Variation in the width of the oven between approximately sixteen and nineteen inches does not materially affect the shatter and abrasion indices, providing the carbonizing rate is the same, but wider ovens produce a greater proportion of large-size coke.

(3) For a given coal an increase in the carbonizing rate results in a decrease in the shatter indices and the size of the coke produced.

(4) The height of the oven between approximately ten and fifteen feet does not materially affect the shatter and abrasion indices.

(5) Within a given coal-field, increase in B.S. Swelling Index above five to six is not necessarily associated with an increase in shatter or abrasion indices. The Panel in noting this emphasized that coals of high B.S. Swelling Index are valuable as materials for blending with coals of lower swelling indices, and as far as possible should be used as such.

(6) Fine grinding normally associated with decrease of bulk density in modern top charging practice, increases the shatter indices.

This work, involving a careful examination of results from a large proportion of the British coking plants showed that alteration to the traditional plant design can do little to influence coke quality once the predominating influence, coal quality, is fixed. There is, as would be expected, considerable divergence of opinion both in America and in Great Britain as to what are the desirable properties of a blast-furnace coke. So far as we are aware, no over-all standards have been laid down in the United States but in Great Britain the British Iron and Steel Research Association and the British Coke Research Association have jointly considered a statement on coke quality, the salient points of which are:

1. *Size.* Blast-furnace coke should not be less than a size of the order of one inch, allowing a tolerance of 5 per cent of coke less than the agreed size.

2. *Moisture.* The moisture content should not exceed 3 per cent. Variations in moisture should be avoided.

3. *Ash Content.* The ash content must be uniform within a tolerance of 1 per cent. The average ash content should not exceed 10 per cent.

4. *Strength.* Coke should show at least 85 per cent on the 1½ inch shatter test; the ½ inch shatter index should not fall below 97 per cent.

It is noted that the attainment of these figures will involve some selection in the choice of coals for coke making.

5. *Sulphur.* The sulphur content should be as low as possible.

This statement is not an accepted measure of the quality of blast-furnace coke in Great Britain neither does it serve as a specification. It is included here to indicate what the iron and steel industry in Great Britain considers desirable. The difficulty of accepting a specification of this nature is that the available quantities of coal which would produce coke of this quality are insufficient to meet the total demand. The properties listed above could only, in general, be secured in Great Britain by utilizing almost exclusively the best coking coals from the Northern and South Western Divisions and, as stated earlier in the paper, both the reserves and economic output from these two coal-fields are insufficient to meet the total demands of the steel industry. It is unlikely that cokes generally utilized for blast-furnace purposes in the United States would conform to the above standards. On the other hand, American coke is more consistent in quality than in Great Britain. In both countries increasing emphasis is being placed on consistency which it is agreed can best be achieved in large modern plants provided with comprehensive blending and control services. In this way inferior coking coals can give coke which can be used in the blast-furnace with reasonable results.

DEVELOPMENTS IN COKE OVEN PLANT DESIGN

The general pattern of the trend in coke oven design is very similar in America, Great Britain and Germany though there is different emphasis on certain features. The principal constructional companies in each country are associated with their counterparts abroad, and so far as Great Britain is concerned this association, involving interchange of views on design data and of research results, is encouraged. The American coking industry is much the biggest (see Table I) and generally speaking is in the forefront of advances in design and plant research because of its greater opportunities although designers in both Great Britain and Germany make valuable contributions to the improvements in oven constructional efficiency. The size and disposition of the British coking industry has tended towards conservatism in practice, especially during the war years when coke oven constructional work was entirely limited to essential replacements, whereas in America, despite keen competition, many more opportunities for introducing modifications in design are available because of the size of the industry and the relatively high rate of construction which was maintained throughout the war. In Germany, again, the indications are that progress in new design and research was halted in 1939 and that from then onwards almost the whole emphasis was laid on production.

The following notes indicate the broad lines of recent developments in plant layout and design.

Plant layout. Coke oven plants both in America and Germany are substantially larger and more spacious than in Great Britain. British practice is being brought into line in post-war building.

Coal blending. Coal-blending plants are of basically similar sequence in America, Great Britain and Germany. The sequence is usually blending bunkers, crusher and service bunker. A recent survey of facilities in Great Britain (7) shows that whilst in general the older plants possess either no blending or only limited mixing facilities, the newer plants and particularly those at the iron and steel works, are well equipped in this way. Blending for uniform ash content is widely practised in America. Recommendations for coal blending under optimum conditions were given by the British Coke Research Association in this recent publication.

Oven design. In America, Great Britain and Germany, the construction of coke ovens follows similar, well defined lines, many batteries in the three countries being built to identical basic designs. Underjet designs are now generally accepted and their adoption probably represents the most significant advance in recent years. Underjet heating was originally introduced at the beginning of the century and all builders are now constructing plants of this type. It seems clear that the closest heat control and highest heating efficiency are to be obtained by such means.

The common design of underjet ovens provides underjet heating on coke oven gas only. A recent German development, for which the Otto Company are mainly responsible, allows of the use of underjets for air supply as well as for the gas. To do this the heating wall is divided into hairpin flues (pairs) each of which has its own pair of regenerators. In this way, air or lean gas can be individually metred and regenerated. By 1946 the Otto Company had constructed ten batteries of such entire underjet ovens. Owing to the vagaries of wartime operation none of these batteries had been able to maintain more than short periods of steady operation so that the value of the system from the heating efficiency point of view is still to be confirmed. It does however appear that further economies, particularly in the field of lean-gas firing, can be obtained in this way.

The British Investigational Teams which visited Germany in 1946 (8) concluded that "this design of oven offers a logical approach towards greater heat economy, that its full potentialities have not been explored and that its consideration in this country (Great Britain) might be advantageous".

In America the underjet oven has also received much attention of late years but up to the present no battery of ovens has been erected of the "entire underjet" type. There is little impetus in America at the present time to increase underfiring efficiency at the expense of other factors and this is reflected in the fact that the principal contractors do not guarantee the heat consumption of their ovens.

Great emphasis is now placed upon fast coking so as to secure the maximum possible output per unit of capital involved and it is probably along the lines of increased heat penetration that future developments will take place. All ovens built in America in recent years have been of the "all silica" type whereas in Great Britain and Germany, ovens of the Otto design carry the silica to a point four courses below sole level. The Koppers type of oven, as built in Great Britain and Germany, and the Woodall-Duckham-Becker type as built in Great Britain are of "all silica" construction.

Very few coke-oven batteries have been built in America or in Germany in recent years with clay-luted doors. Experience with self-sealing doors has not, however, proved to be satisfactory during wartime conditions in Great Britain and there has of late years been a tendency to "play safe" by the use of the clay-luted door. Statistical work carried out by the British Coke Research Association (9) has clearly shown a relationship between oven-end deterioration and the use of self-sealing doors, and much thought is being given to the design of a self-sealing door which will prove satisfactory under British conditions. Neither in America nor in Germany is there any desire to return to clay-luted doors, indeed the tendency is the reverse. In Germany, and to a certain extent in America also, the coals carbonized are of lower volatile-matter content (usually coals of about 26 to 27 per cent of volatile matter) than those normally carbonized in Great Britain. Where the volatile content exceeds 30 per cent, in Germany, the self-sealing doors in use would not be regarded as satisfactory by British standards. In none of the three countries have machines been devised which will clean self-sealing doors satisfactorily, though aids to this end are many.

American coke oven design is characterized by a robustness rarely observed in British plants where capital expenditure is to some extent restricted. Evidence does not show that any single design feature is responsible for the greater success and lesser oven-end damage with self-sealing doors in the United States. The operating conditions imposed by the war probably had a very appreciable effect in accelerating the deterioration of British ovens.

The development of machine-made silica shapes has progressed further in America than in either Britain or Germany. Oven machines in the three countries are on broadly similar lines although extreme robustness and exactness of construction of the American machines are noteworthy and account to some extent for enhanced ease of operation.

COKE QUENCHING AND DRY COOLING

Coke quenching is almost invariably accomplished by water in the traditional manner. Dry cooling is only in operation at one coking plant in America and one in Great Britain, where it is successful. Dry cooling has been installed at several Continental plants, but in two known instances it has been replaced by wet quenching. Capital costs are high and in the opinion of many technologists outweigh the advantages of the process. In America the problem of fuel efficiency has not yet attained the important position it occupies in Great Britain and this may account for the lack of interest in the dry cooling of coke in the United States.

Table II. Estimated Reserves of the Various Types of Coal to be Developed in the Period 1942 – 2042

(Per cent of total developed reserves)

GREAT BRITAIN

Coal type	*100*	*200*	*301*	*400*	*500*	*600*	*700*	*800/900*	*Un-classified*	*Total*
Division:										
Scottish	0.1	—	—	—	0.1	1.0	1.5	7.3	0.3	10.3
Northern	—	—	1.2	6.0	6.5	1.8	2.9	0.6	—	19.0
North Eastern	—	—	—	0.4	5.6	6.3	5.0	3.1	0.5	20.9
North Western	—	—	<0.1	0.2	0.9	1.9	1.5	0.8	0.6	5.9
East Midlands	—	—	—	0.1	0.8	1.8	2.0	8.7	0.6	14.0
West Midlands	—	—	—	0.7	0.6	0.8	1.0	6.9	—	10.0
South Western	3.3	6.7	4.0	2.0	0.2	0.3	0.2	0.1	0.1	16.9
South Eastern	—	1.1	0.6	<0.1	—	—	—	—	—	1.7
Total per cent	3.4	7.8	5.8	9.4	14.7	13.9	14.1	27.5	2.1	98.7
Total (Million tons)	704.6	1,589.7	1,183.3	1,935.1	3,009.9	2,830.2	2,894.4	5,634.1	446.9	20,228.2

In addition to the above there are reserves of 272.2 million tons of coal which have been affected by igneous intrusions in Scotland with a volatile-matter content o from ten to thirty per cent. This is 1.3 per cent of the total.

Table III. The Gross Output of the Various Types of Coal in 1947

(Per cent of total output)

GREAT BRITAIN

Coal type	*100*	*200*	*301*	*400*	*500*	*600*	*700*	*800/900*	*Un-classified*	*Total*
Division:										
Scottish	0.2	—	—	—	0.2	0.2	1.0	6.3	2.8	10.7
Northern	—	—	1.8	7.0	6.4	1.4	2.5	0.7	0.1	19.9
North Eastern	—	—	—	0.6	6.8	7.0	3.4	2.6	0.1	20.5
North Western	—	—	<0.1	0.1	1.5	2.2	2.2	1.1	<0.1	7.2
East Midlands	—	—	—	0.1	0.5	2.8	3.2	11.8	<0.1	18.4
West Midlands	—	—	—	0.1	0.5	0.8	1.3	5.9	—	8.6
South Western	1.8	6.3+	3.1	1.1	0.3	0.3	0.3	0.1	<0.1	13.3
South Eastern	—	0.2+	0.4	0.2	—	—	—	—	—	0.8
Total Per Cent	2.0	6.6	5.3	9.2	16.2	14.7	13.9	28.5	3.0	99.4
Total (Million tons)	3.8	13.0	10.4	18.1	31.8	29.0	27.4	56.1	6.0	195.6

In addition to the above there are 1.246 million tons of Scottish coal between ten and thirty per cent of volatile matter which has been affected by igneous intrusions. This is 0.6 per cent of the total.

BY-PRODUCT RECOVERY PLANT

By-product recovery plants in America, Germany and Great Britain are generally on similar lines and semi-direct recovery is normally practised. Tar removal by impingement rather than by electrostatic methods is in favour in Germany. It is claimed that this minimizes corrosion because of the protective action of the skin of tar formed inside the mains when utilizing impingement methods.

Benzole scrubbing by means of creosote wash oil is standard practice although in Germany where the coke oven gas is raised to a high pressure for distribution purposes, benzole washing is carried out at pressures from 8 to 20 atmospheres. In such circumstances it is possible to achieve an increased benzole content of up to 5 per cent in the wash oil. Oxide purifiers are also used for the removal of H_2S at these high pressures. Liquid processes are used for the partial purification of gas for industrial purposes only. Several such processes are available in Germany. Of these the Thylox process treats gas at ordinary pressures and is worked in conjunction with a sulphur distilling plant. The ammonia washing process is also designed for normal pressures and the potash process has been developed for gas which has been compressed for distribution through the grid system. In the latter the washing medium is potassium carbonate and the sulphur is recovered in a Claus kiln.

Oil stripping plants based on pipe stills are common practice in Germany, the smallest economic size being for batteries of the order of 800 to 1,000 tons of coal per day. More products are made than is normal in Great Britain. The refining of benzole under pressure has been adopted in at least one works in Germany where the raw benzole after washing with 0.6 per cent to 0.8 per cent of a 40 per cent sulphuric acid solution is maintained at a pressure of 25 atmospheres in horizontal autoclaves at 225 degrees C for seven hours. The pressure is then gently released when the benzole distils off.

The disposal of effluent continues to be a problem in each of the three countries. No fully developed and comprehensive scheme is available in either America, Germany or Great Britain, although it is understood that the Woodall-Duckham Company of Great Britain is co-operating with other interests in the development of a process for the satisfactory disposal of effluents.

CONCLUSION

The term "coking coal" covers a wide range of types and the supply problem is closely connected with the requirements of the gas industry as well as that of the coke oven industry. Coke quality is largely determined by the nature of the coal carbonized and oven design and carbonizing practice has only a small effect compared with the nature of the coal. The nature of the coking coal varies considerably from one coal-field to another and even within the same coal-field. Increasing use will probably have to be made of lower-rank coals and greater attention given to blending and the control of quality to produce a consistent coke; consistency being a most important factor in blast-furnace economy.

Generally the layout, design and construction of coking plants in the next few years will follow the present trends which are mainly directed to a higher over-all thermal efficiency of the process with the maximum throughout per unit of capital commensurate with reasonable maintenance costs. By-product recovery practice is at present stereotyped and there is not likely to be any major advance in the near future. Increasing attention is however being given to the preparation of pure products in secondary by-product plant and the utilization of coke oven gas as a basis for the preparation of chemical products. The problem of effluent disposal calls for urgent action.

APPENDIX

A CLASSIFICATION OF BRITISH COALS

(Code numbers and definitions)

100—Anthracite[1] Non-caking (coke type A–B). V.M. 9.5 per cent or less.
- 100a. Anthracite, Non-caking (coke type A–B). V.M. 4.5–6.5 per cent.
- 100b. Anthracite, Non-caking (coke type A–B). V.M. 6.6–9.5 per cent.

200—Low volatile steam coals. V.M. 9.6–20.0 per cent.
- 201. Dry steam coals, Non-caking (coke type A–B). V.M. 9.6–14.0 per cent.
  Sometimes divided into·
  - 201a. V.M. 9.6–12.0 per cent.
  - 201b. V.M. 12.1–14.0 per cent.
- 202. Coking steam coal, Weakly caking (coke type C–G). V.M. 14.1–15.5 per cent.
- 203. Coking steam coal, Medium caking (coke type G_1–G_4). V.M. 15.6–17.5 per cent.
- 204. Coking steam coal, Strongly caking (coke type G_5–G_8). V.M. 17.6–20.0 per cent.
- 206. Scottish "navigation" coal. Non-caking or weakly caking (coal type A–D). V.M. 9.6–20.0 per cent.

Medium volatile coals:
- 300. Scottish medium volatile coal. Usually non-caking or weakly caking (coke type A–G_2). V.M. 20.1–30.0 per cent.
- 301. Coking coal. Very strongly caking (coke type G_7 and over). V.M. 20.1–30.0 per cent.

High volatile coals:
- 400. Very strongly caking coal (coke type G_9 and over). V.M. over 30.0 per cent.
  - 401. V.M. 30.1–37.0 per cent. For Durham this type has been divided into:
    - 401a. V.M. 30.1–33.0 per cent.
    - 401b. V.M. 33.1–37.0 per cent.
  - 402: V.M. over 37.0 per cent.
- 500. Strongly caking coal (coke type G_5–G_8). V.M. over 30.0 per cent.
  - 501. V.M. 30.1–37.0 per cent. For Durham this type has been divided into:
    - 501a. V.M. 30.1–33.0 per cent.
    - 501b. V.M. 33.1–37.0 per cent.
  - 502. V.M. over 37.0 per cent.
- 600. Medium caking coal (coke type G_1–G_4). V.M. over 30 per cent.
  - 601. V.M. 30.1–37.0 per cent.
  - 602. V.M. over 37.0 per cent.
- 700. Weakly caking coal (coke type E–G). V.M. over 30 per cent.
  - 701. V.M. 30.1–37.0 per cent.
  - 702. V.M. over 37.0 per cent.
- 800. Very weakly caking (coke type C–D). V.M. over 30 per cent.
  - 801. V.M. 30.1–37.0 per cent.
  - 802. V.M. over 37.0 per cent.
- 900. Non-caking coal (coke type A–B). V.M. over 30 per cent.
  - 901. V.M. over 30.1–37.0 per cent.
  - 902. V.M. over 37.0 per cent.

[1]In the original Coal Survey Coding system the anthracites were divided into four classes—types 101, 102, 103 and 104. Although the division into two classes (100a and 100b) satisfies most requirements, it may sometimes be necessary to recognize four or even five classes.

Bibliography

1. British Standards Institution, B.S. 1016, 1942, London.
2. Fuel Research Technical Paper No. 44, part II, H.M.S.O., London.
3. British Standards Institution, B.S. 705, 1942, London.

4. "A Study of Pressures Developed by British Coals during Carbonization", B.C.R.A. Technical Paper No. 2, December 1948, London.
5. "A Rapid Survey of Coal Reserves and Production", Fuel Research Survey Paper No. 58, H.M.S.O., London.
6. "The Study of Oven Dimensions in relation to Coal and Coke Quality", B.C.R.A. Panel No. 4, London.
7. "Coal Blending for Carbonization in Coke Ovens", B.C.R.A. Panel No. 8, London.
8. "The German Coking Industry", B.I.O.S. Final Report No. 1680, London.
9. "Practical Plant Problems", B.C.R.A. Panel No. 6, London.

Overcoming Shortages of Metallurgical Coke

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ABSTRACT

Temporary shortages of coke in the United States during World War II were relieved by reconditioning and putting into service all available slot-type and beehive ovens, since enough new ones could not be built in time. Wherever possible operations were accelerated by increased temperatures and earlier pushing of coke. Non-essential uses were curtailed, and economies in essential consumption were effected through improved uniformity and quality of coke resulting from better cleaning, blending and mixing, and higher bulk density.

The threat of continuing shortages resulting from the depletion of premium grades of coking coal may be met by increased exploration, and by conservation through limitations on the use of coking coal for other than coke production, and the reduction of mining losses. Conservation is aided by improved cleaning methods which permit lower grades to replace premium grades of coal, and by blending that broadens the range of metallurgical coals

New methods of blast-furnace operation and gas production give promise of reducing coke requirements, and there are prospects of developing coke-free methods of iron ore reduction.

Continued research is essential for eliminating or preventing future shortages and to develop ovens capable of coking a broader range of coals.

Metallurgical coke is a pre-eminent factor in the production of pig-iron in the United States. Any interruption in the supply of coke retards the production of steel, the most vital of raw materials in our highly mechanized economy. This was shown by our experience in World War II when it required concentrated effort by government and industry to meet the emergency of greatly increased demands.

In this paper we will review briefly the manner in which these temporary shortages of blast-furnace coke were overcome and will point out the lessons taught by these experiences which may serve as guides in future emergencies.

Continuing shortages of metallurgical coke caused by lack of coking-coal resources will be discussed in the latter part of this paper.

OVERCOMING TEMPORARY COKE SHORTAGES

The modern by-product coke-oven plant involves large capital investment and requires a considerable length of time to install. Temporary shortages cannot, therefore, be relieved by the construction of additional coke ovens. Neither is it feasible to have a number of stand-by ovens available, first, because of their high capital cost, and second, because of the damage to the structure of a modern slot-type oven and the high cost of starting and stopping the operations. However, beehive ovens, because of low capital cost, can be constructed for peak demands.

Temporary shortages during peacetime normally are made up by diversion of coke from non-metallurgical to metallurgical use, reduction of exports, increasing beehive-oven operation, and importing coke if possible.

REDUCTION OF NON-ESSENTIAL USES

During the Second World War, the full-time service of all slot-type ovens and beehive ovens that could be reconditioned was necessary to relieve coke shortages. All domestic and non-essential industrial uses of coke were drastically reduced, and a large part of the 20 per cent of the coke-oven capacity normally used for non-metallurgical purposes was diverted to blast-furnace use.

INCREASE OF OVEN THROUGHPUT AND IMPROVEMENT OF QUALITY OF COKE

The second step for increasing coke and pig-iron production during the war was the appointment of a government-industry advisory committee to the Bureau of Mines who conducted a survey of coke-oven and blast-furnace operations, with a view to increasing the throughput of coke ovens and improving the quality of the coke with reference to increased production of pig-iron. This survey showed that production of pig-iron could be increased noticeably if the blast-furnaces could be supplied with a more uniform coke. (27)[1] Non-varying percentages of ash, sulphur, and fixed carbon in the coke, together with uniform physical characteristics, such as size, strength, and porosity, greatly aid the blast-furnace operator in developing an operating schedule for maximum production of pig-iron. The more uniform his raw materials, and coke probably is the most important, the more efficiently he can run his furnace with consequent savings and increases in output.

Next to uniformity the most desirable factors in blast-furnace coke were found to be low contents of ash, sulphur, phosphorus,

[1] Numbers in parentheses refer to items in the bibliography.

and moisture, and high strength in order to decrease size degradation both in handling and in the furnace. The ash content of the coke has a direct effect on production capacity. Tests made by several steel companies showed that a 1-per cent reduction in ash increased the rate of iron production 3 to 6 per cent. From practical experience the Iron and Steel Industrial Council, British Iron and Steel Federation, has evolved a few rough and ready rules, thus:

(1) A reduction of 1 per cent ash is equivalent to an increase of 2 per cent of fixed carbon.

(2) Coke breeze below ½-inch size is practically useless and can be eliminated completely without affecting coke consumption. (12)

Improvement in the uniformity and quality of the coke must start with selection of coal at the mines, and continue at all possible points along the line until the coke is consumed in the blast-furnace.

CLEANING OF COAL

The cleaning of coal is essential for the production of good coke, because it reduces the ash and sulphur content and makes the coke more uniform. Lack of coal-washing plants at mines where coal was diverted to metallurgical use during the war led to the production of considerable high-ash coke. Some help was obtained by pressing into use available commercial coal-cleaning plants.

BLENDING OF COALS

The majority of American coke ovens operate on a blend of high-volatile and low-volatile coals. Many operators during the war increased the percentage of low-volatile coal in the blend to improve the quality and increase the yield of coke. This is particularly advantageous for overcoming coke shortages, because it offsets the tendency toward decreased quality intrinsic to increased rates of production obtained by using higher coking temperatures.

Cokes produced from blends containing up to 10 per cent anthracite were found satisfactory for use in foundries, but there was considerable disagreement over the merits of coke containing small percentages of anthracite fines for blast-furnace use. (8, 9)

EXPANSION TESTS

Shortages in supply of both low-volatile and high-volatile coking coals from mines customarily used for this purpose made it necessary during the war to use coals from mines not hitherto used for supplying coking coal. In considering such coals it was essential to avoid coals or mixtures of coals that expanded strongly on coking in slot-type ovens, as they caused considerable damage to the brick-work. This limitation was overcome by judicious blending of expanding and contracting coals. It was necessary to determine both the amount of expansion of low-volatile and medium-volatile coals and the amount of contraction of high-volatile coals to insure a satisfactory mix and bulk density for charging the ovens. Further, a coal mixture that was safe when carbonized slowly at a low temperature proved dangerous when coked at higher temperatures or faster rates. (4) Before new blends were tried in full-scale ovens, it was found advisable to make expansion tests in experimental ovens to determine whether or not excessive expansion pressure might be expected. This is especially important, for experimental tests have indicated that some blends may exert dangerous expansion pressures during carbonization and still be pushed from the oven without difficulty. (23)

USE OF PHYSICAL AND CHEMICAL TESTS OF THE COAL AND COKE

As will be seen later, determinations of moisture and screen size of the crushed coal are important for the control of the bulk densities of the oven mix and the control of the sulphur and ash contents of the coal is important in producing uniform coke and thus increasing blast-furnace efficiency. If the coal must be stored, it is helpful to determine the rate of oxidation when in contact with air and its effect on the coking power. (25) Most coals, when oxidized to an appreciable extent, yield a poor coke, although very plastic coals are improved by slight oxidation. In some mines the analysis of the coal-bed shows a wide range of sulphur and ash content. In such cases the uniformity of composition of the mine product can be improved by selective mining, blending at the mines, and by surface preparation. (11)

Screen tests are very important for the close control of the sizes of coke charged to the blast-furnace. A single index for coke strength may also help greatly in the selection of the coke. (7)

CONTROL OF BULK DENSITY OF THE COAL MIX

Control of the bulk density is a major factor in the capacity of a coke oven. High bulk densities result in a denser and larger coke. In addition, where a coal is weakly coking or oxidized, higher bulk density improves the strength of the coke. Expansion difficulties can often be overcome by bulk density control. (16)

Fluctuation of bulk densities and the resulting variation in the weight of coal per oven also causes variations in the quality of the coke due to changes in rate of heat penetration through the charge.

Considerable control of bulk density is possible in the coke plant by (*a*) control of surface moisture, (2) (*b*) control of crushing, (*c*) the addition of oil, (*d*) by tamping, (*e*) by dropping the coal from a considerable height above the oven, (26) or by a combination of these. Oil added to the coal mix can be used to obtain a more uniform bulk density regardless of moisture content. Addition of oil seems to be an easier method of control than greater addition of water. The bulk density attained by the use of oil may increase production under certain conditions, but it is necessary to observe caution in a plant that uses coals whose expansion pressure already is near the permissible maximum. (20, 28)

Both uniformity and production increase with increased bulk density provided that the flue-heating system of the ovens is adequate enough to supply the additional heat required to coke the larger charge. This is likely to be the case in modern ovens, but not necessarily in ovens of obsolete design.

CONTROL OF RESIDUAL VOLATILE MATTER

Blast-furnace coke frequently may be improved by earlier pushing. During the final period of coking, particularly when flue temperatures are high, as on fast coking time, the coke may shrink and cause many cross fractures. The number of cross fractures leading to small-size coke can be reduced by pushing the coke when it still contains from 1 to 1½ per cent of residual volatile matter. The fast coking time still further reduces the over-all coking time.

OVERCOMING CONTINUING COKE SHORTAGES

LACK OF SUITABLE COAL IS PRINCIPAL CAUSE OF SHORTAGES

Continuing shortages of coke for metallurgical use over a period of years result primarily from a lack of suitable coal for blending and carbonization, and not from a shortage of coke-oven capacity. While temporary shortages since the beginning of the Second World War have been due principally to lack of oven capacity where the metallurgical coke was needed, and in lesser degree to exceeding the capacity of existing metallurgical coal-mines, continuing shortages of premium grades of metallurgical coal are threatened in the United States. We have skimmed the cream of our coking coal and are facing the need of utilizing our reserves of successively lower ranks and grades of coking coal.

Although the quantity of coal used in 1948 exceeded the wartime record year of 1944 by 3,144,934 tons, the coke output was increased by only 927,049 tons. In terms of percentage of coal charged, the coke yield was 71 per cent in 1944, and only 69.7 per cent in 1948, a drop of 1.3 per cent. The relative decline in coke production was caused principally by the poorer quality of coal charged and also by the deterioration of a large number of over-age ovens which had been operated at exceptionally high rates since the beginning of the Second World War. Reduction in quality because of ash and sulphur is reflected directly in the amount of coke required to produce a ton of pig-iron. The consumption of coke per ton of iron produced in 1941 was 1,745 lb.; it required 1,900 lb. of coke to produce a ton of pig-iron in 1947. (6)

EXPLORATION

Because of the decline in known reserves of high-grade coking coals, the Bureau of Mines and the Geological Survey have started a survey to obtain information on the quantity and quality of our minable reserves of coking coal. Analyses and tests are being made of the lower-grade coals available for the production of metallurgical coke.

In general, the plan of this investigation involves field studies to determine the extent of areas of coals of known coking quality as shown by development of mines and exploration data possessed by the various mining companies. Where quality data are not available, samples of coal are collected for analysis and for pilot-plant scale tests. The survey includes grades of coal lower than those now required by the steel industry.

In certain regions where mining companies are unlikely to drill, it is desirable in the national interest that the Bureau of Mines continue core drilling to determine mineable reserves, as it has done in the past five years. By such drilling the Bureau has established in Colorado and Wyoming more than 700 million tons of coking-coal reserves, which are of great importance to the development of the steel industry in Utah and California.

CONSERVATION

It is also important to extend the life of the presently known reserves of coking coals by conservation. Because of their excellent burning characteristics, high-quality coals suitable for coking are strongly in demand for other uses. Recent progress in the development, on a commercial basis, of coal-burning processes and devices to eliminate smoke and produce energy units from lower grades of coal will aid in conserving many millions of tons of excellent coking coals which would otherwise be burned for general steam-raising purposes and for household consumption. This condition is being aggravated by the adoption of more severe smoke-abatement ordinances in such large cities as St. Louis and Pittsburgh, thus creating an increased demand on the low-volatile coal so badly needed for blending in furnace coke. Therefore, there should be continuous research on high-efficiency utilization of lower-grade coals.

MINING METHODS

It is not always profitable to mine marginal coals. As a result, coal left in the ground after mining operations still constitutes one of the major mining problems and represents an enormous waste of natural resources. An essential part of any long-range programme of fuel conservation is to determine the amount of such losses and to develop methods of reducing them.

CLEANING OF COAL

Coals high in ash and sulphur and costly to mine may, nevertheless, be suitable for producing coke that has excellent physical properties. However, to increase the uniformity, improvements must be made in coal-preparation practice with special reference to reduction in sulphur and ash.

It is now generally recognized that almost all coal for use in the production of metallurgical coke requires washing to reduce the ash and sulphur to the lowest possible limits consistent with reasonable recovery. (3) Furthermore, this washing problem becomes increasingly difficult as depletion of high-grade coal reserves compels the use of lower-grade coals. Fortunately, progress is being made in the development of methods of cleaning low-grade coals, such as heavy-medium float and sink processes, and methods especially designed for handling small sizes of coal. High-sulphur coking coals may be made suitable for metallurgical use by the development of a precisely controlled process of separating the coal at very low specific gravity and disposing of the sulphurous intermediate fractions for other uses. (13) The increasing sulphur content of the remaining reserves of coking coals may also be offset by better control of other operating variables in the blast-furnace. (17)

BLENDING

We already have discussed blending coal to improve the uniformity and the quality of coke, and thereby lower the amount required for pig-iron production.

Blending also is important from the long-range or conservational point of view, for it makes available a broader range of coals for metallurgical coke production. The use of granular medium-temperature or low-temperature chars and anthracite fines may conserve low-volatile coking coals by making it possible to substitute high-volatile coals which have been subjected to a sufficient degree of devolatilization. Properties of cokes are not always an average of those expected from the proportions of the constituent coals used. Each blend must be considered as a separate problem. Accordingly, much remains to be done in studying the behaviour of various blends and to correlate the data to make it possible in the future to predict the behaviour of any combination of constituents in the coke oven or in the blast-furnace. New oven construction should take this into account and provide more coal bins to enable handling a greater number of coals. (14, 24)

REDUCING THE CONSUMPTION OF METALLURGICAL COKE

The short-term approach to reducing the demand for metallurgical coke is based on improving the quality and maintaining the uniformity of the coke, and the drastic curtailment of all uses metallurgical coke for less essential purposes. For the long-term reduction in demand it is necessary to go beyond this. The quantity of coke required per ton of pig-iron can be reduced much further by redesigning the blast-furnace to permit new methods of operation which already have given indications of coke saving. Recent trials conducted by the Republic Steel Corp. with increased blowing pressures and throttling the top gases in blast-furnace operation have shown that iron production has been increased 11 to 20 per cent with a decrease of 13 per cent in the coke per ton. (19)

Similar results may be expected by using oxygen-enriched air for the blast, (15, 22) but more experience is required to establish this application.

Further research should be encouraged to develop entirely new methods of iron-ore reductions in which the use of coke may be eliminated. Direct reduction processes may prove to be capable of producing high-grade iron and steel alloys. (10) Bureau of Mines tests have been conducted on sponge iron production (5, 30) including one in which it was shown that producer gas from a very poor grade of coal served as a good reducing agent. (29)

Another possibility is to carbonize coking coal mixed with iron ore for direct charging to the blast furnace. A variant of this method is to take char, produced by carbonizing non-coking coals, and briquetting it with iron ore using pitch as a binder, and then recarbonizing it at high temperatures. Some work has been done in making ferrocoke by this method. (1,21)

REDUCING CONSUMPTION OF NON-METALLURGICAL COKE

It is also necessary to curtail the use of coke wherever substitutes can be developed. Thus, is gas production, the use of coke could be eliminated if the present-day cyclic water-gas process were modified or replaced by processes operable on other fuels. The advent of low-cost oxygen makes this possible, and much research is now directed toward making oxygen the basis of future large-scale gas-generating operations in which lower-grade and lower-rank fuels will be used. (18)

FUTURE RESEARCH

Much future research is needed in planning the prevention or elimination of coke shortages. Correlations of test data on coal and coke should receive increased attention. The complex interrelationships between various properties, as measured by methods now used, need further study to evaluate their place in the entire picture.

In the interest of conservation, research on carbonization of coal should be continued in the high-temperature, medium-temperature, and low-temperature fields. High-temperature coke must be improved both in uniformity and quality to meet the more exacting demands of future metallurgical processes. The operation and construction of coke ovens should be studied with the objective of broadening the range of coals that may be used for the production of metallurgical coke.

SUMMARY

In conclusion we may summarize American experience in overcoming temporary coke shortages during the Second World War as follows:

1. Put all beehive and slot-type ovens into full operation.
2. Eliminate all non-essential uses of coke, and reduce the need for non-metallurgical coke to free ovens for metallurgical coke production.
3. Produce a uniform grade of coke of good quality to permit more efficient operation of the blast-furnace, thereby reducing the coke consumption of the blast-furnace.
4. Increase the capacity of the available coke ovens by judicious blending of low-volatile coals, improving the bulk density of charge, and by earlier pushing of coke, thereby reducing the over-all coking time.

Continuing coke shortages should be anticipated and met by using the methods for overcoming the temporary shortages, and in addition by the following methods:

1. Construct new plants.
2. Reduce the consumption of metallurgical coke:
   (a) By more efficient blast-furnace operation,
   (b) By developing new metallurgical processes which do not require coke.
3. Reduce the consumption of non-metallurgical coke by developing processes which can operate on substitute fuels.
4. Explore the national resources to find additional reserves of coking coal.
5. Conserve the existing reserves of coking coals:
   (a) By limiting their use for coke production only,
   (b) By improved mining methods to ensure more complete recovery.
6. Develop preparation processes to make lower-grade coals more usable. Improve the control of other operating variables in the blast-furnace to offset increasing sulphur content of the coke.
7. Investigate blending methods to make lower-grade and lower-rank coals suitable for blending with the higher grades and higher ranks of coal.
8. Develop coke-oven operating techniques to improve the quality of the coke with the available coals, and develop ovens capable of using a broader range of coals.

A well-integrated research and development programme to carry out these suggestions should be undertaken and supported by government and industry.

Bibliography

1. Anonymous, "Manufacture of Pig-Iron from Ore Fines and Non-Caking Coals", *Iron and Coal Trades Review*, vol. CLVI, no. 4186, June 4, 1948, pages 1173–77.
2. H. S. Auvil, L. D. Schmidt and H. G. Graham, *Control of Bulk Densities in Coke Ovens*, Bureau of Mines Report of Investigations 3935, May 1946, 21 pages.
3. F. M. Becker, "Reserves and Future of Coking Coals in the United States", *Proceedings* of Blast Furnace, Coke Oven and Raw Materials Committee of the Iron and Steel Division, A.I.M.E., 1947, pages 3–22.
4. W. T. Brown, "Plan to Improve Blast Furnace Coke", *Blast Furnace and Steel Plant*, vol. 30 (1942), pages 1137–1145, 1255–1263.
5. R. C. Buehl, E. P. Shoub and J. P. Riott, *Control of Sulfur Content of Sponge Iron Produced in Rotary Kilns*, Bureau of Mines Report of Investigations 4075, March 1947, 102 pages.
6. Bureau of Mines, Coke and Coal Chemicals Chapters in Minerals Yearbooks; also Mineral Industry Surveys, Monthly Coke Reports.
7. R. W. Campbell, *Physical Testing of Coke and Correlation with Furnace Operation*, Chicago District and Eastern States Blast Furnace and Coke Oven Assn., Joint Meeting, 1936.
8. J. D. Clendenin, K. M. Barclay and C. C. Wright, "Use of Anthracite Fines in By-Product Coke Production", *Trans.* A.S.M.E., August 1945, pages 405–415.
9. J. D. Clendenin and Joseph Kohlberg, *The Blending of Anthrafines in Coke Production, Mineral Industries Experiment Station*, Tech. Paper 136, State College, Pennsylvania, 1948.
10. R. S. Dean, *Sponge Iron, A Progress Report*, Bureau of Mines Report of Investigations 3790, 1945, page 3.

11. HENRY E. DEKAY JR., LOUIS A. TURNBULL, JAMES N. SCUDDER and ALBERT L. TOENGES, *Control of Sulfur and Ash in Mine-Run Metallurgical Coal*, Report I, Bureau of Mines Report of Investigations 3742, December 1943, 28 pages.
12. E. C. EVANS, Letter to W. C. Schreeder, August 25, 1943.
13. THOMAS FRASER and WILLIAM L. CRENTZ, *Washing Characteristics of the Pittsburgh Coal in a High-Sulfur Area in Greene County, Pennsylvania*, Bureau of Mines Technical Paper 689, 1946, 85 pages.
14. Fuel Research Committee, *The Blending of Coals for Coking*, Board of Scientific and Industrial Research Report No. 2, Council of Scientific and Industrial Research (India) 1948.,
15. WILLIAM A. HAVEN, "Use and Production of Oxygen for Blast Enrichment, I—Use of Oxygen", *Proceedings* Blast Furnace, Coke Oven, and Raw Materials Committee of the Iron and Steel Division, A.I.M.E., 1947, page 50–55.
16. W. C. LANDERS, L. D. SCHMIDT and W. SEYMOUR, *Control of Bulk Densities in Coke Ovens*, Bureau of Mines Report of Investigations 3807, April 1945, 22 pages.
17. H. H. LOWRY, "Coke Ash and Coke Sulphur in the Blast Furnace", *Industrial and Engineering Chemistry*, vol. 41 (March 1949), pages 502–510.
18. L. L. NEWMAN, "Oxygen in the Production of Hydrogen or Synthesis Gas", *Industrial and Engineering Chemistry*, vol. 40, April 1948, pages 559–582.
19. B. S. OLD and E. R. POOR, "Potentialities of the Pressure Blast Furnace", *Mining and Metallurgy*, vol. 29, no. 499 (July 1948), pages 385–387.
20. C. J. RAMSBURG and G. V. MCGURL, "Carbonization of Coal-Oil Mixtures". A.G.A. *Proceedings*, 1940, pages 666–681. See also U. S. Patent 2,378,420. June 1941.
21. FRANK H. REED, *Some Observations on Coking Practice in Germany, Part I. Metallurgical Coke; Part II, Slanting Type Didier Coke Ovens, Städtische Werke Karlsruhe*, Bureau of Mines Information Circular 7462, June 1948, 74 pages. See page 57.
22. R. J. ROCCA and M. B. BEVER, "Some Quantitative Aspects of the Use of Oxygen in the Iron Blast Furnace", *Proceedings* Blast Furnace, Coke Oven, and Raw Materials Committee of the Iron and Steel Division, A.I.M.E., 1947, pages 67–82.
23. C. C. RUSSELL, *Measurement of Pressure Developed During the Carbonization of Coal*, American Institute of Mining and Metallurgical Engineers Tech. Pub. 1118, 1939, 14 pages; *Trans.* Coal Div., vol. 139, 1940, pages 313–327.
24. PHILIP S. SAVAGE, *The Blending of Coal to Improve Coke and Extend Our Coking Coal Reserves*, Presented at Eastern States Blast Furnace and Coke Oven Association, Pittsburgh, Pennsylvania, February 11, 1949.
25. L. D. SCHMIDT, "Effects of Storage on Oxidation of Coal Upon Coking Properties", *Iron and Steel Engin.*, vol. 18, March 1941, pages 64–70.
26. L. D. SCHMIDT, *Low-Temperature Coke by the Krupp-Lurgi Process*, Bureau of Mines Information Circular 7395, February 1947, 18 pages.
27. L. D. SCHMIDT, W. C. SCHROEDER and A. C. FIELDNER, *Increased Pig Iron Output Through Improved Coke*, Bureau of Mines Report of Investigations 3711, 1943, 58 pages.
28. WILLIAM SEYMOUR and L. D. SCHMIDT, *Control of Bulk Density of the Coal Charge in By-product Coke Ovens*, Bureau of Mines Report of Investigations 3743, December 1943, 13 pages.
29. D. R. TORGESON, T. E. EVANS and R. G. KNICKERBOCKER, *Pilot Plant Investigations—Production of Sponge Iron with Producer Gas*, Bureau of Mines Report of Investigations 3994, December 1946, 42 pages.
30. C. E. WILLIAMS, E. P. BARRETT and B. M. LARSEN, *Production of Sponge Iron*, Bureau of Mines Bulletin 270, 1927, 175 pages.

Production of High-Grade Metallurgical Cokes from Coals of Poor Coking Quality[1]

J. SABATIER

ABSTRACT

After recalling the fact that France, which is rich in iron ore but poor in coking coals, has to import more than two-thirds of the coke she requires, the author emphasizes the importance of the Lorraine coal-basin, which lends itself to intensive exploitation, but yields coals that are unsuited to standard methods of coking.

The shortage of French coal for the manufacture of coke to supply the Lorraine ironworks and the steadily increasing output of the Lorraine collieries give prominence to the problem of producing metallurgical cokes from the Lorraine coals.

After stating the characteristics required of blast-furnace cokes and those of the three classes of Lorraine coal (fat coals, flaming fat coals and flaming dry coals), the author describes the current industrial tests aimed at obtaining blast-furnace cokes by means of the following processes:

Coking by the normal method of a mixture containing as much Lorraine coal as possible;

Coking of a stamped triple mixture of Lorraine coal, coke-dust and coking coal (Carling) or of a dry mixture of Lorraine coal, Saar fat coal and semi-coke derived from flaming dry coals (Marienau).

The tests have not yet been completed, but the results already obtained justify the conclusion that it is possible to manufacture satisfactory metallurgical cokes from Lorraine coals (fat and flaming fat coals). The development of these processes should make it possible to extend the range of cokable coals and thus to achieve a better utilization of the coal output in France as well as in other countries.

The obtaining of the coke necessary for the production of iron is of fundamental importance to the French economy.

France possesses large deposits of iron ore, particularly in Lorraine, where the reserves amount to more than 3,500 million tons. On the other hand, she has very little coal, particularly "coking coals", which may be defined as those coals which yield high-grade cokes when subjected to the standard processes. These happen to be the cokes that are required for the reduction of the Lorraine ore in large-capacity blast-furnaces.

This situation obliges France to enter the world fuel market as a big importer of coke and coking coal.

The figures for 1930 may be quoted as an example: out of a total of 12 million tons of coal turned into coke by the French coking plants, one-third was imported, as well as half the coke consumed by the iron industry. Altogether that industry depended, directly or indirectly, upon imports for two-thirds of its coke requirements and in the case of the iron-basin of Lorraine the proportion amounted to three-quarters.

In the same region, however, there is a coal-basin, a prolon-

[1] Original text: French.

gation of the Saar basin, which has undergone a continuous development from the beginning of the century, as the following figures show:

Year	*1900*	*1913*	*1929*	*1938*	*1948*
Production (in millions of tons)	1.1	3.8	6.1	6.7	8.3

This development is to continue and the output is planned to reach 13 million tons in 1952.

The size of its reserves, which, at 5,000 million tons, represent one-half of France's coal reserves, and the nature of the coal-seams, which are suited to intensive exploitation, means that this basin has a big future and will play an important part in the economy of the area. There remains a difficulty, however, inasmuch as these coals, owing to their weak coking properties, have not hitherto made more than a very small contribution to the manufacture of metallurgical coke.

Thus the shortage of coal for the manufacture of the metallurgical coke needed by the Lorraine iron industry, and the development of the output of the neighbouring collieries, have led to serious consideration being given to the problem of producing high-grade metallurgical cokes from Lorraine coals, from the point of view of the correct utilization of the country's natural resources.

CHARACTERISTICS REQUIRED OF BLAST-FURNACE COKES

The low iron content and comparative friability of the Lorraine ore make it impossible to employ large-capacity installations unless the coke used complies with certain minimum requirements, in particular from the point of view of its mechanical properties. These minimum characteristics naturally depend on the preparation given to the charges to be reduced.

In France the mechanical properties of cokes are determined by the Micum drum test using 40 mm., 20 mm., and 10 mm.-mesh screens. Special importance is attached to the percentage of screening refuse derived from the 40 mm. screen, a large figure indicating lack of fragility, and the percentage derived from the 10 mm. screen, a small figure indicating a strong coke of low friability, a "high-cohesion" coke.

Studies which have been going on for several years[2] of the behaviour of cokes in the blast furnace in relation to their mechanical properties, based on an analysis of the results obtained industrially, have led experts to regard as an important parameter the bulk density of coke, i.e., the weight of loaded dry coke per unit volume, measured in a fairly large capacity vessel (charging-wagon, for example). The following definition has therefore been proposed for an index, called the "T index", to represent the physical value in terms of the bulk density and the results obtained from the Micum test:

$$T = M_{40} + M_{20} - M_{10} - 0.2\ d$$

where M_{40} is the percentage retained on the 40 mm.-mesh screen after the Micum test;
M_{20} is the percentage retained on the 20 mm.-mesh screen after the Micum test;
M_{10} is the percentage passing through the 10 mm.-mesh screen after the Micum test;
and d is the bulk density in kg./cub. metre.

[2] See CH. G. THIBAULT, "Contribution to the Study of Blast Furnace Cokes" in the *Revue de Métallurgie* (Paris) No. 5, May 1943.

The sum of the first three terms, which relate to the Micum test and indicate more particularly the mechanical properties of the coke, is known as the Micum C cohesion:

$$C = M_{40} + M_{20} - M_{10}$$

Empirical though this may be, the use of these parameters (results of the Micum test and bulk density) and indices (index T and cohesion C) supplies a positive factor of appraisal, without absolute value, it is true, but of indisputable practical utility.

In particular, while the real value of a coke can, as in the past, be determined only by an industrial test in the blast furnace, it is nevertheless possible by means of these parameters and indices to define the general characteristics of the types of coke which are or are not likely to be suitable for the proposed use.

According to blast-furnace practice, cokes may thus be divided into three groups from the point of view of their physical and mechanical properties:

(*a*) "Good cokes", having the following properties:
Micum test $M_{40} =$ 78 to 82 per cent
$M_{20} =$ 89 to 93 per cent
$M_{10} =$ 5 to 7 per cent
Bulk density d = 450 to 470 kg./cub. metre
Cohesion C = 160 to 170
T index T = 66 to 80

(*b*) "Medium cokes", which can be used without difficulty and which appear to be defined empirically as those with a T index greater than 60.[3]

(*c*) "Marginal cokes", possessing the minimum characteristics beyond which cokes do not appear to be capable of being used. These marginal characteristics are naturally difficult to determine. On the one hand they depend on the conditions of use and, in particular, on the degree of preparation given to the charges. On the other hand, since such cokes are on the borderline of possible use, they cannot be generally evaluated by means of a simple formula, since serious inadequacy in one respect cannot be compensated by better performance in other respects. In particular, the degree of independence between chemical and physical properties becomes very limited for such cokes.

The only possible definition of marginal cokes would therefore be that they are cokes the main properties of which, taken separately, do not exceed certain limits. Pending more exhaustive experiments, it would seem that for cokes of normal chemical value, the minimum physical characteristics should be approximately as follows:

Micum test $M_{40} =$ 60
$M_{10} =$ 13
Cohesion C = 140
T index T = 50

All these figures, incidentally, should be further defined by investigations conducted jointly by mining and metallurgical experts.

GENERAL CHARACTERISTICS OF THE LORRAINE COALS

It is standard French practice to classify coals by means of the index of volatile matter (in relation to pure coal) on the one hand, and by means of the index of swelling during rapid heating in a silica crucible, on the other.

[3] See CH. G. THIBAULT, *loc. cit.*

The systematic study of the Lorraine coals which has been carried out during recent years, has shown that within the range of coals with between 32 and 44 per cent of volatile matter, and having a swelling index between 1 and 9, three main categories may be distinguished: fat coals, flaming fat coals and flaming dry coals, with the following general characteristics:

	Fat[1]	*Flaming fat*	*Flaming dry*
Index of volatile matter	32–40 per cent	35–42 per cent	37–44 per cent
Swelling index .	4 ½–9	2–4	1–1 ½
Dilatometer test.	Melt and swell	Melt but do not swell	Do not melt
Proportion in output ...	20 per cent	52 per cent	28 per cent

[1] Among the fat coals it is usual to distinguish between fat A with an index between 7 and 9 and fat B with an index between 4.5 and 7, the latter being the most widespread in Lorraine.

These investigations have also brought out the very definite influence of depth in producing an increased swelling index, and therefore better coking properties, and, on the other hand, the harmful effect of the presence of ash beyond a certain limit. They have also shown the importance, in order to retain the caking properties of coal, of eliminating as carefully as possible the finest fraction (0 to 0.5 mm.) which is very rich in fusain, and the advantage to be gained from selective crushing, the 0.5 to 3 mm. fraction being used directly and only the fraction above 3 mm. being crushed.

The table given above shows the large percentage of the flaming fat coal class and consequently the advantage of bringing this class within the range of coals which may be used for the manufacture of metallurgical coke possessing the requisite qualities.

The suitability of these coals for the manufacture of such cokes, at least when subjected to standard coking techniques[4] is low, even in the case of fat coals,[5] except perhaps the best of them, while that of the flaming fat coals is very low indeed.

The production of high-quality cokes from most of the fat coals, as from the flaming fat coals, meets, in varying degrees, with the same difficulties, which derive essentially from the inadequate cohesion of the coke, on the one hand, and from its excessive cracking during contraction, on the other.

The insufficient cohesion of coke is a result of the conditions under which the fusion of these coals takes place when they are treated according to the standard technique. They are viscous when fused and do not swell sufficiently. The phenomena are more marked in the case of flaming fat coals in particular, and hardly any swelling takes place. Under these conditions, fusion does not allow the elementary particles of viscous matter from the original coal grains to become bonded together solidly enough to ensure the subsequent cohesion of the coke.

The remedies that have been considered have consisted either in making up for the deficiency of these coals in this respect by mixing with them a certain proportion of bituminous coal with excellent fusion and swelling properties, or in regulating the conditions of coking so as to accentuate the tendencies making for swelling, this result being obtained chiefly by ramming down the charges so as to give them as high a charge density as possible at the outset.

Among the industrial processes which may be used for the latter purpose, two have been tried out: the well-known tamping process, and the use of dry coals.

With regard to the cracking of the coke, which governs both its fragmentation and its fragility, the usual remedy consists in incorporating a suitable granulated thinning agent which, acting as an inert substance, limits the shrinking and checks the development of the cracks. Bearing local resources in mind, the thinning agents which have been studied are coke-dust and the crumbling "semi-coke" obtained by the low-temperature distillation of Lorraine flaming dry coals.

Thus, the industrial research directed at adapting the technique of carbonization to the specific properties of the Lorraine coals for the purpose of producing high-grade metallurgical cokes has proceeded in the two following directions:

On the one hand, the use of dry coals and the carbonization of triple mixtures consisting of Lorraine coal, added fat A coal and "semi-coke" dust from dry flaming coals; and

On the other hand, the use of tamping and the carbonization of triple mixtures consisting of Lorraine coal, added coking coal of the Pas-de-Calais type and coke-dust.

Tests have also been undertaken to determine the possibility of using Lorraine coals in existing coke ovens.

TESTS WITH STANDARD COKING TECHNIQUE

The object of these tests was to determine experimentally what proportion of Lorraine fat coal (fat B coal) could be used, mixed with suitable additions of more fusible coals, without departing from the standard coking technique. The tests were conducted in ovens 380 mm. broad. Heating was carried out for 14 to 15 hours in some of the tests (temperature: 1270 degrees C) and for 17 to 19 hours in others (temperature: 1160 degrees C).

Industrial tests have shown that by carefully removing the dust from Lorraine coals in order to eliminate the high-fusain fractions, mixtures of a type containing

50 to 65 per cent Lorraine fat coal,
25 to 20 per cent standard "coking coal",
25 to 15 per cent semi-fat coal,

yielded cokes with characteristics falling within the following limits:

Micum test,	M_{40} =	60 to 66 per cent
	M_{20} =	85 to 87 per cent
	M_{10} =	10 per cent
Micum cohesion,	C =	135 to 143
T index,	T =	50 to 56

These cokes have been used in blast-furnaces without any difficulty.

The tests showed that, if cokes with near-marginal characteristics were accepted, up to 65 per cent of Lorraine fat coal (fat B) could be incorporated in the coke mixture, using standard coking processes.

[4] Techniques involving the use of large ovens charged with damp paste by coal car.

[5] In this connexion the reader must not be confused by the term "fat", as applied to those coals of the Saar-Lorraine basin with the highest properties; although their swelling index is high, these coals are not comparable, for the manufacture of high-grade metallurgical coke, to the fat "coking" coals of the great deposits stretching from the North of France to the Ruhr.

USE OF DRY COALS AND SEMI-COKE AS THINNING AGENT ADAPTATION OF THE CARBOLUX MANUFACTURING TECHNIQUE

One of the accepted formulae for trying to obtain high-grade cokes from Lorraine coals by an adaptation of the coking technique consists, as already mentioned, in the employment of dry coals, in order to obtain a sufficient charge density, and of triple mixtures containing, as a thinning agent, "semi-coke" obtained by low-temperature distillation of small flaming dry coal.

This technique is one that was succesfully developed between 1925 and 1930 in the Pas-de-Calais basin by the Compagnie des Mines de Bruay for manufacturing a low-temperature household coke, called "Carbolux", from that Company's flaming coals, which could not readily be used for the production of metallurgical coke.

The work done by the Compagnie de Bruay showed that it was possible to obtain from these low-grade coals a hard compact fuel with excellent mechanical properties in the following way:

The least fusible of the flaming coals is precarbonized at about 450 to 500 degrees, and the semi-coke thus obtained is crushed separately to a suitable fineness.

This semi-coke is mixed with the most suitable of the flaming coals in a proportion of 30 per cent of semi-coke to 70 per cent of flaming coal.

The mixture is fed dry into coke-ovens of standard type but reduced width (about 350 mm.), and the heating is stopped when the temperature reaches 700 degrees C in the centre of the mass.

Production has been continuing on this basis for eighteen years and the annual output now exceeds 2.5 million tons.

The similarity between the flaming coals of Bruay and the Lorraine coals has led experts to enquire whether an adaptation of that technique could not solve the problem of coking the latter. Preliminary experiments in manufacturing Carbolux, using Lorraine coals instead of Bruay coals, and in manufacturing metallurgical coke by heating the mixture used for Carbolux to a high temperature, gave satisfactory results.

Hence, in order to carry out a complete series of experiments permitting the adjustment of the various factors affecting the coking process, it was decided to set up an experimental centre at Marienau in the Lorraine coal basin composed of:

An experimental coking plant with four chambers, each 4 metres high, 6 metres long and varying in width between 250 mm. and 450 mm. and

A mixing installation which would make it possible, as soon as a formula had been worked out at the experimental coking plant, to feed a near-by coking plant with this mixture so as to give the coke a blast-furnace test.

The building of this plant is well on its way to completion, and it will be started up before the end of the present year.

Pending the results of these tests, laboratory work and semi-industrial oven tests are continuing.

They have shown, among other things, that with the mixtures used a charge density of the order of 0.8 may be obtained, provided that their moisture content is reduced to 2 to 3 per cent. In addition to this effect, it appears that the use of dry mixtures should result in a certain improvement in the characteristics of the coke.

As regards the composition of the mixtures, the standard mixture taken as a basis is as follows:

60 per cent Lorraine coal (fat B)
20 per cent fat A coal
20 per cent "semi-coke" from flaming dry coal.

Tests on an industrial scale will make it possible to fix the composition of the mixtures for treating the flaming fat coals.

Finally, as an indication, we give the characteristics of the coke obtained in the test which consisted in the high-temperature carbonization of the mixture used for manufacturing Carbolux. They are:

Micum test, $M_{40} = 76.2$
$M_{20} = 89.2$
$M_{10} = 9.6$
Micum cohesion, $C = 156$
T index, $T = 70$

Furthermore, semi-industrial kiln tests carried out on Lorraine coals indicate that the Micum cohesion for mixtures of the type referred to above lies between 150 and 160.

USE OF THE TAMPING METHOD

It is well known that the tamping method, because it makes it possible to achieve high charge densities, is of particular interest in connexion with the coking of difficult coals such as the Lorraine coals.

The Carling coking plant of the Lorraine Basin Collieries has been using this technique for a long time past for the manufacture of domestic cokes, and research was recently undertaken there with a view to the manufacture of satisfactory metallurgical cokes by a combination of the tamping method with that of triple mixtures (consisting of Lorraine coal, an admixture of highly fusible coal and an admixture of thinning agent).

After numerous laboratory tests and by the use of the oven method, formulae have been perfected for the coking both of fat and of flaming fat coals. These formulae are based on the application of the following rules:

(*a*) The lower the coking qualities of the Lorraine coals, the more care must be exercised in their preparation. In particular they must be freed from dust as far as possible, to a limit of 0.5 mm. for the fat coals and 0.8 to 1 mm. for the flaming fat coals. The ash content should be watched. A fairly fine crushing is recommended.

(*b*) The coal which is to form the fusible admixture must be chosen from among the bituminous coals possessing excellent fusibility and good swelling properties.

(*c*) The thinning agent used for the tests was very finely ground coke-dust. Semi-industrial tests showed that equivalent results could be obtained by using small coal distilled at low temperature.

(*d*) The mixture of the three constituents is tamped in order to obtain a charge density of at least 1, the moisture content being of the order of 10 per cent.

The effect of tamping was clearly demonstrated by a characteristic experiment: the same mixture[6] coked first with, and then without, tamping gave the following results:

Micum test of coke manufactured	*With tamping per cent*	*Without tamping per cent*
M_{40}	68	68
M_{10}	10.7	16

[6] 72 per cent Lorraine coal ($^2/_3$ fat B and $^1/_3$ flaming fat), 17 per cent Pas-de-Calais fat coal, 11 per cent coke-dust.

The coke made without tamping was badly fused and could not be employed in the blast-furnace.

The effects of adding fusible coal and a thinning agent are clearly shown in the following table:

Mixture	Micum test M_{40} per cent	Micum test M_{10} per cent
Pure flaming coal	24.4	8.2
95 per cent flaming coal, 5 per cent coke-dust	30.6	9.0
50 per cent flaming coal, 50 per cent Lorraine fat coal	38.4	8.2
67 per cent flaming coal, 25 per cent added coal[7], 8 per cent coke-dust	72.6	8.4

Points worth noting are the good fusion of the pure flaming coal coked after tamping (M_{10} = 8.2 per cent), and the considerable improvement resulting from the addition both of a thinning agent and of a bituminous coal.

The following table gives the characteristics of the three basic formulae which have been developed:

Formula A for the treatment of fat coals (fat B);

Formula B for the treatment of a mixture of ⅔ fat B and ⅓ flaming fat and coals; and

Formula C for the treatment of flaming fat coals.

Composition of mixture	*Formula A*	*Formula B* ⅔ *fat B* ⅓ *flaming fat*	*Formula C* *flaming fat*
Lorraine coal (fat B)	75 per cent	72 per cent	65 per cent
added bituminous coal	9 per cent	16 per cent	28 per cent
coke-dust	16 per cent	12 per cent	7 per cent

Characteristics of cokes	*Formula A* (1)	*Formula B* ⅔ *fat B* ⅓ *flaming fat* (2)	*Formula C* *flaming fat* (3)
Micum test:			
M_{40}	70.6 per cent	77 per cent	78.1 per cent
M_{20}	89 per cent	89 per cent	90 per cent
M_{10}	7.5 per cent	8.8 per cent	8 per cent
Micum cohesion	152	157	160
Bulk density (dry)	478 kg./cub. metres	482 kg./cub. metres	486 kg./cub. metres
T index	57.5	61	62.6

(1) Average characteristics of the cokes manufactured in January 1948.
(2) Average characteristics of the cokes manufactured in February 1949.
(3) Average characteristics of the cokes manufactured in March 1949.

These various types of coke are consumed in the blast furnaces without any trouble and are proving satisfactory.

It is evident from these tests, which by the end of March 1949 had involved the manufacture of 60,000 tons of blast-furnace coke, that a proved method is now available for using Lorraine coals to make metallurgical cokes which rank with cokes of ordinary grade. The range of Lorraine coals which can thus be used includes not only the fat coals but also the flaming fat coals, or more than three-quarters of the Lorraine output.

CONCLUSIONS

Although the investigations that have been undertaken are not yet completed, the results hitherto obtained justify the conclusion that it is possible, by using suitable methods, to manufacture metallurgical cokes of satisfactory quality from fat, or even flaming fat, Lorraine coals.

The development of these techniques, which are of great importance for France's economy and also for that of other countries in the world, should make it possible to widen appreciably the range of cokable coals and thus achieve a better utilization of natural resources.

[7] Pas-de-Calais (Drocourt) fat coal.

A New Electric Process for the Carbonization of Non-Coking Bituminous Coal

OLAF JENSEN

ABSTRACT

Norway has large quantities of unutilized water power which, without having to be transferred over long distances, can be supplied in quantities of 200,000 to 400,000 kw. of power annually to at least ten different places along the Norwegian coast, where it is possible to build large factories directly adjacent to ice-free ports. Norway also has large sources of coal available in Spitsbergen. These coal sources consist mainly of high-volatile bituminous coal from the tertiary age which is quite unsuitable for the production of coke in ordinary coke ovens.

The Norwegian industrial undertaking, *Norsk Hydro-Elektrisk Kvaelstofaktieselskab* (*Société norvégienne de l'azote et de forces hydro-électriques*) together with the Norwegian Government has now worked out a new electrical method for the production of coke briquettes with great mechanical strength and high reactivity and for synthetic gas which is obtained directly by the coking process. If the synthetic gas is used for the production of gasoline and diesel oil, e.g., in accordance with the Hydrocol process, the following quantities can be obtained with a coal consumption of $1^1/_2$ million tons per year and a power consumption of about 300,000 kw. per year in all:

Approximately 700,000 tons of coke briquettes with low ash content,
Approximately 750,000 barrels of low-temperature tar,
Approximately 2 million barrels of gasoline and diesel oil.

By means of this new electrical method, Norway would be able to cover its requirements of coke and liquid motor fuel.

Pre-war hydro-electric power production in Norway was of the order of 9,000 to 10,000 million kwh. yearly with a generator installation of about 2.2 million kw. After liberation, new installations, some of which were started during the war, have brought the total installed generator capacity as of 1 January 1949 to about 2.7 million kw. with an expected yearly power production of about 14,000 million kwh. About three-quarters of this energy is used by the industries, the remainder for lighting and domestic purposes.

Norway's water-power resources were previously estimated at about 80,000 million kwh. yearly at minimum flow, but recent investigations have indicated that this figure can be appreciably increased. It is of particular interest to the electro-chemical and electro-thermical industries to ascertain how much low-cost, undeveloped power is still available at ice-free coastal harbours in blocks of 200,000, to 400,000 kw. for each particular location. A conservative estimate shows that at least ten locations on the west coast of Norway can meet these conditions.

Pre-war construction costs were approximately $ 100 per kilowatt-year, which gave power costs of about 0.1 per kwh. delivered at the factories. Current construction costs would raise this figure to about 0.15 to 0.25 cents per kwh. delivered. As this power is available on a continuous yearly basis at ice-free coastal locations with good overseas connexions, conditions would appear to be favourable for a vigorous development of electro-chemical and electro-thermical industries in Norway. Of the various plans for industrial utilization of these power resources, this report will deal with the proposed benefication of Spitsbergen coals.

Spitsbergen (the Norwegian name is Svalbard), which was mandated to Norway under the treaty of Versailles, contains large coal resources. A conservative estimate gives total reserves of about 8,000 million tons of coal of various types. Of particular importance are large deposits of bituminous coals of the tertiary age which are presently being extracted by two Norwegian mining companies at Longyear City and the Svea Mine. A proximate analysis of Longyear City coals shows the following composition: Moisture 0.70 per cent; Ash 5.44 per cent; Volatile 39.60 per cent; Fixed carbon 54.26 per cent; and B.T.U. 13,000 (min.).

Ultimate analysis: C, 78.90 per cent; H, 5.38 per cent; N, 1.50 per cent; S, 1.90 per cent; O, 6.18 per cent.

The Svea mine coals show a similar composition except for a somewhat higher ash content.

Pre-war freight rates for coals from Spitsbergen to Norway were no more than from the east coast of England or Polish ports. Norwegian ships then as now handled this traffic on an efficient basis. Spitsbergen coals therefore sold at competitive prices on the Norwegian market. However, the pre-war coal output from the Spitsbergen fields never exceeded 300,000 to 400,000 short tons per year or only about 10 per cent of Norway's coal and coke consumption. This low production had various causes:

(1) Since underground temperatures in Spitsbergen mines are minus 2 degrees C, the coals are frozen and disintegrate completely on thawing out, so that they are not very suitable with ordinary methods of firing. The ash also has a detrimental effect on acid-type firebrick due to its low fusing point and alkaline reaction.

(2) The coals are unsuitable for coke manufacture in the usual type of coke ovens. The coke is highly porous, of low mechanical strength and disintegrates badly during transport and storage.

In order to utilize Spitsbergen coals to the extent justified by the large reserves, new methods of beneficiation must be applied, and it would be natural in Norway to tie these in with further utilization of the country's large water-power resources. With this object in view, the large Norwegian company, *Norsk Hydro-Elektrisk Kvaelstofaktieselskab* (*Société norvégienne de l'azote et de forces hydro-électriques*), in co-operation with the Norwegian Government, commenced work during the late war on a new electric process for the manufacture of high-quality coke from Spitsbergen coals. This work has now progressed to the stage where a plant of industrial size can be built. The following paragraphs contain a brief description of the process as planned for a plant in Norway.

The coal is crushed and then briquetted. Two methods of briquetting have been tried, both with good results. The first method consists of pulverizing the coal followed by high pressure briquetting (2,500 kg./sq. cm.) without use of any binder, in a ring roll press. This type of press was originally built for brown-coal (lignite) briquetting and is adaptable to Spitsbergen coals provided certain measures are taken. The method produces strong briquettes which can stand storage under water.

The second method uses concentrated sulphite waste liquor as a binder. In this case it is not necessary to crush the coal so finely as in the first method. The briquetting may be done at a pressure of only 100 to 200 kg. per sq. cm. in a press of simpler construction.

The choice of method will depend primarily on economic factors such as availability of and transportation costs for sulphite waste liquor supplies, but also to some extent on the use for which the coke-briquette product is intended. The latter question will be considered later.

The coal briquettes are thereupon pre-heated to 150 degrees to 200 degrees C. This can be done in a separate apparatus or in connexion with the subsequent coking process.

It is a well-known fact[1] that by a sufficiently slow rate of heating, coal briquettes can be made into high-temperature coke without cracking, deformation or fusing together. The resulting coke briquettes have high mechanical strength, a dense structure and are far more reactive than standard high temperature coke. They will consequently be superior as a reducing agent in various metallurgical processes and as a smokeless fuel for domestic use. The demand for both uses is steadily increasing and it is expected that such a product will be readily saleable at an advantageous price. Particularly in Norway where coke is used for domestic heating to a far greater extent than in more southerly, warmer climes, production of coke from native coals using cheap hydro-power will be of great importance to the national economy.

By-products of the coking process are coal tar and gas. The resulting low-temperature coal tar will furnish a welcome raw material not hitherto available to Norwegian industry. Utilization of the gas is a more difficult and complex problem. On account of the cheap hydro-power available in most parts of the country, gas consumption is small even in the larger cities. This is the main reason why the country, in spite of a large coke consumption, has so far been unable to meet more than about one-tenth of this by domestic production. A coke production corresponding to the country's requirements would give a gas production so large that only a synthetic chemical industry, primarily for motor fuels, could provide a market for it. It would be logical, then, to attempt direct production of the most suitable gas mixture from the coking process. The problem can be solved as follows:

A charge of pre-heated coal briquettes enters the top of a vertical shaft and descends at an even rate in counter current with gas at 1000 degrees C. The briquettes are thereby heated evenly at an easily-controlled rate. At the same time the gas is cooled to about 200 degrees C.

At the lower end of the shaft is an electric furnace of a somewhat greater cross-section. This furnace contains two sets of three-phase electrodes. The carbonized briquettes, being now conductive, form the resistor element which provides the heat for the process. The lower end of the furnace has a conical extension through which the coke briquettes are discharged as a finished product.

The hot gases, in ascending the shaft section, acquire an admixture of tar and coke gases and pass from the top of the shaft through a Cottrell unit for removal of tar, thence through a cooler for oil separation. With a temperature of 50 degrees to 60 degrees C and saturated with steam, the gas then re-enters the bottom of the electric furnace through its conical extension where it cools the coke briquettes and becomes pre-heated. In passing through the electric furnace section, the gas temperature is raised to about 1000 degrees C. At the same time a reaction takes place between its hydrocarbons and the steam, forming carbon monoxide and hydrogen. Part of the heated gas is used for carbonization of a fresh charge of coal briquettes, while the remainder is piped off to be used for synthesis.

The attached diagram shows the apparatus for the process described above:

(1) Briquette bin with gas-tight feeder for charging.
(2) Pre-heater for coal briquettes.
(3) Circulator for pre-heating gas.
(4) Heat exchanger for heating the pre-heating gas by means of produced warm gas.
(5) Shaft for coking.
(6) Electric furnace for heating the coke briquettes.
(7) Cooling of coke briquettes by cold circulating gas.
(8) Arrangement for regulation of speed of downward travel of briquettes and gas-tight discharge of same.
(9) Cottrell unit for tar separation.
(10) Gas cooler and steam injection unit.
(11) Circulator for coke gas.
(12) Annular flue for discharge of hot gas.
(13) Upper electrodes (3-phase).
(14) Lower electrodes (3-phase).

One short ton (907 kg.) of Longyear coal yields 1,250 to 1,300 lb. of coke briquettes, 20 to 52 gallons of low-temperature coal tar of a high phenol content, and about 24,000 cub. ft. of gas of the following composition: Approximately, 70 per cent H_2; 27 per cent CO; and 3 per cent CO_2 - CH_4 - N_2.

Power consumption corresponds to about 40 kwh. per 1,000 cub. ft. of produced gas. As the market value of the coke briquettes and coal tar at least equals the cost of the coal briquettes, the total cost of the produced gas consists of the above-mentioned electric power plus plant operating and capital costs (depreciation and repairs). Plant operation should be a simple matter and repair costs low.

It will be noted that the gas produced by this electric coking process contains about 70 per cent H_2. In order to get a gas mixture suitable for synthesis of the composition $H_2/CO = 2$ it will be necessary to add common water gas. This can be done by blowing in a larger quantity of steam with the circulating gas, at the same time increasing the electric power load drawn by the furnace. An increased gas output will then be obtained at the expense of more valuable coke production, which means higher cost gas. A better procedure would be to separate the raw coal into two products, one to give low-ash coke (about 4 per cent ash) and another to give high-ash coke (about 30 per cent ash). The latter product can then be gasified by steam in an

[1] *Glückauf*, 1924, page 191.

electric furnace of same construction as above, but without the vertical shaft.

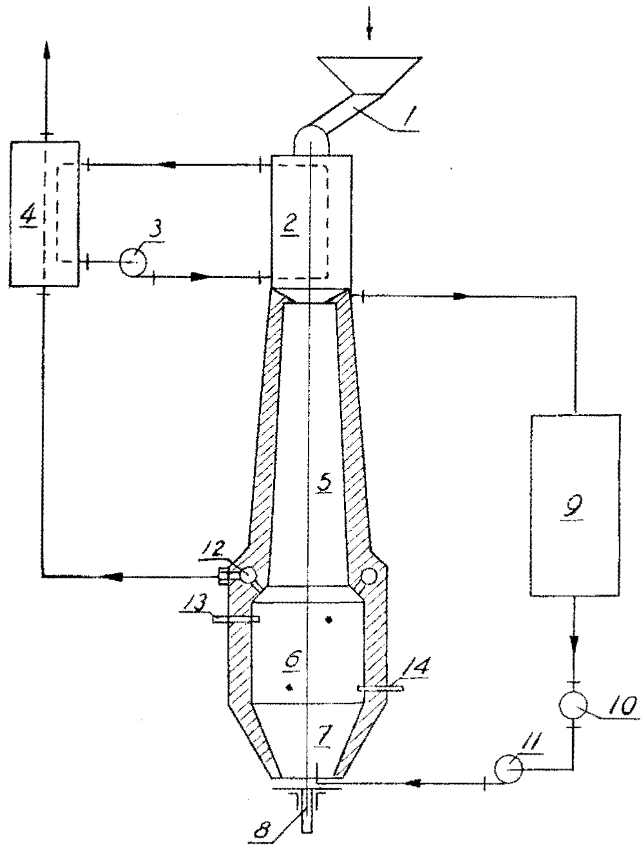
If the gas mixture is to be used for synthesis of gasoline or diesel fuels, e.g., by the Hydrocol process, a plant capable of converting say, 1½ million short tons of Spitsbergen coals yearly, will give the following products: Approximately 700,000 tons of low-ash coke briquettes, 750,000 barrels of low temperature coal tar, 2 million barrels of gasoline plus diesel fuel.

The approximate power requirements would be 300,000 kw. A plant of this capacity would meet the country's requirements of coke and liquid motor fuels and furnish valuable raw materials for the chemical industry.

At the current price index, the estimated production costs for the gasoline product will be on the order of 20 cents per gallon, which is about double the present laid-down cost of imported gasoline. As the price increase for imported gasoline during and after the war has been much less than for other imports, it is probable that a gradual price adjustment will take place. This could eventually result in such a small difference between import price and production costs, that a domestic production of gasoline might be feasible. If production of a synthesis gas is not wanted, an alternate gas fuel with a heat value of say 500 B.T.U. per 1,000 cub. ft. can be produced by disconnecting one set of electrodes with a corresponding decrease in the power load. The resulting gas consists mainly of methane, hydrogen and carbon monoxide with no heavy hydrocarbons. Electric power consumption will in this case decrease to about 400 kwh. per ton of coal, possibly less for larger furnaces. One ton of Spitzbergen coal will in this case produce about 1,350 lb. of coke briquettes, 20 to 25 gallons of low temperature coal tar and 10,000 to 11,000 cub. ft. of gas with a heat value of about 500 B.T.U. per 1,000 cub. ft.

The next coke plant to be built is expected to have a daily input of about 25 tons of coal briquettes. As will be apparent from the attached diagram, this process will encounter no difficulties in regard to the cross-sectional distribution of briquettes and gas in the furnace. The heat distribution will also be very good. As concerns the furnace capacity, the only limiting factor will be the required electrode voltage. Even for a furnace of 150 tons daily input capacity, electrode voltage will not exceed 150 volts which hardly presents any technical difficulties.

The resulting coke briquettes will have the properties of high temperature coke with 1 to 2 per cent volatiles. They will have a compressive strength of up to 500 kg. per sq. cm. Chemically they will be highly active, at least as good as low temperature coke. If sulphite waste liquor is used for briquetting, highly active coke will be obtained in any event.



Where no binder is used as in high-pressure ring roll presses, reactivity can be controlled to suit various requirements (i.e., for metallurgical, foundry or domestic use).

The present technically proven pilot plant design can also be used for wood distillation, producing a gas-free, mechanically strong charcoal with recovery of all valuable by-products.

By minor changes in plant design it is possible to produce a very pure water gas from coke and steam, or alternatively pure carbon monoxide gas from coke and carbon dioxide by a continuous operation. Furthermore, green waste wood can be converted directly to synthesis gas in a simple operation without any by-products whatever, except for the pure carbondioxide removed in the purification of the gas.

It will be apparent from the foregoing that this technically proven electric coke furnace may be a valuable tool for beneficiation of any type of raw fuels in countries possessing cheap and ample hydro-power, and thus provide a basis for an organic-synthetic industry.

Possibilities of Reducing Coke Consumption in the Production of Iron and Steel

MAGNUS TIGERSCHIÖLD

ABSTRACT

In view of the urgent need of coke conservation, the discussion deals with the factors which affect the consumption of coke in the blast-furnace process. The beneficiation and sintering of iron ores is especially pointed out, and a brief survey is given of the development of the present coke blast-furnace practice in Sweden, where the coke consumption has been brought down to 650 kg. per metric ton (1,300 lb./short ton). Among the means of attaining a low coke-consumption the high-pressure top furnace is mentioned as well as the possibility of using oxygen-enriched air in the ordinary blast furnace and in the low-shaft furnace. The advantages and disadvantages of the electric pig-iron furnace are reviewed. Finally, a survey of direct processes is made, in which special consideration is given to the Höganäs and the Wiberg sponge-iron methods and the Krupp-Renn process.

It is stated that of the world's coal resources one-third can be used for the production of coke. In most of the great industrial countries, however, the best coal for this purpose has become more and more scarce, and the depletion of the best coking coal has been fully recognized as a quite serious problem. As the blast-furnace is the dominating consumer of coke, it is highly justified to make every possible effort to reduce the consumption of coke in the production of pig-iron, or to find ways to use coke of inferior quality or other fuels for the reduction of iron ores.

It probably is a unique occurrence that a method like the blast-furnace process, invented more than 500 years ago, is still working on unchanged principles. The reason is that this method is scientifically sound and that it has been possible to develop the originally small and ineffective furnaces into gigantic units of high efficiency. This development no doubt is one of the greatest achievements of modern engineering science. The United States and Germany have been the leading countries in blast-furnace construction, not only in developing the profile of the furnace and the charging devices but also in mastering the transportation problems related to the great flow of raw material into the furnace.

In the United States the result is the "1,500 ton a day" blast-furnace constructed mainly for the use of Mesabi ores. The total height of this furnace often exceeds 33 metres (105 ft.) and the effective volume 1,270 cub. metres (45,000 cub. ft.). While the steady increase of furnace volume has resulted in a higher production and thus reduced the capital, labour and overhead costs per ton of pig-iron, the coke consumption has not dropped, and because of its great height this furnace is more sensitive to the quality of the coke than earlier constructions. An excellent report on American blast-furnace practice has been made by T. J. Ess (1)[1], and Fritz Wesemann (2) recently published an interesting paper on investigations of German blast-furnaces.

IMPORTANT FACTORS AFFECTING COKE CONSUMPTION IN THE BLAST FURNACE

The most important factors effecting a low coke consumption in the blast-furnace are the following:

1. High iron and low silica content of the ore.
2. Good reducibility of the ore.
3. Appropriate distribution of ore and coke in the charge of the blast-furnace, leading to an effective pre-heating of the burden and a high percentage of indirect reduction.
4. Highest possible blast temperature.

[1]Figures in parentheses refer to items in the bibliography.

The influence of the blast temperature on coke consumption has been well recognized. The maximum temperature that can be used, however, is to a large extent dependent upon the character of the ore burden. The Mesabi ores for example cannot be smelted at a higher blast temperature than about 540 degrees (1,000 degrees F). If the temperature is raised, serious troubles in the form of hangings will occur. Other ores, like sintered Swedish magnetites, can advantageously be smelted at a blast temperature of 800 degrees C (1470 degrees F).

Within certain limits the pre-heating and indirect reduction in the blast-furnace can be influenced by a well-balanced production according to the furnace dimensions. Probably the most beneficial effect on the high-pressure top method is a better heat transfer from the blast-furnace gas to the burden, which simultaneously results in a higher indirect reduction.

Of still greater importance, however, is the quality and the treatment of the ore burden. In my opinion, this factor has hitherto not been sufficiently recognized in the majority of the large steel-producing countries. In Sweden, however, where fuel is very expensive, different lines have been followed in the development of blast-furnace practice and construction. Until the beginning of this century, charcoal exclusively was used as blast-furnace fuel in Sweden. More than 30 per cent of the Swedish pig-iron produced is still made in charcoal blast-furnaces, and the constantly rising price of charcoal has necessitated the most strenuous efforts to bring down the fuel consumption.

The Swedish ore resources mainly consist of dense magnetites. It was recognized in old days that a preceding oxidizing roasting of the magnetite ore contributed to a lower consumption of charcoal in the blast-furnace. In the roasting the magnetite is more or less completely transformed from Fe_3O_4 into Fe_2O_3. It is well known that Fe_2O_3 at a low temperature is reduced to Fe_3O_4 by blast-furnace gas. In this way a micro-porosity is obtained, and the magnetite thus treated will become more easily reducible than natural magnetite.

During roasting the magnetite is further changed by development of fine cracks in the ore lumps. The question whether the cracking or the micro-porosity has the greater effect should be investigated. It was recognized at an early stage that the roasting temperature should be kept below the point where iron silicates are formed.

These experiences have been of the utmost value to Swedish blast-furnace engineers. Today nearly 100 per cent of the ore burden in Swedish blast-furnaces consists of concentrates in sintered form. In the sintering process we aim at obtaining a porous but still strong product consisting mainly of Fe_2O_3. Today sinter is regularly produced in Sweden, with a degree of oxidation as high as 98 per cent. This means that 98 per cent of the iron in sinter appears as Fe_2O_3. An excellent paper on this subject was written by Birger Hessle (3) who made an investigation of the production of highly oxidized sinter at Hofors in Sweden.

There has always been an extremely good co-operation between Swedish blast-furnace engineers, and the results obtained at one plant have quickly been adopted all over the country. As mentioned above, practically all Swedish blast-furnaces are now using 100 per cent sintered rich ore in the burden, resulting in a saving of 20 per cent and more in the consumption of charcoal in a charcoal blast-furnace. When producing pig-iron with about 1 per cent Si and 1 per cent Mn, the charcoal consumption calculated as coke is brought down below 600 kg. per metric ton (1,200 lb. short ton).

RESULTS FROM A SWEDISH COKE BLAST-FURNACE PLANT

Nowadays nearly all of the Swedish pig-iron for ordinary steel is produced in coke blast-furnaces. For quality-steel production charcoal pig-iron is used exclusively, and about 30 per cent is still made in charcoal blast-furnaces. To the members of an international assembly a review of the recent development of the coke blast-furnace in Sweden might be of special interest.

The finest work in this field has been done at Domnarfvet where the use of 100 per cent sinter was started in 1934. This among other measures has led to an extremely low coke consumption, which probably can be indicated as a world record. The furnaces are only 17 metres high (56 ft.), and though during recent years the hearth, bosh and top diameter have been appreciably enlarged, no alteration of the furnace height has been made. The adjoining diagram shows the production per day and per furnace as well as the consumption of coke, ore and lime from 1925 to 1948. During the whole period Thomas iron (basic Bessemer) was produced with 0.2 to 0.5 per cent Si, 0.8 to 1.0 per cent Mn, 1.8 to 2.0 per cent P and 0.03 to 0.05 per cent S. The coke consumption until 1932 was about 1,035 to 1,075 kg. per metric ton (2,070 to 2,150 lb./short ton), the average being about 1,060 kg. (2,120 lb.)[2]. The ore burden at that time consisted of lump ore only, of which the Grängesberg ore represented about 50 per cent. The consumption of ore per ton of pig-iron was about 1,830 kg. per metric ton of pig-iron (3,660 lb./short ton), and the limestone addition was 366 kg. per metric ton (732 lb./short ton).

A sintering plant of the Greenewalt type was completed in August 1934, which made it possible to use 95 per cent sinter made from rich concentrates. Five per cent of the ore burden was still in the lump state and consisted of an iron ore high in manganese and of some slag from the Thomas converters. The ore burden dropped to about 1,650 kg. per metric ton of pig-iron (3,300 lb./short ton) and the limestone that was still charged as lumps could be lowered to 150 kg. per metric ton of pig-iron (300 lb./short ton).

Through these steps the coke consumption immediately dropped to 700 kg. per metric ton of pig-iron (1,400 lb./short ton), on which level it could be kept during the years from 1935 to 1942. It might be mentioned that the coke consumption at the beginning of 1934, even before the starting of the sintering plant, had been brought down to 870 kg. per metric ton of pig-iron (1,740 lb./short ton) by using a richer lump ore in the burden and by a redesigning of the furnaces. Among other alterations the hearth diameter was enlarged.

At the beginning of 1943, so-called lime sinter was introduced, in other words, the necessary limestone was finally crushed and mixed with the ore concentrate before sintering. After some preliminary experiments it was possible to add all the necessary limestone in this way.

A further improvement of the blast-furnace performance was achieved in 1944, when all the manganese-bearing lump ore was finely crushed and mixed with the concentrates before sintering. Since then, during almost five years, the blast-furnaces have been operated with an ore and limestone burden consisting exclusively of sinter with a composition accommodated to the pig-iron analysis and the slag composition wanted. Through this alteration the coke consumption dropped to 650 to 680 kg. (1,300 to 1,360 lb.). Due to inferior coke with high water-content the consumption increased somewhat during the years 1944-1945, but as soon as better coke was available it dropped to an average value of 650 kg. per metric ton (1300 lb./short ton).

Because of the low height of the blast-furnaces no difficulties or decreases in the pig-iron production occurred when inferior coke was used. The iron content of the burden has only occasionally been somewhat higher than in earlier years when sinter and limestone in lump form was used. Consequently, the latest decrease in coke consumption is not caused by a richer burden.

The blast temperature is now about 800 degrees C (1,470 degrees F). It has varied somewhat during different periods, but its influence on the coke consumption has proved to be less than the influence on other measures. Much care has been taken in producing a sinter containing as little FeO as possible. When limestone was mixed with the ore before sintering, the oxidation degree of the sinter increased from 94 to 95.5 to 96 to 97 per cent (this means that now 96 to 97 per cent of the iron in the sinter appears as Fe_2O_3). A still higher value, about 98 per cent degree of oxidation, has now been obtained by using finely-ground coke breeze, the maximum being 3 mm. (1/8 in.) for the sintering. The consumption of coke breeze, due to the use of finely-ground coke breeze, is as low as 50 kg. per metric ton of sinter (100 lb./short ton), even though limestone is added to the concentrates before sintering.

After introducing the more easily reducible lime sinter, the production of the blast-furnaces could be raised. The average production has thus increased from about 157 to about 200 metric tons (174 to 220 short tons) a day. These figures are extremely low when compared with American practice, but the working volume of the furnaces is only 140 cub. metres (4,944 cub. ft.) and the hearth area as small as 7.5 sq. metres (80 sq. ft.). This means a production per unit of working volume of 1.42 metric tons per cub. metre and per day (44.5 short tons per 1,000 cub. ft.). This figure is about 50 per cent higher than is obtained in American blast-furnaces.

[2]The coke consumption is taken as weighed for the furnace at charging; no deduction has accordingly been made for the content of moisture or ash in the coke.

The present results are due to improvements made at the concentrating plant, by which the percentage of SiO_2 in the ore has dropped, which has made it possible to use less limestone in the burden. At present the concentrate contains about 63 per cent Fe and 5 per cent SiO_2 only. The lime sinter (including lime, manganese ore and some Thomas slag) contains 54 per cent Fe. The slag volume consequently is very low being about 430 kg. per metric ton of pig-iron (860 lb./short ton).

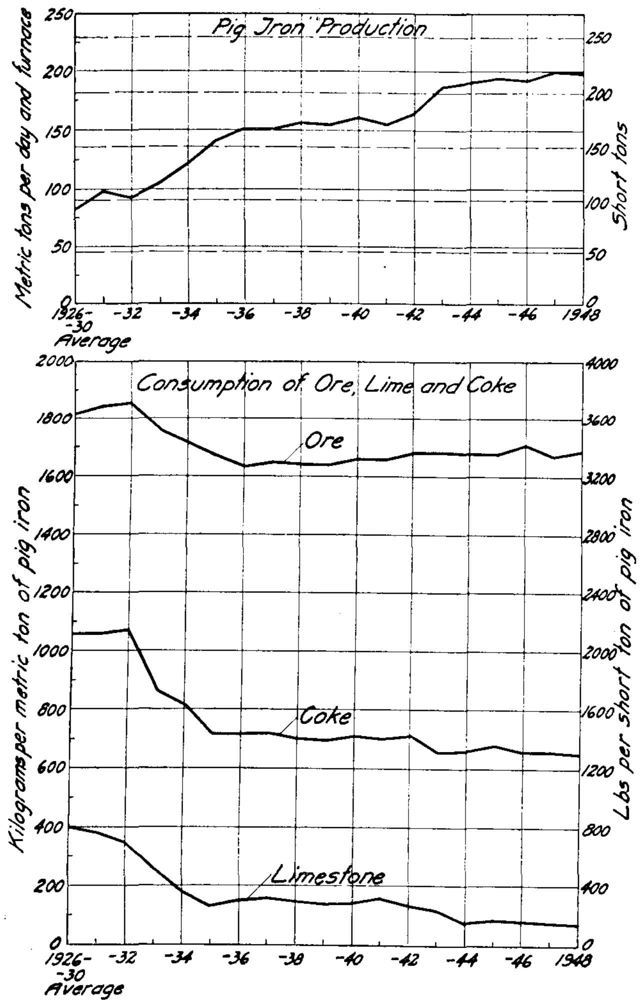


Diagram showing the pig-iron production per day and furnace at Domnarfvet and the consumption of ore, lime, and coke from 1926 to 1948.

The air blown is 330 cub. metres per minute (11,600 cub. feet) as measured, while the calculated volume is only 240 cub. metres per minute (8,500 cub. ft.). The CO_2 content in the blast-furnace gas was 9 to 11 per cent when lump ores were used. When sinter was first introduced, the CO_2 content was raised to 13 to 15 per cent and is now, when lime sinter is used, 15 to 17 per cent in spite of the fact that in this case no CO_2 is formed from the limestone which is calcined in the sintering pan already. The CO/CO_2 ratio is as low as 1.4 and the heat value of the blast-furnace gas has dropped to 690 kilo-calories per cub. metre (77.5 B.T.U. cub. ft.). The volume of blast-furnace gas is about 2,450 cub. metres per metric ton (78,000 cub. ft./short ton). The top temperature is about 250 degrees C (480 degrees F). No water is added at the top of the furnace.

The furnaces are provided with single Parry bells and cones. Much care is taken to attain an appropriate distribution of sinter and coke. This important factor has also been studied thoroughly at other blast-furnaces in Sweden. In spite of the high production per unit of working volume, the dust losses are not higher than 20 to 40 kg. per metric ton of pig-iron produced (40 to 80 lb./short ton).

The author is most indebted to the present management of Domnarfvet for the permission to publish for the first time these really interesting results.

At Fagersta, where 18 metres (59 ft.) high charcoal blast-furnaces have been rebuilt into coke blast-furnaces, a corresponding development has been accomplished. When producing pig-iron for open-hearth furnaces with about 1.2 per cent Si and 1 per cent Mn, the coke consumption now has been brought down to about 700 kg. per metric ton of pig-iron (1,400 lb./short ton).

I am well aware that the prime reason for the good results achieved in Sweden is the fact that our excellent resources of magnetite ore can be beneficiated economically to rich concentrates which can be transformed into an easily reducible sinter. Another great advantage is that this sinter allows the use of a high blast temperature.

Similar conditions exist only in a very few districts of the world, but the pioneering work done in Sweden has shown ways and means which, if they were more generally adopted, would no doubt result in an appreciable saving of coke at many blast-furnace plants.

When in the future the American blast-furnaces will have to change their ore burden from the present Mesabi ores with about 51 per cent Fe into rich concentrates with 62 per cent or more Fe made from taconites, the results obtained in Sweden probably will be of still greater interest. It might be found that the present gigantic blast-furnaces in the United States could be cut down to a lower height and thus enable the use of inferior coke.

PELLETIZING

The pelletizing process which at present is being investigated in the United States will probably be of the greatest importance. In Sweden as well, interesting experiments are being carried out on this process, which seems to be especially suitable for the treatment of Swedish magnetite concentrates. Through this method it is possible to obtain a regularly-sized ore burden, which no doubt will result in a more regular blast-furnace performance.

The effect of sized and nodulized Mesabi iron ores on blast-furnace performance has been shown by large-scale experiments at the Edgar Thomson works. As far as can be judged by the fine report by Herman J. Dobscha (4), the agglomerates used were not ideal. The fact that the density was higher in nodulized ores than in the unprepared material shows that the temperature in the rotary kiln was kept so high that a considerable formation of iron silicate probably took place.

OTHER WAYS FOR ACHIEVING A LOW COKE CONSUMPTION

Of very great interest are the experiments made in the last years at Cleveland and Youngstown with the so-called high-pressure top furnace (5) (6). An appreciable saving of coke and a higher production has been attained. This method offers an advantageous possibility, especially in places where fine ores are used. The dust losses are reduced appreciably, but it might turn out that still more can be attained by combining a high top-pressure and a sized and sintered ore burden.

Among other developments the excellent work by Brassert should be mentioned. At Corby in England and at the Hermann-Goering works in Germany he introduced a method of melting poor siliceous ores with a low lime addition. The desulphurization of the pig-iron is not as good as in ordinary practice, but by treating the pig-iron with soda ash in the ladle, the sulphur can be brought down to a sufficiently low figure. If these ores were melted with a basic slag of the usual composition, the coke consumption would be prohibitive. This method is a valuable contribution to the utilization of low-grade siliceous ores.

The world's blast-furnace engineers, with great excitement, are awaiting the results from the large-scale experiments with oxygen-enriched air which will soon take place at the blast-furnaces of the Bethlehem Steel Company, Johnstown, and at the Weirton Steel Company, Weirton. As suggested by B. S. Old and collaborators (7), the results may show that a combination of the high-pressure top and the oxygen-enriched air will be a highly interesting solution for further developments.

THE LOW-SHAFT OXYGEN FURNACE

The very temperamental and somewhat choleric Professor F. Wüst once called the blast-furnace "a lazy nuisance" (*ein faules Ungetüm*). Now Professor Robert Durrer of Switzerland (8) (9) has taken up this challenge against the classical process. His suggestion is a low-shaft furnace operated with nearly pure oxygen instead of air. The furnace can be regarded as a gas producer making an excellent fuel gas from a cheap fuel and producing pig-iron more or less as a by-product.

It is interesting that a furnace of this type was tried for a short period during the war at the *Süddeutsche Kalkstickstoffwerke* at Trostberg, Bavaria. According to the report made (10), pig-iron was succesfully produced with the use of 40 to 42 per cent oxygen in the unpreheated blast. Coke consumption was 1,400 kg. per ton of pig-iron, but the thermal value of the gas was measured at 1,300 kcal. (147 B.T.U./cub. ft.). So far only crushed and screened coke has been tried, the size being 15 to 40 mm. (5/8 to 1½ in.). Probably a certain amount of coke breeze could have been admixed, and there is no reason why anthracite or non-coking coal could not be used, at least to a certain extent. Probably a higher oxygen content in the blast would prove advantageous, thus resulting in a still higher calorific value of the gas.

Even if this process could be used to a limited extent only, it surely is of enough interest to emphasize that systematic tests should be carried out at a steel plant as soon as possible. According to a verbal communication from Professor Durrer, he now has a small furnace of this type under construction at Gerlafingen, which will be put into operation in August 1949. This process offers an interesting solution of the fuel problem for an integrated steel plant and should be of special interest in countries where first-rate coke is not available.

ELECTRIC PIG-IRON FURNACES

In countries where fuel is expensive but electric power available at low prices the electric pig-iron furnace offers an advantageous solution. In 1928, after many years of experiments, a low-shaft electric pig-iron furnace (the Tysland-Hole furnace) of industrial size was put in action at the Christiania Spigerverk, a steel plant near Oslo. Its name derives from two Norwegian engineers, Georg Tysland and Ivar Hole, who made valuable contributions to the design. A pig-iron furnace of similar type has been constructed by Siemens.

Altogether 25 Tysland-Hole and a few Siemens furnaces have been installed and several new furnaces are under construction. Due to the low height of the furnace, it is much less dependent on the strength of the fuel than is the blast-furnace. An ideal fuel is 50 per cent coke and 50 per cent coke breeze, but charcoal, lignite, peat coke, and anthracite can also be used as additional fuels in mixture with coke.

About 400 kg. of coke is needed for producing 1 metric ton of pig-iron (800 lb./short ton). The consumption of electric power is about 2,400 to 2,600 kwh. per metric ton, depending on the quality of ore used and on the analysis of pig-iron produced. The maximum capacity of furnaces hitherto in operation is about 100 metric tons (110 short tons) of pig-iron per day, but a 200-ton unit is under construction for the new government steel plant in Norway. For a 100-ton unit the transformer capacity is about 12,000 kva., while for a 200-ton unit the transformer capacity is 24,000 kva. Regarding the construction of the furnace and its operation, I refer to the technical literature in this field (11) (12) (13).

In order to decide if in a certain district an electric pig-iron furnace should be built instead of a coke blast-furnace, the following views should be kept in mind:

Advantages

1. The electric pig-iron furnace is remarkably insensitive to the quality of raw materials used, especially that of the reducing agent. This implies that in many countries fuels from domestic sources which are not suitable for the blast-furnace may be used for producing pig-iron electrically.

2. Due to an excellent desulphurization, good pig-iron can be produced in electric pig-iron furnaces from raw materials of inferior quality.

3. The furnace can be run at half capacity and thus serve as a consumer of peak loads and occasional surplus power. As an example it may be mentioned that at one steel plant the electric pig-iron furnace, during short periods of power shortage, was operated during weekends only.

4. The electric pig-iron furnace gas is not diluted with nitrogen and thus is much richer than blast-furnace gas. The calorific value is approximately 2,500 kcal. per cub. metre (290 B.T.U./cub. ft.). The quantity of gas formed is about 650 cub. metres (23,000 cub. ft.) per ton of pig-iron. It is an excellent fuel gas and it can also be used for chemical synthesis, production of hydrogen etc.

Disadvantages

1. As the maximum capacity of the electric pig-iron furnace probably cannot be raised above 200 tons a day, the erection costs per ton of the annual production will be somewhat higher than for a coke blast-furnace of modern size.

2. The operating costs with regard to man-power and repair costs are somewhat higher than for a coke blast-furnace.

3. Due to the rather high consumption of electric power, the economy of the electric pig-iron furnace is largely dependent on the price of electricity.

In its present state the electric pig-iron furnace already offers an interesting possibility of reducing the coke consumption for pig-iron production. Promising experiments are now running in Sweden with pre-reduced ore for the furnace. This method was invented by M. Wiberg, and thorough calculations show that it should be possible to save 20 to 30 per cent of the consumption of coke and power and at the same time raise the production appreciably. All gas formed will be used for the pre-reduction furnace, and it is a matter of local conditions if the savings made will balance the value of the gas thus made unavailable for other purposes.

SPONGE IRON PROCESSES

The possibility of producing a low carbon iron directly from the ore has been the subject of much research and many very expensive experiments all over the world. In most of the proposed processes the ore is reduced at a temperature well below its melting point. The product thus obtained is called sponge iron and consists of a porous mass of more or less completely reduced iron. The gangue of the original ore remains in the product. It is always of great importance, therefore, to use the richest possible ore as a raw material for sponge iron production. This is especially the case when the product is used for the manufacture of iron powder, but it is of importance also when the product is used as raw material in steel-making furnaces.

Powder metallurgy is a new and very interesting possibility for the mass production of small complicated parts of iron. In the United States and Canada a few installations have been built producing iron powder according to different methods. The use of this material probably will increase appreciably, but the tonnage no doubt will remain below a limited level.

There is a possibility that sponge iron in large quantities will be used as melting stock, i.e., as a substitute for scrap and pig-iron or together with pig-iron for the production of quality steel. Commercial scrap has become more and more contaminated by impurities — copper, nickel, and tin being the most dangerous — and thus is a well-recognized difficulty in the production of quality steel.

By extensive experiments it has been shown (14) (15) that sponge iron can be used not only as raw material in electric steel furnaces but also, if certain measures are taken, as a substitute for scrap and pig-iron in open-hearth furnaces. In acid furnaces successful trials have been made with 70 per cent sponge iron and 30 per cent domestic scrap. In basic open-hearth furnaces, however, the addition of sponge iron probably must be kept lower.

It can hardly be predicted that sponge iron will be used to a larger extent for the production of commercial steel in the large steel-producing countries. If sponge iron, however, could replace commercial scrap in the production of quality steel, a corresponding amount of scrap would be available for the production of commercial steel, thus reducing the quantity of pig-iron necessary for maintaining the production. The development of the sponge iron processes thus could contribute to a lower consumption of coke for the entire steel industry.

Regarding the production of sponge iron for melting stock, two processes only have so far been in industrial operation. Both were invented and are in operation in Sweden.

The Höganäs process invented by Sieurin has been in regular operation since 1911 at Höganäs, a ceramic factory in the south of Sweden. Its principle is well known from the technical literature (16) and much work has been done in the United States and in Canada (17) (18) for the further development of this process.

At Höganäs rich iron concentrates are packed into ceramic saggers in layers with coke breeze mixed with limestone. The saggers are heated in a ring furnace of the same type as is frequently used for burning bricks. The maximum temperature of the furnace is 1,200 degrees C (2,192 degrees F). To obtain a high degree of reduction the saggers must be kept in the furnace for an appreciable time, about eight days. The sponge iron produced is obtained in porous cakes of regular form. The density is 2. Due to the addition of lime, no contamination of sulphur occurs, and in some cases even a reduction of the sulphur content of the ore takes place.

The greatest part of the heat necessary is obtained by burning the carbon monoxide formed at the reduction of the iron ore, but some extra heat is needed and is attained by an additional combustion of ordinary producer gas. A surplus of coke breeze must be charged to the saggers to prevent reoxidation of the product. Most of the surplus, however, can be recovered and used again. The consumption of coke breeze can thus be kept below 700 kg. per metric ton of sponge iron (1,400 lb./short ton). The extra heat needed amounts only to a few per cent of the total consumption.

As all the heat necessary for the reduction is conducted to the charge through the sagger walls, the production largely depends on the conductivity of the sagger material and of the charge as well as of the total heat-exposed area of the saggers. According to Eketorp (16) the furnace at Höganäs holds 35,000 saggers. The furnace volume is about 3,000 cub. metres (106,000 cub. ft.), of which the effective volume is about 2,500 cub. metres (88,500 cub. ft.). The total heat-exposed area of the saggers is about 17,500 sq. metres (188,300 sq. ft.). With a daily production of 70 metric tons (77.5 short tons), only 4 kg. of sponge iron is produced per day and per sq. metre of sagger area (0.83 lb./sq. ft.), while 28 kg. is produced per day and per cub. metre of effective furnace volume (1.7 lb./cub. ft.). From the latter figure it is obvious how expensive the construction of a sponge iron plant of this type must be.

The raw material used at Höganäs is an extremely rich and pure iron concentrate from the Lappland mines containing 71.5 per cent Fe, and thus the sponge iron produced contains more than 97 per cent Fe. The degree of reduction usually exceeds 96 per cent which means a remaining oxygen content of about 1 per cent in the form of FeO. The content of gangue usually is about 1.6 per cent, and the carbon runs as low as 0.1 per cent.

The product has mainly been used as melting stock at Swedish quality-steel plants, and in spite of the fact that the production never has exceeded 25,000 tons per year, this product has been of considerable value for the Swedish steel industry. In recent years an increasing part of the production has been used for the manufacture of iron powder. After grinding, the powder has been subjected to magnetic separation and to an additional reduction, thus forming a product with a very low content of gangue and oxygen.

Of great interest is the Wiberg process which was invented in 1918 (19), (20). According to this method the ore is treated and reduced in a continuous shaft furnace. The reducing agent is a hot gas consisting of about 70 per cent CO and 25 per cent H_2. The gas is formed by circulating a part of the waste gases from the zone for final reduction through an electrically heated carburettor, where CO_2 and H_2O are reduced with carbon to CO and H_2. In this process the ore must be in coarse shape, a suitable burden being sized-lump ore or sinter.

The development of this process into an actual producing unit has taken a very long time and is no doubt an exceedingly fine engineering job. Now the Wiberg process has been running continuously for more than eight years at Söderfors, and two more plants of large size will be built in the near future by other Swedish steel companies.

At the beginning the carburettor was constructed for the use of charcoal, but recently successful experiments have been carried out with coke as fuel. The sulphur in the gas can be completely removed in a lime or dolomite filter placed between the carburettor and the furnace.

Much work has also been done to enable the use of pellets instead of sinter in the Wiberg process. The results, so far, are promising but not final. The Wiberg process is built upon theoretically sound principles, and the consumption of heat is the lowest ever obtained in industrial operation at the reduction of iron ore. Per metric ton of reduced iron the coke consumption is about 250 kg. (500 lb./short ton) and the consumption of power is about 1,100 kwh. per metric ton (1,000 kwh./short ton).

The difficulty of building the Wiberg furnace in large units might limit the use of the process. The furnace at Söderfors is producing only 10,000 tons a year, but the new furnaces now under construction will have a rated production of about 20,000 tons a year.

Another limitation might be the poor behaviour of certain ores in the reduction. The ore used must not disintegrate nor have a tendency to stick at the reduction temperature.

In many cases it might be difficult to decide which sponge iron process should be used. A summary of the advantages and disadvantages might be helpful for this purpose.

HÖGANÄS PROCESS

Advantages

1. The raw material can be any crushed ore with a grain size less than ½ in. Some experiments have been made using sized-lump ore as raw material, and further experiments might show the possibility of using such a raw material for the process. There are no limits as to the minimum size of the ore, and the process is remarkably insensitive to the properties of the ore used.

2. Generally no sintering or other previous treatment of the fine ore other than drying is needed. No contamination by sulphur takes place, and in certain cases a desulphurization of the material is accomplished.

3. The Höganäs process makes it possible to obtain a high degree of reduction, about 96 per cent. If iron silicates are present in the ore, the degree of reduction is lowered, but this is true for any sponge iron process.

4. Inexpensive fuel can be used for reduction and heating. At present coke breeze mostly is used for the reduction, while the producer gas is generated from a low-grade coal.

5. The finished product is obtained as cakes which in spite of their porosity are remarkably strong and free from any tendency to form fines.

Disadvantages

1. Construction costs are high. The furnace volume is large in comparison to production.

2. Labour costs are rather high.

3. The limited life of the saggers is a weak point in the process.

WIBERG PROCESS

Advantages

1. Lump ores as well as sinter can be used. The sulphur content of the ore is reduced to a very low figure in the oxidizing zone in the upper part of the furnace.
2. The heat consumption is remarkably low.
3. The furnace is relatively inexpensive in construction.
4. The process is continuous and well mechanized, and consequently labour costs are very low.

Disadvantages

1. Ore concentrates must be sintered before reduction, and the process is more sensitive than is the Höganäs process to the properties of the ore that is used.

2. At present the process is limited to first-rate coke or charcoal as fuel.

3. It will probably be difficult to build the furnace in large units.

When developing the Höganäs as well as the Wiberg process, the general principles of heat economy have been well attended to. The waste gases consist of N_2, CO_2 and a certain amount of O_2 leaving the furnace at a low temperature. In the Wiberg process the thermodynamic laws of equilibrium have been well recognized and utilized in the construction and maintenance of the furnace.

The Höganäs as well as the Wiberg process can be improved. The former process could be more mechanized in order to decrease labour costs. Reconstruction of the furnace and systematic research on the sagger problem are recommended.

It has not yet been tried, but apparently there are great possibilities of replacing the Wiberg carburettor by a gas producer for oxygen-enriched air. This would mean that no electricity for the heating of the furnace would be necessary. In a paper by Kalling and Stålhed (20) it is also pointed out that natural gas, coke oven gas, and even oil could be transformed into a suitable reducing gas for this purpose, and thus the coke consumption could be reduced to a still lower level.

Brassert and his collaborators are proposing a new sponge iron process, where the reduction should be made at elevated pressure. An oxygen gas producer might also be introduced in this system.

At a first glance the problem of reducing iron ore into sponge iron seems very simple, and therefore an extremely large number of proposals have been announced, patented, and sometimes tried on a relatively large scale. Directors of development and research at the steel plants as well as other prominent men with metallurgical experience no doubt can certify that a good deal of their time has been spent in dispelling more or less fantastic ideas of solving the problem of making sponge iron.

In judging the value of a sponge iron process, it should be kept in mind that the method must be theoretically sound and the construction as simple as possible. Processes giving a surplus gas and basing their economy on a favourable price for the waste gases used for purposes extraneous to the process, seldom can compete with processes utilizing the supplied heat within the sponge-iron furnace itself.

When gaseous reduction is applied, it should be kept in mind that the reduction with H_2 is highly endothermic while the reduction with CO is exothermic. In manufacturing such an expensive product as iron powder, hydrogen alone could be used for the reduction but this usage seems impossible for economical reasons for the production of melting stock.

It is practically impossible to tell in advance how an ore will behave during reduction, and it is certainly necessary to make large-scale experiments before taking up a sponge iron process.

THE KRUPP-RENN METHOD

The Krupp-Renn method was invented between the two world wars by Johannsen (21) in Germany. It is a direct process in which the product consists of small lumps of iron obtained in a half-melted form together with a slow-flowing slag. The furnace is a large rotary kiln heated with pulverized coal. The finely divided ore is fed into the furnace together with a sufficient amount of coke breeze or anthracite dust. The burden is successively pre-heated by the powdered coal flame and by the combustion of surplus coke and of carbon monoxide formed by the reduction of the ore. The temperature is kept below the point where the iron is melted but high enough to obtain the slag in a slow-flowing state. The mass coming out of the furnace is cooled and crushed, and the small iron lumps are detached from the slag by a magnetic separator. The product is not very clean, the iron content being only about 95 per cent and the sulphur very often running as high as 0.3 to 0.8 per cent. The carbon usually is about 0.8 per cent. A good description of the process is given by Durrer (8). The more recent developments were reviewed by the author in 1944 in a Swedish journal (22).

The greatest advantage of the process is that poor, highly siliceous ores and also ores with a high content of titanium can be utilized and that low-grade fuel can be used to a great extent. The total consumption of fuel is about 650 to 1,100 kg. per metric ton (1,300 to 2,200 lb./short ton), depending on the iron content in the ore burden. The process has been used to quite a large extent in Germany and Japan; in the latter country ten or more large furnaces were running during the last war.

The proper composition of the ore is essential, and very often additions must be made to produce a suitable slag. The temperature in the hottest zone must be kept within narrow limits, and it is very difficult to prevent the sticky slag from forming rings on the furnace wall. The consumption of refractories is rather high, and thus the repair cost of the furnace is a heavy item. The building costs also are rather high. The product is used as melting stock in open-hearth and electric furnaces, but the high sulphur content is a considerable limitation to a wider application of the process.

FUTURE ASPECTS OF NEW METHODS

An accelerated expansion of the steel industry can be expected within the next decades, and many countries where there is no or very little steel production are planning a large steel industry of their own.

It is a great advantage that new methods are now available for the production of pig-iron and steel. When planning a steel industry in a new district, all essential factors must be taken into consideration for the choice of the most suitable method. The specific properties of the ore, the cost of electricity and the price and quality of fuel are extremely important factors. In many cases a careful study no doubt will lead to the application of new processes.

Bibliography

1. T. J. Ess, "The modern blast furnace", *Iron and Steel Engineer*, vol. 23, no. 4 (April 1946), page BF-17.
2. Fritz Wesemann, "Relations between the specific production of blast furnaces and their consumption", *Stahl und Eisen*, vol. 68, no. 1–2 (1 Jan. 1948), page 1.
3. B. Hessle, "New metallurgical experiences with sintering", *Jernkontorets Annaler*, vol. 129 (1944), page 383.—Also *Iron and Steel Institute* in England, Translation no. 289, 1946.
4. H. F. Dobscha, "Effect of sized and nodulized Mesabi iron ores on blast furnace performance", *Yearbook of the American Iron and Steel Institute*, 1946, page 78.
5. J. H. Slater, "Operation of the iron blast furnace at high pressure", *Blast Furnace and Steel Plant*, vol. 35, no. 9 (Sept. 1947), page 1083.
6. B. S. Old, E. L. Pepper and E. R. Poor, "Progress in high pressure operations of blast furnaces", *Iron and Steel Engineer*, vol. 25, no. 5 (May 1948), page 37.
7. B. S. Old, A. R. Almeida, R. W. Hyde and E. L. Pepper, "Economics of the Blast Furnace", *The Iron Age*, vol. 160, no. 12 (September 1947).
8. R. Durrer, *The reduction of iron ores*, Düsseldorf, Stahleisen m.b.H., 1943, pages 115, 119 and 122.
9. R. Durrer, *The fundaments of iron and steel production*, Bern, Francke, A.G., 1947, pages 75 and 76.
10. W. M. Pollitzer, "Utilization of oxygen in the German iron and steel industry", F.I.A.T. Final Report, no. 1203, 14 June 1947, London, H.M. Stationery Office. Also Heinrich Hellbrügge, "Ore Reduction with Oxygen-Enriched Air", *Stahl und Eisen*, vol. 69 (1949), page 256.
11. I. Hole, "Electric pig iron melting", *Kjemi og Bergvesen* vol. 18 (1938), page 161.
12. H. Cowes, "Smelting iron ores electrically", *The Iron Age*, 1942, 3 and 10 December.
13. E. Gehrig, "Electric smelting plant at Choindez", *Von Roll Mitteilungen*, vol. 4 (1945), page 26.—Also *Journal of the Iron and Steel Institute*, England, vol. 156 (1947), page 293.
14. M. Tigerschiöld, "The use of sponge iron for steel production in Sweden", *Jernkontorets Annaler*, vol. 131 (1947), page 295.—Also *Metallurgia*, vol. 37 (1948), page 167; and "Blast Furnace Coke Ovens and Raw Material, A.I.M.E. *Proceedings*, 1947, page 177.
15. R. C. Buehl, M. B. Royer and J. P. Riott, "Use of sponge iron in steel production", U.S. Bureau of Mines, R.I. 4096, July 1947.
16. S. Eketorp, "Höganäs sponge iron process", *Jernkontorets Annaler*, vol. 129 (1945), page 703.—Also *Iron and Steel Institute* in England, Translation no. 275, July 1946.
17. V. H. Gottschalk, E. S. Beebe and R. S. Cole, *Manufacture of sponge iron in ceramic tunnel kilns*, U.S. Bureau of Mines, R.I. 4271 April 1948.
18. P. E. Cavanagh, "Manufacture of sponge iron in kilns", *Journal of the Canadian Ceramic Society*, vol. 17 (1948).
19. E. Améen, "Production of sponge iron at Söderfors according to the Wiberg method", *Jernkontorets Annaler*, vol. 127 (1943), page 227.—Translation, *The Iron Age*, vol. 153 (20 Jan. 1944), pages 55, 150 and 27 Jan., page 56.
20. B. Kalling and J. Stålhed, "Manufacture of sponge iron by the Wiberg-Söderfors method". To be published in *Blast Furnace and Steel Plant*.
21. F. Johannsen, "The Krupp-Renn method", *Stahl und Eisen*, vol. 54 (1934), page 696.
22. M. Tigerschiöld, "Metallurgical methods for increasing the iron recovery in the concentration of lean ores"; *Jernkontorets Annaler*, vol. 128 (1944), page 423.—Also *The Iron and Steel Institute* in England, Translation no. 238, 1945.

In addition to the above references, the author would like to draw the reader's attention to the following articles recently published in this field:

P. E. Cavanagh, "Economics of Ferrous Smelting in Canada", C.I.M.M.E. *Transactions*, vol. 51 (1948), pages 205–215.

H. F. Dobscha, "Effect of Sized and Sintered Mesabi Iron Ores on Blast Furnace Performance", American Institute of Mining and

Metallurgical Engineering—Blast Furnace, Coke Oven and Raw Materials, *Proceedings*, 1948, page 49.
EARLE C. SMITH, "Experience to date of Iron Production and Methods other than Coke Blast Furnace: Direct Reduction", pre-print read before the General Meeting of the American Iron and Steel Institute at New York, 26–27 May, 1948.
E. P. BARRETT, "Gaseous Reduction Methods for the Production of Sponge Iron", U.S. Bureau of Mines, R.I. 4402, February 1949,
T L. JOSEPH, "The Blast-furnace Process and Means of Control". American Institute of Mining and Metallurgical Engineering, Iron and Steel Division, 1946, page 15.
T. P. COLDCLUGH and I. S. SCOTT-MAXWELL, "Trends in Pig Iron Manufacture", *Journal of the Iron and Steel Institute*, England, vol. 159, June 1948, page 186.

Methods for Reducing the Amount and Quality of Coke Used in Smelting Iron Ore

P. E. CAVANAGH

ABSTRACT

There has been great interest in recent years in exploring the possibilities of reducing the quantity and quality of coke necessary for iron smelting. A study of suggested methods and commercially proven processes for achieving these aims has been carried on in Canada.

Reduction in coke consumption and quality can be achieved at present either by using modifications of present blast-furnace practice or by using some smelting process other than the blast-furnace.

It was immediately evident on detailed study of alternative processes that they could not produce large tonnages of more than 600 tons of pig-iron per day at a price competitive with the blast-furnace.

Sufficient details of typical construction and operating costs of the most suitable electric smelting and sponge iron processes are given in the paper to permit a decision on the question: which iron smelting process is worth detailed study in a country or region where construction of a blast-furnace cannot be justified. These processes may be suitable for supplying a small local market if the production cost is lower than the local price for imported blast-furnace pig-iron.

Since it is evident that there is no present possibility for large-scale use of alternative iron smelting processes, the hope for major coke conservation in iron smelting lies in improving blast-furnace practice. Modifications of present techniques, particularly by the use of ore beneficiation, high pressure in the furnace and improvements in coking practice, offer hope for considerable reduction in the average amount of coke required to smelt a ton of iron.

For the distant future there is a good prospect that low-cost oxygen will allow construction of low-shaft blast furnaces which can use poor quality, low-strength and, therefore, much cheaper coke.

During the last few years the Ontario Research Foundation, on behalf of the Ontario Research Council, has made a detailed study of methods for smelting iron ore in use throughout the world. Two of the objects of our studies of iron smelting processes were:

(1) To discover whether any proven process is capable of producing small quantities of iron at a reasonable cost at locations remote from coal deposits; and

(2) To discover whether any process could be recommended for future application in Canada if metallurgical coke were no longer available to us in the required quantities and quality to carry on iron smelting in blast-furnaces.

Canada now produces about three million tons of steel a year and ranks sixth among steel-producing countries of the world. Canada is fortunate that major markets in this country are situated close to the ore and coal fields of the United States. By far the greatest part of the iron ore smelted in Canada is imported from the United States. Most of the required coal for making metallurgical coke is also imported from the United States.

It is certain that at some time in the distant future there will be a foreseeable end to high-quality coking coal in the United States. At this future time it is unlikely that the United States will look favourably on the continued purchase of high-quality coking coal by Canada.

While this situation is not likely to arise soon, it has seemed wise to us in Canada to study what our actions would be under such conditions and whether iron smelting in Canada could be carried on using some process other than the standard blast-furnace, which would require either much less coke, or coke of a poorer quality and lower strength. At present, of course, any reduction in the amount of American coking coal imported into Canada would have the happy effect of saving American dollars.

Some of our findings and conclusions are of interest to many other countries besides Canada.

SMELTING OF IRON ORE IN THE BLAST-FURNACE

In order to have a clear understanding of the advantages and disadvantages of alternatives to blast-furnace smelting of iron ore, it is necessary to describe briefly the tremendous present advantages of modern blast-furnaces over all other present types of commercial iron smelting and to outline the present developments in blast-furnace techniques aimed at reducing the coke required to produce one ton of iron.

Iron ore is a mineral from which iron can be produced at a profit.

The most profitable method of smelting iron ore under present conditions is to first treat it in a blast-furnace, producing pig-iron, and then refine the pig-iron further in other furnaces to produce steel.

Theoretical objections may be made to this seemingly roundabout method of producing the metal from the ore, but economically this two-stage process is the cheapest and most practical in most countries of the world.

The fact that blast-furnaces have attained such tremendous size makes possible the mass production of iron and steel which is the basis of our present civilization, such as it is. The huge size of present blast-furnaces introduces some factors which make the use of these furnaces very advantageous in a highly industrialized country with supplies of good coking coal, but almost out of the question for countries with very little heavy industry and no high-grade coking coal.

The modern blast-furnace producing over 1,000 tons[1] of pig-iron per day, is a huge stack about 28 ft. (9.1 metres) in diameter and 100 ft. (33 metres) in height. As shown in Figure 1, it is charged with a mixture of iron ore, coke and limestone. On reaching the bottom of the stack the iron ore and limestone become fluid and about ⅓ of the weight of the 80-ft. (27 metres) column of charge must be supported on the coke which remains. Only the finest coking coals will produce coke of the required strength to withstand this pressure.

Such coking coals are not common. When it is also realized that the sulphur and ash contents must be low in the coke, it becomes apparent that satisfactory coal for making blast-furnace coke for large blast-furnaces is not as common an occurrence as good iron ore.

The location of major iron smelting centres in the world today is determined more by the availability of high-grade coking coal than by the availability of good iron ore.

The iron blast-furnace has advanced tremendously in production rate in the last twenty-five years.

As the size of furnaces increased, the shaft diameter reached a point where the blast of air does not reach to the centre of the shaft at the bottom. From a purely theoretical viewpoint such a large shaft is too big for maximum efficiency, but the smelting of iron is not a theoretical process. (1)[2]

As the blast-furnaces grew in size, large industrial areas grew up around them and wage rates became higher and higher. Since costs for ore, coke, power and other items are fixed unless the technique is radically changed, the man-hours per ton of pig-iron became the only major controllable item in pig-iron costs. The labour requirement per ton of pig-iron in a modern large blast-furnace has been reduced to about 0.75 man-hours, representing about 2 per cent of the cost of a ton of iron. The labour cost a hundred years ago was 55 per cent of the cost of a ton of iron.

The sequence of events has been that in order to get large unit production to satisfy the market and to keep labour costs down, blast-furnaces have increased far beyond the size for maximum smelting efficiency to a size giving the best possible labour efficiency. Attempts are now being made to change the techniques used to increase smelting efficiency without increasing labour costs.

The charge in a blast-furnace is by no means uniform in size or distribution. The three solid materials present, ore, coke and limestone are not uniformly mixed. The gas path between the solid pieces of the charge is not uniform, varying across the cross-section of the shaft and from top to bottom. (2) For this reason it is often difficult to obtain full utilization of all the gas passing up the shaft. This hot gas, rich in carbon monoxide and hydrogen, must reduce the iron oxide ore to iron and preheat the charge at the top of the furnace. Some of the gas also reacts with the coke resulting in "solution loss" of part of the coke. Better utilization of the gas and its contained heat will reduce the amount of coke necessary to produce this gas and, therefore, the amount of coke consumed per ton of iron produced.

[1]Note that all tons in this paper are—Gross tons = 2,240 lb. = metric tons = 1,000 kg.

[2]Numbers within parentheses refer to items in the bibliography.

METHODS OF REDUCING COKE CONSUMPTION IN THE BLAST-FURNACE

Heated blast: Air blast is blown into the blast-furnace at the bottom, burning the coke in the smelting zone and producing the required temperature to melt the charge. The utilization of waste heat in gases issuing from the top of the furnace, and of special stoves to pre-heat the blast, was introduced some years ago and is now standard practice. This technique has resulted in major savings in coke consumption.

Blast volume: At present the volume of air blown into the furnace per minute per unit of area of shaft cross-section is being increased tremendously in an attempt to obtain better smelting efficiency and higher production in very large furnaces. (3)

Sized feed: A great deal of work has been done to determine whether it is practical to select ore in a certain size range and charge it along with coke and limestone, which can also be sized, so that the gas path in the furnace shaft will be more uniform. (4) This simple change in technique gives savings in coke consumption and increased production in some cases. It is profitable where coke costs are high and difficulty is experienced in smelting the ore as received.

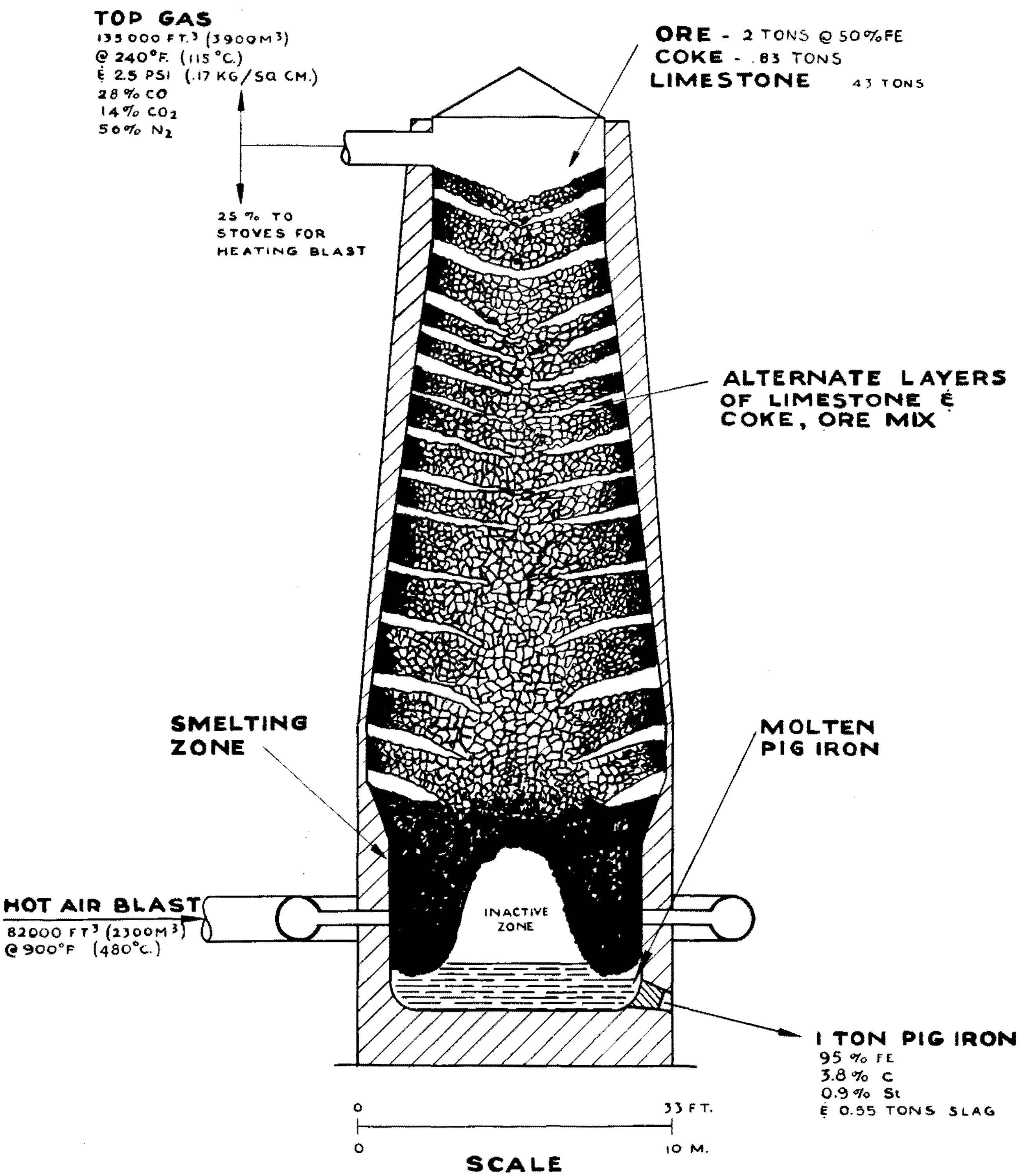
Sintered and pelletized feed: Many ores must be ground very fine in order to concentrate them to a level of iron content which can be smelted at a profit in a blast-furnace. Finely ground ore cannot be charged to a blast-furnace, since it will simply blow out of the top. It is therefore necessary to consolidate such ore by sintering. The ore is mixed with a small percentage of coke or coal and moisture and fired. The resulting clinker or sinter has a porous, open structure giving ready access to the reducing gases in the furnace. (5)

The use of sintered feed has spread rapidly in recent years even to places where ore is available which does not have to be concentrated. (6)

Some ores which cannot be sintered easily can be moistened and formed into small balls or pellets. (7) This pelletizing process may be cheaper than sintering and provides an ideal form of ore feed. Extensive investigation of this process is going on at present in the United States, Sweden and Canada.

Increased blast pressure: With most iron ores the rate of reduction is governed mainly by the rate at which the reacting gases can reach the ore particles. Only in very dense ores is the diffusion rate of gas into the ore particle a controlling factor in production rate of blast-furnace. (8) In an attempt to get more gas in contact with an ore particle in unit time, pressure in the furnace is being raised considerably in the United States. (9). Further favourable effects are obtained because the gas stream is slowed down and less dust is blown out of the top of the furnace. Since the reduction reactions are carried out more efficiently, less coke is consumed per ton of iron produced.

Blast enrichment: Another similar approach to the same problem is to enrich the air blown into the furnace, with oxygen. Increasing the oxygen content gives more rapid combustion



OPERATION OF STANDARD BLAST FURNACE
WITH 27 FOOT HEARTH MAKING 1200 TONS OF IRON
PER DAY
ALL QUANTITIES ARE PER TON OF BASIC
PIG IRON

Figure 1

of coke at the bottom of the furnace and gives a richer reducing gas rising through the charge.

The production rate of the furnace will therefore be increased, but work on standard blast-furnaces appears to have proved that the consumption of coke will rise. (10)

The latest oxygen plants which produce low-purity oxygen in huge quantities are attaining costs less than $ 5.00 per ton (24,000 cub. ft.) of oxygen. (11) Even at this price it appears that oxygen can only be used as a medicine in a modern blast-furnace; that is, when the operation of the furnace becomes irregular, the hearth becomes cold, or the furnace gets some other disease, the oxygen content of the blast can be increased to correct this condition.

Present operations in North America: In the United States there is no need for drastic modification of the standard blast-furnace and smelting techniques. The United States has been extremely fortunate in having enormous supplies of rich, easily smelted iron ore and good coking coal.

With regard to the supply of metallurgical coke, there is no immediate prospect of serious difficulties in obtaining suitable material. Washing of coal and other measures are helping to maintain coke quality and to produce metallurgical grade coke from lower quality coals. The grade of available metallurgical coke is, however, slowly becoming worse and the coke consumption per ton of iron is therefore rising slowly in most American iron smelting plants. As a practical illustration of the effect of this decline in quality, coke consumption in American blast-furnaces was about 5 million tons higher in 1947 than it would have been if coke of the same quality as was available in 1941 could have been purchased.

Our situation in Canada is rather different, since we are at present almost completely dependent on imported coal for making metallurgical coke to carry out iron smelting operations. Canada now has available large reserves of excellent iron ore and has cheap electrical power in some regions. For these reasons there is more incentive for Canada to develop modifications of present blast-furnace technique to reduce coke consumption, or to use alternative processes.

Future evolution of modern blast furnace: Anyone examining the information being obtained at present on modifications of present blast-furnace technique can see the trend towards increasing the rate and uniformity of contact between the reducing gas and ore by several methods or combinations of these methods. It appears to be true that the maximum benefits of such a plan as enriching the blast cannot be obtained in a blast-furnace of standard design, since the reduction and smelting process is modified considerably and the furnace design no longer takes maximum advantage of the conditions in different zones of the stack.

This indicates that in the distant future the blast-furnace may be modified to quite a different form from its present design. The pilot operation of such furnaces which can use low strength and fine solid fuel has already taken place in Switzerland, Germany and Russia. Such a furnace appears to be the only predictable hope for achieving the required large unit production rates which are absolutely necessary to maintain iron and steel production at the present rates and costs if the supply of high-grade metallurgical coke is seriously reduced in the future.

ALTERNATIVE IRON SMELTING PROCESSES

Only a few years ago anyone wishing to smelt iron ore in quantities of more than 5 tons or so a day, smelted the ore in a blast-furnace or did not smelt it at all. This is no longer true. Recent technical advances have made available several commercially proven processes which will produce iron from ore profitably under certain very specific economic conditions. Our task has been to discover these economic conditions and to find out whether such conditions exist anywhere in Canada or, in fact, anywhere in the world. (12)

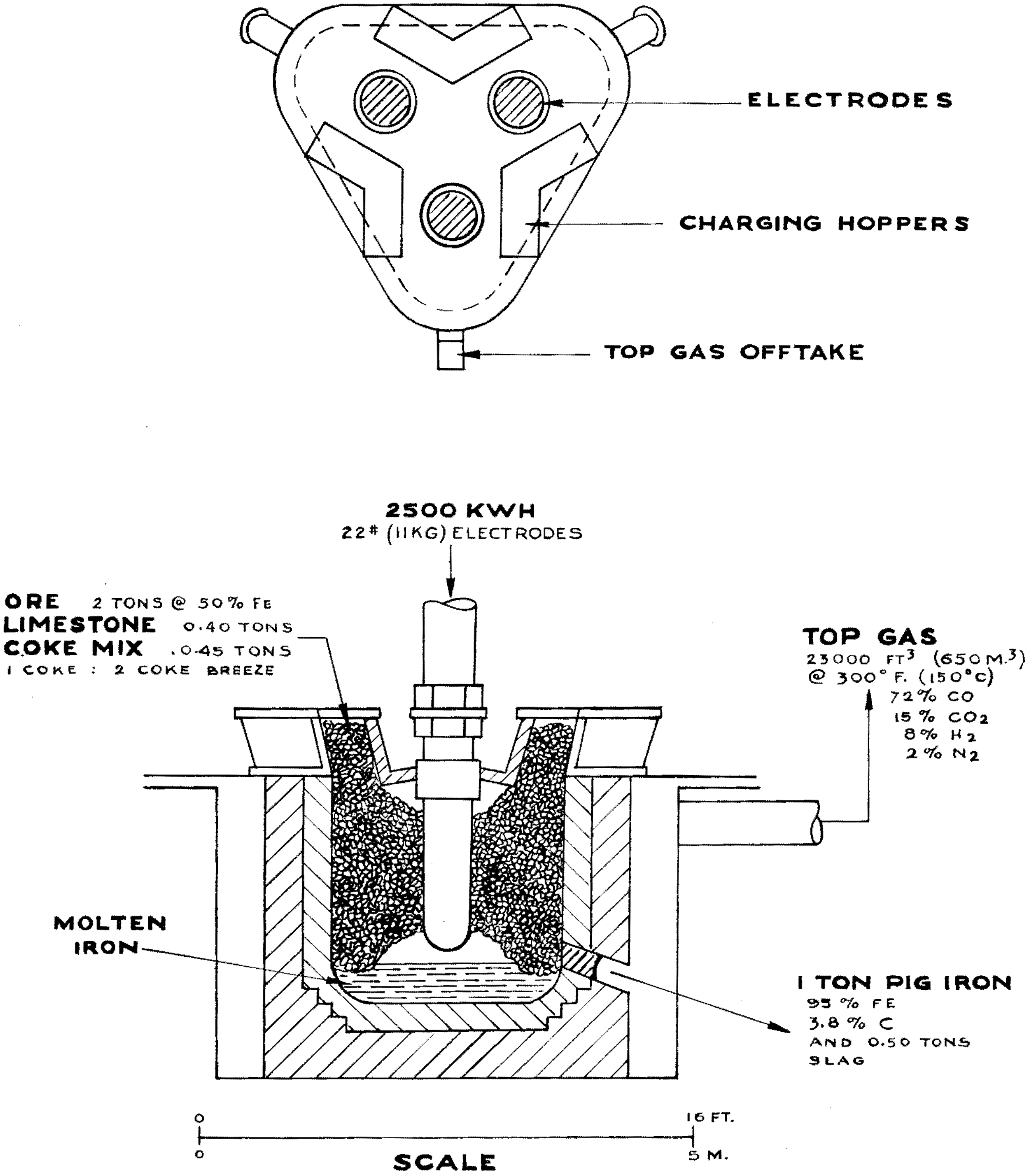
We have studied some 150 processes for producing iron from ores. Only a few of these have been commercially proven by operation for five years or more. The most important feature of these processes from our viewpoint is the amount and quality of fuel needed. We have confined our detailed studies to commercially proven processes because we could not find any proposed processes which showed enough promise at present to justify spending large sums of money to develop them to the commercial stage, rather than spending the same sum of money to install a commercially operating plant according to a proven process.

The following discussion, then, is based on data obtained from commercially operating furnaces, with costs given in such a way that the final values represent production costs in Canada but the items listed in costs are in such a form that local values for materials, labour etc., can be substituted to get corresponding approximate production costs anywhere in the world.

Location and size: It must be emphasized that the most important factor in deciding whether or not an iron smelting industry should be established or expanded in a certain location is the size of the market which can be reached at a competitive price from this location. For purely economic reasons a blast-furnace smelting plant must be located close to the source of fuel and close to the market for its product, rather than close to the iron ore.

In the most commonly used combination of equipment, namely blast-furnace and open hearth furnace to produce steel, about .85 tons of iron ore must be brought to the smelting furnaces in order to produce 0.5 tons of iron required to make 1 ton of steel. This ore costs about $ 7.00 at the furnace. To this iron must be added about 1.8 tons of coal, 0.5 tons of scrap steel, limestone and other materials which cost about $ 36.00. The freight charges on ore, which obtains commodity rates, are much lower than the freight charges on finished iron and steel, which are classed under product rates. These factors make it evident that it is cheaper to bring the iron ore to the coal deposit which generally has a heavy industrial centre and steel market associated with it. This means the minimum shipment of materials to the furnace and the minimum distance for shipment of the product to the heavy industrial market. For these reasons, then, it is generally true that it is more economical to ship ore from a new discovery to existing smelting centres than to establish new smelting centres near the ore deposits unless high-quality coking coal and a market are located near the new ore body.

This is not a very pleasant conclusion for countries such as Sweden, Venezuela and Canada where excellent deposits of iron ore exist at places remote from any sizeable markets or deposits of good coking coal. However, recent technical developments have demonstrated that it is possible, by reducing the amount of coke needed to smelt a ton of iron ore, to establish profitable small-scale smelting operations at locations remote from coal deposits. Certain other economic conditions must be satisfied in such a case. The most important is that the market to be



OPERATION OF ELECTRIC SMELTING FURNACE

ALL QUANTITIES ARE PER TON OF BASIC PIG IRON

Figure 2

satisfied must be so small that the installation of a blast-furnace cannot be considered.

Description of processes: Full details of the processes described can be found in the references. The following brief descriptions only emphasize the major points of difference.

Blast-furnace: Modern blast-furnace installations are part of a highly integrated industry. In addition to producing pig-iron, the furnace also produces slag, which may be used in making building blocks and other products. The gas from the top of the furnace is a very useful fuel in an integrated steel plant. The by-products of the coke ovens which are associated with modern blast-furnace installations are a profitable source of income. These facts are mentioned mainly to emphasize that the replacement of blast-furnaces on any sizeable scale is almost out of the question at present because no other alternative process provides the many useful and necessary by-products for use in an integrated industry. (See Figure 1 and Table 1).

Small blast-furnaces: In North America it is generally felt that a blast-furnace must have a daily capacity of at least 800 tons to compete with existing installations. While this may be true in the United States unless special care is taken with furnace operation, it is not necessarily true everywhere.

Table 1. Blast-Furnace: Typical Production Costs per Ton of Basic Pig-Iron, Canada 1948

(One furnace: 800 tons per day, 280,000 tons per year)

	$	$
Coke: 0.83 tons from own coke plant at $11.25/ton	9.35	
Ore: 2.0 tons at 50 per cent Fe and $7.25/ton	14.50	
Limestone: 0.43 tons at $2.25/ton	0.97	
		24.82
Labour: 0.82 man-hrs. at $1.20 (including transport)	0.94	
Repairs and maintenance	0.50	
Cooling water: 14,000 gals. at .003 cents/gallon	0.42	
Overhead, miscellaneous and casting	3.65	
		5.51
Production cost		30.33
Gas credit		1.90
Net production cost		28.43

This does not include fixed charges on an investment of about $28 million or any profit for the operation.

Table 2. Coke Consumption in a Small Blast-Furnace using Feed of Sintered Ore plus Flux, Domnarfvet, Sweden, 1947

(Coke per ton of basic iron: 0.660 tons)

Production	182 tons per day
Hearth diameter	9 ft. 14 in. (3.1 metres)
Working height	55 ft. 8 in. (17 metres)
Working volume	4,850 cu.ft. (137 cub. metres)
Tuyeres	8
Air blown (N.T.P.)	11,600 cub.ft./min. (330 cub. metres/min.)
Blast pressure	8.6 lb./sq.in. (0.6 kg./sq.cm.)

The advantages to be gained in efficient operation of a small blast-furnace are well illustrated by the efficient use of sintered feed at Domnarfvet Steel Works in Sweden. (See Table 2).

At this plant the charge to the small blast-furnace is only sinter and coke, since all required fluxes and additions are mixed with the fine ore before sintering. These blast-furnaces were only able to produce 90 tons of iron some years ago, and are now producing about 200 tons. This increase in capacity has been achieved mainly by increasing blast volume and careful attention to preparation of feed.

The consumption of coke per ton of pig-iron is remarkably low. The results obtained demonstrate that by using proper techniques a small blast-furnace can be efficient and profitable in the right location.

Electric smelting: The Tysland-Hole furnace is at present accepted as the most satisfactory standard furnace for electric smelting. (13) (14) (15) In this process the coke required to melt the charge for the blast-furnace is replaced by heat obtained from electrical energy. The quantity of coke used is only one-half that required in the blast-furnace. The quantity of gas escaping is only about one-sixth. This gas performs reduction and pre-heating of the charge, but since the volume is so much less, its work is completed after only a very short distance of travel up the shaft. There is, therefore, no necessity for a high shaft, and the pressure on the coke in the low-shaft electric smelting furnace is only a fraction of the pressure in a blast-furnace. For this reason, low-strength coke may be used.

Since the volume of gas is so small, it is not so important to have a large percentage of voids in the charge and a much greater percentage of fine coke or fine ore may be used.

The furnaces are a desirable type of load for an electrical supply system, and may be run as low as 65 per cent of rated capacity without difficulty, thereby affording an opportunity to take advantage of seasonal or off-peak excess power. The product is molten pig-iron, as with the blast-furnace.

Table 3. Tysland-Hole Electric Smelting Furnace: Typical Production Cost Estimates per Ton of Basic Pig-Iron, Canada—1948

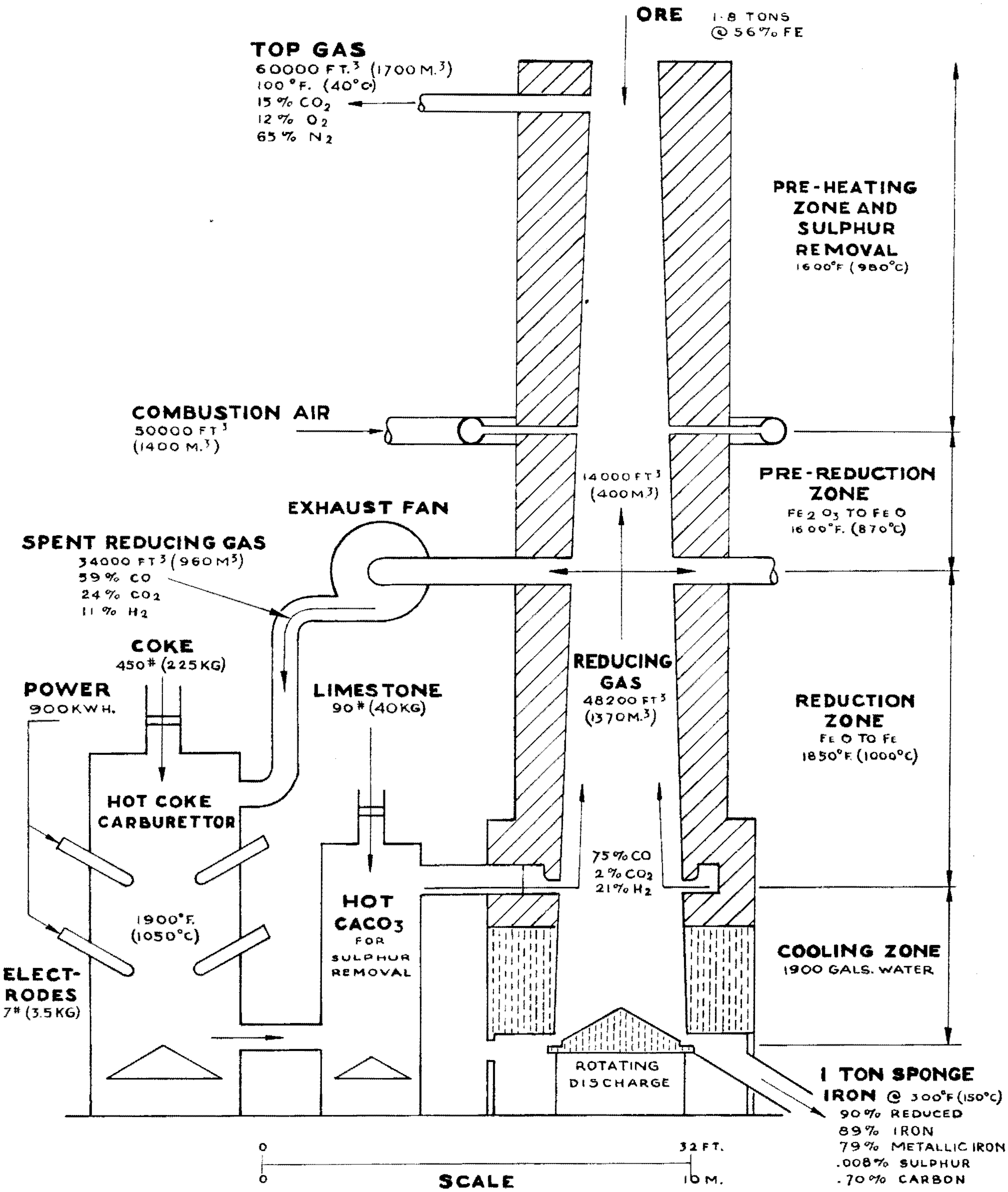
(Three Furnaces, each 12,000 kva., producing 100 tons per day Plant production: 300 tons per day, 110,000 tons per year)

	$	$
Coke: 0.45 tons purchased coke mix	5.12	
(0.15 tons metallurgical coke at $16.50/ton)		
(0.30 tons coke fines at $8.25/ton)		
Ore: 2.0 tons at 50 per cent Fe and $7.25/ton	14.50	
Limestone: 0.40 tons at $2.25/ton	0.88	
Electrodes: 0.015 tons at $134./ton	1.80	
Power: 2,500 kwh. at 0.3 cents/kwh.	7.50	
		29.80
Labour: 1.9 man-hrs. at $1.20 (including transport)	2.19	
Repairs and maintenance	0.95	
Cooling water: 11,000 gallons at .003 cents/gallon	0.33	
Overhead, miscellaneous and casting	3.80	
		7.27
Production cost		37.07
Gas credit at 25 cents/million B.T.U.		1.75
Net production cost		35.32

This does not include fixed charges on an investment of about $9,750,000 or any profit for the operation.

There is evidence that it is easier to make a standard pig-iron with poor raw materials in this type of furnace, than in the blast-furnace. (See Figure 2 and Table 3).

Wiberg-Söderfors sponge iron process: In this very efficient process iron ore is reduced to metallic iron without ever being melted. (16) (17) (18) The temperature in the furnace is about 1850 degrees F. (1000 degrees C.) so that the refractories are not required to withstand such extremes of temperature as in other processes. No coke or flux is introduced into the furnace. All the impurities present in the ore, with the exception of sulphur, occur in the final product. No further impurities are introduced from coke as they are in processes producing molten iron.



OPERATION OF WIBERG — SODERFORS FURNACE

ALL QUANTITIES ARE PER TON OF SPONGE IRON

Figure 3

The method of recycling the spent reducing gas and regenerating it in an electrically-heated carburettor accounts for the excellent efficiency of the process. Best results are obtained with a rich easily-reducible ore. (See Figure 3 and Table 4.)

CHOICE OF PROCESSES

Comparative investment costs are shown in Table 5 for processes mentioned so far.

In studying the possibility of establishing an iron smelting industry in any locality, the choice between these processes is limited by local conditions. The local occurrence of iron ore is not the most important of these conditions. The size of the market to be served is the most important consideration. Market size imposes the following restrictions on choice of processes:

(1) With a *market for over 600 tons per day* (200,000 tons a year) a standard blast-furnace is the only choice. The location of blast-furnaces will be determined by the availability of satisfactory coke and the distance to the market.

Table 4. Wiberg-Soderfors Sponge Iron Furnace: Typical Production Cost Estimates per Ton of Sponge Iron, Canada—1948

(Two furnaces, each producing 64 tons per day of 90 per cent reduced sponge iron, 128 tons per day, 45,000 tons per year)

	$	$
Coke: 0.22 tons purchased coke at $16.50/ton	3.60	
Ore: 1.8 tons selected lump steep rock ore at 56 per cent Fe and $11.50/ton	20.75	
Limestone: 0.04 tons at $2.25/ton	0.09	
Electrodes: 0.003 tons at $134./ton	0.40	
Power: 900 kwh. at 0.3 cents/kwh.	2.70	
		27.54
Labour: 2.1 man-hrs. at $1.20 (including transport)	2.52	
Repairs and maintenance	1.65	
Cooling water: 2,200 gallons at .003 cents/gallon ...	0.06	
Overhead and miscellaneous	3.25	
		7.48
Net production cost		35.02

This does not include fixed charges on an investment of about $3 million or any profit for the operation.

(2) *If the market is less than 600 tons per day, but greater than 400 tons per day,* the choice will be between electric smelting and a small blast-furnace. A small blast-furnace should use sintered or pelletized and sized feed to obtain comparable costs and coke consumption to those achieved in larger blast-furnaces. A small blast-furnace would be the best choice unless cheap excess electric power is available and coke is expensive.

The use of electric smelting is particularly attractive if seasonal or off-peak power can be used (Figure 4). The smelting site usually cannot be more than about 200 miles from a hydro-electric generating station. The construction of hydro-electric stations solely for the purpose of electric smelting is almost out of the question. Present construction costs of hydro-stations are between $ 160 and $ 250 per horsepower in Canada.

(3) *If the market is less than 400 tons per day,* the choice is between electric smelting and the Wiberg-Söderfors sponge iron process.

If electricity is particularly cheap and plentiful, if pig-iron is the product desired for foundry use as well as steel-making, and if the rich fuel gas from electric smelting furnaces can be used in the rest of the steel-making plant, electric smelting is the better choice.

If there is no use for a rich fuel gas and particularly if high quality steels are to be made, the Wiberg-Soderfors method is an attractive process.

In considering the choice of process in a particular country or region and keeping the above limitations in mind with respect to size of the market, the following rules are helpful:

1. In a heavily industrialized region with plentiful supplies of high-grade coking coal, the standard blast-furnace combined with open hearth steel-making furnaces which consume steel scrap available in an industrialized country is the best combination of steel-making equipment for ordinary steels.

2. In an industrialized region with a small market for steel and with satisfactory coking coal, and where electric power is expensive, a small efficiently run blast-furnace is the most interesting process to study.

3. In a region with plentiful cheap electric power and no coking coal electric smelting may be practical to satisfy small markets.

4. In a region having no heavy industry the combination of the Wiberg-Söderfors process with electric steel-making furnaces may form the basis for a very small steel industry.

When the sponge iron produced is used in an electric steel-making furnace, no purchased scrap additions need to be made to the charge. This is an important factor in countries which do not have any heavy industry.

5. In a country where a small blast-furnace or electric smelting may appear profitable, the choice of steel-making equipment will be largely determined by the amount of purchased scrap available in the country. If the region is not highly industrialized there may not be sufficient purchased scrap available to operate open-hearth furnaces. In such a case the use of Bessemer converters to produce steel from molten pig-iron may be the best choice.

6. The fact that the Wiberg-Söderfors sponge-iron process reduces the ore to metallic iron without melting it, eliminates the possibility of contamination of the very pure ore with impurities from the coke in contact with molten iron in other processes. The high purity of some sponge-iron makes possible the application of the sponge-iron process in some very special situations. If a very pure, easily-reduced ore is available and high-quality steel is to be produced, the installation of some sponge-iron capacity may be justified even in the centre of a highly industrialized area where blast-furnaces are operating profitably.

CHOICE OF PROCESSES IN CANADA

It may be of interest to show how the above rules apply in Canada.

In studying the suitability of various processes to Canadian conditions it is necessary to divide the country into distinct zones determined by the availability of metallurgical coke, of excess electric power and of iron ore.

The accompanying map (Figure 5), illustrates the entirely different conditions which exist in different regions of Canada.

OTHER SPECIAL PROCESSES

Krupp-Renn process: The Krupp-Renn rotary kiln type of process has been installed in many countries throughout the world. (19) It has been successful in producing iron from high-silica ores which cannot be treated profitably by other methods.

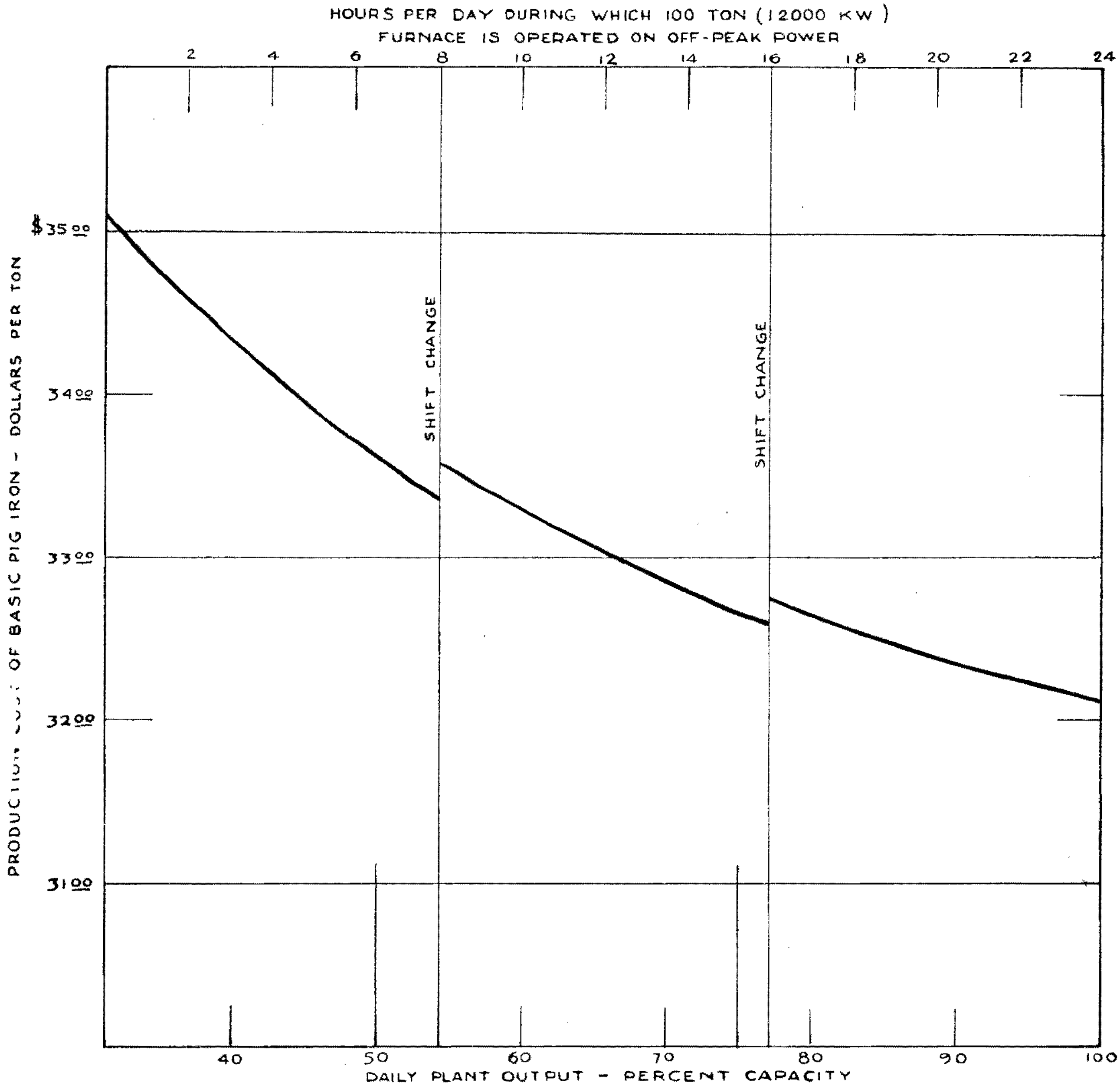


FIG. 4

PRODUCTION COSTS OF BASIC PIG IRON IN CANADA

50 TON (6000 KW) FURNACE OPERATED CONTINUOUSLY ON FIRM POWER

100 TON (12000 KW) FURNACE OPERATED FOR ANY GIVEN DAILY PERIOD ON ALL OFF-PEAK POWER

LABOUR COST

BOTH FURNACES OPERATING – $2.19/TON

100 TON FURNACE ON STANDBY – $1.85/TON

ELECTRIC POWER COST

FIRM POWER – 0.3¢/KWH

OFF-PEAK POWER – 0.1¢/KWH

NO PROFIT – NO FIXED CHARGES

Figure 4

Table 5. Comparative Investments

(These costs are not meant to be exact and do not apply to any particular location. They are representative costs for Canada in 1948 and can only be used for purposes of comparison)

Process	No. of furnaces	Total yearly output (Thousands of tons)	Plant costs (in thousands of dollars): Furnaces & auxiliary equipment	Buildings	Ore & materials-handling equipment	Coke ovens	Working capital (6 months)	Engineering and contin-gencies	Total investment (Thousands	Investment per ton–year (Dollars): Including Coke ovens	Without coke ovens
Blast-furnace	1	280	12,000	2,000	2,000	6,000	4,000	2,000	28,000	100	79
Tysland-hole	3	110	5,000	1,000	1,000	—	2,000	750	9,750	89	89
Wiberg-Söderfors ...	2	45	1,300	400	300	—	750	250	3,000	67	67

Costs include stock piling and materials-handling equipment, office and plant buildings, power lines, sewers, boiler house and steam lines, foundations and all other necessary auxiliaries on a new site.

Blast-furnace requires docks and ore bridges. Docks are not provided for in estimates for Tysland-Hole and Wiberg.

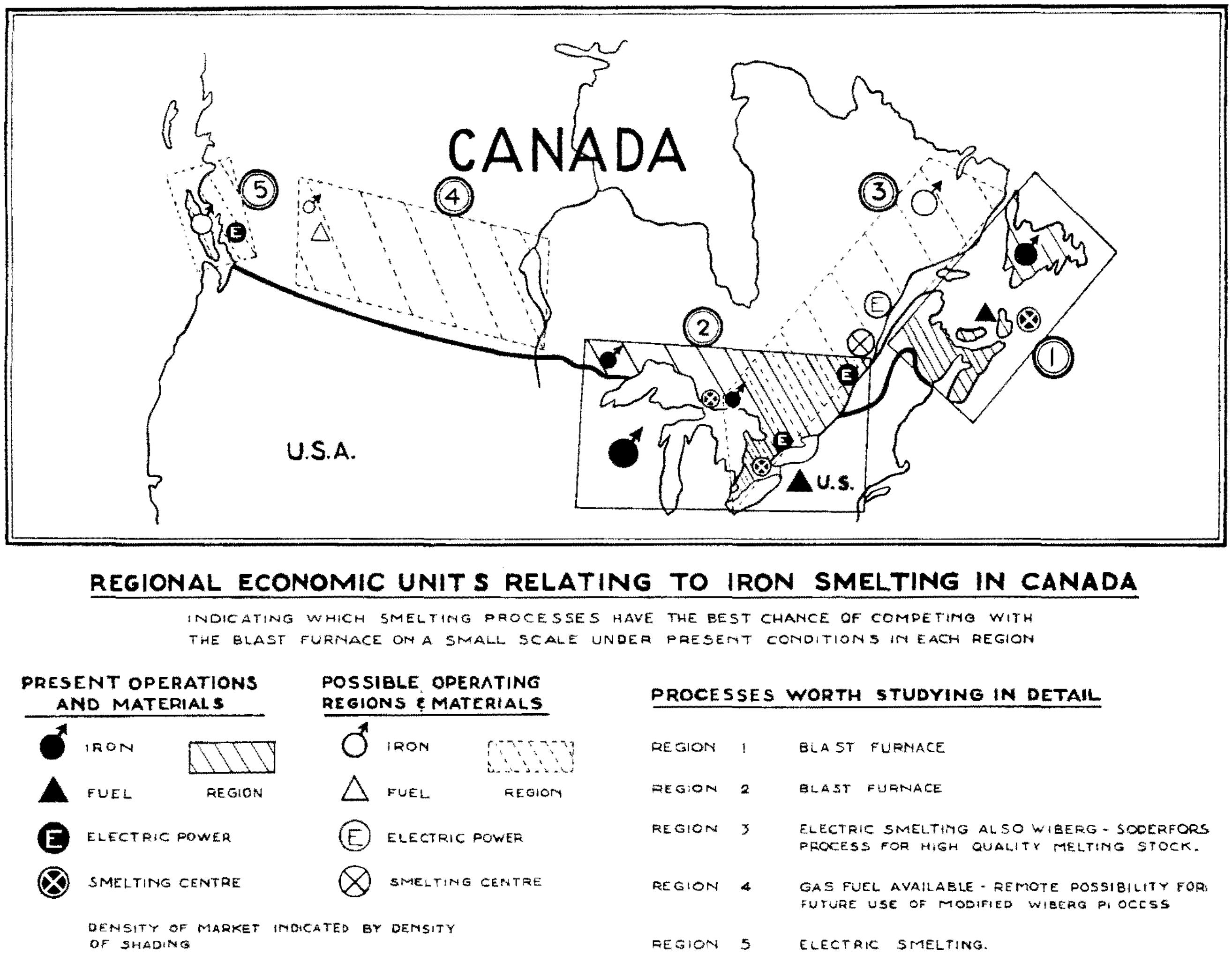
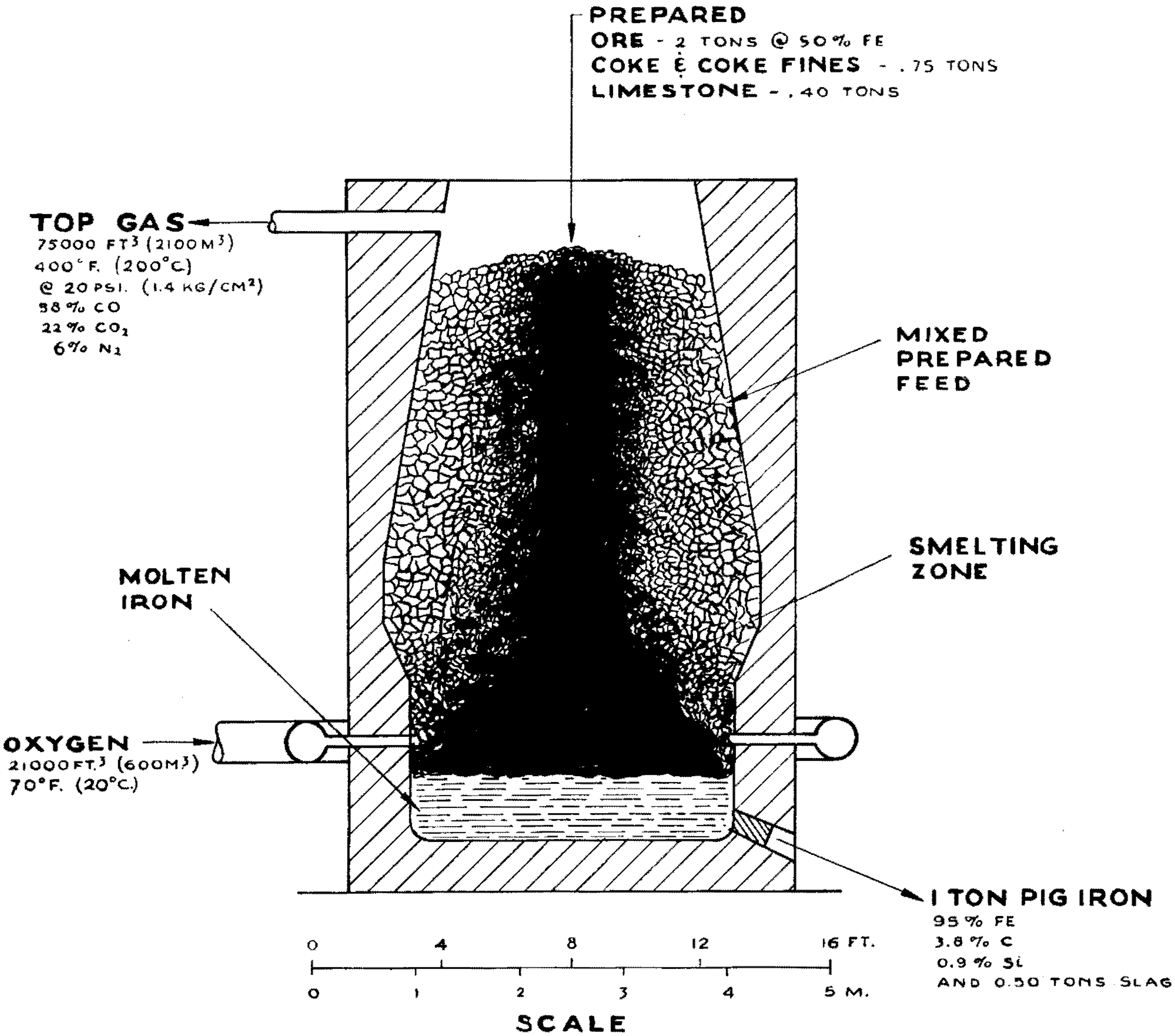


Figure 5

The output per unit is very small and the operating difficulties make its wider application very doubtful.

Brick-kiln process: This process has been studied exhaustively in the United States as a possible method for supplying a substitute melting stock when steel scrap is scarce or very expensive. (20) We have followed up and extended the work done by the United States Bureau of Mines. (21) It appears that this process is a useful method of suddenly obtaining an increase in the supply of steel melting stock in a country where modern brick-making kilns are plentiful.

Fine ore is charged into containers or saggers along with fine coke dust. Charging methods have been developed so that the ore and coke may be laid in alternate horizontal or vertical layers. Methods have also been developed for automatically charging ore columns into the containers through steel tubes which are then withdrawn from the container.



OPERATION OF LOW SHAFT OXYGEN BLAST FURNACE

HEARTH DIAMETER ABOUT 12 FEET

ALL QUANTITIES ARE PER TON OF BASIC PIG IRON

Figure 6

Labour requirements for this process are relatively high and the production costs are higher than for other methods of producing melting stock, although the consumption of coke is low and waste fine coke may be used.

This process is regarded in Canada purely as an emergency measure, or as a source of extra income for brick companies which may have idle equipment from time to time.

FUTURE PROSPECTS

Low-shaft oxygen furnace: One apparent hope for the future conservation of coke in iron-smelting is the low-shaft oxygen furnace presently being developed. (22) (23) (Figure 6). As in the low-shaft electric smelting furnace, the small amount of gas rising in the shaft makes it unnecessary to have a very high shaft, since the work done by the gas is completed in a very short length of travel up the furnace. The low shaft naturally reduces the pressure which must be borne by the coke in the charge, making possible the use of low-strength coke. From the point of view of coal conservation, this is a very desirable development.

The modern blast-furnace utilizes the best available coking coal and produces a low-grade gas fuel. From the conservation point of view this is a somewhat unsatisfactory use for the highest quality coking coal, if a lower-grade coal can be used just as satisfactorily in the smelting of iron ore. The electric smelting furnace, or the low-shaft oxygen furnace can use a

Table 6. Coke Conservation by Modifying Present Standard Blast-Furnace Practice

	Operating conditions					
Changes in practice	*Iron production*	*Blast volume*	*Top pressure*	*Blast oxygen content*	*Flue dust losses*	*Coke consumption*
Normal*	100	100	100	100	100	100
Increased blast volume ...	120	*125*	100	100	150	110
Top pressure .	115	100	*160*	100	50	87.5
Blast oxygen .	117	100	100	*125*	105	110
Blast volume and top pressure ...	136	*125*	*160*	100	90	92
Blast volume and oxygen.	140	*125*	100	*125*	160	110
Top pressure and oxygen.	135	100	*160*	*125*	90	89
Volume and pressure and and oxygen.	158	*125*	*160*	*125*	100	94

*Normal blast-furnace producing about 1,000 tons per day taken as reference = 100 using 60,000 cu.ft./min. (1760 cu.m./min.) blast volume, preheated air blast, 2.5 lb. per sq.in. (0.17 kg./sq.cm.) top pressure, losing .09 tons flue dust.

much poorer solid fuel with a large percentage of fines and produce a rich gas fuel.

It is not possible at present to predict the size or characteristics of a large low-shaft oxygen furnace.

Low-purity oxygen for this process is produced by compressors driven by electric motors or gas motors. This process, then, requires either cheap electric power or natural gas for compressor motive power.

The use of pure oxygen combined with high pressure appears to give the best prospects of using the minimum amount of poor coke and keeping the cost of pig-iron somewhere near the present level. In order to achieve this result the cost of oxygen must be less than $ 5.00 per ton. Such a low cost cannot be attained unless oxygen is produced in quantities of about 1,000 tons a day. This means that the oxygen blast-furnace cannot compete in production costs with the standard blast-furnace until it achieves a size which will produce about 1,000 tons of iron per day.

Although such a furnace would not require the equipment for pre-heating the blast and some of the other standard blast-furnace equipment, and it would be much smaller, the total investment would be almost the same as for a standard blast-furnace, since a very large oxygen plant must be provided.

Pre-reduced feed: The gas issuing from a Tysland-Hole electric smelting furnace and from a low-shaft oxygen furnace is a good reducing agent. If there is no alternative use for this gas which takes full advantage of its high calorific value, it may be used to perform partial or complete reduction of iron ore in suitable equipment. This plan allows a further saving in consumption of solid fuel per ton of steel produced. (24) (25)

Use of natural gas in the Wiberg-Soderfors process: Preliminary investigations have indicated that there are no great technical difficulties to the introduction of natural gas or oil refinery gas into the Wiberg gas cycle to reduce the consumption of solid fuel in the carburettor. Using the present process, modified only by adding suitable gas to the carburettor, will reduce solid fuel consumption to a negligible amount but will not reduce electric power consumption. The added gas will crack in the carburettor, forming mainly hydrogen and carbon monoxide. Proper control of the quantity of a suitable gas added, of temperature and gas analysis can give exactly the same gas analysis entering the furnace shaft as used in the present process.

Alternatively, the hot reducing gas may be manufactured by a suitable "synthesis gas" process. This method will probably prove slightly more expensive than the above modification of the Wiberg-Soderfors carburettor, but it does not require large amounts of electric power.

The commercial proving of these alternative modifications of the Wiberg-Söderfors process will be of great value to countries possessing rich iron ore, large reserves of natural gas or oil, and a small market for steel. If natural gas very high in carbon content is available for less than 8 cents per thousand cubic feet ($ 2.80 per thousand cub. metres) the detailed economic study of this process is certainly worth while.

CONCLUSIONS

For the present no major savings in coke consumption in iron smelting can be achieved except by modifying present standard blast-furnace techniques. Such modifications are being investigated by many blast-furnace operators. Table 6 shows the approximate fuel savings which may be expected to result from various methods of improving the efficiency of gas utilization in the blast-furnace.

It can be safely assumed that this trend toward increasing efficiency of gas utilization will gain momentum as the grade of available metallurgical coke declines.

These figures represent the theoretical benefits which can be obtained by the changes in practice shown if the blast-furnace design is such that full advantage of the changes can be realized.

Blast volume, for instance, cannot be increased indefinitely. For each furnace there is a practical optimum blast volume for most economical operation.

The conditions specified in this table will not necessarily reduce operating costs under present conditions. The coke savings and production rates shown should be regarded as ideal figures which may be approached in practice in furnaces of this size.

Increasing top pressure appears at present to be the most economical means of decreasing coke consumption particularly in specially built new furnaces.

Minor savings may be made, particularly in establishing new iron smelting centres, by choosing alternative processes which do not require as much coke, or as high a grade of coke as the blast-furnace. These processes are only profitable when used on a small scale in certain special conditions.

For the future there is a prospect of effecting considerable saving in the consumption of high-grade coking coal in the smelting of iron in low-shaft oxygen furnaces. In regions where oxygen can be produced for less than $ 5.00 per ton, large low-shaft oxygen furnaces may be profitable in the future.

Bibliography

1. T. L. Joseph, "The Blast Furnace Process and Means of Control", A.I.M.E. *Transactions*, vol. 167 (1946), page 15.
2. (a) M. Brun and M. Legendre, "Remarks on Modern Blast Furnace Practice", *Métallurgie*, vol. 80 (June 1948), page 9.
   (b) R. H. Sweetser, *Blast Furnace Practice*, New York, McGraw Hill Publishing Co., 1938.
   (c) M. Pavlov, *Métallurgy of Pig Iron*, Moscow, State Scientific-Technical Publishing House for Ferrous and Non-Ferrous Metallurgy, 1945.
   (d) E. Gardner, "Effect of Coke Quality on Blast Furnace Iron

Tonnage", *Blast Furnace & Steel Plant*, vol. 36 (June 1948), page 707.

3. (a) F. WESEMANN, "Relation Between Blast Furnace Production Per Unit Volume and Coke Consumption", *Stahl und Eisen*, vol. 68 (Jan. 1, 1948), page 1.
(b) O.P.R.D. Project No. 123. "Supplementary Investigation on Increasing Iron Blast Furnace Capacity", Final Report, Case School of Applied Science, 30 Sept. 1945.
4. (a) CROMWELL and COVINGTON, "Proper Sizing, Screening & Crushing of Blast Furnace Coke", *Blast Furnace & Steel Plant*, vol. 36 (Aug. 1948), page 965.
(b) S. P. KINNEY, "Effect of Sized Ore on Blast Furnace Operation", U.S. Bureau of Mines Technical Paper 459, 1930.
5. B. HESSLE, "New Metallurgical Experience with Sintering", *Jernkontorets Annaler*, vol. 129 (1945), page 383; Iron & Steel Institute Translation No. 289 (Swedish).
6. (a) J. MAUTHE, "Sinter Quality and Effect of Sinter on Blast Furnace Practice", *Blast Furnace & Steel Plant*, vol. 36 (July 1948), page 817.
(b) P. HENRY, *Sintering Iron Ores*, Publication du Centre Document. Sidérurgie Fr., 1947.
7. (a) M. F. MORGAN, "Methods of Agglomeration and the Problem of Agglomerating Fine Taconite Concentrates", Mines Exp. Station, University of Minnesota Inf. Circular No. 5, Sept. 1945.
(b) H. F. DOBSCHA, "Effect of Sized and Nodulized Mesabi Iron Ores on Blast Furnace Performance", Am. Iron & Steel Institute *Yearbook*, 1946.
8. T. L. JOSEPH, "Porosity, Reducibility and Size Preparation of Iron Ores", A.I.M.E. *Transactions*, vol. 120 (1936), page 72.
9. (a) OLD, PEPPER and POOR, "Progress in High Pressure Operation of Blast Furnaces", *Iron & Steel Engineering*, vol. 25 (May 1948), page 37.
(b) J. SLATER, "Operation of the Iron Blast Furnace at High Pressure", *Blast Furnace & Steel Plant*, vol. 35 (Sept. 1947), page 1083.
10. (a) I. BARDIN, "The Oxygen Blast", *Bulletin of the Academy of Sciences* (USSR), Oct. 1947, page 1363.
(b) W. POLLITZER, "Utilization of Oxygen in the German Iron and Steel Industry", Fiat No. 1203, June 14, 1947.
(c) W. A. HAVEN, "Renewed Interest in Oxygen Enriched Blast", *Blast Furnace & Steel Plant*, vol. 35 (Jan. 1947), page 95.
(d) M. PLATON, "Trials with Oxygen Enriched Blast at Neuve-Maison", Circ. Inf. du Centre Docum. Sidérurgie Fr., 1948.
11. (a) W. LOBO, "Low Cost Oxygen for Metallurgical Uses", *Iron Age*, vol. 160 (17 July 1947), page 49.
(b) DOWNS and RUSHTON, "Tonnage Oxygen", *Chem. Eng. Progress*, vol. 1 (1947), page 12.
12. P. E. CAVANAGH, "Economics of Ferrous Smelting in Canada", C.I.M.M.E. *Transactions*, vol. 51 (1948), page 205.
13. M. KASSEN, "Smelting Iron Ore in the Electric Low-Shaft Furnace", *Schweizer Archiv.*, vol. 11 (1945), page 87.
14. W. M. BONHAM, "Iron and Power", *Canadian Mining Journal*, January 1948, page 55.
15. R. DURRER, "Electric Smelting Plant at Choindez", *Iron & Steel Institute Journal*, vol. 156 (June 1947), page 293.
16. E. AMEEN, "Production of Sponge Iron at Soderfors According to the Wiberg Method", *Jernkontorets Annaler*, vol. 127 (1943), page 277; *Iron Age*, vol. 153 (Jan. 20), page 55.
17. KALLING and STÅLHED, "Manufacture of Sponge Iron by the Wiberg-Soderfors Process", *Blast Furnace & Steel Plant*, 1949.
18. P. E. CAVANAGH, "Commercial Production of Sponge Iron", *Iron Age*, 1949.
19. (a) JOHNSTON and MAHAN, "Laramie Sponge Iron Pilot Plant", U.S. Bureau of Mines R.I. 4376, Sept. 1948.
(b) W. POLLITZER, "The Krupp-Renn Plant at Salzgitter" Fiat No. 727.
(c) T. JOHNSTON, "Sponge Iron in Japan", U.S. Bureau of Mines Inf. Circ. No. 7440, March 1948.
20. (a) GOTTSCHALK, BEEBE and COLE, "Manufacture of Sponge Iron in Ceramic Tunnel Kilns", U.S. Bureau of Mines R.I. 4271, April 1948.
(b) S. EKETORP, "The Höganäs Sponge Iron Process", *Jernkontorets Annaler*, vol. 129 (1945), page 703.
21. P. E. CAVANAGH, "Manufacture of Sponge Iron in Kilns", *Canadian Ceramic Journal*, vol. 17 (1948), page 77.
22. W. POLLITZER, "Utilization of Oxygen in Smelting Low Grade Ores", Report P.B. 81385 Office of Technical Services, Department of Commerce, Washington, D.C.
23. R. DURRER, "Production of Iron & Steel with Oxygen Enriched Blast", *Iron & Steel Institute Journal*, vol. 156 (June 1947), page 253.
24. R. DURRER, "Electric Smelting", *ibid.*, page 257.
25. M. WIBERG, "Recent Development in the Swedish Steel Industry", *Jernkontorets Annaler*, vol. 130 (1946), page 294.

Summary of Discussion

The CHAIRMAN stressed the general interest of the question of coal carbonization in connexion with the conservation of resources. The question had two aspects: that of carbonization itself, which was dealt with in three papers, and that of methods of iron and steel production that conserved coke, which formed the subject of three further papers.

The Chairman asked speakers not to summarize their papers but rather to stress their most important features from the point of view of the conservation of resources.

Mr. LEE presented a paper on "The Coking Industry, with Special Reference to Great Britain", prepared by Mr. Hicks and himself. The experience of the last fifty years in the United Kingdom had shown that the progress achieved in the utilization of coke and coal was not leading to a reduction in demand. No exact estimate of the quantity and quality of world coal resources had as yet been made; the old estimates had generally speaking been too high.

The classification of world coal reserves had not been sufficiently accurate up to the present. The United Kingdom had been one of the first countries to carry out a physical and chemical study of its coal reserves. Such a classification required uniform methods and unified nomenclature. Even in the United Kingdom a uniform system of classification had only recently been adopted. The United Kingdom National Coal Board had adopted the system of classification established in the course of the study of the quantity and quality of the coal resources of the country. Experience alone would show whether that classification would meet all trade requirements. It seemed logical and necessary to try to establish an international system of coal classification; the first steps in that direction had been made by the Coal Committee of the Economic Commission for Europe.

In general, it appeared that the coal resources of the United Kingdom would be sufficient to meet the demand for metallurgical coke. However, if the consumption of metallurgical coke exceeded present estimates, it might become necessary to reduce the supply of those categories of coal to other consumers. All the coke needed for the British iron industry could not be supplied solely from coking coals of the best quality. It would therefore be necessary in future to make increasing use of lower rank coals, blending them with coals of higher quality. Coal quality was largely determined by coal type and consistency of coke quality should be a primary aim.

It was unlikely that blast-furnace technique would alter in any major respect in the near future. That fact was very important considering that in many countries, including the United Kingdom, the coking industry was entering upon an extensive reconstruction and modernization programme. In Great Britain the programme would provide the basis of United Kingdom production for the next twenty or twenty-five years. The installation of coke ovens was very costly; it was therefore essential that it should be carried out in accordance with the latest technical developments, so as to provide the best possible conditions for production.

The American industry was in the forefront of advances in design and plant research and the British industry was greatly interested in American technique.

The British coke oven construction industry had made valuable contributions during recent years especially in the improvement of fuel consumption with consequent increase in gas for sale, the uniformity of distribution of heat and in the improved regeneration of waste heat.

The problem of obtaining uniformity in the quality of coke was of great importance; up to the present, however, no uniform method of analysing qualities and types of coke or coal, or even a standard nomenclature, had been achieved, as was clearly evident from the papers submitted to the section. If the conference decided to propose the establishment of international standards for the analysis of coal and coke, a very considerable step forward would have been made. The United Kingdom intended to raise the matter at a meeting of the International Standards Organization in March 1950.

The principal coke oven constructional organizations in America and Europe had connexions with their counterparts which were of benefit to the industry as a whole.

Mr. NEWMAN presented the paper prepared by Mr. Fieldner and himself on methods of "Overcoming Shortages of Metallurgical Coke." He pointed out that it had been possible to relieve the temporary shortages of coke which had occurred in the United States during the Second World War by reconditioning and putting into service all available slot-type and beehive ovens, since not enough new ones could be built in time. Wherever possible, operations had been accelerated by increased temperatures and earlier pushing of coke. Non-essential uses had been curtailed and economies in essential consumption had been effected, through improved uniformity and quality of coke resulting from better cleaning, blending and mixing, and higher bulk density.

The threat of continuing shortages, resulting from the depletion of premium grades of coking coal, might be met by increased exploration, and by conservation through limitations on the use of coking coal for other uses than coke production, and the reduction of mining losses. Conservation was aided by improved cleaning methods which permitted lower grades to replace premium grades of coal, and by blending that broadened the range of metallurgical coals.

New methods of blast-furnace operation and gas production gave promise of reducing coke requirements, and there were prospects of developing coke-free methods of iron ore reduction.

Continued research was essential for eliminating or preventing future shortages and to develop ovens capable of coking a broader range of coals.

Mr. CHERADAME presented the paper prepared by Mr. Sabatier, entitled "Production of High-Grade Metallurgical Cokes from Coals of Poor Coking Quality." He stressed that the paper gave an example of how the problems outlined in the preceding papers could be solved, by showing the methods of utilization employed in France for the coking of coal that could not be used previously. France, which was rich in iron ore but poor in coking coals, had to import more than two-thirds of the coke it required. Moreover, its largest coal reserves were found in the Lorraine coal basin, which lent itself to intensive exploitation but yielded coals that were unsuited to standard methods of coking.

The shortage of French coal for the manufacture of coke to supply the Lorraine ironworks and the steadily increasing output of the Lorraine collieries gave prominence to the problem of producing metallurgical cokes from the Lorraine coals.

After stating the characteristics required of blast-furnace cokes and those of the three classes of Lorraine coal (fat coals, flaming fat coals and flaming dry coals), Mr. Cheradame described the following industrial tests:

For coking, by the normal method, of a mixture containing as much Lorraine coal as possible;

Coking in the Carling plant provided with a stamping device of a triple mixture of Lorraine coal (flaming, bituminous and semi-bituminous), coke-dust and coking coal;

The tests made in an experimental plant at Marienau of a dry mixture of Lorraine coal, Saar fat coal and semi-coke derived from flaming dry coals (Marienau).

The tests had not yet been completed, but the results already obtained justified the conclusion that it was possible to manufacture satisfactory metallurgical cokes from Lorraine coals (fat and flaming fat coals). The development of those processes should make it possible to extend the range of cokable coals and thus to achieve a better utilization of the coal output in France as well as in other countries.

The CHAIRMAN opened the discussion, and requested speakers to deal exclusively with questions pertaining to coal carbonization.

Mr. LOWRY emphasized that the quality of coke was largely determined by the characteristics of the coal from which it was produced. As various types of coal were used for the manufacture of coke, the characteristics of the coke produced were also extremely varied. It was, however, difficult to determine the exact relationship between the quality of the coke and its efficiency in blast-furnaces. The economic efficiency of coke manufactured from poor coking coals was not necessarily inferior to that of other types of coke. The most important quality from the metallurgical point of view was consistency. (It was, however, incorrect to speak of inferior types of coke; rational uses for allegedly inferior types of coke could be found in certain conditions.) Indeed, the blast-furnace manager could become accustomed to any quality of coke provided that the quality remained constant. The correlation between the properties of the coke and its output had not been established. Thus, a large percentage of ash was not always harmful. Similarly, it was possible to utilize coal with a higher sulphur content than had formerly been thought possible. The possibility of using even poor-quality cokes, provided they were uniform, might considerably increase the resources available.

Mr. MULCAHY said most experts considered that few types of coal could be used for the production of very high quality coke; an endeavour must therefore be made to discover what blends would give the best results both qualitatively and quantitatively.

The main characteristics used for determining the quality of any given coke were size and, above all, consistency.

He emphasized the need for adopting, as soon as possible, a world nomenclature for describing the characteristics of various types of coal and cokes, without which it would always be difficult to draw the necessary conclusions from the research and experiments carried out in various countries. The establishment of definite standards in that field should not entail great technical difficulties.

He was glad to note that many countries, such as France and the United States, were trying to produce coke from types of coal which had hitherto been considered unsuitable for the purpose.

In conclusion, he said that since the production of high quality coke depended on the quality of the various coal blends, it was necessary first of all to establish a world classification of the different types of coal.

Mr. POTTER said that the United States would experience a shortage of coke if a crisis were to occur at present, because the country was making increasing use of natural gas and a large number of coke plants were no longer in use. Nevertheless, reserves of coking coal seemed to increase rather than decrease because of the possibility of developing and utilizing methods which were now at an experimental stage in various countries.

He opposed the suggestion of Mr. Newman, that the use of high-grade coking coal for other purposes than the production of metallurgical coke should be limited. He expressed full agreement with the ideas outlined by Mr. Lowry and thought that such ideas should form the basis for a modernization of the coke industry.

Mr. CRICHTON described one of the unfortunate aspects of the use of coking coals in the United States. Steel companies have been demanding low sulphur, low ash coals of very best quality, and it is becoming more difficult to get coals of the standard they have required in past practice. Good coking coals in the western part of the United States are becoming scarce. A method of treating high volatile coals by reducing the volatile content to around 18 per cent, seems to offer a solution for many of the high volatile, weaker coking coals of the west. They are now shipping low volatile coking coals from Oklahoma and Arkansas to Colorado and Utah for mixing with the high volatile coals to add character to the coke. He hoped that concrete measures would be taken in all countries in the near future for the rational utilization of all types of coking coal.

The CHAIRMAN congratulated the authors of the three communications which had been submitted to the conference. He believed that very interesting conclusions would be drawn from both the documents and the discussion.

He then proposed that Mr. Jensen, Mr. Tigerschiöld and Mr. Cavanagh should submit their respective communications.

Mr. FALKUM presented the communications prepared by Mr. Jensen on a new electric process for the carbonization of non-coking bituminous coal.

Norway had at present a considerable amount of hydro-electric power at her disposal. In particular, from 200,000 to 400,000 kw. per year could be developed at a low cost in ten Norwegian ice-free coastal harbours. That power could be used for the development of electro-chemical and electro-thermical industries. The Norwegian Government had tried to use part of those power resources for the processing of Spitsbergen coals.

There were various types of coal in Spitsbergen, but most of them were bituminous and unsuitable for coking by ordinary means. Consequently, the *Norsk Hydro-Elektrisk Kvælstofaktieselskab* and the Norwegian Government had jointly studied and developed a new electrical method for the production of high quality coke from Spitsbergen coal. An experimental plant was now in operation.

Mr. Falkum then described the new electrical process outlined in this paper. He mentioned some of the results achieved recently and emphasized their interest from the industrial point of view; they opened the possibility of establishing in Norway the synthesis of gasoline and diesel oil.

He explained that wood distillation had also been made possible by the new electrical process perfected in Norway. That method was therefore particularly interesting for all areas which had or could develop hydro-electric power in large quantities and at low cost.

Mr. VELANDER presented the paper prepared by Mr. Tigerschiöld on the "Possibilities of Reducing Coke Consumption in the Production of Iron and Steel".

He first recalled the factors affecting coke consumption in blast-furnaces. He pointed, in that connexion, to the special conditions in Sweden, which compelled that country to continue using charcoal and thus to pay great attention to the question of coke consumption.

He felt that in most countries insufficient importance was attached to the treatment of the ore burden. He then emphasized the results which had been obtained at the Swedish coke blast-furnace plant at Domnarfvet; details were given in Mr. Tigerschiöld's paper.

He drew attention to the work of Professor Durrer in Switzerland who was endeavouring to replace blast-furnaces by low-shaft oxygen furnaces. That would be an excellent solution of the problem of fuel consumption. Another solution was provided by the electric pig-iron furnace, such as the Tysland-Hole furnace, which had been in use in Sweden since 1928. The advantages and disadvantages of that furnace were set forth on pages 12 and 13 of Mr. Tigerschiöld's paper.

Mr. Velander regretted that he had not time to give a more complete analysis of Mr. Tigerschiöld's paper; he hoped that it would receive the detailed study which it deserved.

Mr. CAVANAGH, in introducing his paper on "Methods for Reducing the Amount and Quality of Coke Used in Smelting Iron Ore", recalled that the question had two main aspects: the conservation of raw materials and their utilization.

With regard to conservation, the policy should be to achieve the greatest economy by improving current processes or by using those processes to the best advantage. Two methods could be used for that purpose: that of changing the physical and mechanical properties of the raw material in order to adapt it better to the processes in use; or, on the contrary, that of changing the processes in view of the special characteristics of the raw materials. Coke consumption, for example, could be considerably reduced by increasing the volume, the temperature or the pressure of air, or by changing the structure of the ore through sintering or pelletizing. Mr. Cavanagh noted in that regard that it was not always necessary to resort to the latter process, which had not yet been studied sufficiently.

With regard to the utilization of raw materials, Mr. Cavanagh referred to various new processes which had certain advantages but which, on the other hand, required different types of blast-furnaces. The Wiberg-Söderfors process, for example, required less heat, whereas the Tysland-Hole electric smelting furnace allowed a saving of coke of approximately fifty per cent as compared with the classic blast-furnace process. That process was particularly advantageous in areas where electric power was cheap, but it could not replace the blast-furnace system for quantity production; nevertheless it would permit the establishment of ironworks in areas where it would have been impossible in the past through limited demand.

Mr. Cavanagh pointed out that the use of different methods was linked with commercial and political considerations, and also depended upon the particular conditions prevailing in the different countries.

Mr. JACQUé recalled that considerable progress had been achieved in the field of gasoline synthesis through the use of catalysts in suspension in reacting gases. It was obviously difficult to foresee what the future development of such techniques would be; it might, however, prove to be very useful to the metallurgical industry in the future if it could be adapted to the treatment of ores. That method would have the advantage of solving the knotty problem of the sulphur content of coals.

Mr. YANCEY referred to Mr. Jensen's paper and pointed out the advantages of the process which had made it possible in Norway to produce coke from non-coking bituminous coal, and to manufacture briquettes without use of any binder by high-pressure exclusively. Mr. Yancey considered that to be a most useful achievement and recalled that similar methods had been used in Germany.

With reference to Mr. Cavanagh's remarks, he stated that the techniques which had been briefly outlined by the latter would be of particular interest in the State of Washington, which had good coking coal but no blast-furnaces.

Mr. NEWMAN referred to the problems of coal blending and of the quality of cokes, which had been raised at the beginning of the meeting, and stated that he could not share completely Mr. Lowry's view that a large increase of ash content was not harmful. He felt, moreover, that the cessation of operation of certain coke oven plants in the United States would create a serious problem, and pointed out, in that connexion, that the cause was not merely age and deterioration of the coke ovens but also increased utilization of natural gas.

Mr. CAVANAGH asked Mr. Falkum what average quantities of coke could be produced in Norway by the process which Mr. Jensen had outlined in his paper.

Mr. FALKUM replied that current production was about 1 ton a day; it would soon be considerably increased, as a new installation capable of producing 25 tons of coke a day was being constructed.

Mr. YANCEY enquired about the type of press that was used in Norway for manufacturing briquettes without the use of a binder.

Mr. FALKUM expressed regret at being unable to give any specific information on that point.

Mr. CHERADAME wished to know the amount of ash content generally acceptable in the United States.

Mr. NEWMAN thought that it was difficult to give an exact reply as the acceptable ash content varied over a wide range, and that the upper limit was steadily rising.

Mr. LOWRY explained that the ash content of coke in the United States ranged up to 22 per cent, with two per cent sulphur content. No strict limit was set, however, and it was not even unusual for the ash content to exceed that ratio. He pointed out, in that connexion, that in Sweden and Canada the need had been expressed for coke of greater crushing strength in view of the height of the burden in the shaft, but published measurements of this property indicate that even the weakest cokes are more than sufficiently strong to resist the static load of the burden.

Mr. CRICHTON observed that in certain cases cokes with up to 30 per cent ash content had been used. It frequently happened that the available raw materials had to suffice.

Mr. CAVANAGH drew attention to the paper prepared by Mr. Tigerschiöld and remarked that it dealt with very special circumstances, since Swedish ores consisted mainly of dense magnetites. With regard to the hardness of the coke, Mr. Cavanagh considered that that factor was of importance mainly before the charging. In that connexion he indicated that the coke available in New Zealand had little resistance.

Mr. LEE wished to clarify some of his remarks; he had not meant to say that the development of other methods of iron production besides the blast-furnace was to be avoided, but simply that in the United Kingdom the utilization of other methods on an economic scale was very improbable.

Conservation in Utilization of Fuel for Space Heating

1 September 1949

Chairman:

LIANG-FU CHEN, Director, National Resources Commission of China, New York, U.S.A.

Contributed Papers:

Conservation in Utilization of Fuel for Space Heating
NEIL B. HUTCHEON, Professor of Mechanical Engineering, University of Saskatchewan, Saskatoon, Canada, and
ROBERT F. LEGGET, Director, Division of Building Research, National Research Council, Ottawa, Canada

Conservation of Fuel in Space Heating with Special Reference to Insulation
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Conservation in Utilization of Fuel for Space Heating
R. H. ROWSE, Fuel Research Station, London, England,
J. C. WESTON, Building Research Station, Garston, England, and
F. C. LANT, Ministry of Fuel and Power, London, England

Use of Electricity as a Heating Agent in Norway
J. HOLMGREN and ALF O. HALS, Norwegian Institute of Technology, Trondhjem, Norway, and
H. J. LINDEMANN, Oslo Municipal Electric Supply System, Oslo, Norway

The Heat Pump as a Conservation Device
EMORY N. KEMLER, Associate Director, Southwest Research Institute, Houston, Texas, U.S.A.

Space Heating by Solar Energy
MARIA TELKES, Research Associate, Department of Metallurgy, Massachusetts Institute of Technology, Cambridge, Massachusetts, U.S.A.

Economics in Heating
O. MASTOVSKY, Professor, Technical University, Prague, Czechoslovakia

Summary of Discussion:

Discussants:

Messrs. IGNATIEFF, DILL, MACFARLANE, HALS, TASKER, CHERADAME, LINDEMANN HUNTER, E. A. HARDY, SHERMAN, KEMLER, TELKES, BLOCH, GOLDSCHMIDT, PAIGE, ERSELCUK, HUBBERT

Programme Officer:

MR. W. A. MACFARLANE

Conservation in Utilization of Fuel for Space Heating

NEIL B. HUTCHEON and ROBERT F. LEGGET

ABSTRACT

The economic importance of space heating in Canadian life is illustrated by a statement of degree-days for leading Canadian cities. Estimates of the total energy used in the Dominion are given and figures are quoted which show that the equivalent of 20 million tons of coal yearly is used for space heating or about 26 per cent of the country's total energy consumption. Heating practices in Canadian homes are analysed and discussed and recent trends in space heating installations are outlined. The predominance of wood construction in Canadian house building is noted and the measures adopted in house design and construction to conserve heat are described. A brief section is included with reference to space heating in industrial plants and suggestions are made as to possible economies in this particular use of fuel. This leads to a general discussion of the possibilities for energy conservation in space heating in Canada, concluding with brief reference to the matter of district heating, the development of which in Canada is problematical in view of the low annual load factor for space heating (30 to 35 per cent).

The bulk of Canada's population is to be found in a belt paralleling the Canada-United States boundary from the Atlantic to the Pacific Ocean, extending northward in width for a distance of 200 to 500 miles from the international boundary. All buildings in this area which are used for human habitation and normal human activity, for the housing of most industrial activities, and for the storage of goods liable to damage by low temperature require varying degrees of heating during the period from October to May. The maintenance of comfort conditions may require some heating in all but two or three months of the year.

The most convenient and widely used measure of the heating load is the number of degree days, found by calculating from the weather data for any particular locality the summation of the number of Fahrenheit degrees each day by which the mean daily outdoor temperature falls below 65. The following table shows the degree days for several Canadian cities listed in order from East to West, together with normal, minimum and average temperatures and average wind velocity. (1)[1]

	Degree days	*Normal Temp. Oct. 1–May 1*	*Lowest Temp. reported*	*Average Annual minimum*	*Avge. wind vel.—Dec. Jan. Feb.*
Halifax......	7,682	—	—	—	—
Montreal ...	8,341	28.1	—29	—18.4	11.3
Toronto	7,715	32.6	—26	—11.2	13.6
Winnipeg....	11,130	17.2	—54	—37.7	10.1
Edmonton ...	10,289	22.8	—57	—41.3	7.5
Vancouver...	5,755	42.6	+ 2	13.1	4.5

ENERGY USED IN CANADA

There is no doubt but that Canada pays a high price in human effort and resources in achieving essential space heating. Statistics on the cost of space heating to the nation as a whole are extremely difficult to obtain, since in the industrial field the energy requirements for this purpose are not readily separated from over-all data. Attempts in recent years to estimate the energy obtained annually in Canada from various sources have produced only rough approximations since the statistics on wood fuel are far from complete. This important source of energy is estimated to provide in some years about 10 per cent of the energy obtained from all sources.

Estimates of total energy obtained from water power and the mineral fuels for 1944 are given below, based on the total heat energy released from fuels under ideal combustion conditions. Secondary electric power was converted at its actual heat equivalent, while the primary electric power generated from hydraulic sources is given in terms of the total heat energy of the coal required to generate that amount of electricity in thermal plants. (2)

Major Energy Sources in Canada 1944
(in units of 1,000,000,000,000 B.T.U.)

Water Power, domestic coal equivalent		656
Coal		
Domestic	383	
Imports	764	
Total		1,147
Petroleum Fuels		
Domestic	61	
Imports	259	
Total		320
Natural Gas, domestic		48
Total of above		
Domestic	1,147	
Imports	1,023	
Total		2,170

There are several features of Canada's over-all energy picture which deserve further comment, since they have considerable present and possible future influence on space heating practice.

(*a*) *Water Power:*

Canada had by 1945 some 10,283,610 h.p. in water power turbine installations; it is estimated that known water-power resources will permit of a total installation of 51,780,000 h.p. About 97 per cent of the electrical energy produced in Canada is derived from water power, but only about 6.5 per cent of this is used for domestic service. Although there are houses heated entirely by electricity in some Canadian cities, the use of primary electric power for space heating is very limited. It has been stated (3) that, because of the low annual load factor of from 30 to 35 per cent in space heating, the development of hydro-power for this purpose cannot seriously compete with coal, even after full allowance is made for the convenience of electricity.

[1] Figures in parentheses refer to items in the bibliography.

Secondary power generated by hydro-plant is used largely for steam raising in electric boilers, their capacity being equivalent to about 1.7 million tons of bituminous coal each year. Only a portion of the steam thus generated is used in space heating; one installation of 45,000 kw. capacity has been installed chiefly to provide supplementary steam for district heating purposes.

(*b*) *Mineral Fuels:*

The production of mineral fuels in Canada in 1945 was as follows (4):

Coal	15,227,819 short tons
Natural Gas	48,411,585 thousand cubic feet
Petroleum	8,482,796 barrels

The consumption of coal for all purposes was, in the same year, 39,749,347 short tons, or at the rate of 3.28 short tons *per capita,* with Canadian production accounting for only 38 per cent. About one-quarter of the total consumption is used in railway locomotives; somewhat more than one-quarter is sold at retail prices and presumably used largely in domestic heating.

Probably about half the natural gas produced in Canada is used for space heating.

As in the case of coal, Canada imports the major portion of her petroleum requirements. The production indicated above for 1945 will probably be doubled in 1949 due to the recent development of new oil-fields in Western Canada. There was a steady increase in the use of oil for domestic and building heating throughout the 1930's, reaching a peak in 1941 when 147 million Imperial gallons were delivered for domestic and building heating and 290 million gallons for industrial heating and power. (5) In 1941 there were 67,000 dwellings in Canada heated principally by oil whereas by 1947, after the wartime restrictions on the use of oil were removed, this had risen to 388,000, indicating the continuing marked trend toward oil heating. (6)

(*c*) *Wood as Fuel:*

About half the households in Canada are believed to rely on wood for fuel, and over 25 per cent of the annual forest depletion is believed to be used for domestic use. It is estimated that about 8½ million cords of wood are cut on farms and about an equal amount cut in operations in the Canadian woods each year. This amount of wood is the equivalent of 5 to 6 million short tons of good coal. Probably more than 80 per cent is used for heating. It is probable that sawdust and mill waste used for fuel provide the equivalent of from ½ to 1 million tons of coal.

In summary, about 10 million tons of coal are used each year for domestic heating (or almost one ton per head of population). To this may be added some 24,000 million cub. ft. of natural gas equivalent to about 960,000 tons of bituminous coal and the equivalent in wood fuel of about 5 million tons of coal. The present consumption of oil for space heating is not known but may amount to not less than the equivalent of 4 million tons of coal at the present time, indicating a probable total consumption of fuel for space heating of the equivalent of about 20 million tons of coal yearly, or about 26 per cent of Canada's total energy consumption.

HEATING CANADIAN HOMES

The use of different fuels and types of heating systems in Canadian homes, according to a recent estimate, are as shown in the table (6). The popularity of the coal-burning furnace and the wood-burning stove is clearly indicated. It may be noted also that oil is widely used as a fuel in heating stoves. It is estimated that some type of supplementary heating is used in about 48 per cent of the homes in Canada. The cookstove or range or the heating stove are used in 87 per cent of the homes with supplementary heating, with wood or coal being used in 74 per cent of the cases as the supplementary fuel.

The ideal in space heating for human occupancy is the production of a constant degree of comfort for each individual, with a minimum of cost in equipment, energy and labour. Most of the practical forms of space heating in use in Canada attempt with varying degrees of success to produce and maintain reasonably constant air temperatures (70 degrees F. and above) throughout the occupied zone on the manifestly false but still reasonably practical premise that uniform air temperatures will produce uniform comfort conditions. The extent to which uniform comfort conditions are produced and maintained depends upon the way in which heat is provided as determined by the design, installation and operation of a given heating system. It is equally affected however, by the ways in which the heat energy is dissipated as determined by the shape and by the thermal and air leakage characteristics of the building being heated. The simpler and less costly types of heating systems are usually installed in low cost houses, with the result that often the house which because of its general design is hard to heat is provided with a type of heating system which is least able to heat it.

CANADIAN HOUSE CONSTRUCTION

At present, almost four out of five dwellings built in Canada are of wood frame construction. (7) The materials used for the exterior vary from wood clapboard (47 per cent) to brick veneer (20 per cent) and stucco on lath (12 per cent). Wood frame walls as normally constructed provide greater resistance to heat flow, without any added insulating material, than almost any type of simple masonry construction. They can also be insulated at lower cost than any masonry wall since a space already exists within the wall for the placing of blanket, batt or fill type insulating material, broken only by the wood studding which is itself reasonably resistant to heat flow. It is now common practice to provide substantial added resistance

Heating of Canadian Homes (1947)

	Coal	*Coke*	*Oil*	*Wood*	*Gas*	*Other*	*Total*	*Percentage*
Steam or hot water furnace	338,000	11,000	96,000	11,000	12,000	—	470,000	15
Hot air furnace	621,000	24,000	64,000	100,000	57,000	22,000	888,000	28
Cookstove or range	230,000	—	72,000	352,000	17,000	11,000	683,000	22
Heating stove	467,000	—	154,000	409,000	38,000	—	1,079,000	34
Other	—	—	—	—	—	—	16,000	1
Total	1,661,000	44,000	388,000	873,000	130,000	40,000	3,136,000	100
Percentage	53	1	12	28	4	1	100	

to heat flow in the form of insulation to walls and ceilings of dwellings. This does not, however, affect the heat losses resulting from heat transmission through windows and doors, and from the infiltration of cold outside air. Double windows are provided in most houses by fitting glazed storm sash ("double windows") to the outside of a normal window during winter months. Double glazing in conventional window frames is now being introduced but is still rather expensive.

Babbitt (8) has shown for a representative Canadian house but without insulation or storm sash, that it is possible to reduce the heat loss by 13 per cent by the addition of storm sash and weatherstripping. The addition of two inches of a good insulating material to walls and ceilings is shown to decrease the heat loss to one-half of its original value. Similarly, he shows that the optimum economic thickness of insulation for Canadian homes is from two to four inches, depending on the severity of the heating season. (9)

The use of insulation is not without its attendant difficulties, largely associated with the need for control over the flow of water vapour from the inside to the outside of a wall or ceiling in winter, in order to prevent the condensation of the vapour within the wall or in the cold attic space. The general procedure in providing vapour control by the use of vapour barriers on the warm side and of permeable construction on the cold side of a wall is now well established in Canada although not yet universally practised. The difficulty of providing vapour control in existing structures so that they may be insulated without danger of incurring condensation troubles is often a deterring factor in the use of insulation in these cases.

METHODS OF SPACE HEATING

The simple heating stove was for many years accepted as an adequate means of heating for houses and is still very widely used in Canada. The limitations of the stove as a means of providing uniform comfort conditions in a house are well known, but it is interesting to note that there was little necessity for basements under houses so long as the stove was used. The ordinary heating stove is incapable of preventing large temperature gradients from floor to ceiling. Heat losses through ceilings and the upper parts of walls are increased unnecessarily because of the high ceiling temperatures. When only one stove is provided to heat several rooms, the variations in space temperatures may be still more pronounced throughout the various rooms, and temperature differences of 30 degrees from floor to ceiling are not uncommon under these conditions.

These deficiencies in heating comfort provided by stoves, coupled with the need for handling fuel and ashes in the living space, have led to the development and widespread use of the gravity furnace systems of heating including the warm air, hot water, and the steam systems with gravity return of condensate. It is possible with these systems to obtain good distribution of heat to and throughout each room. The furnaces however must be located below the floor to be heated, requiring the provision of basements. The handling of fuel and ash is then confined to the basement, which may also be used for fuel storage as well as for other uses. Heat losses from the furnace provide sufficient heat for the basement itself. These systems of heating are still the best available to the home owner who does not have electric power for the newer forced circulation systems.

In recent years there have been developed the forced circulation systems of warm air heating employing electrically driven fans and the forced circulation hot-water systems employing pumps. The furnaces may be located where desired in the house, allowing considerably greater freedom in house design. Forced warm air systems are used to provide winter air conditioning involving filtration, humidification and controlled ventilation. Forced circulation units are available for addition to gravity systems to improve faulty circulation and to provide some refinements. The forced hot-water system is well adapted to radiant heating which is now receiving much publicity, and which appears to have special application in the case of slab floors laid on the ground for houses. Increased heat losses through floors may result, however, unless greatly improved insulating procedures can be developed; these heat losses may lead to problems involving groundwater.

In general the use of improved systems and refined types of fuels leads to higher efficiencies, varying from a value of about 40 per cent in the case of solid fuel used in stoves, to as high as 80 per cent in the case of gas, and of oil burned in the best types of equipment. The higher efficiencies are obtained with the liquid and gaseous fuels which are in demand for other uses, and relatively less abundant and are therefore more valuable from a conservation point of view. The greatest potential savings in over-all fuel use for domestic heating would, however, appear to be in the improvements possible in building practice which can decrease over-all heat requirements and through education to improve operating practice with existing systems.

INDUSTRIAL SPACE HEATING

Heating practice in small commercial buildings is very similar to that used in homes. In general, greater emphasis is placed on fireproof construction, resulting in the widespread use of wall constructions having over-all thermal conductivities of from 2 to 4 times those of the better types of house walls. As the size of the building increases, however, the ratio of heat loss to volume decreases, so that the heat required per cubic foot of space for larger buildings is often less than that required in well-insulated houses.

Space heating in larger commercial and industrial buildings is largely by means of steam. Radiators at floor level or high output space unit heaters are most commonly used. The space unit heaters are equipped with fans or blowers to provide high air velocities over their heat transfer surface and thus provide extremely high output. They are commonly located overhead to conserve floor space and to facilitate piping, and must then be arranged so that the high velocity warm air stream is directed toward the floor to break down the stratification of warm and cold air which tends to develop. They do not, however, find their best use in heating living space because of the noise and high air velocities produced.

The provision of ventilation over and above that obtained by natural air inleakage will often increase the heat requirements by from 2 to 6 times over that required for heating alone. The temperature differential determining heat requirements in ventilation is identical with that for heating alone so that for any given building the ratio of ventilating to heating load is independent of temperature difference. It is common practice to use separate systems of heating and of ventilating so that ventilation may be provided when required.

Laundries, dairies, garages, auditoria, schools and many industrial process buildings require high rates of ventilation to remove air contaminants, to control humidity, or to provide a satisfactory atmosphere for human occupancy and are involved in a high ventilation loss usually amounting to several times that involved for heating alone. Heating systems thus used are usually central systems, designed to use 100 per cent fresh air, that is without recirculation. A substantial reduction in fuel requirements can be achieved in Canada by the application of sound engineering to the design of systems which are capable of being operated with part of the exhaust air being recirculated, either with or without filtering, odour or moisture removal, at times when the full over-all ventilation rate is not required.

FUEL CONSERVATION AND DISTRICT HEATING

Fuel saving in general may be accomplished in two ways – by reducing the heat lost, and by increasing the efficiency of production and distribution of heat. These two are not unrelated, since the nature of the heat distribution may to an appreciable extent determine the heat required.

Heat requirements may be reduced by improved building designs to reduce heat losses, principally by the incorporation of insulating materials in walls, ceilings, floors and roofs. The reduction of the amount of outside air to be heated, by reducing unnecessary air inleakage and by regulating the intentional air intake for ventilation more nearly in accordance with need, offers a potentially substantial saving in full requirements.

Heat can be used only when needed, and improved methods of control to maintain the rate of heat supply in balance with the need are capable of providing substantial savings. Where the heat requirements of different zones served by one system may vary independently, the use of separate controls in each zone will reduce heat requirements. It has been found that the application of zoned automatic control to a heating system previously manually operated may result in savings in heat of 30 per cent.

The gravity flow furnace systems presently widely used in Canada are capable of providing over-all heating efficiencies of the order of 50 to 65 per cent when hand fired with coal. The greatest potential increase in efficiency is possible through the use of automatic firing and a change to liquid or gaseous fuel. Higher efficiencies of the order of 75 per cent are obtained from larger commercial types of boilers, and under exceptional conditions 85 per cent may be achieved. There has therefore been some considerable interest in the possibility of district heating in which one large plant is used to provide heat to all the buildings in an area.

Against the higher efficiency of a large central plant, which can also use lower grades of fuel successfully, must be weighed the loss in transmission of heat which may be of the order of 15 to 40 per cent in Canada. District heating does not therefore offer a great saving in over-all energy requirements, but does permit the use of lower grades of fuel. The capital investment is high when compared to the cost of the individual fuel-burning devices which alone are replaced, the remainder of the normal individual heating system still being required. The cost of the distribution system is high, being of the order of 50 per cent of the total cost. The poor yearly load factor of 30 to 35 per cent in heating makes the high capital cost of the system a serious one. It would appear that steam provided for district heating will seldom be sold at a cost approaching the cost of fuel alone for an individual system, and may often be considerably more.

Whether or not district heating will be developed will depend on the price which the individual owner is willing to pay for freedom from handling and firing fuel, increased cleanliness, release of space occupied by equipment and fuel storage, and for the reduction in first cost of the house-heating system. Should the cost of oil in relation to coal increase in Canada there will no doubt be increased interest in district heating possibilities, since Canadians in increasing numbers are demanding automatic domestic heating.

Bibliography

1. *Heating, ventilating and air conditioning guide, 1946*, vol. 24, New York American Society of Heating and Ventilating Engineers, 1946, page 259 and 381.
2. Bank of Canada, Statistical summary, Ottawa, Oct.–Nov. 1946.
3. Canada, Royal Commission on Coal, *Report*, Ottawa, 1946, 663 pages.
4. *Canada year book, 1947*, Ottawa, Dominion Bureau of Statistics, 1947, 1,239 pages.
5. J. M. Casmy, *Petroleum fuels in Canada—deliveries for consumption, 1927 to 1940*, Ottawa, Canada, Bureau of Mines, Report 808, 1940, 31 pages.
6. Canada, Dominion Bureau of Statistics, *Heating facilities, radios and telephones in Canadian homes—August 1947*, Ottawa, 1948, 12 pages.
7. Canada, Department of Reconstruction and Supply, *Manpower and material requirements for a housing programme in Canada*, Ottawa, 1946, 137 pages.
8. J. D. Babbitt, *The insulation of houses*, Ottawa, National Research Council of Canada, N.R.C. No. 1386, April 1946, 23 pages.
9. J. D. Babbitt, "The optimum thickness of insulation for Canadian homes", *Engineering Journal*, vol. 23, no. 1 (Jan. 1940), pages 20–24.
10. J. M. Casey, *Petroleum fuels in Canada—deliveries for consumption, 1940 to 1944*, Ottawa, Canada, Bureau of Mines, Report 814, 1944, 25 pages.

Conservation of Fuel in Space Heating with Special Reference to Insulation

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ABSTRACT

In the United States, most dwelling houses now being built are insulated, at least in some degree, and insulation is being installed in many existing houses. In the north, insulation is used to save heat and, in the south, to exclude heat and thus promote comfort. The use of insulation was actively promoted by Government agencies during the recent war as a fuel conservation measure. This, with increased fuel prices and a general desire for more adequately heated houses, has caused a wider use and more prevalent interest in insulation in recent years. A great variety of insulating materials is on the market and the designer or user can make a choice based on type of construction and economic considerations. English units of measurement have been generally accepted for expressing the properties of thermal insulating materials and the guarded hot-plate apparatus is the accepted standard for determining the properties of such materials. The guarded hot-box apparatus is available in several laboratories for testing composite walls. Fuel savings of 50 per cent or more can be realized by application of insulation to a typical house. Condensation in buildings is a problem which has accompanied the growing use of insulation. Various means including ventilation and vapour barriers are being employed to alleviate it.

INTRODUCTION

In the United States of North America very few, if any, dwelling houses are now designed without consideration of the use of thermal insulation. The climate of this country is such that houses and buildings are insulated to retain heat in cold regions or seasons and to exclude heat in hot regions or seasons. Since the present subject concerns fuel conservation, the following discussion will be confined to the winter or cold weather condition.

It is now generally understood by the public, as well as by engineers and architects, that thermal insulation is an effective means for improving the comfort of houses, by reducing the temperature gradients within them, and for saving heat and reducing fuel costs. During the recent war, use of insulation was actively advocated by Government agencies as a fuel-saving measure. The increased use of insulation in dwelling houses in recent years is undoubtedly attributable to the increased cost of fuels, to technological advances in heating methods and an increasing demand by householders for more adequately heated dwellings.

In the United States today an adequately heated house is tacitly defined as one which is comfortably warm throughout regardless of the severity of the weather, and "comfortably warm" usually implies an air temperature in excess of 70 degrees F. Lower limits for wall-surface temperatures are sometimes specified since such temperatures affect the heat lost by radiation from occupants of rooms, and hence their feeling of comfort. An insulation requirement is thus implied.

The term "thermal insulation" applied to a house or building denotes some material included in its structure the sole or chief purpose of which is to retard the flow of heat through exposed surfaces or elements such as walls, floors, ceilings or roofs. Statistics are meagre but those available indicate that in 1940 some 25 per cent of the houses under construction contained insulation in the ceiling or roof while 10 per cent of those under construction contained insulation of some form in the exposed walls. There were many houses, of course, built prior to 1940 for which statistics are not available. There are now in the United States some 40 million dwelling units, including a small proportion of apartments, and the building rate is some 1 million dwelling units per year. As indicated above, it is believed that practically all of the new houses are insulated in some degree, and insulation is being installed in many of those already built. Probably the best indication of the actual fuel saving being effected nationwide is the experience of the Federal Housing Administration. For one and two living unit dwellings, offices representing different regions of the country find it possible to limit the computed or design heat requirements to an average of about 60 B.T.U. per square foot of floor area whereas in 1940 the figure is thought to have been on the order of 100 B.T.U. per square foot as a national average.

TYPES OF INSULATING MATERIALS

Many different kinds of thermal insulating materials from which a user can make a choice are on the market. One list of commercial insulations contains 210 trade names. Usual types can be classified as flexible material, fill material, batts or pads, slabs, structural insulating board, or reflective insulation. Flexible insulations are supplied in the form of blankets or quilts and are made of vegetable fiber, animal hair, mineral wool or other fibrous materials. Organic constituents are commonly treated for fire, moisture and vermin resistance. Fill insulation may consist of fibrous, granular, or powdered material. Vermiculite, mineral wool and some vegetable fibers are used in this manner. Rock wool, slag wool and glass wool are all known to the trade as mineral wool. Batts are usually made 15 or 23 in. wide to fit between the studs in conventional constructions and in various lengths up to 4 ft. Flexible insulation and batts are usually encased in paper covers and the paper on one side is treated to form a vapor barrier. Typical insulating slabs are cork board, the traditional insulator of the refrigerating industry, but cork is little used as house insulation, presumably on account of its comparatively high cost and limited availability. Structural insulating board is made of wood or sugar cane fiber, and is formed under pressure and heat, so that it has some structural strength in addition to its insulating value. It is often used as sheathing under clapboards or shingles or as lath to support plaster. Reflective insulation is usually aluminum foil although steel sheet with reflective surfaces treated to resist corrosion has been sold for the purpose. At least one reflective insulation consist of a suitable paper on which an aluminum flake is deposited. Double or storm windows and doors are also accepted insulating means and their use is prevalent in the northern part of the country.

METHODS OF APPLICATION

Insulation is applied in the walls, ceilings and floors of various buildings, and the method of application must depend on the kind of insulation used and the type of construction. The number of combinations is, therefore, very large. In a typical new house of frame construction, insulating board or insulating batts or blankets from 1 to 3½ in. thick may be found in the stud spaces, or one or more sheets of aluminum foil may be used in the same location. In older houses insulation is installed by the blowing-in process since it is inconvenient and expensive to make the installation by another method. Fibrous products, usually mineral wool, are used for this purpose. Openings are made in the walls, usually on the outside, so that the material can be installed by the blowing process. Flexible material, batts and fill material are all used on upper floor ceilings. This is in fact probably the most common use of insulation. Sometimes flexible material or batts are installed in the sloping roofs of houses, being stapled on or between the rafters. In some cases reflective material is used in upper floor ceilings or roofs, particularly to exclude heat in the summer. The greater effectiveness of a reflective insulation in retarding heat-flow downward compared to its effectiveness in retarding heat-flow upward is generally recognized. Concrete floors are now being installed in large numbers and the desirability of insulating such floors, particularly at exposed edges, is now understood by builders and designers. Such floors are often laid over crushed stone or gravel as a means of insulating them from the earth beneath. Insulation is obviously essential when heating coils or ducts are installed in such floors to form floor heating panels.

UNITS OF MEASUREMENT AND TESTING METHODS

In American practice, British units of measurement are used to express the thermal characteristics of materials and structures. The conductivity of a material, symbol "k", is defined as the heat flow in B.T.U.'s per hour in the material through an area of one square foot due to a temperature gradient of 1 degree F. per in. Resistivity is considered the reciprocal of conductivity. The term "conductance", symbol C, applies to the heat flow through a composite wall or structure and is expressed in B.T.U. per hour per square foot for each degree F. temperature difference through the wall or structure from surface to surface. The term "transmittance", symbol U, denotes the heat flow in B.T.U. per hour through a square foot of a wall or of a heat barrier due to a temperature difference of one degree F. in the air on the two sides, with a 15 m.p.h. wind on one side and zero wind on the other. This factor is useful when the air temperature inside and that outside of a house are known or assumed.

The accepted test equipment for thermal insulating materials at present is the guarded hot-plate apparatus adopted by the American Society for Testing Materials and described in their publication entitled, "Tentative Method of Test for Thermal Conductivity of Materials by Means of the Guarded Hot Plate" (ASTM designation: 177-45, issued 1945). The guarded hot-plate apparatus consists essentially of a hot plate and two cold plates. For a test, two similar oven-dried specimens of a material in the form of slabs are used, one on each side of the hot plate. The cold plates are then placed against the outside of the specimens. The cold plates are usually water-cooled, being either cored or provided with a coil of tubing, soldered on, for the purpose.

The hot plate is electrically heated and this plate is divided into two parts: an outer or guard section or "ring" and an inner "measuring" section. The energy supplied to the measuring section is measured and the amount, together with the temperature difference through the specimens and their thickness and area indicates the conductivity of the material tested. The guard ring is kept at the same temperature as the measuring section and serves to diminish any error due to edge effect. The hot-plate apparatus now in use at the National Bureau of Standards has plates 8-in. square, and the measuring section is 4-in. square. This apparatus accommodates specimens 8-in. square and up to 1¼-in. thick. Larger apparatus, with plates up to 3-ft. square, has been used at the National Bureau of Standards and in other laboratories.

A standardization program is now in progress, sponsored by the American Society of Heating and Ventilating Engineers and the American Society of Refrigerating Engineers. In connexion with this some 20 laboratories, including two foreign laboratories. tested specimens of insulating material in their guarded hot-plate apparatus and then submitted the specimens for test to the National Bureau of Standards. A limit of a 3 per cent difference between the results obtained by a laboratory and those obtained by the Bureau was established as a criterion and, based on this, about half of the participating laboratories qualified without difficulty. The results and the testing equipment are now being discussed with some of the laboratories. A major objective of the program is the elimination of discrepancies in the handbook data on thermal insulating materials and a considerable effect is expected in published material in the next two or three years.

Apparatus of the hot-box type is used for determining the heat transfer characteristics of composite walls. The transmittances of many simple walls can be satisfactorily computed from hot-plate data, but some masonry walls and some walls including air spaces or metal in their structures are so complicated that such computations become unreliable and use of the hot-box apparatus is therefore desirable. Such an apparatus consists essentially of three boxes, each with one side open to be placed against the test wall. The cold box, cooled by a refrigerating machine, is placed against one side of the wall and the hot box, containing the metering box, is placed against the other side. The metering box is heated electrically and the energy required is measured and, with the area and the temperature difference through the specimen, indicates the conductance of the specimen. The hot box is heated electrically and kept at the same temperature as the metering box to minimize heat transfer to or from the metering box except through the specimen wall. The apparatus at the National Bureau of Standards accommodates specimens 5 ft. wide, 8 ft. high and up to a foot or more in thickness. Apparatus in various laboratories requires specimens of different dimensions. Neither the hot plate nor the hot-box type of apparatus is a standard commercial product. It is usual for laboratories desiring such apparatus to design and construct it for their own use or to contract for this to be done.

ESTIMATED SAVINGS

Estimates of fuel consumption in houses and savings due to insulation are seldom, if ever, exact since they depend on a great variety of factors including the size and shape of the house, the number and size of the windows, the infiltration loss, the climate, etc. Sometimes in answer to a general inquiry on this subject a rough approximation is found satisfying. It is assumed that the walls, windows and the ceiling or roof of a house each lose 25 per cent of the heat supplied and that the remaining 25 per cent of the heat supplied is lost by air leakage or infiltration. On these assumptions, insulation of the house elements indicated in the following table are expected to save fuel approximately in the percentages shown.

Insulation	*Saving*	*Per cent*
1-inch in ceiling or roof	50 of 25 per cent loss	12.5
2-inch in ceiling or roof	64 of 25 per cent loss	16.0
3-inch in ceiling or roof	70 of 25 per cent loss	17.5
1-inch in exposed walls	50 of 25 per cent loss	12.5
2-inch in exposed walls	64 of 25 per cent loss	16.0
3-inch in exposed walls	70 of 25 per cent loss	17.5
Storm windows	50 of 25 per cent loss	12.5

CONDENSATION IN BUILDINGS

Engineers, architects and the public are now realizing that windows, exposed walls and roofs of buildings can be wet by the condensation of water evaporated or boiled within a house or building. Insulation does not necessarily cause condensation, but condensation is regarded as an accompanying problem because at the same time that the use of insulation has become more prevalent to save fuel, dwelling houses have been made smaller and more nearly airtight for the same purpose. In consideration of the condensation problem, it is regarded as bad practice to install insulation against the roofing boards in dwelling houses. A space between the insulation and the roof boards ventilated with external air is desirable. The use of vapor barrier materials in new houses is prevalent. A typical vapor barrier used in building construction consists of a strong paper saturated and coated with asphalt, two plies of strong paper cemented together with a heavy layer of asphalt or of a metal foil sheeting, sometimes cemented to paper or building board. The desirability of ventilation and of limiting the water vapor liberation in houses to alleviate the condensation problem is becoming generally recognized. Ventilation of the internal spaces in walls, particularly in metal-sheathed walls, and in roofs has received experimental attention in several laboratories.

CONCLUSION

It is probable that the use of insulating materials in house construction will continue to increase as the advantages of the practice become more apparent to the public, particularly since fuel prices are likely to continue their advance. Prospective purchasers are expected, in the future, to regard insulation as an essential element of a house. Condensation and other problems accompanying the use of insulation will be better understood, and therefore solved. Wider use of standard test methods will facilitate comparisons and selection of materials.

Conservation in Utilization of Fuel for Space Heating

R. H. ROWSE, J. C. WESTON and F. C. LANT

ABSTRACT

Practically all of the fuel used in Britain for space heating is coal and fuels derived from it. Heating of homes is generally by means of the open-fire type of appliance, but in offices and factories hot-water and steam heating are commonly used.

During the late war an intensive study was made of Britain's heating problems with a result that greatly improved heating standards are now being recommended by the Government. Many improved domestic appliances have been developed. The performance of these appliances and of new heating systems is studied both in the laboratory and in actual houses. In addition, investigations have been made into the economics of the application of structural insulations to houses.

Considerable interest is being shown in the heating of housing estates from a central source. Already twelve schemes have been sanctioned and four are under construction.

An industrial fuel efficiency drive which started during the war is now being continued and consolidated. There is a technical advisory service whereby technical information on the use of fuel is prepared and widely distributed; in addition the services of a pane of engineers are available to industrial concerns to advise on problems of fuel utilization.

In Great Britain practically the whole of the fuel used for space heating is coal and fuels derived from it. Very little electricity obtained from water power and very little wood, peat and oil are used for this purpose. About 180 million tons of coal are used in Great Britain annually; of this quantity about one-half is used for domestic purposes, which include water heating and cooking, and for heating offices and factories.

In British homes the main source of heat is the open fire or some modification of it such as the combination grate in which a single open fire provides space heating, water heating and cooking. Buildings such as offices are usually heated by means of hot water but steam is commonly used for heating in factories where it is generated for process work.

DOMESTIC HEATING

STUDY OF BRITAIN'S POST-WAR HEATING PROBLEMS

It was realized early in the war that the bombing of British cities and the cessation of house building during the war would mean a considerable post-war building programme. At this time also the importance of conserving the nation's fuel was being more fully realized. In order to take fullest advantage of the opportunity which would be offered for conserving fuel by installing more efficient fuel-burning appliances in post-war houses it was decided to make a full and comprehensive study of the whole problem of domestic heating.

A committee, which was predominantly scientific in membership, was set up to review existing information and practice in Britain and abroad on the heating and ventilation of dwellings and to make recommendations for practice in post-war building.

In this study consideration was given to basic physiological requirements and to the reaction of the individual to various methods of heating. Factors affecting the loss of heat from houses were considered and recommendations made as to desirable standards of structural insulation. The amounts of fuel required to provide heating by different methods were assessed, and an attempt was made to relate consumptions of gas, coke and electricity to the amount of raw coal required to produce these fuels. The cost and harm to the community caused by atmospheric pollution were considered and the need for reducing the emission of smoke and oxides of sulphur into the atmosphere was stressed. The investigation also included a detailed survey of heating methods and the use of fuel in over five thousand homes.

There were many practical problems still unsolved and in dations for greatly improving the standards of heating in British homes and at the same time conserving fuel, and these are becoming widely accepted.

The report of the committee contained specific recommen- addition technical and economic evidence was needed to confirm the findings of the committee. Immediate action was taken to solve these problems and to supply the necessary data; at the same time long-term researches were initiated.

THE APPLIANCE

It was quite clear that no marked advance could be made in heating practice except by the use of appliances having a much higher efficiency than the open fire. British gas and electric appliances had already reached a high standard of performance but much had to be done in connexion with solid fuel appliances. Intensive development work was undertaken by appliance manufacturers but it was found necessary to supplement this by authoritative tests on appliances, both to assess their ability to provide heating to the new standards and to assist in making still further improvements. Moreover the test data were valuable for demonstrating to housing executives the economic and practical advantages of these new appliances which must of necessity be more expensive in capital cost than the customary appliances.

The testing of solid-fuel appliances is undertaken by the Government Fuel Research Station in collaboration with other independent testing laboratories. Methods of test have been devised so as to take into account not only such technical factors as thermal efficiency under laboratory conditions but also the performance of the appliance under practical conditions in the home. Importance is attached to the ability of appliances to burn a wide range of fuels and tests are normally carried out using bituminous coal, gas coke, anthracite and sub-bituminous coal.

Throughout the tests full collaboration is maintained with the manufacturers of the appliances and many important modifications have been made to appliances as a direct result of the tests. It is required that the thermal efficiency and general standards of performance shall be considerably above those of appliances now in general use. In addition attention is given to appearance and convenience. Appliances which conform to the agreed thermal and practical requirements are recommended by the Government to Local Authorities who are, at present, responsible for the majority of houses being built in Britain. As a direct result of this work recommended appliances are now becoming available in increasing quantities.

CALORIMETER ROOMS FOR APPLIANCE RESEARCH

The testing methods which have been devised are generally satisfactory for differentiating between the modern efficient appliance and its inefficient predecessor. Further development, however, will depend to a large extent upon more precise and more detailed information being available to appliance designers and to architects and heating engineers. In order to provide such information four full-size calorimeter rooms have been erected at the Fuel Research Station.

THE APPLIANCE AND THE HOUSE

Data on which executive decisions could be based were required in relation to the capital costs and running costs of different heating systems and in relation to the economics of structural insulation. As a result the Building Research Station have undertaken an extensive programme of research into the performance of heating systems in actual dwelling houses. Twenty-eight houses have already been built specially for this purpose and others are being constructed.

Eight houses were built having structural insulating values ranging from typical pre-war values to somewhat better than those which have been recommended for post-war housing. Each house is equipped with a magazine-fed boiler; six houses have ceiling-panel heating and the other two have conventional hot-water radiators. During the winter of 1945–1946 the houses were unoccupied and predetermined temperature conditions were maintained. In the following winter they were occupied by tenants who used the heating system as they wished without interference. The experimental results which have now been published provide valuable information for assessing the fuel savings which can be anticipated by the use of structural insulation.

Twenty houses in semi-detached pairs were built in order to investigate the relative performance of a number of different heating systems. All of these houses were similarly insulated. The space heating in most of the houses was provided by modern appliances but in some of the houses pre-war heating appliances were installed for the purpose of comparison. As the houses were being constructed a detailed cost appraisal was made of the heating system and any building or other work associated with it. At first, with the houses unoccupied, the heating systems were operated to a predetermined schedule. This phase of the experiment is now complete and investigations are now continuing with tenants in the houses. As many physical factors as possible are being studied. The measurements are being recorded remotely in a central recording hut so as not to interfere with the tenants. Records are being obtained of the temperatures in all rooms, of the position of doors and windows, of hot water usage, of ventilation, of air movement etc. Some new techniques have had to be developed, e.g., all of the houses have been equipped with apparatus for measuring ventilation by means of instruments outside the house. This particular measurement has proved to be most important as preliminary results have shown that with some of the heating arrangements as much as half of the heat loss from the house may be by means of ventilation. Although the experiment is primarily to obtain physical and economic data, arrangements have been made to note reactions of the tenants to the various heating systems.

Four houses of the "open-plan" type are now being constructed for experimental purposes. In addition the Ministry of Fuel and Power is arranging for a number of demonstration open-plan houses with full house heating to be built in various parts of Britain to obtain tenant reaction and to introduce this type of house-plan to the British public.

In order to obtain fuller information on tenants' reactions one hundred and fifty houses with various heating systems are to be built in different parts of the country.

DISTRICT HEATING

An intensive study has been made of district heating particularly in relation to fuel conservation and to the cost of providing heat services in the home. Local authorities responsible for building new housing estates are being encouraged to consider district heating as a means of providing space heating and domestic hot water. Since the war twenty schemes have been submitted to the Government for approval; twelve of these schemes have been sanctioned. Four of the schemes are under construction, and two are in partial operation.

INDUSTRIAL HEATING

Generally the standard of fuel utilization for space heating in factories has not been of a high order. The abundance of cheap coal has probably been the greatest contributory factor. Inefficient appliances have often been used or the heating system has been tacked on to the process steam services. In addition many factory buildings have lacked structural insulation and there has been a considerable infiltration of cold air.

When the conservation of fuel became a vital necessity during the late war the Ministry of Fuel and Power launched an intensive fuel economy drive. This work was so successful that it is now being continued, and consolidated. Fuel Efficiency Committees were set up on an industrial basis to advise on specialized problems arising in various industries. Information is disseminated by means of technical bulletins, a monthly pamphlet "Fuel Efficiency News" and advertisements. This advisory service is augmented by visits of experts to factories to advise on specific problems and to survey heat utilization practice. In addition courses of instruction are arranged for stokers and executives. These arrangements have covered the use of fuel for space heating as well as for process work. Savings of fuel have been achieved by improved stoking, by improved boiler maintenance, by lagging steam and hot-water pipes, by improved steam trapping and the use of waste steam and condensate for space heating. Factory buildings have been insulated and excessive air changes reduced. The fuel savings have in many cases been spectacular. Not only has fuel been saved but in factories where the boilers have been overloaded it has been possible to increase output by economies in heat utilization. Attention has been given to the satisfactory utilization of lower-grade fuels so releasing better quality fuels for purposes for which they are more urgently needed.

The heat pump is being tried, and whilst at present it would appear that its economic application is likely to be limited, its possibilities continue to interest the Ministry of Fuel and Power. It is anticipated that further trials on a large scale may be made in the future.

TRAINING

During the late war, the heating and ventilating industry established a training scheme for its design and operative staffs. Following the war, and in conjunction with the Ministry of Education and the industries concerned, the further step was taken of establishing a National College for Heating and Ventilating, Refrigeration and Fan Engineering. The facilities to be provided by the college include research work.

CONCLUSION

The importance of the more efficient utilization of fuel for space heating is now becoming more fully appreciated in Britain. Research on appliances, houses and heating systems is being pursued and strenuous efforts are being made to disseminate information. The results of this work are becoming increasingly apparent and are most encouraging.

Bibliography

World Power Conference, British National Committee, *Reports on Fuel Economy Since 1939*.

Ministry of Works, Post War Building Studies No. 19, *Heating and Ventilation of Dwellings*, His Majesty's Stationery Office.

Ministry of Fuel and Power, *Domestic Fuel Policy*, Report by the Fuel and Power Advisory Council, His Majesty's Stationery Office.

Ministry of Fuel and Power, *Fuel and the Future*, vols. 1–3, His Majesty's Stationery Office.

Use of Electricity as a Heating Agent in Norway

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ABSTRACT

The heat requirements in Norway for domestic purposes amount to 800 kg. of coal *per capita*. Before the last war approximately 57 per cent of this requirement was covered by peat and wood. The remaining 43 per cent was covered by imported fuel, two-thirds of which was coke. During the war the import of fuel completely ceased, and the requirements had to be met by an increased use of wood and peat, and also from water-turbine-driven electricity plants. Experiments with regard to the heating of houses have shown that approximately 3 kwh. are needed to replace 1 kg. of coke in central heating plants. In buildings occupied only for some hours during the day this figure may be considerably reduced, especially if automatic switches are used. Surplus power may also be utilized by means of various apparatuses, especially electrode boilers, which are employed in conjunction with fuel-burning boilers. When power is used in this way, approximately 5 kwh. are needed to replace 1 kg. of coal or coke for heating purposes. With respect to future developments in Norway, efforts will be made to replace the entire import of fuel and one-half of the peat and wood used to-day for heating purposes with electricity produced in water-power stations. This possibility has been confirmed by developments since the war.

In Norway dwelling houses must be heated for 220 to 320 days per year, according to their location. Naturally, the period during which heating is necessary is shorter in the southern coastal regions than in the mountain regions and the northern part of the country. Along the coast the climate is humid and stormy, and the temperature may change rapidly, falling and rising around freezing point. As a rule the periods of frost last only for a few days. Inland the climate is more stable, less windy and not subject to such sudden changes, but on the other hand the periods of frost are more severe and prolonged. However, the greater part of the population lives in the coastal regions.

Prior to the Second World War solid fuel was mainly used for heating. Houses in the country and old blocks of flats in the towns had stoves in each room, but some of the newly constructed houses, shops and public buildings had central heating. In the country, wood from the neighbouring forests was the fuel most commonly used while peat was the usual fuel in the outermost coastal regions. In the towns, coke was the most common heating agent both for stoves and central heating plants, but until recently quite a large amount of coal and smaller quantities of oil were also used. Coke, coal and oil were imported.

After the First World War there was an enormous increase in the fuel prices in Norway, and as a result electric heating gradually gained some favour. Portable electric heaters were mainly used. As a rule they were used in conjunction with the usual stoves. During the spring and autumn these electric heaters were sufficient. However, during the winter it was necessary to use the ordinary stoves. The reason why electric heating did not become more popular at that time was that the charges for current then in force on economic grounds allowed only limited use. These charges did not give consideration to the size of the flats.

These conditions lasted for many years, and heating by electricity alone could therefore only be used with advantage, for example, in churches because the electrical works on Sundays delivered the necessary current for such purposes at a cheap rate.

The annual consumption of the various kinds of fuel for domestic use before the last war was as follows: Wood (including sawmill waste), approximately 4 million cub. metres, equivalent to approximately 1,100,000 (metric) tons of coal; peat, 1,500,000 cub. metres equivalent to 210,000 tons of coal; coke, 600,000 tons; coal, 300,000 tons; oil, 40,000 tons. The total amount of fuel is equivalent to approximately 2,300,000 tons of coal, of which approximately 1 million tons were imported fuel. In 1937 the population of Norway was 2.9 million, so that the average annual fuel consumption was 800 kg. of coal per head. This consumption compares favourably with that in other countries, and indicates that fuel as a heating agent has quite a high efficiency.

During the last war the average annual consumption of imported fuel for domestic use (including heating of hospitals, schools, churches and other public buildings) dropped by 870,000 tons, so that in all only approximately 90,000 tons were imported. To compensate this reduced import the average annual felling of wood was, in spite of difficulties, increased by 2 million cub. metres, and the output of peat by 500,000 cub. metres. These increases in production together equal 550,000 tons of coal. There was thus a deficit in the supply of fuel for domestic purposes of approximately 320,000 tons of coal per year. To some extent electricity was used to cover this deficit.

Since the war, wood and peat production has again decreased, but as fuel is still rationed, the previously stated figures from before the war must be assumed to give a true picture of the position if fuel had been unrationed. It must also be mentioned that fuel oil to-day has replaced a considerable amount of the coke previously used, and that the population in Norway has somewhat increased, so that the demand for imported fuel for domestic use is estimated to have increased from 1 million tons to 1,150,000 tons per year. The imported fuel is mainly used for the heating of dwelling houses in towns and densely populated areas. At present approximately 75 per cent of all the households in these places use electricity for cooking and heating of water.

It is probable that the total volume of buildings in these areas will increase by just over 1 per cent annually. The heat insulation in the new houses will be far better, but this will probably not entail a smaller consumption of fuel, for it is possible that the increase in the total volume of buildings will counteract any saving in fuel. Thus it must be supposed that the demand for fuel will increase by at least an estimated 1 per cent per year.

The most common types of outer walls in old houses have the following loss of heat per hour and per square metre of outer surface at 1 degree C. difference in temperature and no wind: 14 in. brick wall, 1.35 kcal.; concrete walls heat-insulated inside with wood fibre plates, 1.3 kcal.; wooden walls in small houses, 0.8 kcal.; (1 kcal./sq. m/degrees C/h = 0.2048 B.T.U./sq. ft./degrees F/h).

Last year the Government issued building regulations containing minimum requirements for the heat insulation of walls. These requirements vary according to the climate at the place where the house is situated. In short they limit the permissible heat transmission coefficients of cooling surfaces to the following values: fireproof walls in large buildings, 0.8 to 1.1 kcal.; fireproof walls in small buildings, 0.7 to 1.0 kcal.; wooden walls and roofs or ceilings with open-air or unheated room above, 0.6 to 0.9 kcal. To-day's facilities in heat insulation make it an economically sound proposition to use wall constructions with considerably smaller heat losses than are indicated in these regulations. The policy of the electricity undertakings to restrict the permissible heating load of new houses also stimulated the use of heat insulation. Lately, particularly in the Oslo area, considerably improved building methods have been introduced. Ten-in. brick walls and 6 in. concrete walls are now insulated on the inside with 10 to 12½ cm. porous concrete plates, the loss of heat thus being 0.75 kcal. The loss of heat for wooden houses and prefabricated houses is only 0.5 to 0.6 kcal.

In the 1930's conditions permitted the electricity works to take interest in a more extensive use of electric heating for domestic purposes. Sufficient quantities of electricity at a reasonable price were provided for the heating of dwellings houses, and experiments were commenced in connexion with the various types of heaters. These experiments showed that it was advantageous to use low-temperature heaters with large surfaces, arranged under the windows. The fronts of such heaters have an average surface temperature of approximately 80 degrees C., and they are insulated at the back so that the temperature here is generally about 60 degrees C. These heaters appeared to give off up to 45 per cent of the heat as radiation. By arranging the heaters under the window the loss of heat from a person near the window was compensated by the radiation from the panel heaters.

During and after the Second World War experiments have also been carried out on other types of heaters; skirting-board heaters have proved to be especially advantageous. These are approximately 125 mm. high and are arranged close to the floor along the outer walls. By means of tests in specially equipped experimental rooms it has been proved that skirting-board heaters and panel heaters in conjunction with each other provide a very good temperature distribution in the rooms, and it is therefore usual to-day to have a combination of these two heaters.

Electric heating has also been recently introduced for shops, offices, workshops, schools, hospitals etc. The skirting-board heater is used extensively in business premises, as these heaters can be placed close to the floor along the counter and the shelves, and thus do not occupy valuable space. This placement also provides a good distribution of heat, especially to that part of the premises where the assistants are. The type of heater which is to-day mainly in use in workshops and schools is the tubular heater, as these are very solidly constructed in mechanical respects. For schools, tubular heaters, arranged in batteries, proved more effective than panel heaters and also the radiant heat from the panel heaters troubled the pupils.

However, the heating of flats and single rooms has at present attracted the greatest interest, and a considerable number of installations have been affected. Electric heating has to a great extent been introduced in all new buildings, but at the moment the electrical works allow only a limited quantity of electricity for this purpose, dependent on the size of the flat. Due to this factor and in order to avoid additional heating by stoves, it has become common practice to insulate extensively as described above. During the war double windows were fitted into many of the old houses, and they are now fitted into all new buildings. Precise measurements have been taken and the results analysed in order to ascertain the best methods of insulating new buildings. In this connexion consumption charts (on which the consumption is dependent on the temperature) have been drawn up. These charts are of great importance to the electrical works, as they can be used to predetermine the electric power required for the heating of houses and areas, and to calculate the size of the distribution circuit and the placement of the transformers and sub-transformers.

As mentioned above it is now usual to employ panel heaters and skirting-board heaters or a combination of these two for the heating of the living rooms. Bathrooms are equipped with either high-temperature heaters, preferably arranged under the wash-basin, or tubular heaters if there is sufficient wall space for them. In halls the most common practice is to arrange a tubular heater under the space used for hanging outdoor clothes, and thus in the spring and autumn such clothes are dried and during the winter suitably warmed.

For the heating of schools and churches it is usual to regulate the heat with thermostats in conjunction with contactors, and it is also usual to utilize time switches to couple the current on and off at certain times, thereby saving current. Adequate power must therefore be available. On the basis of practical experiments in the churches, charts have been drawn up and tables made which show how many hours before the service commences, depending on the outside temperature, the heating must be coupled on to reach a suitable temperature.

For the heating of churches tubular heaters were arranged under the pews as it appeared that a better utilization of the heat was obtained than if the heaters were placed along the outer walls. After the last war two of the newest public halls and churches were equipped with heating cables which are protected by pipes and arranged in the floor, with additional panel heaters placed on the outer walls, preferably under the windows. By this arrangement heaters under the pews are avoided, but on the other hand there is a somewhat poorer utilization of the electricity. In view of the present prices of fuel and electricity, heating by electricity will nevertheless prove very advantageous.

The rates for schools have shown, however, that at present it will be more economical to have a somewhat smaller quantity coupled on also during the hours when the school is not used.

The power available for offices, shops and factories must be adequate for all the heating. In extremely cold periods the heating must be coupled on continuously day and night. On the other hand, the most common practice for dwelling houses, as mentioned before, is to place a limited amount at disposal, so that the consumers during extremely cold periods must either cut down somewhat the heating in the bedrooms and outer rooms, or supplement the supply of heat by using ordinary stoves. In order to make this possible it is necessary that all new buildings be equipped with chimneys, so that each flat can have a stove. As to the actual installation, the plans provide for each room to be heated by electricity only, because it is difficult to say in advance which room will be most used as a livingroom. One advantage of such an installation is that rooms which for some reason or other have not been heated can be heated comparatively quickly to a comfortable temperature.

Taking Norway as a whole, it appears that there are comparatively few periods of extreme cold. Also the winters may often be mild without extremely cold periods. The reduced quantity of electricity which is placed at the disposal of consumers will, therefore, be sufficient as a rule to heat their premises by this means alone. In this way the comparison between the total consumption and the maximum quantity of electricity which can be placed at disposal is: 3,500 hours for flats and 3,000 hours for offices and business premises, etc. The lower figure for offices is due to the fact that a larger amount of power than that made available for dwelling houses has been placed at their disposal and because all the current made available to dwelling houses for lighting, cooking, heating and water-heating is sold and calculated under one heading. The present prices of fuel and electricity in Norway show that heating by electricity is considerably cheaper, and thus it is only the restrictions, due to the lack of new power-stations and distribution circuits, which hinder a universal change-over to electric heating in towns and densely populated areas.

With regard to flat dwellers it may also be added that when they wish in cold weather to cook food or do other things for which much current is needed, they must reduce the heating somewhat, but this requirement which might perhaps seem perplexing under other conditions has become just as natural as the action during electricity shortages of switching off the light in a room not in use.

In Norway nearly all the electricity is obtained from water-power, but as it is impossible, owing to the lack of sufficient reservoirs, to utilize all the rivers for the production of electricity, there will be during the summer months a surplus amount of power which may be used to replace coal for industrial purposes, for instance, to produce steam in electrode boilers. From 5,000 to 10,000 v. are used, and the boilers consume up to 20,000 kw. These boilers are also used in hospitals and large baths, where even in the summer months there is a demand for quite large quantities of hot water.

In many old blocks the flats are supplied with hot water from a central heating plant where the surplus power may be utilized during the summer months. As it is not desirable to have the low-tension distribution circuit earthed in electrode boilers, heating apparatuses with resistance filaments for 20 to 100 kw. or more (230 v.) are used.

On comparing fuel with electricity for heating, the consumption of electricity and of fuel is of the greatest importance. The amounts depend on many factors. According to the premises in question, answers will be divergent as to how many kwh. are required to replace 1 kg. of coal or coke for heating purposes. The figures we have arrived at may, therefore, be of some interest.

Experiments carried out in Norway have shown that if one compares two similar blocks of flats, one being heated by means of a modern central heating plant and the other by electric heaters in the rooms, 1 kg. (2.2 lb.) of coke or coal for the first block will be equal to 2.6 to 3.0 kwh. in the second block. If one in the same way compares two similar blocks, one being heated by stoves and the other by electric heaters, it appears that 4.2 kwh. are necessary to equal 1 kg. of fuel for heating purposes. Finally, if one compares schools and large business premises which are heated for short periods during the day only and which are not used on Sundays, it appears that only 1.5 kwh. are necessary to equal 1 kg. of fuel under the assumption that a fuel-burning central heating plant is used.

All the results described above are attained by comparing direct electric heating with heating by a central-heating plant or stoves in the rooms. If electricity is used for the production of steam or hot water for domestic purposes in the electrode and resistance boiler mentioned above, it appears that as a rule one must use from 4.5 to 5.75 kwh. to replace 1 kg. of coke or coal in the fuel-burning boilers, which are economical as regards fuel, against approximately 2.8 kwh. for the heating of living quarters. All these figures are average figures for the whole of the heating season, and it is supposed that the fuel-burning boilers have no economizers.

All comparisons between fuel and electricity are made under the assumption that the coal or coke used has a heat value of 6,800 to 7,000 kcal./kg. (12,200 to 12,600 B.T.U./lb.).

As an average figure for the replacement by various types of electric heating equipment of imported fuel, it can be assumed that 3.0 kwh. are needed to replace 1 kg. of coal or coke. If all the requirement, mentioned earlier, of approximately 1 million tons of fuel is to be replaced by electricity, 3,500 million kwh. will be required.

It will also be possible to replace a substantial part of the home-produced fuel by electricity. Felling, chopping and transport of wood, as well as the carrying of wood to rooms, demands a considerable amount of labour which may be more profitably employed for some other purpose. Since it is apparently difficult to procure the timber necessary for timber refining and for the paper industry, it would be an advantage to release timber for this purpose. This applies in particular to timber from fir and pine trees, the only kind of timber which can be used for the manufacture of paper. The annual accretion of the Norwegian forests amounts to about 10 million cub. metres of coniferous trees and 2 million cub. metres of hardwood trees (birch). Industry annually consumes 7 million cub. metres and the farms, 1,200,000 cub. metres of coniferous trees for non-fuel purposes. Practically the entire remainder of the wood accretion is used as fuel divided in equal amounts between coniferous and hardwood trees. An increase in the supply of wood to industry therefore depends on a corresponding decrease in the consumption of fuel wood.

The use of peat fuel reduces intrinsic natural resources. The amount of fuel peat in the Norwegian moors is equivalent to at least 100 million tons of coal. At the normal rate of production up to the present, the resources will therefore last for 500 years or more. It is possible, however, that in the future fuel peat may also be used for other purposes, especially for the manufacture of synthetic products. There is also a possibility that electricity produced from peat in gas turbine plants may be used for some of the islands. But the most important factor which prevents any great increase in the use of peat fuel is the amount of work required for its production, transport and handling. It is particularly difficult to reduce the water content from 90 per cent to about 30 per cent in the raw peat.

Before the Second World War wood and peat were generally used for heating, cooking and heating of water. Only 20 per cent of the 450,000 country households possess kitchens fitted with electrical appliances. It may be assumed that in the country districts fuel corresponding to 500,000 tons of coal is required for the purpose of cooking and heating of water. Naturally, this fuel also helps to heat the houses. The remainder of the wood and peat, corresponding to 800,000 tons of coal, is used in stoves.

Various preliminary investigations which have been made would indicate that approximately half of the fuel supplied by wood and peat can be replaced by electricity. On the assumption that in this connexion 3.5 kwh. are equivalent to 1 kg. of coal, 2,300 million kwh. would be required to replace the requirements of 650,000 tons of coal. It may be assumed that the other half of the peat and wood would be used in the country districts and towns for additional heating during the cold periods.

The programme outlined above for the replacement of domestic fuel by electricity will thus demand approximately 5,800 million kwh. per year. The programme is already under way and it can be estimated that approximately 1,200 million kwh. per year are now being used for this purpose. Therefore, approximately 4,600 million kwh. per year remain to be supplied to consumers. If losses are also taken into consideration, the water-power stations must annually produce 5,500 million kwh. Since this requirement must be assumed to increase on an average by approximately 1 per cent per year, a total of 7,000 million kwh. will be required in 1975.

As to the possibility of supplying this amount of power from the water-power stations, it may be stated that the maximum supply of power from the water-power stations in Norway is estimated to represent approximately 90,000 million kwh. annually. There are no difficulties with regard to the distribution of the necessary power for electric heating throughout the country, as there are adequate power resources practically everywhere. Only in a few places in northern Norway and perhaps on islands lying off the coast of western Norway is a power shortage probable.

However, in places where there is an inadequate supply of electricity it is possible to use heat pumps as a source of heat. A sufficient quantity of not too cold water is one of the conditions applying to the use of heat pumps. In western Norway and in northern Norway, where there is a shortage of power, the sea-water, owing to the Gulf Stream, never has a temperature lower than plus 3 degrees C. Consequently, there is ample suitable water for the heat pumps. It is possible, by means of heat-pump plants, to produce twice as much heat as that given by direct heating by electricity. The disadvantage of this method is that it is not economical to raise the temperature of the water to such an extent that it completely replaces fuel for heating. The additional heat needed on cold and stormy days must thus still be supplied by fuel. However, no heat-pump plants have yet been built in Norway, and it remains to be seen how large the expense entailed in the execution of the plans would be. Heat-pump plants are at present rather expensive, and they can be worked economically only where large areas can be supplied with heat by this means; even then, as stated before, it is possible to cover the base load alone. There are few places in northern and western Norway where this type of plant can to-day be constructed economically. But, of course, it is possible that in the future small types of heat pumps may be manufactured in the leading industrial countries at lower prices.

It has been pointed out previously that only a limited amount of power is supplied to the various consumers of electricity for domestic purposes. In order to obtain adequate quantities of hot water for domestic purposes it is therefore necessary to heat the water during the night. For this reason small accumulating hot-water heaters for domestic use have been manufactured. In ordinary flats it is usual to have a small water heater in the kitchen holding 30 litres, and a larger heater in the bathroom holding 120 litres. The main quantity of water used in the flat during the day is thus heated during the night.

As mentioned before there will always be during the summer months a certain amount of surplus power which may be used advantageously for the heating of water in centrally-heated blocks of flats, to provide hospitals and public baths and industrial plants with adequate supplies of hot water and to replace fuel for the production of steam.

The Heat Pump as a Conservation Device

EMORY N. KEMLER

ABSTRACT

Utilization of the heat pump in the United States has progressed rapidly during the past two years. There are probably over 150 residential units installed in homes in this country and over 200 units in use in commercial buildings. These vary in size from 550 h.p. to three horsepower. Installations have been made in at least thirty-two states. In those areas where cooling becomes desirable, enthusiastic response to the heat pump has been reported.

The heat pump in the United States has been used as a space conditioning device to give cooling when required, as well as heating. The industrial uses which offer large fuel savings have not developed in this country mainly because of the availability of low-cost basic energy in the form of coal, oil or gas. Future heat-pump developments can be expected to give improved performance, reduction of energy requirements and the reduction of cost of operation. Improved performance results in conservation of basic energy or fuels.

The heat pump as a device for year-round space conditioning is a natural development to meet continued improvements in our standard of living and to provide the most efficient working conditions in plants and offices. While the heat pump has long been a device of academic interest, it has only been recently that manufacturers have gone ahead with research and development and reduced the heat pump to a reality. While the heat pump has not revolutionized space-heating practice, it has proven that the general idea is workable and that the heat pump as a mechanical device can be made to operate satisfactorily and in competition with other forms of space conditioning equipment, particularly where cooling is desired.

Heat-pump developments can be conveniently divided into three general categories: first, industrial uses; second, large commercial uses; and third, residential and small commercial uses. These categories each have different application problems and have different economic considerations. It is interesting to note that the utilization of the heat pump in Switzerland for industrial uses has come about through economic considerations. The applications there have largely been industrial and have been on the basis of savings in cost of operation and conservation of fuel. The high cost and general unavailability of coal and gas as energy sources have accelerated the use of the heat pump in that country. In the United States, the low cost of basic energy reduces the economic advantages of using the heat pump for industrial applications. As the cost of basic energy in the form of coal or gas increases, more and more heat-pump applications in industrial plants will develop.

It is in such applications as involve evaporation and condensation that the heat pump can show great savings in fuel requirements. Coefficients of performance (ratio of heating effect to heat equivalent of electrical energy input) of the order of twenty have been obtained and higher values are possible. Industrial applications using gas or diesel engines or coal-burning gas turbines are also a possibility for industrial uses. Such applications would reduce fuel requirements over direct-fired units by a factor of as much as two or four and in some cases possibly more.

The heat pump for large commercial applications, that is space conditioning in office buildings, public buildings and factories, has been used both in Switzerland and in the United States. The earlier installations in this country by Southern California Edison and American Gas and Electric Corporation have been to small office buildings. (1)[1] More recent installations by the New Haven Power and Light Company (2) and the Equitable Building (3) in Portland, Oregon, represent the continued trend both with regard to size and economic advantage of the heat pump for year-round space conditioning. These applications of the heat pump have been made because cooling as well as heating is required. The heat pump as a year-round type of comfort-producing device fills an economic need. The Portland application, being in a hydroelectric area, results in reduction of basic energy requirements. This 550 h.p. installation is now the largest in the United States.

The applications to residential and small commercial uses is treated separately primarily because heat-pump units for these installations are of a packaged type. These units have been almost exclusively used in this country and primarily in areas where cooling as well as heating is desired. The generally low cost and availability of fuel for heating in the United States does not make the heat pump attractive for residential use when considered for heating alone. Its principal advantage arises from the fact that it furnishes cooling as well as heating with the same mechanical equipment. The electrically-operated heat pump, however, can compete on an economic basis with other types of basic energy.

Practical consideration seems to indicate that a coefficient of performance (ratio of heat output to heat equivalent of electrical energy input) of about four for normal operating conditions and with reasonable temperature heat sources such as are available in most of this country would be obtainable with units of five horsepower and larger. In the more temperate regions, a coefficient of performance appreciably higher than this could be obtained for an annual average when considered on a heating basis. When considering the electrically-operated heat pump, therefore, it would appear that the heat pump is able to deliver slightly over one B.T.U. for heating purposes for each B.T.U. of fuel burned in a central power plant. This means that from the standpoint of conservation of fuel, the saving, when compared with the theoretical heating value of coal, would not be great. Since most small home heating devices are very inefficient when considered over a complete season, the heat pump on a practical basis would probably conserve from twenty-five to fifty per cent of the fuel. The heat pump does permit the utilization of hydro-

[1] Numbers in parentheses refer to items in the bibliography.

power indirectly for heating in a very efficient manner. On this basis, therefore, the residential heat pump might be considered a fuel conservation device.

The most recent development in the heat-pump field has been a gas-engine-driven heat pump. This device has a coefficient performance (ratio of heat output to heat equivalent of gas input) of approximately two. This means therefore that when utilizing some basic form of prime mover such as the gas engine to drive the heat pump, the requirements of fuel are reduced approximately in half for the heating function. This same general principle would appear to apply to any other type of prime mover which might utilize basic energy. Some of the potentialities in this direction are the utilization of the diesel engines and in the case of larger installations, the possibilities of utilizing a coal-burning gas turbine as a basis for conversion of energy. (4) Such applications would apply to small buildings and apartment houses. Under these conditions, reductions in the amount of fuel by a factor of perhaps two when producing heating would be accomplished. This type of installation is particularly attractive where the heating load is considerably larger than the cooling load.

The installations which have been made in the United States vary from the 550 h.p. installation in the Portland Equitable Building to the 3 h.p. packaged type unit available for residential use. Information furnished by the heat-pump committee shows approximately 150 commercial installations and 110 residential installations as of January 1949. (5) There are many other installations on which reports have not been furnished and there are likewise many experimental installations. Installations have been made in all of the Pacific coast and Gulf coast states. These areas are particularly adaptable for use of the heat pump in that cooling is a desirable feature for a considerable portion of the year and the heating requirements are not severe. The installations of the heat pump have not, however, been limited to these areas as installations have been made in South Dakota, Wisconsin, New York, Pennsylvania and practically all of the north central states. When it is considered that most of these installations have been made within a two-year period, it indicates a very rapid development of the heat pump. This number of installations, while not proving conclusively that the heat pump is a factor in the over-all space conditioning field, does show that a great deal of progress had been made and that continued developments are to be expected. In those areas in which cooling is an important factor, enthusiastic response to the heat pump has been reported.

One general indication of the progress, which has been made in connexion with the over-all heat-pump development has been the activities of some of the professional and trade groups. The Southeastern Electric Exchange, since 1945, maintained at the Southern Research Institute a research project concerned with a general over-all evaluation of the heat-pump possibilities. The continued interest of the electric utilities in the heat pump resulted in the formation of a joint AEIC-EEI heat-pump committee which is composed of membership of the Association of Edison Illuminating Companies and the Edison Electric Institute. (5) This committee has largely acted as a co-ordinating group and through their activities has carried out, on a committee basis, general surveys of the heat-pump activities and research by the general industry. More recently the American Society of Heating and Ventilating Engineers has formed a heat-pump research committee to review the heat-pump activities from the standpoint of that particular industry. The Air Conditioning and Refrigerating Machine Association and the American Society of Refrigerating Engineers Association also have committees on the heat pump. There are at the present time a considerable number of research projects relating to heat-pump development under way in various parts of the country. These activities are an indication of the general interest of the industry in the future possibilities of the heat pump.

Heat pumps are currently manufactured in the United States and offered for sale by the Muncie Gear Works, Muncie, Indiana, who make a water-to-air or earth-to-air unit and the Drayer-Hansen Company of Los Angeles, California, who manufacture an air-to-air unit. The Muncie Gear Works make both an electrically-powered and a gas-engine-powered unit. Other manufacturers who have made experimental units but have not as yet offered them for sale include General Electric Company, Bloomfield, New Jersey; York Corporation, York, Pennsylvania; and General Engineering and Development Company, St. Louis, Missouri. In addition, there are undoubtedly many other companies who are doing experimental development work on the heat pump.

The future of the heat pump is primarily dependent on the extent and direction of research activities on the various problems associated with it. (6) The most important problem which needs to be solved in so far as the general usage of the heat pump is concerned, is that of heat sources. (7–8) While no simple and universal heat sources have as yet been developed, there are many possible lines of attack on this problem so that there seems to be little doubt that some development which will solve this need of the heat-pump industry will be developed which will make the heat pump a universal type of equipment. Continued developments which will result in simplification of equipment and controls, reduction of size and cost, and increase in coefficient of performance are to be expected. These developments will improve the competitive position of the heat pump, result in more satisfactory performance and reduce energy requirements.

Bibliography

1. SPOM, AMBROSE and BAUMUSTER, *Heat Pumps*, John Wiley & Sons, New York.
2. "Experience with a Heat Pump System; Building of United Illuminating Company; with Cost Data", *Electrical Engineering*, vol. 63, Oct. 1944, pages 167–70.
3. J. DONALD KROEKER and RAY C. CHEWING, "A Heat Pump in an Office Building", *Heating, Piping and Air Conditioning*, vol. 20, March 1948, page 121.
4. E. N. KEMLER, "Possibilities of Heat Pump Expansion", *Heating & Ventilating*, October 1948, pages 80–85.
5. "Industrial Survey of Heat Pump Research", *Edison Electric Institute Bulletin*, March 1948, pages 85–87.
6. E. N. KEMLER and N. KULIK, "Research Aspects of the Heat Pump", *Heating, Piping and Air Conditioning*, vol. 20, no. 4 (April 1948), pages 107–112.
7. E. N. KEMLER, "Heat Sources for the Heat Pump", *Heating, Piping and Air Conditioning*, vol. 19, no. 1 (January 1947), pages 80–84.
8. E. N. KEMLER, "Design of Earth Heat Source Systems", *Heating and Ventilating*, vol. 45, no. 8 (August 1948), pages 70–73.

Space Heating with Solar Energy

MARIA TELKES

ABSTRACT

Space heating consumes a considerable part of the fossil fuel produced. Fossil fuel and wood is the product of photosynthesis, but forests convert less than 0.1 per cent of the incident solar energy into fuel.

The direct utilization of solar energy is possible, with efficiencies as high as 50 per cent. Solar water-heaters have been used and experimental test structures have been built using water as the heat-storage medium. They require an excessively large heat-storage tank, or they have to use auxiliary heating during the inevitable sequence of cloudy days.

A new method has been tested in an experimental house built at Dover, Mass., using the heat of fusion of chemical compounds for heat storage. Low-cost materials are available, melting in the favourable temperature range of 90 to 100 degrees F and capable of storing eight to ten times more heat than is possible with water, when equal storage volumes are compared. The chemical compound stores solar energy while it melts and the heat is regained again as the material recrystallizes. The chemical compound is permanently sealed and does not have to be renewed. It is possible to incorporate sufficient heat storage for an average house into a small space. During preliminary tests the new heating system operated with a 41 per cent efficiency, which is about 400 times greater than the natural photosynthetic efficiency of forests.

Solar energy is our greatest untapped energy resource and future development in its utilization should be regarded as one of the most important and fruitful projects.

Space heating consumes nearly 30 per cent of the fuel used in the United States. (1)[1] The yearly value of this fuel has been estimated at 3,500 million dollars. In other parts of the world an even greater percentage of the fuel produced is burned, to maintain comfortable temperatures. Scarcity of fuel depresses the standard of living and the availability of fuel is one of the most important factors in the progress of civilization.

Is it necessary to rely on fossil fuel alone? Would it be possible to eliminate the difficult task of mining and transporting coal or collecting wood? It is well known that fossil fuel is the result of photosynthesis during geological ages, while wood is the product of the contemporary action of solar energy. The forests utilize less than 0.1 per cent of the solar radiation incident upon them. (2) Even under the most favourable conditions, the efficiency of photosynthesis is less than 2 per cent.

The important question is: can we compete with nature in capturing and storing solar energy with a much greater technical and economical efficiency? Is it possible to solve the task of space heating by using the omnipresent solar power, replacing, when possible, fossil fuel with solar energy as a new fuel resource?

Solar Energy Received on One Square Foot of Surface, During an Average Day at Optimum Incidence

	B.T.U.	*Fuel equivalent in pounds of coal*
Tropical, yearly average . .	3,000	0.25
Temperate zone: (Lat. 35–40 degrees, U.S.A.)		
Summer, average	2,000	0.17
Winter, maximum	2,000	0.17
Winter, average	1,000 to 1,500	0.08–0.12

[1] Numbers in parentheses refer to items in the bibliography.

THE AVAILABLE AMOUNT OF SOLAR ENERGY

Weather Bureau records give the number of sunshine hours during each month for a large number of locations. Quantitative data have been collected at a limited number of observing stations. The amount of solar energy varies considerably and it is not a simple function of the geographical latitude. The following table gives a very broad estimate and serves merely to show the magnitude of the available energy.

For the purpose of evaluating the possibilities of solar space heating, let us consider a small home, receiving 1,000 to 1,500 B.T.U. per square foot during an average winter day, with a heat load of 400,000 B.T.U. per day, corresponding to conditions of 1000 degree-days per month. These are typical conditions for Lat. 35 to 40 degrees in the United States. If it were possible to use for space heating at least 50 per cent of the average winter solar energy, that is 500 to 750 B.T.U. per square foot during an average winter day, the above home would require a solar energy collecting surface of 500 to 800 sq. ft. Such a surface cannot be regarded as excessive and it may easily be incorporated in the roof or south wall of the house. In warmer locations the solar energy collecting area could be correspondingly smaller.

PREVIOUS EXPERIMENTS WITH SOLAR HEATING

During the past 20 years solar water-heaters have become increasingly popular in Florida and in California. In these states clear weather occurs nearly 70 per cent of the possible time and a cloudy day is seldom followed by another cloudy day. These water-heaters consist of a collector of solar energy, mounted on the roof, and an insulated storage tank, large enough to store at least two days' supply of hot water. The collector is a well insulated flat box, covered with one or two air-spaced glass panes, to transmit solar energy, which in turn is absorbed by a thin black metal plate with water circulating pipes soldered to it. According to various reports (3) (4), the efficiency of such heaters is rather high in Florida and in California. If properly designed, the solar heaters can convert at least 50 per cent of the incident solar energy for the purpose of heating water. The most difficult problem is the need for storing enough hot water for the inevitable cloudy days.

Experiments have been conducted at the Massachusetts Institute of Technology in Cambridge, Mass., since 1940, incorporating a large water-heater in the roof of a test structure. (5) It was found that the two-room structure could be heated during the winter, but this required an excessively large storage tank. Similar experiments are now in progress in a small home, located near the Massachusetts Institute of Technology, using a roof-type water-heater with a storage tank, capable of accumulating a two days' supply of heat, with additional electrical heating provided for the inevitable sequences of cloudy days. Similar tests have been carried out in Switzerland.

Another home in Colorado used crushed rocks as the heat storage medium. Solar heat was collected on the roof, behind air-spaced glass panes and the warm air was circulated through the house, or through an insulated compartment filled with heat storing rocks. (6) This house used a conventional fuel burning furnace because solar heat could be stored only overnight.

South-facing windows transmit considerable amounts of the low slanting rays of the winter sun. The use of large, south-facing windows has been popularized recently. Such architectural "solar houses" may collect a great deal of solar heat during clear winter days, often overheating the house. The gain is rapidly lost at night and on cloudy days and consequently a true "net gain" is probably limited to warmer climates.

THE EFFICIENCY OF SOLAR HEAT COLLECTION

The type of solar heat collector, used for water heating, if properly designed can be very efficient. The thin black painted metal plate absorbs solar heat and transfers part of this heat to a circulating medium. Air-spaced transparent panes serve to diminish the outward heat losses, due to re-radiation and convection. The number of such "heat trapping" panes is limited, because there is a loss of 10 per cent, due to reflection, on each transparent pane. The optimum number of panes appears to be two, transmitting about 80 per cent solar energy at near optimum incidence. If re-radiation and convection losses are limited to 30 per cent, the balance of 50 per cent is the "net gain", that is, the collector utilizes the incident solar energy with an efficiency of 50 per cent.

These figures should be considered as average figures throughout the day. Solar radiation is of variable intensity, lower during the early morning and late afternoon than the noontime peak, therefore higher efficiencies will be observed during the noon hours. The re-radiation and convection losses increase with the temperature difference between the collector plate and the outdoor air. Higher temperatures of collection, at a high enough efficiency, could only be reached with solar energy of higher intensity. It appears, therefore, that higher collector efficiency can be attained only with collectors operating at a moderate temperature, preferably below 110 degrees F.

SOLAR HEAT STORAGE, THE CRITICAL PROBLEM

The need for storing solar heat, not only overnight, but also during a sequence of cloudy days, is obviously a critical problem. If the collector temperature is limited to a 110 degrees F. maximum for reasons of collection efficiency, the temperature of heat storage must be lower. For space heating an average indoor temperature of 70 degrees F. is required and therefore the temperature of heat storage must be greater than this value, consequently the temperature change of the heat storage medium will be limited to a rather narrow range, possibly not more than 20 degrees F.

Using the specific heat of water for heat storage purposes, it is probable that not more than 20 B.T.U. can be stored effectively per pound of water during one winter day. The specific heat of other materials (rocks, etc.) is lower than that of water and their heat storage capacity per pound will be lower too.

Fortunately the specific heat effect is not the only heat storage possibility. The heat of transformation, or heat of fusion of chemical compounds, appears to offer much higher heat capacity for storage. Several chemical compounds, or mixtures, are available, with heat storage capacities in excess of 100 B.T.U. per lb. of material. Some of these compounds melt within the 90 to 100 degrees F. temperature range and are readily available at a very low cost. Typical materials are for instance, sodium sulphate decahydrate, $Na_2SO_4.10H_2O$, melting at 90 degrees F., or disodium phosphate dodecahydrate, $Na_2HPO_4.12H_2O$, melting around 95 degrees F. There are several other suitable mixtures.

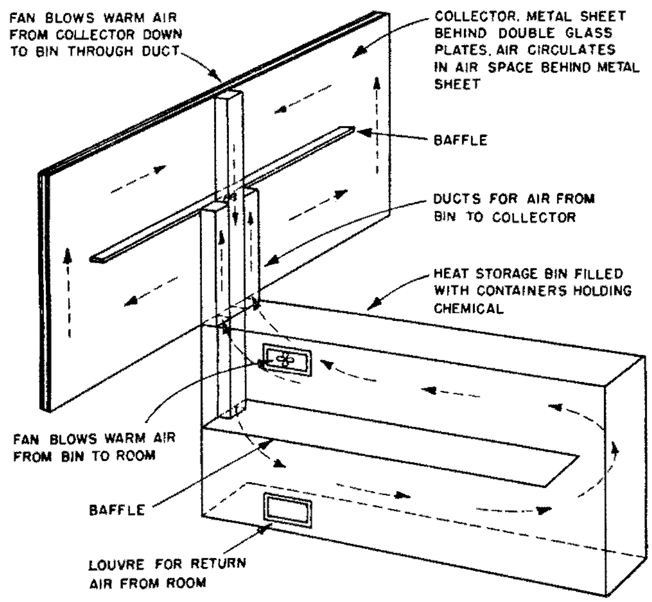

Fig. 1. Heating System of Sun-Heated House Dover, Mass. 1948

The amount of heat required to melt these compounds is stored in them; when heat is abstracted the materials re-crystallize again. The process of fusion and re-solidification can be repeated continuously. The chemical compound is placed in closed containers and it never needs to be renewed. Some of these materials are capable of storing eight to ten times more heat than is possible with water, when equal volumes are compared. The use of these heat-of-fusion materials therefore diminishes the heat storage volume required for space heating with solar energy. (7) The diagram shown in figure 1 is one of the possible solutions of arranging a solar energy collector and the heat storage material, assembled in a "heat bin".

While the heat of fusion is a definite physical constant, it is not sufficient to fill containers with this material. Several problems must be met, such as the prevention of corrosion of metallic parts, the promotion of recrystallization by preventing undercooling and the most advantageous shape factors for efficient heat transfer. This form of heat storage is basically a heat exchange problem, based upon the first law of thermodynamics.

EXPERIMENTAL HOUSE, BUILT AT DOVER, MASS.

An experimental house, located in Dover, Mass. (15 miles from Boston), was completed in December 1948. The house uses the heat-of-fusion principle for solar heat storage. The south-facing vertical collector of the 720-square-foot area is located in the attic of the house. Air warmed by solar energy is circulated by fans to the heat storage units, "heat bins" located between the rooms. Figure 1 shows the diagram of the heating system, while figure 2 is a view of the house.

The total volume of the chemical mixture used is 470 cub. ft. (3,500 gallons) and its weight is 21 tons, capable of storing about 4 million B.T.U. at 88 to 90 degrees F. The house has a volume of 10,000 cub. ft. The average winter heating requirement of the house is 400,000 B.T.U. per day, therefore the completely charged "heat bins" should be capable of providing space heating for ten consecutive sunless winter days.

The heat is transferred from the storage units into the rooms partly by radiation through the walls of the bins and partly by circulating the air of the rooms through the bins. It is obvious that several other locations for the collector and the storage units are equally possible, as well as other systems of heat transfer.

Designed by Eleanor Raymond, architect, the house has several south-facing double windows to make use of additional winter sunshine. This project has been sponsored by Amelia Peabody of Boston and it is not connected with the Cambridge project.

Preliminary data, collected during the past February, indicate that the collection efficiency during the entire month was 41 per cent of the total incident solar energy. During this month there were ten days when no heat could be collected at all. The total amount of solar energy recorded during these ten cloudy days was less than the amount received during an average clear day. The collection ranged in efficiency from 45 to 60 per cent during clear days, but it was lower on partly cloudy days. The longest sequence of cloudy days was five, which is in accordance with weather statistics in this vicinity.

During the summer the ducts of the collector are opened and the cool night air is circulated through the storage system, lowering its temperature. The specific heat capacity of the solidified chemical compound is sufficient to keep the house comfortably cool during the warm summer days. In this way the winter storage system can be operated "in reverse" during the summer.

FUTURE DEVELOPMENT

Compared to the efforts made in the past during the development of efficient space-heaters using fossil fuel, the efforts made so far in the utilization of solar energy are infinitesimal. Considerable research and development work is probably needed, before solar space-heaters will be readily available for general use. The basic principles have been established and the trend of development is clearly indicated.

The use of solar space-heating offers numerous advantages. The relatively low temperatures encountered during its operation preclude any fire hazards. There are no problems due to smoke, ashes and their disposal. The fuel it saves can be used for other purposes. After the initial cost of installation, the upkeep of the solar heater is very low. Solar space-heating should be an important economical factor in regions where coal is scarce or where it has to be imported.

In addition to space heating in homes, solar energy offers other possibilities of utilization, such as greenhouse-heating, water distillation and ultimately electrical power production.

Solar energy is the greatest untapped energy resource of the world and its utilization should be one of the most important and fruitful projects.

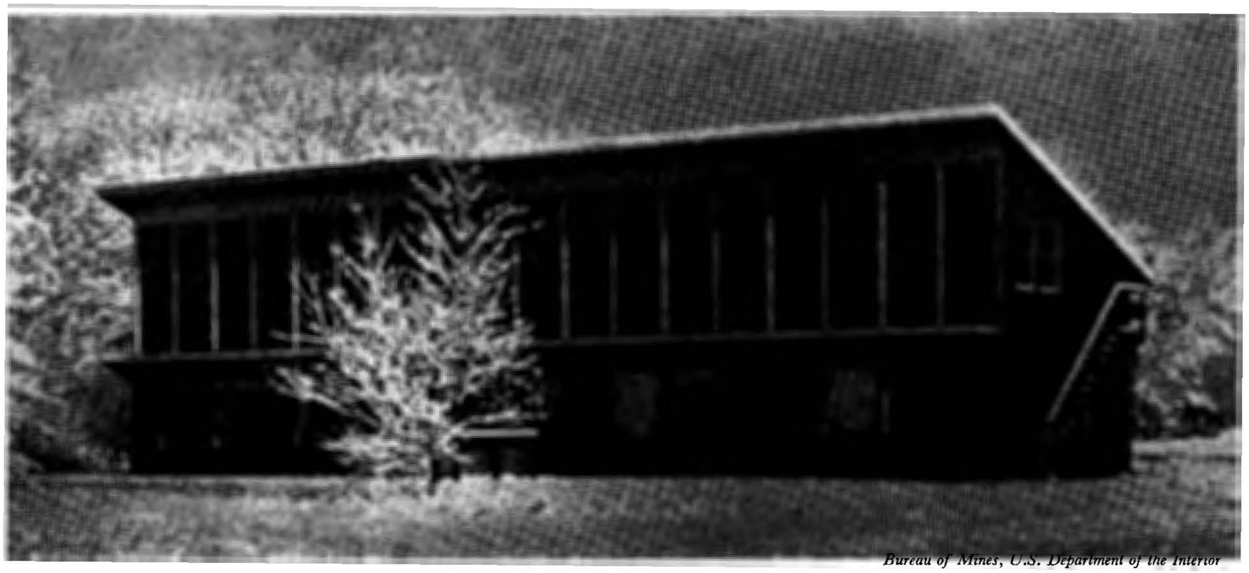

Fig. 2. Sun-Heated House, Dover, Mass., 1948. Owner: Amelia Peabody. Architect: Eleanor Raymond

Bibliography

1. EUGENE AYRES, "Major Sources of Energy", American Petroleum Institute 28th Annual Meeting, Division of Refining, 1948, pages 109–142.
2. FARRINGTON DANIELS, "Solar Energy", *Science*, vol. 109 (Jan 21, 1949), pages 51–57.
3. F. A. BROOKS, *Solar Energy and its Use for Heating Water in California*, University of Cal. Agricultural Experiment Station Bull. 602, Nov. 1936.
4. H. M. HAWKINS, *Solar Water Heating in Florida*, University of Florida Engineering Experiment Station Bull. 18, Sept. 1947, 26 pages.
5. H. C. HOTTEL and B. B. WOERTZ, "The Performance of Flat-Plate Solar-Heat Collectors", Am. Soc. Mech. Eng. *Transactions*, vol. 64 (Feb. 1942), pages 91–104.
6. G. O. G. LOF, *Solar Energ v Utilization for House Heating*, U.S. Office of the Publication Board, PB 25373, 1946.
7. MARIA TELKES, "Solar House Heating—a Problem of Heat Storage", *Heating and Ventilating*, vol. 44, 1947, pages 68–75.

Economies in Heating[1]

O. MASTOVSKY

Czechoslovakia's energy economy is based almost exclusively on coal, which supplies approximately 95 per cent of all energy consumed while wood accounts for only 3 per cent, and water-power for 2 per cent.

As in other countries in the temperate and cold zones, a substantial portion of the total energy consumed is used for heating purposes. In 1948, the State Bureau of Planning and the Coal Distribution Centre allocated to households about 15 per cent of the total coal consumed in the country. In addition to providing energy for space heating, this fuel also serves for the preparation of food, the heating of water, and other domestic purposes. On the other hand, approximately 1.5 per cent of the total coal consumed was devoted to space heating and domestic purposes in the form of refined energy — gas, electricity and central station heat. It is estimated that in all 36×10^{12} kcal. are devoted to space heating in households and industry, representing a *per capita* consumption of approximately 3 million kcal. annually for the 12.2 million inhabitants of the Republic.

Per capita consumption of energy for heating purposes in Greater Prague (population 922,000) is 7 million kcal., or more than twice as great as the *per capita* figure for Czechoslovakia as a whole. The number of consumers in various categories of consumption and their total and average allocations are given in the following table:

Annual Consumption of Coal for Heating in Greater Prague
(in tons of pit coal equivalent)

Category of consumers	*Number of consumers (per cent)*	*Total allocation (tons)*	*Total allocation (per cent)*	*Average allocation per consumer (tons)*
Households with heating stoves ...	82.8	460,000	42.5	1.48
Small traders and large consumers .	10.45	275,000	25.4	7.0
Central and floor heating	2.35	332,100	30.7	37.5
Allocation for cooking and washing alone	4.4	15,000	1.4	0.92

It is possible to estimate theoretically the space-heating requirements for Prague, which is located on the 50th parallel and which has a heating period of about 180 days, when the average temperature is 3 degrees C. and the lowest temperature is about −20 degrees C. This results in heating requirements of 3,050 degree-days and a theoretical utilization of heating equipment for 1,830 hours. According to experience, the effective annual utilization is only 1,500 hours and may possibly be as low as 1,000 hours. Space-heating requirements for the whole heating period are theoretically estimated at 60,000 to 137,000 kcal. per cub. metre, depending on the type of building, while actual consumption is estimated at 20,000 to 80,000 kcal. per cub. metre.

The relatively smaller consumption in actual practice, as compared to the theoretical computation, does not appear to be caused by insufficient fuel allocation, for in 1936 when coal was not rationed consumption was even lower. Rather it appears to be explained by the specific properties of heating equipment and the manner in which they were used; e.g., restriction of heating, in the case of stoves, in order to minimize attendance, as well as for economy reasons.

The following table summarizes data, based on actual practice in Greater Prague, showing heat energy supplied according to various methods.

Annual Output of Heat Energy, by Heating Method, Greater Prague

Heating Method	*Total Useful Heat Output (10^9 kcal.)*	*Heat Consumption per Space Unit (1,000 kcal. per cub. metre)*
Heating stoves ..	1,000	20–50
Central heating..	1,100	40–80
Long-distance heating	75	48–56
Electricity	22	30–50
Gas	16	30–40

It is possible to compute further the amount of fuel energy which is expended to achieve a given amount of useful heat or to heat a unit of space. The data given in the table below show, from the viewpoint of energetics, that the most favourable method is long distance heating, the working conditions of which permit a substantial production of "waste" current — up to 0.25 kwh. per kg. of steam — and where energy consumption may be as low as 10,000 kcal. per cub. metre. The other extreme is heating by electricity generated at condensing steam plants where the energy consumed may be up to 300,000 kcal. per cub. metre.

[1] This is a condensed version of a longer paper prepared by the author which includes more detailed data underlying the summary figures presented here. These detailed data embody the results of a sample questionnaire survey of Prague consumers and a study of the allocations to consumers by the Central Coal Board.

Specific Energy Requirements by Heating Method

Method of heating	*Energy required per 1,000 kcal. of heat output (kcal)*	*Energy required per unit of space (1,000 kcal. per cub. metre)*	*Heating cost per space unit (korunas per cub. metre)*
Heating stoves	1,800 (about)	36– 90	5.40–13.50
Central heating, coal ...	1,430	80–120	9.00–18.00
Central heating, coke ...	2,400	96–180	10.00–20.00
Long-distance heating ..	300–1,900[1]	10–100	12.00–22.00
Electricity	1,900–6,000[1]	60–300	23.00–40.00
Lighting gas	1,250–2,100	60– 80	26.00–35.00

[1] The lower values apply to central heating plants with a considerable current production.

In the case of large-scale industrial establishments, space heating is usually closely connected with the production of industrial heat and electricity. An important step in the direction of fuel economy, the Government, pursuant to a 1947 decree, regulates this activity, giving special attention to the training of heat and power plant personnel and controlling investments for the construction of new power plants and the adaptation of existing plants.

The concentration of the public utilities producing and distributing electricity, gas and long-distance heat in a single national corporation is another innovation which will contribute to the more efficient use of the energy resources of the Republic.

Summary of Discussion

The CHAIRMAN said that the consumption of fuel for domestic heating accounted for 30, 40 or even 50 per cent of the total fuel consumption in countries where space-heating was comparatively advanced. Heating was no longer considered a luxury, but was recognized to be necessary for the health of the people and to ensure efficient work. It was therefore essential to concentrate on conserving fuel and to seek the most economical and efficient methods of space-heating.

The first part of the discussion would deal with the general practices and recent developments in space-heating in various countries of the world. The second part would be devoted to two new developments, namely the use of the heat pump, and the use of solar energy for space-heating.

Mr. IGNATIEFF presented the paper on "Conservation in Utilization of Fuel for Space Heating" on behalf of Mr. Hutcheon and Mr. Legget. The first part of the paper comprised a statistical survey of the existing position in Canada and the second part analysed the heating methods with special regard to the question of conservation.

One of the chief factors to be taken into account in Canada was the relatively rigorous climate in winter. The chief fuel used was coal, which was mostly imported from the United States so that the high cost of transportation had to be taken into account. Very little electrical energy derived from water power was used for domestic heating and there was considerable reliance on wood, although the use of oil was increasing.

Most of the houses in Canada were of wood-frame construction and they all had insulation in some form or another. The paper further described the developments in space-heating methods from the simple heating stove to the newer forced circulation systems. The development of district heating in Canada was problematical in view of the low annual load factor for space-heating.

In conclusion, he said that future development would depend on considerations of economy as well as on a constantly rising standard of living. Because of the country's dependence on imports for its supply of coal, there was a definite tendency to use the most efficient equipment, which could consume the cheaper varieties of fuel. The higher standard of living had led to greater demands for comfort so that, whereas 68 degrees F. had at one time been considered a good average indoor temperature, people were now beginning to expect temperatures of 72 degrees F. Thus, some of the fuel saved by improved heating methods was being used to provide higher temperatures.

Mr. DILL summarized his paper on the "Conservation of Fuel in Space Heating with Special Reference to Insulation". The paper indicated the growing use of thermal insulation in the United States, described the types of insulating materials and discussed methods of application, units of measurement, testing methods and the problem of condensation in buildings.

Estimates of fuel consumption in houses and savings due to insulation were seldom, if ever, exact, but it was shown that effective insulation of a house could save approximately 50 per cent of the fuel consumption.

Mr. MACFARLANE presented the paper on "Conservation in Utilization of Fuel for Space Heating" on behalf of Mr. Rowse, Mr. Weston and Mr. Lant. The problem in the United Kingdom resembled that of Canada and the United States inasmuch as about 30 per cent of the fuel production of the country was used for heating purposes. In other respects, however, the situation differed greatly. In the first place, the climate in England was generally equable and, in the second place, heavier clothing was worn than in the United States.

For many years the open fire had been the chief characteristic of heating in the United Kingdom, but since the Second World War the scarcity of coal and the increase in its price had caused people to turn to other methods. In the past, heating had been considered in terms of each individual room rather than of the house as a whole, since it had been possible, if not always comfortable, to heat rooms only when they were actually occupied.

The paper described some of the research that had been carried out to test the new appliances that have been designed, and investigations of the possibilities of district heating.

Mr. MACFARLANE drew special attention to the experiment mentioned in the paper in which twenty houses had been built in semi-detached pairs in order to investigate the relative performance of a number of different heating systems. The first part of the experiment had been carried out with the houses unoccupied, but during the second phase they would be occupied and the reactions of the tenants would be noted. It would be very interesting to see what temperature conditions were preferred by the average householder in the United Kingdom. Illustrating his remarks with slides showing the relative cost and efficiency of the various methods, he concluded by stating that the first phase of the experiment had shown that the savings in fuel with a central heating system went far to counter-balance the higher cost of installation.

Mr. HALS summarized the paper which he had prepared in collaboration with Mr. Holmgren and Mr. Lindemann on the "Use of Electricity as a Heating Agent in Norway". Before the Second World War, 43 per cent of the fuel needed for domestic heating purposes had been imported. During the war, the import of fuel had ceased and the requirements had been met by an increased use of wood and peat as well as from water-turbine-driven electricity plants. Experiments had shown that, for domestic heating, approximately 3 kwh. were needed to replace 1 kg. of coke in central heating plants. Efforts would be made in the future to replace the entire import of fuel, and half of the peat and wood consumed for heating purposes, by electricity produced in water-power stations.

Mr. TASKER said that the question of heating costs was of very great importance both to householders and to industry. It was the task of the competent experts to lower heating costs and at the same time to provide the people with the comfort they wanted. The calculation of the fuel requirements for heating enclosed spaces involved many factors, including outdoor weather conditions, indoor air temperatures and possibly humidity, the thermal properties of building materials and the amount of outside ventilation air introduced either deliberately or by chance. The research now being carried out in the United Kingdom would undoubtedly yield most valuable information on all those points. It was interesting to note that people had become accustomed to and were now asking for higher temperatures inside their homes. It was necessary to ascertain the range of temperatures which they regarded as essential for their comfort. In industry, any reduction of the excessive heat which some workers had to endure would save fuel and improve working conditions. The studies now being carried out in many countries made it possible to look forward to considerable savings in fuel and to a marked increase in personal comfort both at home and at work.

Mr. CHERADAME pointed out that central heating installations in France were relying more and more on fuel oil instead of coal or coke, not only because of the price factor but also because there was some difficulty in recruiting the necessary personnel for coal boilers. Indeed, both boiler operation and temperature regulation were much easier with fuel oil than with coal.

France had always experienced some difficulty in finding outlets for surplus coke from gas-works and for small-size coke unsuitable for industrial problems. Hence, the French authorities were now advocating the use of those types of coke for central heating purposes. One of the disadvantages, however, was that, all things being equal, a coke boiler was necessarily much larger in size and more expensive than an anthracite boiler. Efforts were also being made to improve the efficiency of domestic appliances. A special centre had been set up to study the heating efficiency of the various heating appliances, i.e., the proportion of utilized heating as compared with the calorific power of the fuel. Some of the appliances averaged an efficiency of 70 and even 80 per cent. French research had also been concerned with the possibility of utilizing particular types of coal, such as the sub-bituminous coal from Provence; this will be followed by research concerning "flaming" (*flambant*) coal from Lorraine.

Mr. LINDEMANN said that measures to provide the whole of Oslo with electric heating for all purposes had been initiated in 1936. Tests were carried out in specially equipped experimental rooms to find out how to obtain the best temperature distribution in the rooms in order to save electric power. Panel heaters and skirting-board heaters had proved very successful in that connexion. The experiments had shown that it was possible to heat the City of Oslo, which had a population of 300,000 inhabitants, with a total peak load of 600,000 kw. That figure included 100,000 kw. for industrial purposes. The present winter peak load stood at 175,000 kw. including 50,000 for industry. The use of electric heating in most of the homes would lead to an annual saving of between 400,000 and 500,000 tons of coal. Another important factor was that consumers had to pay less for electric power than for coal.

Mr. HUNTER said that, in the final analysis, conservation of fuel could only be accomplished by people, namely, the architect or builder, the tenant or owner, the designer of the heating system, the contractor who installed that system and the manufacturer responsible for the design of the various components of the system. In that connexion, he wished to emphasize that one of the characteristics of the situation in the United States was the trend towards joint co-operation by organizations of professional people and manufacturers who endeavoured to find solutions to technical problems of mutual interest by pooling technical knowledge and finance. Those organizations included the American Society of Heating and Ventilating Engineers, The American Society of Mechanical Engineers, the Institute of Boiler and Radiator Manufacturers, The Steel Boiler Institute, The National Warm Air Heating and Air Conditioning Association and several others. Any individual or nation faced with the responsibility of conservation and utilization of fuels would find it useful to study the findings of those organizations.

Mr. E. A. HARDY said that he was very interested in the Oslo experiment because a similar one had been carried out in Western Canada thirty years previously. It had failed because, owing to insufficient insulation, the cost of electric heating had proved too high. Present-day insulation in Canada was causing many difficulties because of condensation of frost within the walls, in the chimneys, etc. and the problem was still being debated. The tendency in new buildings was to utilize improved insulation and install larger windows to admit as much sunlight as possible.

Mr. SHERMAN said that, although the cost factor was predominant in industry, the same was not always true of comfort heating. Indeed, various circumstances often prevented the adoption of the most economical fuel. For instance, many people lacked money for the purchase of necessary equipment, even though the saving in fuel cost thus achieved could amortize the investment in a reasonable period of time. Furthermore, personal tastes and habits were often more powerful than the desire for economy. In his opinion, no form of heating was more convenient and provided for greater comfort than the district heating system, namely the supply of hot water or steam from a central plant.

Mr. KEMLER summarized the paper he had prepared on "The Heat Pump as a Conservation Device". The heat pump as an idea was over a century old and a working unit had been developed by Haldane in Scotland about thirty years ago. As a preserver of energy the device was demonstrating its efficiency in over two hundred units in commercial buildings and one hundred and fifty residential units operating in the United States. With a 5 h.p. motor, electrical energy capable of producing one B.T.U. could be transformed into four B.T.U. The application of the device in the United States had been rather limited, because the comparatively low cost of fuel did not give much of an economic advantage to the heat pump in residential space heating. In Switzerland, where the cost of fuel was relatively high, the heat pump had found wider application.

When a larger horse-power was employed, the heat pump displayed a greater coefficient of performance than the four to one previously indicated. For example, in the 550 h.p. unit in Portland, Oregon, there was a coefficient of five to one, and when the important aspect of space cooling, applicable in other sections of the plant, was taken into consideration, the productive output was even higher.

The gas-engine-driven heat pump was the most recent development in the field and indicated the possibility of using diesel engines and, in the case of larger installations, coal-burning gas turbines as prime movers.

Mr. Kemler estimated that the saving in fuel from the application of the heat pump principle, even at its present stage of development, to homes would vary from 25 to 50 per cent according to conditions. The most important research problem which had to be solved was that of heat sources for the pump, but there was little doubt that a solution of that need of the heat-pump industry would be found, making the heat pump a universal type of equipment.

The CHAIRMAN, in introducing the subject of solar energy, recalled the recent public statement of United States Secretary of the Interior Krug on the interest of his department in that subject.

Miss TELKES outlined her paper on "Space Heating with Solar Energy". Thirty per cent of the fuel used in the United States was consumed by space heating and it was a question whether fuel alone had to be relied upon for that purpose, since fossil fuel was the result of photosynthesis during geological ages and wood was the product of the contemporary action of solar energy. In view of the fact that the forests utilized less than 0.1 per cent of solar radiation and the efficiency of photosynthesis was less than 2 per cent, science had the possibility of competing with nature in capturing and storing omnipresent solar power.

In the average United States latitude, a small home received 1,000 to 1,500 B.T.U. per sq. ft. during an average winter day and if 50 per cent of that winter solar energy could be utilized for space heating, such a home would require a solar energy collecting surface of only 500 to 750 sq. ft. During the past twenty years experiments with solar heating had used water or crushed rocks as the heat storage medium. Solar water-heaters had become increasingly popular in Florida and California. Experiments at the Massachusetts Institute of Technology with a solar water heater resulted in the successful heating of a two-roomed structure during the winter by stored hot water, but an excessively large storage tank had been required. Although many "solar houses" were being built with south-facing windows, which transmitted considerable amounts of the low slanting rays of the winter sun, the gain was rapidly lost at night and the heating was ineffective on cloudy days.

After discussing the problem raised by the search for an efficient heat storage medium, in order to overcome the difficulty of cloudy days and night time, Miss Telkes outlined a new development. The latent heat of fusion of chemical compounds appeared to offer much higher capacity for heat storage than the specific heat of such materials as water and rocks. There were several chemical compounds, such as sodium sulphate decahydrate and disodium phosphate dodecahydrate, which possessed heat storage capacities in excess of 100 B.T.U. per lb., in addition to the specific heat capacity of the materials. The amount of heat required to melt such compounds was stored in them, and when the heat was abstracted the materials simply recrystallized. The process of melting and recrystallization could be repeated continually when the compound was placed in closed containers.

Utilizing the chemical approach to the heat storage problem, an experimental house was completed in Dover, Massachusetts, in December 1948. When the "heat bins" of the house were completely charged, that is, when the chemical mixture had absorbed its full capacity of heat, it was estimated that they should be capable of providing space heating for ten consecutive sunless winter days. During February of the current year, when there were ten cloudless days, preliminary data indicated that the collection efficiency for the month averaged 41 per cent of the total incident solar energy. During the summer months, by opening the ducts of the collector, the cool night air lowered the temperature of the storage system sufficiently to keep the house comfortably cool in the daytime.

The speaker emphasized that efforts made so far in the utilization of solar energy were infinitesimal and considerable research was needed before solar space-heaters would be readily available for general use; but the basic principle had been established and the trend of development was clearly indicated. After considerable research, solar energy, the greatest untapped energy resource, would ultimately be a source of power production.

Mr. BLOCH stated that the subject of solar energy was one of great interest to Israel. The sub-tropics had an ample supply of solar energy, and the great need there was the cooling of houses. While the houses were cooled at night by the wind, they soon became overheated during the day. Insulation alone was not a solution, since heat storage capacity of building materials was as important as insulation, a fact recognized in the Middle East for centuries and responsible for construction of houses with extra thick walls and roofs. The current need for mass production of houses made that type of construction impracticable and the speaker thought that some application of the principle of the chemical storing of heat, as outlined in Miss Telkes' paper, might be a solution to the problem of cooling in summer and heating in winter in sub-tropical regions.

Mr. GOLDSCHMIDT asked Miss Telkes whether any thought had been given to supplementing the storage of solar energy with the storage heat derived from off-peak power.

Miss TELKES thought that the storage of off-peak power offered great possibilities.

Mr. PAIGE wondered how much research had been done in the development of special glass in connexion with solar energy.

Miss TELKES said that in the Dover house ordinary configurated glass had been used since low-reflection glass was very expensive. The use of the latter, however, in combination with a system of multiple panes to trap the heat would greatly simplify the task of collection of solar energy.

Mr. TASKER said that the American Society of Heating and Ventilating Engineers had recently published the results of a careful study of the characteristics of various types of glass with respect to transmittance of solar energy.

Mr. ERSELCUK said that he understood that a solar energy powerplant was already in existence at Tashkent.

Miss TELKES observed that, although some general information was available on the Tashkent plant, details of its operation were not known.

Mr. HUBBERT wondered whether Mr. Kemler had any information on the amount of heat that could be gained from the use of ground holes. For example, could an ordinary house get any benefit from a hole one hundred feet deep?

Mr. KEMLER did not think so, but the question was difficult to answer without an examination of specific conditions.

The CHAIRMAN drew attention to the paper "Economies in Heating" by O. Mastovsky, Czechoslovakia, which had been received too late to be reproduced for the Conference but which would be included in the printed proceedings.

He concluded the meeting with the expression of the hope that the exchange of opinions which had taken place would lead to more intensive research on the problem of conserving fuel utilized for space heating.

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The Integrated Power System

30 August 1949

Chairman:

EINAR FALKUM, Norwegian Hydro-Electric Nitrogen Corporation, Oslo, Norway

Contributed Papers:

The Integrated Power System as the Basic Mechanism for Power Supply
PHILIP SPORN, President, American Gas and Electric Company, New York, New York, U.S.A.

Some Experiences of the Operation of the Electricity Grid System in Great Britain
SIR JOHN HACKING, British Electricity Authority, London, England

The Total Joint Operation of Electrical Power Systems in Sweden
GOSTA NILSSON, Vice President, Swedish State Power Board, Sweden

Utilization of Energy: The Integrated Power System; Possibilities for the Development of a European Power Grid
P. AILLERET, Chairman of the Committee on Electric Power of the United Nations Economic Commission for Europe

French Mine-Mouth Power Stations (1952 Programme); Features Due to the High Ash Content of the Fuel Burned
M. GEORGES, *Ingénieur en chef des mines*, Paris, and
M. GIBRAT, *Professeur à l'Ecole nationale supérieure des mines*, Paris, France

Summary of Discussion:

Discussants:

MR. SPORN, SIR HAROLD HARTLEY, Messrs. MALMSTRÖM, AUBERT, THOMAS, CRARY HANNUM, LINDEMANN, KARPOV, HALS, ANGUS, DE MERIT

Programme Officer:

MR. J. H. ANGUS

The Integrated Power System as the Basic Mechanism for Power Supply

PHILIP SPORN

CONTENTS

I. INTRODUCTION

For some years now there has been a tendency to over-appraise the role of electric power in advancing the economic development and welfare of areas or regions, or even nations. There has been a tendency to assign to electrification a magic role which electric energy is incapable of performing. For, as this conference will stress, abundant electric energy is only one of many essential resources: a balanced development of all of them is important in leading to a high standard of living.

Nevertheless, even an objective appraisal of its true potentialities will show the great importance of electrification in carrying out sound economic development. (1)[1] Certainly in many cases industrial development and development of natural resources are dependent upon an adequate supply of electric energy, and in that sense electric energy, if unavailable, is a critical factor. In brief, electrification can play a vital role in the development of other resources and in their conservation; it can also play a significant role in the conservation of human resources, which is after all the ultimate concern of this conference.

A power supply system for a region or for a country can be developed in a number of ways, and over the years the different ways have been tried in various areas. Of all of these, the integrated power system has come to be recognized as the soundest mechanism for power supply and for the conservation of energy. While elements of the integrated system have been tested almost from the beginning of the power industry, the major development has occurred in the past twenty-five years. That its technique is still undergoing evolutionary changes can be easily understood.

There are available for the student's examination a considerable number of impressive examples of integrated systems, and some examples of what an integrated system should not be. It is, therefore, possible to consider not only theory, but also its exemplification: to determine what the elements of an integrated system are; and what it has to contribute in conservation. Moreover, it should be possible to do so without overstressing the part that electric energy can play in the broad problem of resource development and conservation.

II. FUNDAMENTAL SOCIAL-ECONOMIC OBJECTIVES OF AN INTEGRATED SYSTEM

The main social objectives of an integrated system can be stated very simply: To furnish an area an adequate supply of electric energy, of the proper quality, at the lowest practicable cost.

This is both a broad and a simple statement. It is not confined to the nature of ownership of the power system, government, private, or mixed. It is not qualified by absolute values of price at which the service is to be rendered, this obviously being a local variable. But being a broad statement, it needs to be amplified in detail.

A. ABILITY TO SERVE AN ENTIRE AREA OR REGION

This is inherent in the concept of an integrated power-supply system. As a corollary, the system must be capable of serving any portion of the area, and all portions equally well. Thus, the development of any part of the area will not be restrained by an inadequacy of power supply. At least as far as power is concerned, all parts of an area are put on the same basis.

B. ABILITY TO INTEGRATE NECESSARY SOURCES OF ENERGY TO ASSURE A SUPPLY IN THE MOST ECONOMICAL MANNER

It is apparent that the source of energy is an indispensable part of a power system. If the integrated system is to meet its specification for economy it is essential that the system be capable of integrating all the available sources of energy that can contribute to bring about the most economical supply of electric energy.

C. ABILITY TO INTEGRATE AND EXPLOIT LOCAL ENERGY RESOURCES

The integrated system may be based on steam generation, hydro, or a mixture of the two. Minor energy sources are discussed later but are not being considered at this point.

If the system is based on steam, it must be capable of exploiting the best sites to their maximum, considering the availability of condensing water and the supply of fuel. From the fuel angle each plant should be located to exploit the most economical supply. (2) In the case of coal that may mean the ability to use local coals, even though their quality may be lower than supplies located more remotely. Again the system should be designed to exploit the artificially-made lower-grade fuels such as the end-products of coal carbonization or of refining, the so-called "char", or oil refinery sludges, available in many localities. Obviously the same applies with regard to natural oil or gas deposits or artificially-created oil or gas supplies. If the integrated system is to perform its function, it should be so developed as to be capable of utilizing to its

[1] Numbers in parentheses refer to items in the bibliography.

optimum such oil or gas supply as may be locally available. This does not inevitably mean burning all or even a portion of a supply in every case. And the same principles hold true in the case of any other by-products of industrial or chemical operations capable of combustion.

If the system is based on hydro, it is again apparent that a fundamental requirement is that the maximum economic development of a site be made possible by the availability of the system. This may mean pushing many site developments to higher values of capacity than would normally prevail. In the case of low-grade capacity, i.e., of low, firm availability, this will mean a development, in many cases, that would otherwise not come about at all.

D. ABILITY TO MEET TEST OF PERFORMANCE FROM A STANDPOINT OF ECONOMICAL POWER SUPPLY AND OF CONTRIBUTION TO AREA-RESOURCE CONSERVATION

Essentially an integrated system may be said to have achieved its objective if it has demonstrated its ability to furnish an area or region with an adequate supply of power at the lowest practicable cost in the present and for a reasonable time in the future.

But no integrated system can be said to have met the fundamental social objectives that were sought in its creation if it cannot also meet the test of performance from the standpoint of area-resource conservation. In this case resources need to be considered in the broader sense: specifically, to include human resources; resources in lands and forests; in rivers capable of multi-purpose development; mineral resources; fuel and energy resources such as coal, oil, gas, and hydro sites; capital (plant) resources; and resources in scientific and technological know-how. The conservation and development of these and their use for the benefit of the containing region or area, or for the benefit of the larger area of which it is a part, is the final end-product sought. In so far as the integrated power system contributes to that performance, it achieves its full basic social-economic objective.

III. TECHNICAL BASES AND REQUIREMENTS OF AN INTEGRATED SYSTEM

The statement given in section II above outlines the objectives sought on the social-economic plane. But these can only be implemented by technical components, some of them of vast complexity, put together in a technically skilful manner so as to be capable of being operated, and actually so operated, to bring about that result. This, too, warrants discussion.

But before that is done it may be desirable to explore the bases and the technical requirements of an integrated system.

A. TECHNICAL BASES OF AN INTEGRATED SYSTEM

From a technical standpoint, what is meant by "integration" is this: That all facilities of the system are connected physically into or gathered within the system, and that they all are made to work continuously as part of the system. The presumption is that no facility is needlessly idle; no part of the system is left hanging loose, so to speak; no part of the system is left without the resources and support of the system as a whole.

Applied to energy generation, this means the ability to develop all energy resources capable of economic exploitation and the development of all the resources to their maximum, as well as the elimination of all barriers to development such as local inability to absorb the resources. Again, it means the ability to use the largest units justified by the requirements of the system for any particular station or source, regardless of the requirements of the local area. Still further, it means the ability, as the system grows and develops, to exploit the most efficient units capable of technical projection because other units relatively recently installed but perhaps not as technically advanced can be relegated to a lesser system use. The combined or integrated effect of these is conservation on a vast scale.

As to load centres, the integrated system makes possible the integration of loads of diverse characteristics; it should make available any practicable amount of power to any point on the system independent of the local resources; and, finally, it should make available multi-source supply, without any appreciable economic burden, to all principal points of the system. From that follows the corollary gain: no appreciable amount of capacity need be installed, except where the advantages are large, ahead of market demand in order to utilize reasonably-sized units or to avoid piece-meal development of a site. Capacity is, therefore, not kept idle pending its future use. With all load centres placed on that basis, it becomes possible to develop and conserve all the local resources, and, therefore, from that angle also a major contribution to conservation is made.

From the standpoint of the power system as a whole and its operation as a technical economic entity, the integrated system makes possible the translation of skill and experience from one part of the system to the rest, the fullest utilization of equipment that would otherwise be retired as inadequacy or other obsolescence develops, and minimum requirements in reserves of equipment, supplies and personnel. And here, too, contribution to conservation of resources is brought about.

More detailed propositions relating to requirements follow:

B. GENERATION CENTRES OR SOURCES WILL BOTH INFLUENCE AND BE INFLUENCED BY INTEGRATED SYSTEM DEVELOPMENT

The exact location and the extent of the development of any particular location of energy generation or source is not susceptible of categorical definition. An initial development of one or more favourably-located generating sources may quite properly influence considerably the development of the integrated system. Later as the system reaches a state of fuller development the existence of the system in a particular form may influence the location of new generating centres or the expansion of existing centres. The point is that as far as generation centres or sources of supply are concerned, there is no need to be bound by any rigid preconceptions. The integrated system should be designed to permit the development of the most economical sources and of all sources to their optimum, economically. This should not neglect sources exterior to the area integrated. All other things being equal, the most economical generation is that requiring the least amount of transmission between the source and the load centre.

C. THE PROMOTION OF SUPPLY IN THE MOST ECONOMICAL MANNER REQUIRES ABILITY TO EXPLOIT INHERENT CAPITAL COST ADVANTAGES

To promote supply of electric energy in the most economical manner, the integrated system has a considerable number of inherent economic advantages that show up in lower capital costs. But the system must be set up and developed so as to be able to exploit all of them. To mention the principal ones: ability to utilize larger units; ability to operate with lower reserves; (3) lower margins of overload capacity or safety on much equipment; basic ability to meet emergencies on a lower cost-basis. This will be discussed more fully in section VIII — Economics.

D. ALL GENERATION SOURCES MUST BE INTERCONNECTED AND BY FACILITIES ADEQUATE TO PERFORM THE FUNCTION OF THE INTEGRATED SYSTEM

It is of particular significance that mere nominal or loose ties, so-called "loose-linkage" interconnexions, are not enough and do not in effect constitute the necessary ties for integration. It is not imperative that the ties between generation centres be direct. It is important that the interconnected transmission be able to discharge the full technical responsibility of making possible shifts of load and transfer of power for economical loading, for unit outage, and for completely co-ordinated operation.

E. THE PROMOTION OF SUPPLY IN THE MOST ECONOMICAL MANNER REQUIRES ABILITY TO EXPLOIT INHERENT OPERATING COST ADVANTAGES

Of equal importance with capital cost savings are operating cost savings potentially available in integrated-system operation if the most economical supply is to be assured. These economies also affect the conservation of resources. Thus larger generating units offer not only lower capital costs but also lower operating costs. But of a group of highly economical large units some are bound to be located at points of greater, and some at points of lesser, fuel cost. Besides, in a mixed fuel and hydro system, the hydro is virtually equivalent to zero cost fuel. It is essential, therefore, that the properly designed integrated system make possible maximum operation of the most efficient and most economical units at the most efficient levels. This end will automatically result in maximum conservation of resources.

F. THE INTEGRATED SYSTEM MUST BE CAPABLE OF SUPPLYING ALL LOAD AREAS OR CENTRES REGARDLESS OF THE STATUS OF ANY PARTICULAR GENERATING CENTRE

The essence of requirements "D" and "F" taken together is that all load areas are supplied by the system and that all supply centres are provided with an outlet for their generation through the instrumentality of the interconnecting transmission system acting as the co-ordinating medium. The ties can be indirect. But whether such indirect ties are proper media for bringing about a completely integrated system can be judged only by the criterion of whether they can actually bring about complete co-ordination of generation and load centres. Specifically, this can be stated: Any system where a break in a load tie makes impossible the automatic replacement of lost generation by generation that is available on the system or to the system, is not truly integrated.

G. THE INTEGRATION MUST BE ACCOMPANIED BY A MINIMUM AMOUNT OF TRANSMISSION AND BY A MINIMUM NUMBER OF VOLTAGES

The above is almost axiomatic once the general requirement is accepted that a transmission system should perform its function in the most economical manner. Yet there may be conflicting requirements. For example, the requirement of a minimum number of transmission voltages may call for too high an initial investment in the early stages of the development of the system. Here, as elsewhere, there is need for striking an economic balance between the present and future requirements. The point is that it is essential to so combine the solution to the problem of giving an economical delivery in the present with the capability of economical expansion in the future as to bring about the over-all optimum economic balance.

IV. THE COMPONENTS AND TOOLS OF AN INTEGRATED POWER SYSTEM—COMPONENTS

The integrated power system itself is an integration of three principal components: the generating system, the transmission system, and the distribution system. These three are kept in functioning order by the co-ordinating personnel and made effective by what has been referred to as tools of the integrated system: the protective elements and the regulating elments. It may be well to discuss each of them briefly.

A. THE GENERATING SYSTEM

1. *The system in general.* No attempt will be made to give a detailed technical discussion of all the sources of energy available. Such a discussion would definitely be beyond the scope of this paper. But an effort will be made to indicate the part that each source can and does play in an integrated system, and how the use of each source is affected by the integrated system.

2. *Hydro.* Hydro can be a major, a minor, or some in-between component of the energy source. The integrated power system, however, can make contributions of major significance in the economic exploitation of hydro. It makes possible, for example, the development of sites having little or no firm capacity, the development of small sites, and maximum utilization of each site at minimum cost. (4) It particularly makes possible the backing up and conversion to firm or non-firm hydro, whether the non-firm character is the result of low flow or of excessive discharge.

3. *Diesel.* The diesel engine is essentially handicapped in its application on an integrated power system if other sources of generation can be developed. The fundamental reasons for this are the limitation in the size of the units and the fact that on an integrated system there is no need for special facilities for standby, since the system itself can furnish these from its other generation sources. It may, however, have a place in the development of an integrated system in building up isolated areas before their integration within the system, and particularly so if reasonably economical fuel sources, either gas or oil, are available.

4. *The steam turbine powered by a steam generator (boiler).* Except for hydro, the regenerative steam-turbine cycle has become, and promises to continue for a long time to come, the main reliance as the energy source in areas where fuel is available. Integration accentuates the economic potentialities by making possible the exploitation of maximum-size units, both in turbines and boilers, the operation of the most economical units at the most economical point and at the maximum load factor in the case of new units. All of these make major contributions, not only to operating economies but to conservation of natural resources, both material and human. As an example, at the time of writing, six turbogenerator units, each of 150,000 kw. gross maximum rating

are in the process of installation on a single American system.[2] Each of these is powered by a single boiler, operating on a steam cycle of 2,000 lb. per square inch at the throttle, 1050 degrees F. initial steam temperature and 1,000 degrees F. reheat. The expected performance of this unit is 9,300 B.T.U. per kwh. net output, representing a thermal efficiency of close to 38 per cent, a new high in the efficiency of conversion of coal to electric energy. (5) Developments are probably ahead which will bring about practical high-pressure, high-temperature units of 200,000 to 250,000 kw. rating. When the metallurgical problems of operating at an initial steam temperature of 1,200 degrees are solved, such units should show a performance of close to 8,500 B.T.U. per kwh. – an efficiency of conversion of 40 per cent.

5. *Interconnexions.* Interconnexions with other systems can play a major role in the generating system, both as an auxiliary to generation sources and in lieu of them.

Because of the great importance of "Interconnexion" and the advantages it brings to an integrated system, this subject will be treated more thoroughly and extensively in section VII.

6. *The gas turbine.* At the present time the applications of the gas turbine in a balanced generation programme for an integrated system are somewhat difficult to evaluate. So few applications of the gas turbine for power generation have been made that information is inadequate both as to application principles and performance experience. There is some indication, however, that in areas where economical supplies of either gas or oil are available, the turbine may have an application for end-of-line situations. (6) But on an integrated system these applications are bound to be limited and of short duration. In general, the gas turbine itself is suffering at present from a limitation owing to its inability to burn coal directly. It is clear even now, however, that where coal deposits are available contiguous to properly located plant sites, the gas turbine may eventually have an application as a means of exploiting underground low-cost coal gasification products. In that regard, again, the integrated system has specific value as a resource-conservation measure.

7. *Tidal power.* Tidal power is not only limited as to location but the economics of its application have been extremely difficult.[3] One such example is the Passamaquoddy Project in the United States, abandoned basically on economic grounds. Still another example is the Severn Barrage Scheme in Great Britain, at one time projected for economic application when and if the price of coal reached a figure of 49 shillings per ton. Although coal prices since then have reached that figure and have even exceeded it, the time for economic application of the Severn Barrage Scheme would appear to be just as far off as ever; since the cost indices of all the components entering into such a product have materially advanced upward since that time.

Nevertheless it is essential to point out that when and if a location is found for a tidal power project, the existence of an integrated system would be a material contribution to bring such a scheme to economic maturity. This is because of the fundamentally non-firm character of tidal power.

[2] American Gas and Electric Company System.

[3] "Nevertheless, we must agree with Mr. Nimmo that power from the tides, in spite of Mr. Bernard Shaw, is 'alluring but disappointing' owing to the limited head, the large quantities of water to be handled, the intermittent output and the great cost." — "The Severn Barrage", *London Engineering*, vol. 167, no. 4333, pages 133–134, 11 February 1949.

8. *Wind power.* Wind power, too, like tidal power is limited as to location and the economics are even more difficult not only because of the unfirm nature of the power but also because the technical problems involved in building wind generators of any appreciable size have not been completely solved.[4]

Here again it is pertinent to point out that if wind power can be developed in an amount to be of economic significance, the existence of an integrated system would be of substantial help to bring the scheme into practical existence.

9. *Nuclear energy.* The possibility that nuclear reactors and nuclear fuel might play a part, and perhaps a dominant part, in power generation was considered by those who were responsible for the initial developmental programme which led to the atomic bomb. But even then it was realized that nuclear reactors for power generation would involve a great many difficult engineering problems. Everything that has happened since has definitely shown that the original appraisal of the engineering difficulties was, if anything, an underestimate.

There is every reason to believe that all the problems connected with the practicable application of nuclear reactors to power generation are on the way to being solved. However, the question "Will nuclear power be economical?" has as yet not been answered and there is no information as of the date of this writing that can be used to give a reliable answer.[5] The best that can be said is that it looks as if *it may be possible* to develop economical power from nuclear reactors. Here again, however, the economics may be materially influenced by the availability of an integrated power system to absorb the output of a nuclear fuel plant at the highest practicable load factor, and by the freedom from considerations of location that this availability will give to the planners of the nuclear power project.

B. THE TRANSMISSION SYSTEM

1. *The system in general.* As pointed out in the discussion under section III, the transmission system is the component whose function it is to furnish the co-ordinating medium between all the generation centres and the supply centres at the lowest practicable cost, taking into consideration not only the present but also a reasonable future. Out of this proposition a number of basic technical considerations follow.

[4] "Granting the value of such information, the practical *Power* reader will ask whether there is any reasonable chance that wind power will be a paying proposition in our time. A fair answer must recognize that power systems depending on wind alone are definitely out of the picture, also that storage batteries as standby are prohibitively expensive except for small and remote installations.

"There remains the possibility that well-engineered wind turbines may be economical in certain regions of favourable winds, if they can be tied in with power systems of proper characteristics, preferably systems including both steam and storage-type hydro plants. Under such circumstances wind power can save fuel and at the same time add to the peak capacity of the system by conserving off-peak water." "Pioneering in Wind Power", *Power Magazine*, June 1941, pages 55-59.

[5] "The question is also raised: 'Will nuclear power be economical?' It is one of the aims of the reactor development programme to answer this question. Today we do not have adequate information to make a sensible estimate. It looks as if it might be possible to develop economiçal power from nuclear reactors but many improvements and simplifications will be necessary." "The Development of Nuclear Reactors", by Robert F. Bacher, Member U.S. Atomic Energy Commission, presented before the American Academy of Arts and Sciences, Boston, Mass., 9 February 1949.

2. *Highest practicable voltage. — Minimum number of voltages.* For the transmission network to accomplish its function economically it is important that it be designed on a rational basis, at the highest practicable voltage for over-all optimum economics, using a minimum number of voltages and having its insulation system set up on a fully co-ordinated basis. If the highest economical voltage is to be exploited successfully it is particularly necessary to co-ordinate insulation. This in turn means a fundamental study of transient overvoltages, switching specifications, and protective facilities.

The advantages of choosing the highest voltage, provided no appreciable economic burdens are assumed thereby, are obvious from many standpoints: conservation of material, conservation of labour, and assurance to the highest practicable degree of a minimum danger from obsolescence. The fundamental advantage in the use of a minimum number of voltages between the highest transmission voltage and the voltage of distribution is also apparent.

3. *Ample capacity for integration.* The integrating network should have sufficient capacity in all its transmission elements to permit free and natural flow of power in any part of the system. In other words, there should be no weak links in which it might become necessary to restrict the flow of power by artificial means, such as phase angle shifting devices or series reactors.

4. *Exploitation of full capacity of system.* Each element in the transmission network should be capable of operating at the absolute limit of its capacity, taking into account stability limitations. There should be no restriction on the capacity of the line due to loss of stability when attempts are made to exploit it to its otherwise full capacity. This calls for the use of certain tools which will be discussed later.

5. *System flexibility.* A completely integrated system must provide flexibility in power flow even to the extent of reversal of flow over many of the circuit elements. Under these conditions voltage levels throughout the system must be maintained at more or less constant levels regardless of the magnitude and the direction of power flow. The only practicable method of accomplishing such control is to provide adequate reactive *kva* or kilovar generation at strategic points and particularly at load points throughout the system. The tools for this, such as synchronous condensers and static capacitors, will be discussed later under the heading of "Tools". It is to be noted, however, that a soundly applied and developed system of kilovar supply can be of material help in improving stability.

6. *Reliability.* No electric power system, whether large or small, and therefore no integrated system, can be regarded as adequately planned and engineered unless full consideration has been given to reliability so that the transmission network will always be capable of performing its integrating function. This can be provided only if two fundamental phases are equally effectively covered:

(*a*) Basic design, and

(*b*) Protection.

If the basic design of the network is faulty, reliability will be almost impossible of attainment. Even with the best designs, however, protection elements need to be incorporated. As a matter of fact, the best designs are those that utilize fully the protective devices available.

Essentially this gets down to protection against wind, sleet and lightning. An effective technology has been developed against each and will be discussed under "Tools".

7. *Extra high voltage A-C transmission.* As systems grow in size they bring about the need of transmission of increasingly larger blocks of power; as they grow in extent they may be called upon to develop generation sources at increasingly longer distances from load centres; with growth in the size of the system and in the size of units concomitant problems in transmission for taking proper care of larger unit outages and system co-ordination are bound to develop. All of this is bound to bring about a need for giving consideration to higher voltages of transmission than have been used heretofore, if sound economics is not to be infringed upon.

The use of extra high voltages requires, however, effectively larger conductors, larger towers, higher insulation levels and more expensive terminal equipment. (7) Since their cost increases very rapidly with higher voltage, it becomes increasingly important to design the system so that maximum use is made of the capabilities of the equipment. In developing designs along this line, technical problems on corona, radio influence and adequate switching and lightning protection have been encountered. Considerable data to solve these technical problems is still lacking but research that will lead to the closing of the gap in knowledge is actively under way.

8. *Transmission at high voltage direct current.* The alternative to transmission at extra high voltage alternating current is transmission at high voltage direct current. The proposal to go to direct current is not new. The theoretical fundamental advantages of D.C. have been fully stated although their evaluation is a matter on which considerable disagreement is possible. While the technical problems in the development of high voltage conversion and inversion equipment have apparently been solved, the way to overcome the economic burden introduced by the cost of this terminal equipment has not been worked out. In addition to this the technical difficulty of building a high voltage direct current circuit interrupter has not even been partially overcome. This, coupled with the economic difficulties inherent in direct current transmission (as a result of high terminal costs) seems to make economically successful operation of D.C. transmission, at least in overhead transmission, remote for a considerable period.

C. THE DISTRIBUTION SYSTEM

1. *The system in general and its effect on the transmission network.* The distribution system might be thought as being outside the scope of the main considerations of an integrated power system but such delimitation is only theoretical. Actually the distribution system is vitally tied to the transmission system and must be co-ordinated with it. (8)

While it would appear axiomatic, it cannot be too strongly stressed that a transmission network has to be planned for ease and economy of serving the distribution networks or the sub-transmission centres. This is particularly so if the transmission network is to be designed with the requirement of using the minimum number of voltages and if the same test is to be applied to the distribution systems. It is particularly important in planning distribution and sub-transmission networks supplying the large urban centres. Here more than elsewhere, if the maximum co-ordination between transmission, sub-transmission and distribution is not initially provided, large elements of cost will be encountered which could be almost entirely avoided by proper co-ordination.

2. *Reliability.* The great dependence on electric service in a modern society makes it imperative to incorporate in a

properly designed distribution system every practicable economical element that will assure continuity of service. However, a good deal of the continuity of the distribution system can be furnished or built into it by assuring continuity of supply to the distribution system through reliability of generation and transmission under all normal and most abnormal conditions.

3. *The use of an integrated transmission network as a distribution system.* Frequently an integrated system will not make available to all the parts of the system an adequate and economical supply of electric energy, if the high voltage co-ordinating transmission system is treated strictly as an express highway to be utilized between fixed and limited terminals. To treat the transmission system as otherwise unavailable in the service area it traverses, has no technical justification. The network can, and should be, taken advantage of for serving isolated loads in isolated areas, particularly when they reach a point requiring services or supply in excess of what is available economically by the use of existing distribution or sub-transmission facilities.

V. THE COMPONENTS AND TOOLS OF AN INTEGRATED POWER SYSTEM—TOOLS

The proper functioning of the integrated power system, even where the three principal components — the generating system, the transmission system, and the distribution system — have been properly designed and built, is not an automatic operation; only skilled co-ordinating personnel using certain tools developed over the course of the last twenty-five years or so can bring about the desired result. For convenience these tools can be divided into two groups: protective elements and regulating elements. Each of them is discussed briefly below.

A. PROTECTIVE ELEMENTS

1. *Maximum continuity of interconnexion under normal conditions by switching.* Since transmission interconnexion is fundamental to integrated operation, it is important that such interconnexion be maintained with maximum continuity. In this way all the elements of the system can be tied together and operate as one system under normal and, even more importantly, under abnormal conditions. This makes possible the maximum use of facilities and the installation and use of a minimum of facilities.

The means of bringing this about is switching or bussing of the transmission network. It is impossible to get maximum use of transmission circuits without such bussing or switching. However, if this is not to introduce another element of hazard into integrated system operation, high-speed bus protection must be provided, (9) and switches must be of the utmost reliability. This means that they must possess the characteristics to assure safe opening and closing and to perform with the required speed of opening and closing. (10) A corollary, but only from the economic side, to this is that the switching scheme must be such as to utilize the minimum number of switches. Particularly is this true at extra high voltages, since the cost of a unit of switching goes up faster than the voltage.

2. *Relaying.* If the system is to operate in the most completely interconnected manner under normal conditions for the purpose of getting the maximum utilization of facilities and attaining the minimum costs, the system must be capable of isolating, in the case of any system failure or disturbance, the faulty equipment as near instantaneously as possible without disturbing any other part of the system. If this is to be further accomplished without any artificial restrictions on the normal load-carrying capacities of lines and facilities, this requires that there be no restriction due to relay settings. This almost inevitably leads to the conclusion that relaying must be instantaneous or very nearly so, and switching as close to that as possible. From the standpoint of present technology, this means relaying in not over one cycle and switching or de-energizing in not more than three cycles from the energization of trip coil. The only relay system that can meet this requirement and still be independent of the number of stations in a network is a differential type of system. (11) This can utilize conductors between stations; however, where any appreciable distance is involved, and if the utmost in reliability is sought, carrier current transmission of necessary impulses is the only practical means available.

3. *Ultra-rapid reclosure.* The value of ultra-rapid reclosure as a protective tool in transmission line operation has been fully developed and is thoroughly understood, but is still not as widely practised as would appear to be warranted. (12) It is, however, an indispensable unit in the bag of integrated power system tools. Ultra-rapid reclosure involves a basic change in the concept of the switching function: instead of looking upon the circuit breaker as a device to disconnect a faulted line or piece of equipment, ultra-rapid reclosure makes possible the concept of the switching function as an operation involving the disconnexion of a faulted piece of equipment and its reclosure as quickly as the physical phenomena involved in ionization or restoration of the insulation strength of the circuit will permit. Thus used, high-speed relaying and ultra-rapid reclosure together constitute a most important factor in the control of system stability.

4. *Insulation co-ordination — basic insulation levels.* While insulation co-ordination is basically an idea, ideas themselves can be both tools and weapons. Insulation co-ordination is a tool for obtaining protection against insulation breakdown and, therefore, against circuit failure at the minimum cost. Its adoption is a prerequisite to the development of an economic and reliable interconnecting transmission system. The idea that there must be definite relationship between the insulation strength of all the components or links in the transmission chain and that the ratio between operating voltage and short time or impulse insulation strength needs to be different at different operating voltages and under different operating conditions is simple, but of fundamental importance. Insulation co-ordination is accepted today as basic to transmission insulation design by all the leading practioners of the transmisssion art. The practical working out of this problem has been through the adoption of a series of basic insulation levels which, while as a practical matter are tied to nominal operating voltages, are substantially independent of them. (13) Thus an insulation level covering all the elements in the transmission chain that might be employed on one system operating at a voltage of 287,000 volts, say, could on another system, differently designed and subjected to relatively lower dynamic overvoltages and lower switching surges, be adequate for a voltage as high as 360,000 volts.

5. *The lightning arrester.* The lightning arrester is perhaps the most important single tool in the aggregate group of tools known as insulation co-ordination. Properly designed, the lightning arrester can be made to keep the overvoltage level on transformers and busses down to a pre-

determined value under all conditions of abnormal voltage development on the system. Thus used it serves as an anchor point or foundation upon which to build all the other voltage levels to provide the necessary margins of safety at each point in the transmission chain. It may be possible to design and build a transmission system without the use of the lightning arrester, but no system that seeks to develop the utmost economy can be developed without it where lightning is a factor. (14)

6. *Sleet detection and melting.* No electric power system, whether large or small, can be regarded as properly planned and engineered unless full consideration has been given and procedures worked out for coping with any sleet conditions likely to occur. Sleet formation can lead to the most serious outages of almost any natural hazard in transmission. The damage inflicted by sleet may be caused by sheer excess weight on the conductors resulting in failure of supports; or failure may be brought about by dancing of conductors under only moderate ice coating accompanied by moderate wind conditions.

The only practical solution is a procedure for detection of sleet before it reaches dangerous proportions and for actually melting ice as soon as it begins to form. The technology for detection by means of a radio frequency carrier channel is fully developed. (15) This does not depend on the existence of an integrated system. The obtaining, however, of a heavy enough current flow through the line, involving the necessary reactive and power supply that may run to several hundred thousand kilovars and a lesser but very appreciable amount of kilowatts, is a problem that can be particularly easily solved on an integrated system, since integration makes possible the marshalling of the resources of the system and their application to a relatively limited piece of system or line. Thus the integrated system itself in this case can furnish the means for maintaining itself whole most economically.

B. THE REGULATING ELEMENTS

1. *Synchronous condensers and static capacitors.* The completely integrated system must, in order to provide complete flexibility in power flow, maintain voltage throughout the system at more or less constant levels regardless of the magnitude or direction of the power flow. The practicable method of accomplishing such control other than that obtained from generating plants is the installation of adequate reactive kilovar generation at strategic points throughout the system. (16) For the larger installations, synchronous condensers are the most economical and have the advantage of providing smooth continuous voltage control with automatic voltage regulators. These can be supplemented economically and satisfactorily by installing static capacitors at smaller load points.

The proper use of reactive generation in this manner for maintaining voltage levels at important receiving points on the system, regardless of magnitude and direction of power flow in the lines, also constitutes an important factor in maintaining the stability limits of line and system at the highest possible values.

2. *Voltage regulation and regulators.* The successful operation of an integrated system requires automatic regulation of generator fields at all important generating stations and automatic regulation of the fields of large synchronous condensers. While automatic generator voltage regulators have been used since the early days of electric power generation and transmission, quite recent developments have brought about regulating equipment having greatly improved characteristics. (17)

Specifically, the Amplidyne and Rototrol, and to some extent the electronic exciter and regulator systems are examples of such improved equipment, and both accomplish similar and effective results. (18) A generator regulator and the over-all excitation scheme need to accomplish two things: First, maintain constant voltage level at any desired value and hold this level within the necessary limit of accuracy under normal conditions and, second, maintain the generator system and system voltage level as nearly constant as possible during sudden changes of load on the generator during system disturbances.

The voltage control and excitation system for synchronous condensers is perhaps of even greater importance than that of the generator units since the function of the condenser is entirely one of regulating voltage and furnishing a supply of reactive kva. capable of rapid variation.

The reactive component of current flowing in a transmission line is generally the controlling factor in producing voltage drop or voltage rise, having an effect several times that of the corresponding power component of the current. Voltage levels at strategic points on an integrated system can, therefore, be controlled by regulating the flow of the reactive over the line. Since this flow is generally in the direction opposite to that of the power flow in order to offset the resistance drop due to the power flow, it is apparent that reactive component generation must be available with a considerable degree of independence of power generation. The regulator doing this job automatically obviously needs to meet the same rigid test as the generator regulator discussed above.

Occasionally regulating or tap-changing transformers can be used to advantage to meet special voltage regulator conditions. For the most part, however, the need for regulating transformers can be confined to distribution stations where it is necessary to provide more precise voltage control than that furnished by the main system. Likewise, it is generally true that the most economical use of transmission facilities on an integrated system results when the system is free and not restricted by such artificial regulating means as phase angle shifting or voltage regulating transformers. A properly designed transmission system can keep the need of such equipment down to a negligible point.

3. *Frequency and tie line control.* No extensive integrated system can be properly operated without automatic control of system frequency and power loading over important interconnecting transmission lines. This job, initially done manually by operators, was put on an automatic basis as integrated system technique developed. Starting with one station for such automatic control, it soon became evident that the burden of control must be spread to many stations. This led to the tie line bias principle, in which the control recognizes deviations from scheduled tie line loadings and from standard frequency, then automatically changes the output of the controlling plants dependent upon a predetermined evaluation of the combined effect of the two influences. Some difficulties have been experienced in automatically controlling steam turbine generators because of boiler inertia, but work is now going on looking to the tying of the automatic frequency tie

line controller into the boiler combustion control. This would furnish a means of anticipating the changes in steam pressure perhaps several seconds before the changes occur.

An important development in frequency and tie line control is the so-called net interchange control, now quite commonly used. In this case the predetermined algebraic sum of the loading on all lines out of a station or system actuates the frequency controller, at the same time taking into account the station's responsibility for maintaining frequency. (19)

4. *Communication and telemetering.* Dispatchers must have a reliable communication system between all strategic points on the system to properly co-ordinate its operation. Up to date carrier communication has been most widely used because it has proven most economical and dependable. Carrier communication has a distinct advantage in reliability over open wire or cable circuits because of the high factor of safety introduced into high voltage transmission structures. (20) Each channel on a conventional system may extend as much as 300 miles without repeaters and on continuous circuits not broken by switching stations this distance can be doubled.

The dispatchers and operators also need a continuous record of loadings on stations and important transmission lines. This can be accomplished by telemetering, the technology for which is fully developed. (21)

Here again, carrier current methods are generally employed. The carrier current method has the advantage that the records can be sent over the same long distances as voice communication. In general, it has been the practice to record the load graphically at the receiving end. The development of microwave transmission has indicated the possibility of the application of this newer technology to communication telemetering, relaying and to similar control problems on electric power systems. (22) At this writing, however, the economics of the newer methods still have to be determined.

VI. CO-ORDINATING PERSONNEL

A. THE PLACE OF PERSONNEL IN INTEGRATED SYSTEM OPERATION

The proper functioning of an integrated system involves many technically complex operating problems. No integrated system can be successful if the technical base on which it is built is unsound, if the necessary components have not been designed properly, put together properly, and if the necessary co-ordinating tools have not been furnished to the co-ordinating personnel.

There is no question that the success of a system, no matter how well engineered and built, will be impossible without an efficient co-ordinating personnel fully understanding and conversant with the anatomy of the system and possessing the necessary techniques for carrying on continuously the minute-to-minute, hour-to-hour, and day-to-day control operations that are so necessary to keep the system functioning as an integrated unit.

B. SOME FIELDS IN WHICH OPERATING TECHNIQUES AND SKILLS ARE REQUIRED

No attempt will be made to discuss in detail, or even to list completely, all the operating techniques requiring special skills on the part of a co-ordinating organization. A partial list in addition to the minute-to-minute control of the system is given below. This, together with references, will provide the necessary means of developing more detailed knowledge of the subject for those interested enough in doing so. To list some of these techniques:

1. *Load projection.* The projection of daily loads, so important in day-to-day co-ordination, is definitely a function of a central co-ordinating organization. In some situations the same organization takes on the function of long-term load predictions.

2. *Hydro-electric plant operation.* This requires projections of precipitation, storage and drawdown and the determination of the power available from stream flow and its efficient utilization on the load curve.

3. *Incremental loading of fuel-burning plants.* Incremental loading, the technique which assures that the most efficient combination of turbines and boilers is operated for a given load, requires plant studies and in many cases the carrying out of exhaustive thermal plant tests to determine actual performance on a thermal input-output basis. In addition there must be provided rapid-calculating devices of one sort or another for almost instantaneous determination of scheduling or rescheduling of loading in response to quick changes in conditions of load or capacity availability. (23)

4. *Interconnexion co-ordination.* It is assumed that any extensive integrated system will have a number of interconnexions with other systems. The co-ordination between the system generation resources and those obtainable from the outside is a matter involving thorough knowledge of all the potentialities in the interconnexions and skill in their application.

5. *Sleet patrol.* The continuous supervision via carrier current check of sleet conditions on the system to make certain that no substantial part of the system develops heavy sleet before melting operations are started is again a matter particularly suited to be handled by a central co-ordinating organization.

6. *Supervision over condition of protective and communication gear.* The ability of the protective gear to stay in continuous functioning condition is an indispensable element to the successful performance of an integrated power system. Here, too, a central co-ordinating organization is needed to monitor that operation.

VII. INTERCONNEXIONS BETWEEN SYSTEMS

Past experience has amply demonstrated that properly planned and operated interconnexions between integrated systems will increase the efficiency – the ability to give optimum service at lowest cost – and hence the economic soundness of each system. This is particularly the case where two systems of substantially similar size are involved, one of which is predominantly steam and the other predominantly hydro, or where there is a major difference in the character of the load served by each system. The elimination of the necessity of each system's standing on its own; the opening up of possibilities of co-ordination between two systems; the utilization of facilities or resources that might otherwise not be put to use, including, in cases of conversion between steam and hydro-electric systems, the creation of something – firm capacity – which did not exist before, result in the capture of subsantial economic benefits. (24) A detailed development of these sources of gain follows.

A. REDUCTION OF RESERVES

Interconnexion not only makes possible the reduction of normal spinning and cold reserves carried by each of the interconnecting systems, but makes further possible the marshalling of reserves on all interconnected systems when abnormal emergencies occur on any one system. This can be brought into effect to an extent that could not possibly be economically provided for on any other basis. Since it is a rare occurrence for abnormal conditions to arise simultaneously on all systems, it is possible for each of the systems in an interconnected group to give help to a system in distress in time of need up to the point where the helping system itself is almost jeopardized. For example, a major plant on any one of the interconnecting systems may be lost and by co-operation between the interconnecting systems replaced with no adverse effect on service on any co-operating system.

B. DIVERSITY DUE TO AREA TIME OR BASIC DIFFERENCES IN LOAD CHARACTERISTICS

There are many notable examples of this diversity and of its utilization. In effect this creates new capacity for carrying load on each of the systems participating in the diversity exchange.

C. ECONOMY ENERGY

This calls for the energy supply to a given load at any time from the lowest cost sources by the substitution of generation of one plant or system for another. The replacement of steam generation to conserve fuel by hydro energy that would be otherwise unused falls in this same category.

Both of these operations result not only in economic gain but in major conservation of natural resources.

D. CONVERSION BETWEEN STEAM AND HYDRO SYSTEMS

Here steam generation displaces hydro generation during off-peak periods. The hydro reservoirs which would otherwise be depleted are thus enabled to store water during off-peak periods and to that extent increase the capability of the hydro plants during peak load periods. Capacity is in this way actually created by co-ordinating the operations of steam and hydro systems through interconnexions. The capacity thus created may be very large.

E. CO-ORDINATED MAINTENANCE

The operation of an integrated system makes possible large gains in capacity availability by co-ordinating the overhaul or maintenance of the units within the system. But this co-ordination can be extended where interconnexions exist with neighbouring interconnected systems and thus can be obtained further gain in capability of the installed capacity of the combined systems.

F. STAGGERING OF GENERATING PLANT CONSTRUCTION PROGRAMMES

In order to bring about economical development of any particular generation project or site, it may be, and frequently is, found desirable for a system however well integrated to over-build as against immediate need. With the existence of a substantial interconnexion, it is possible for the interconnecting companies to co-ordinate such a construction programme and to arrange for the purchase of capacity by the system holding back on its construction from the system building in advance of its requirements. The process can be reversed in a subsequent period.

G. SALE OF FIRM POWER

Because of the more fortunate location of one system as contrasted with its neighbouring system from the standpoint of opportunities to develop economical generation, there may be major economies in having the less fortunately located system purchase a substantial block of firm capacity from the neighbouring system for a long period of time, or at least as long as such advantage continues to exist.

VIII. ECONOMICS—PROBLEMS AND LIMITATIONS

The entire discussion carried on up to this point, while aimed at exploring the base upon which a soundly constructed, integrated system must rest, the social-economic objectives it must aim at, and the means of obtaining these, has consistently developed and stressed the economic factors and the economic gains made possible by the integrated system. The economic phase of the integrated system has thus been covered to a considerable extent.

It is important to point out, however, that the economics of integrated operation are not one-sided. There is a liability side as well as an asset side. Conceptions and instruments of this kind carry with them the germs of their own ineffectiveness and even of their undoing. There is, in other words, no automatic formula, no blockless, clear road to a power Utopia. Problems and limitations are bound to develop that could threaten the successful performance of an integrated system. But the problems need not be insoluble and the limitations need not be too restricting if the proper measures are taken and developed in time.

It may be helpful, therefore, to bring together and summarize the elements of economic gain, previously discussed, and then discuss the unfavorable side, the problems and limitations, with a view to showing how they can be minimized or eliminated.

The factors that are favorable to integration possess this in common: In one form or another, they tend to reduce the cost per kilowatt and per kilowatt-hour and to improve service to the ultimate user, taking into account availability, price and quality.

A. FACTORS FAVORABLE TO INTEGRATION

1. *Diversity.* Diversity can come from at least three sources: time differentials, the character of generation and the nature of the major energy-using industries. Diversity arising from these sources provides greater economic stability and higher load factor for the system.

2. *Size of generating and transmission units.* An integrated system can utilize the larger and more efficient generating and transmission units.

3. *Reduction of factors of safety.* Since each part of the system is free from the necessity of standing on its own and, therefore, has open to it the assurance of being able to call upon the support of the rest of the system, contingency items instituted as factors of safety in numerous ways in design and construction can be reduced to a minimum.

4. *Reduction of reserves.* The amount of capacity designated for spinning, cold and extraordinary emergency reserves can be reduced.

5. *Higher use factor.* The higher use factor carries with it major capital advantages and the higher load factor resulting provides substantial operating savings.

6. *Lesser obsolescence.* Material and equipment that is in any manner obsolescent on one part of the system may be entirely suitable for use on other parts of the system.

7. *Maximum exploitation of sites and particularly generating sites.* This has previously been developed in the discussion in section I.

8. *Maximum exploitation of area economic assets such as economical deposits of coal, economical hydro sites and economical gas reserve.* The significance of this benefit is obvious.

9. *Saving in personnel.* Again, an obvious benefit which needs no discussion.

10. *The development of greater skills.* This comes about from the ability to specialize on the part of the personnel to a much greater degree than is possible on a non-integrated system.

11. *Possibility of meeting greater range of demands for service.* In essence this results from the fact that an integrated system can marshall in one spot elements which, brought together in sufficient quantity, can have economic value or saleability otherwise not obtainable. As an example of that might be cited interruptible service for certain chemical or metallurgical operations.

B. FACTORS UNFAVORABLE TO INTEGRATION

The corresponding unfavorable elements are definitely not negligible. Some of these arise from technical considerations unique to the technology involved and others are basic in that they are inherent in the size of an operation and are equally applicable to other than power projects.

1. *The basic problem — size.* The basic problem of size inherent in any corporate growth, biologic or social-economic, has to be contended with in the case of an integrated power system also. The question of how large an integrated system can grow without developing the technical and economic diseases of size in an acute form is not susceptible of categorical answer. To a considerable extent it depends on the particular area, the effectiveness of integration, and the degree, if any, of regulatory control to which the system is subject. But one thing is certain, a system can become so large that its proper functioning is seriously and adversely affected.

2. *Technical problems.* Purely technical problems can develop, particularly in generation and transmission, which can act at a limit to the expansion, or certainly to the sound expansion, of an integrated system.

(*a*) *Generation.* The problem here is the concentration of too much generation tied together into one system. This, however, can be kept under control as long as protection and protective measures are developed on a par with growth and are utilized not only in design but in operation as well. It is to be noted that the converse to this problem is the need of eventually developing all good sites to their maximum.

(*b*) *Transmission and concentration of power on transmission network.* The concentration of energy supply feeding into the transmission network, whether from generating stations or from interconnexions feeding into the integrated system, may be so great that circuit breakers cannot be built to handle the interrupting duty required. So far, however, technical developments have been coming along at a rate slightly faster than requirements.

The size of an integrated system brings with it the concomitant factor of costs. It is entirely possible that the transmission network might be so costly as to carry within itself alone an offset to all the gains.

Another difficulty may be introduced by the growth of transmission requirements as size grows. This, in itself, can present difficult physical problems in getting through or getting into many locations with an adequate number of transmission circuits. Here, however, the availability of extra high voltage would appear to offer a solution good for some time to come.

3. *The tools of integration may be inadequate or too costly.* Any integrated system extending over any appreciable distance must, for effective functioning, have available and be capable of utilizing the tools of integration discussed under that heading. This is particularly true of the tools having for their objective the elimination of distance or barrier between various parts of the system which would otherwise become unco-ordinated. At best, however, they are items of economic burden and they could, conceivably, become too burdensome.

4. *The burden of the co-ordinating organization.* The added organization required to carry out co-ordination, even with the availability of the necessary tools, may again become a major item on the negative side of the ledger.

5. *Social-economic limitation.* The problem of size as it concerns an integrated power system is a problem that must be met in connexion with any large social-economic institution. The increasing concentration of power which frequently accompanies expansion of institutions must somehow be offset, otherwise society will be mastered rather than served. If the power cannot be effectively checked in any other way, then further expansion may have to be curbed. No single aggregation of human and material resources can be permitted to become dominant without placing in jeopardy the welfare of the society which it is designed to serve.

This is a general problem common to many fields. It has a special importance in the case of electric energy corresponding to the special role of that resource. Comprehensive and rigorous public regulation has been applied as one of the devices to meet the problem. The question may properly be asked, can a single power system be regulated if it becomes overly large. It should not be supposed that the answer is any easier where the group is the Government itself. And this is the crucial question that must be answered by society in determining the limits of size of an integrated system, whether the system is publicly owned and administered or privately owned and publicly regulated.

Certainly this question must be answered wisely if the integrated power system is to fulfil its purpose of furnishing an always adequate supply of electric energy at an always reasonable price on an area-wide or region-wide basis. If we are correct in our belief that such a system is the best way to make electric power contribute to the development and conservation of natural and human resources, then we must be sure that our social and economic and political controls keep pace with the development of the essential engineering controls.

An examination of the factors, both positive and negative in the integration ledger, clearly indicates that the advantages inherent in integration may be offset by fundamental disadvantages. In this regard, however, experience has shown that the balance can be heavily in favour of the integrated system. It is true that in order to bring this about, more factors need to be weighed in planning, building and operating. The problems in all these spheres, therefore, become more difficult.

But if all these factors are properly considered and evaluated by those responsible for the planning, building and operating of the system, and if there are brought to the operation of the system the necessary alertness, and the requisite technical and operating skills, the balance can be swung very heavily in favour of integration. That it can actually be accomplished is brought out in the discussion of an example of an integrated system.

IX. AN EXAMPLE OF AN INTEGRATED SYSTEM—DISCUSSION AND POINTING UP OF SOME OF THE PRINCIPLES DISCUSSED

As pointed out in the introduction, there are fortunately available a considerable number of outstanding examples of integrated system development. It should prove profitable, therefore, to examine one such system, particularly from the standpoint of how closely the principles developed in the theoretical discussion of integrated system requirements were followed, and to see what kind of a system resulted therefrom. More specifically, it should be possible to examine such a completed system and to see how well it met the social economic objectives postulated as a basis for its existence.

Since I am most familiar with the system with which I am associated, and with the planning, building, and operation of which I have been intimately connected for the past thirty years, I shall take this as an example.

This is, first of all, a privately-owned system; it has been in successful operation for a period of over forty years. It serves a region covering portions of seven states — Michigan, Indiana, Ohio, West Virginia, Virginia, Kentucky and Tennessee — the outside perimeter of which embraces an area of approximately 80,000 square miles. In this area the system serves slightly over 2,000 communities, very few of them of any appreciable size, the average population being approximately 2,000. In order to develop the illustration sought, the system will be examined from three standpoints.

A. THE GROWTH AND DEVELOPMENT OF THE SYSTEM AND ITS ABILITY TO EXPAND ECONOMICALLY AND TO SERVE ADEQUATELY THE AREA REQUIREMENTS

The growth of this system is typical of others in that in the beginning it comprised a few isolated operations so located that they could be economically co-ordinated; later as other isolated operations were acquired they were in turn co-ordinated and all were integrated to form the present system. The main growth, however, was the result of internal, that is intensive, rather than external, or extensive, development. Further, the development of integration was gradual over many years. Integration measures were first taken within the isolated groups and the then nucleus of the present integrated system was started. Thereafter, growth and integration proceeded until an integrated system was developed and subsequently it was perfected and extended.

This gradual growth, the bringing about of the first step in integration, and the development of the system from a beginning of considerably less than 50,000 kw. demand to its present size of almost 2 million kw. with a projected demand within the next decade of approximately 3½ million kw., can best be illustrated by a series of maps shown as figures 1 to 5 inclusive. The footnotes accompanying each map give the salient facts in the development as carried out up to that time or in the period intervening between the preceding map and the map under discussion, and speak for themselves. It is worth noting, however, that there can be no question that the growth shown and projected, clearly demonstrates the ability of combining gradual or evolutionary development with far-sighted planning, so as to bring a power supply to the integrated area large enough to serve all the requirements of the area. Such, as a matter of fact, has been the experience within the area served by this integrated system.

B. ABILITY TO SERVE ALL THE REQUIREMENTS OF ANY PART OF THE AREA

The basic principles followed in the planning and building of this integrated system, and the many studies made of different parts of the system and of the system as a whole during the years, all gave reason for the conviction that a practically unlimited supply of electrical power could be furnished to almost any community on the system.

The occasion presented itself actually to study this in great detail in 1939 at a time when the system was serving only about 1,400 communities. From this group 100 typical communities were selected for study. Figure 6 shows the communities served and the approximate load of each of these communities at that time. The object of the study was to determine whether an additional block of power as great as 50,000 kw. could be supplied at each of these points and what it would mean to serve such a load. The results clearly showed that in every case there could be no difficulty, and that only minor changes would be involved to supply an additional 50,000 kw. to any of the 100 communities. In some cases there was involved the necessity of tapping the 132,000-volt system, a practice which even then was common. In other cases it was not even necessary to tap the high-voltage line since existing lower-voltage lines were adequate to take care of the new assumed demand. In most cases additional transformer capacity was required, but this was to be expected.

A recent review of this study showed that since this study was first made in 1939, the load in a great many of these communities has doubled, in quite a number of cases it has tripled, and in one case it has increased almost five times. But the conclusions reached prior to and confirmed in 1939 are still valid — a very large block of power could be economically served to any of these many communities.

The ability of the integrated system, well planned and efficiently operated to furnish a supply of electric power in almost any practical amount to every community throughout the area covered by it, would seem to constitute an asset of major proportions from the standpoint of the broad social and economic welfare of the area and the country.

C. CONTRIBUTION TO OPERATING ECONOMIES AND TO RESOURCE CONSERVATION

Mention has already been made of the contribution of the integrated system to resources conservation. This can be illustrated by the savings in coal resulting from higher efficiency in generation, and the savings in coal due to reduction in system losses, that the integrated system makes possible. It has been estimated that in the United States in 1951 the national average use of coal will be 1.19 lb. per kwh. of net output, based on coal having a heat content of 13,000 B.T.U. per lb. The estimate for the American Gas and Electric integrated system in the same year is 0.88 lb. of coal per kwh., figured on the same coal. Expressing the saving in terms of the actual coal employed — with an average heat content of 11,200 B.T.U. per lb. — there is a resulting gain of 0.36 lb. per kwh. The steam plants, it is estimated, will have a net output of 13,000 million kwh. during that year. Thus the higher efficiency will result in a saving of 2,340,000 tons of coal per year as against the national average.

Based on actual past performance, it is expected that the system losses in 1951 on the same integrated system will be 4 per cent under the national average. With a gross system load of 15,300 million which includes production by steam plants, hydro plants, purchases, and interchange with other systems, this saving in losses will amount to 310,000 tons of coal on the basis of the actual coal used. The combined savings as the result of higher efficiency of steam plants and lower system losses will be 2,650,000 tons of coal per year.

This is not only a very substantial figure, whether considered from the economic angle or from the conservation of resources viewpoint, but of equal significance, the savings automatically increase as growth takes place, provided, of course, the basic concepts of a sound integrated system are not infringed upon.

X. SUMMARY AND CONCLUSIONS

It may be well to summarize the important points of the discussions given in the paper and to indicate some conclusions which these discussions lead to. The following are the high-lights:

1. An adequate and economical supply of electric energy is one of the elements needed to give a balanced economy to an area or region.

2. The integrated power system has come to be recognized as the soundest basic mechanism for developing and for making available an adequate and economical power supply system.

3. Since power development is only one of the many phases of resource development it should aim at the same social-economic objectives: the development and conservation of all resources so as to attain a wiser use of all of them for the improvement of life and living.

4. Stated more specifically in terms of power the social-economic objective of an integrated power system is: to furnish an area or region an always adequate supply of energy of proper quality at lowest practicable cost in the present and for a reasonable time into the future.

5. Expanding the criterion in (4) above: this must include the ability to serve an entire area or region; the ability to integrate necessary sources of energy; the ability to exploit local energy resources; and the demonstrated ability to contribute to area resource development and conservation.

6. The technical bases behind a properly set up integrated system are: proper location of generating centres; maximum exploitation of the most economical sources of energy supply; ability to exploit inherent savings in size of units and in amounts of reserve; lowered margins of insurance; lowered cost of meeting emergencies; and interconnexion so set up that all generating and all load centres are integrated as a unit and operated as a basic whole.

7. The components of an integrated system are the generating system, the transmission system and the distribution system. They are kept together and functioning by the co-ordinating personnel through the medium of a series of tools, the protective elements and the regulating elements.

8. Of the many sources of energy available for the integrated system, hydro and fuel-generated steam-electric power are predominant. The diesel generator would seem to have limited application. The gas turbine has so far made little progress. Tidal and wind power are at present of dubious economic status. Nuclear energy is a possibility, but its economic position cannot be foretold until further progress is made in the developmental programme under way. Interconnexions with systems outside can be a source of major energy supply, particularly if one system is predominantly steam-electric and the other predominantly hydro-electric when major "conversion" capacity can be created.

9. The transmission system which is the co-ordinating medium of the integrated system should be designed for the following purposes: to have the highest practicable voltage; to use a minimum number of subsidiary voltages; to be able to provide full capacity for free flow of power in all parts of the system; to be able to stay together in parallel under all operating conditions; to be capable of handling power flows even to the extent of reversal and to do so with utmost reliability.

10. The use of extra high voltage, up to 400,000 volts, in alternating current transmission seems to offer at present the only means of solving some of the transmission problems of capacity and economics in integrated system development. Direct current transmission at present has not solved all the technical problems confronting its practical use, and is labouring besides under a severe economic handicap owing to the cost of terminal facilities.

11. While the distribution system would appear to be beyond the scope of a discussion of the integrated power system, it is, as a matter of fact, vitally tied to it. Properly co-ordinated with transmission it results in major economies in the development of the supply system feeding the ultimate consumer. Besides, as a system grows, existing transmission can and should more and more be given the functions of distribution.

12. Because of the basic handicaps of size and distance, the full utilization of protective elements and regulating elements are essential if a system is to be economically sound and, from a service standpoint, reliable. To accomplish this the system needs to be solidly connected throughout but this in turn means circuit breakers of the utmost reliability and of the fastest speed, bus fault protection, differential carrier relaying of lines, ultra-rapid reclosing, and facilities for melting of sleet wherever sleet is encountered.

13. An important tool to make possible the obtaining of the most economical transmission system is insulation co-ordination. Used in conjunction with the lightning arrester it will give maximum insurance against transmission system failure at minimum cost.

14. The regulating elements available in the development of an integrated system are the synchronous condenser, the static capacitor, the voltage regulators and frequency and tie-line control.

15. If the growth of a system is not to quickly come up against the technical barrier created by distance, reliable and effective communication and telemetering are essential. These are very important tools in the elimination of the barrier of distance to the effectiveness of integration.

16. Essential to the successful operation of an integrated system is a properly trained and highly skilled co-ordinating personnel. This is particularly necessary to provide the day-to-day know-how in such important elements as load projection, management of reservoirs, incremental loading of steam plants, co-ordinating of interconnexion facilities, alertness to handling of sleet, and supervision over the protective, communication, and telemetering gear.

17. While interconnexion with outside systems can serve as a source of firm energy supply it has other major technical economic functions: the reduction of reserve; the integration of inter-area diversities; the maximum exploitation of highly economic sources of energy generation; the co-ordination between steam and hydro; the co-ordination of maintenance; and the staggering of construction of generating facilities. All of these offer major economies; none of them can be disregarded if maximum economy in the supply of energy is sought.

18. The economics of integrated operation are not entirely one-sided since, fundamentally, integration involves the technical and economic burden of the integrating network together with its tools. It is obvious that unless skill is employed in its development the benefits of the integrated system might be more than absorbed by the negative factors. Experience has shown, however, that the balance can be maintained heavily in favour of the integrated system when integration is carried out with competence and skill and the integrated system is maintained and operated on the same basis. However, major problems and limitations are bound to develop that could threaten the successful performance of an integrated system.

19. The technical problems and limitations are those related to size, both in generation and transmission, involving concentration of generating capacity and concentration of short circuit capacity, respectively. Up till now technical developments have been moving ahead at least as fast as power system growth.

20. The limiting economic problems all relate to the burden of the integrated system, tools, and mechanisms of integration. Here, too, technical developments to date have been more than adequate to keep any of these potential limitations from becoming controlling.

21. The problem of size as it concerns an integrated power system is one that must be met in connexion with any large social economic institution. The increasing concentration of power which frequently accompanies expansion of institutions must somehow be offset in the public interest. The problem has a special importance in the case of electric energy corresponding to the special role of that resource, and it is present whether the electric system is publicly or privately owned.

Bibliography

1. PHILIP SPORN, "Potentialities of the Electrical Industry in Shaping the Destiny of America" (The Twenty-First Steinmetz Memorial Lecture, 20 May 1948), *Elec. Eng.*, July 1948, pages 630–636.
2. PHILIP SPORN, "The 2000 psi, 1050 F and 1000 F Reheat Cycle at the Philip Sporn and Twin Branch Steam-Electric Stations", A.S.M.E. *Transactions*, May 1948, pages 287–294.
3. PHILIP SPORN, "Planning and Carrying Out of a Program to Provide Adequate Generating Facilities on an Extensive Integrated Power System", *Power Plant Engineering*, April–May 1938.
4. PHILIP SPORN and E. L. PETERSON, "Design Features of the London and Marmet Hydro Developments", *ibid.*, vol. 41 (1937), pages 80–87.
5. PHILIP SPORN, "Symposium on Resuperheating Turbines and Boilers", Closing discussion 1948 A.S.M.E. Annual Meeting, New York, N.Y. (December 1948).
6. "Discussion by Philip Sporn of a series of papers on gas turbines for power generation at A.I.E.E. Symposium, 3 Feb. 1949". (To be published in A.I.E.E. 1949 *Transactions*).
7. PHILIP SPORN and A. C. MONTEITH, "Transmission of Electric Power at Extra High Voltages", A.I.E.E. *Transactions*, vol. 66 (1947), pages 1571–1577.
8. H. P. ST. CLAIR, "The Use of Multiwinding Transformers with Synchronous Condensers for System Voltage Regulation", *ibid.*, vol. 59 (1940), pages 212–217.
9. PHILIP SPORN, "Bus Protection Gives Service Reliability", *Electrical World*, vol. 106 (1936), pages 1357–1358, 1401.
10. PHILIP SPORN and H. P. ST. CLAIR, "Field Tests and Performance of Heavy-Duty, High Speed 138 kv. Circuit Breakers—Oil and Air Blast", A.I.E.E. *Transactions*, vol. 64 (1945), pages 401–410.
C. L. KILLGORE and W. H. CLAGETT, "Field Tests for Development of 10-Million kva., 230 kv. Oil Circuit Breakers for Grand Coulee Power Plant", *ibid.*, vol. 67, part 1 (1948), pages 271–283.
E. B. RIETZ, "Development and Testing of an Improved High-Voltage, High Capacity Impulse Breaker", Conference Paper presented at A.I.E.E. Winter General Meeting, 31 Jan. to 4 Feb. 1949.
11. PHILIP SPORN and C. A. MULLER, "One-Cycle Carrier Relaying Accomplished", *Electrical World*, vol. 105 (1935), pages 2434–2436.
12. PHILIP SPORN and C. A. MULLER, "Nine Years Experience with Ultra-High Speed Reclosing of High Voltage Transmission Lines", A.I.E.E., *Transactions*, vol. 64 (1945), pages 225–228.
13. PHILIP SPORN and C. A. POWELL, "Basic Impulse Insulation Levels", *ibid.*, vol. 59 (1940), pages 596–598.
14. PHILIP SPORN and I. W. GROSS, "Lightning Arrester Economics", *ibid.*, vol. 55 (1936), pages 84–93.
15. PHILIP SPORN, "Normal Voltage Short Circuiting Removes Conductor Glaze", *Electrical World*, vol. 111 (1939), pages 1456, 1457, 1521.
G. G. LANGDON and V. M. MARQUIS, "Carrier Attenuation Discloses Glaze Formation", *ibid.*, vol. 112 (1939), pages 450–452, 512–513.
16. T. W. SCHROEDER, J. W. BUTLER and N. H. MEYERS, "The Effect of Kilovar Supply on the Design of System for Load Growth", A.I.E.E., *Transactions*, vol. 63 (1944), pages 69–77.
HOLLIS K. SELS and THEODORE SEELY, "Facilities for the Supply of Kilowatts and Kilovars", *ibid.*, vol. 61 (1942), pages 249–254.
17. F. M. PORTER and J. H. KINGHORN, "The Development of Modern Excitation Systems for Synchronous Condensers and Generators", *ibid.*, vol. 65 (1946), pages 1020–1027.
18. M. E. HARTMAN, J. B. MCCLURE and S. I. WHITTLESEY, "Modern Excitation Systems for Large Synchronous Machines", *ibid.*, vol. 65 (1946), pages 939–945.
A. W. KIMBALL, "Two-Stage Rototrol for Low-Energy Regulating Systems", *ibid.*, vol. 66 (1947), pages 1507–1511.
19. R. E. PIERCE, "Interconnected Power System—Automatic Load and Frequency Control", C.I.G.R.E. Conference Paper No. 324 (27 June–6 July, 1946).
S. B. MOREHOUSE, "Inter-system Power Coordination in Southwest Region", *Electric Light and Power*, Dec. 1945, pages 62–68, 70 and 105.
20. PHILIP SPORN, "Experience with Carrier Current Communication on High Tension Interconnected Transmission Systems", A.I.E.E. *Transactions*, vol. 48 (1929), pages 480–486.
T. DEWITT, "TVA Coordinated Communication System", A.I.E.E. Technical Paper 47–121, April 1947.
21. A. W. WALTON and H. W. LENSNER, "System Operation Improved with Carrier Telemetering and Load Control", A.I.E.E. Technical Paper, vol. 48 (September 1948), page 296.
22. RICHARD F. STEVENS, "Microwaves Supplant Present Channels", *Electrical World*, 1 Jan. 1949, pages 39–42.
23. M. J. STEINBERG and THEODORE H. SMITH, "The Theory of Incremental Rates and Their Practical Application to Load Division", A.I.E.E. *Transactions*, vol. 53 (1934), pages 432–445, 571–584.
H. H. JOHNSON and M. S. UMBENHAUER, "Station Loading Slide Rules", *Power*, vol. 82 (1938), pages 600–602.
24. ALEX E. BAUHAN, "Interconnection Services—Their Classification and Evaluation", A.I.E.E. *Transactions*, vol. 50 (1931), pages 1247–1255.
PHILIP SPORN, "Interconnected Power Systems", *Electrical Engineering*, Jan. 1938, pages 16–25.

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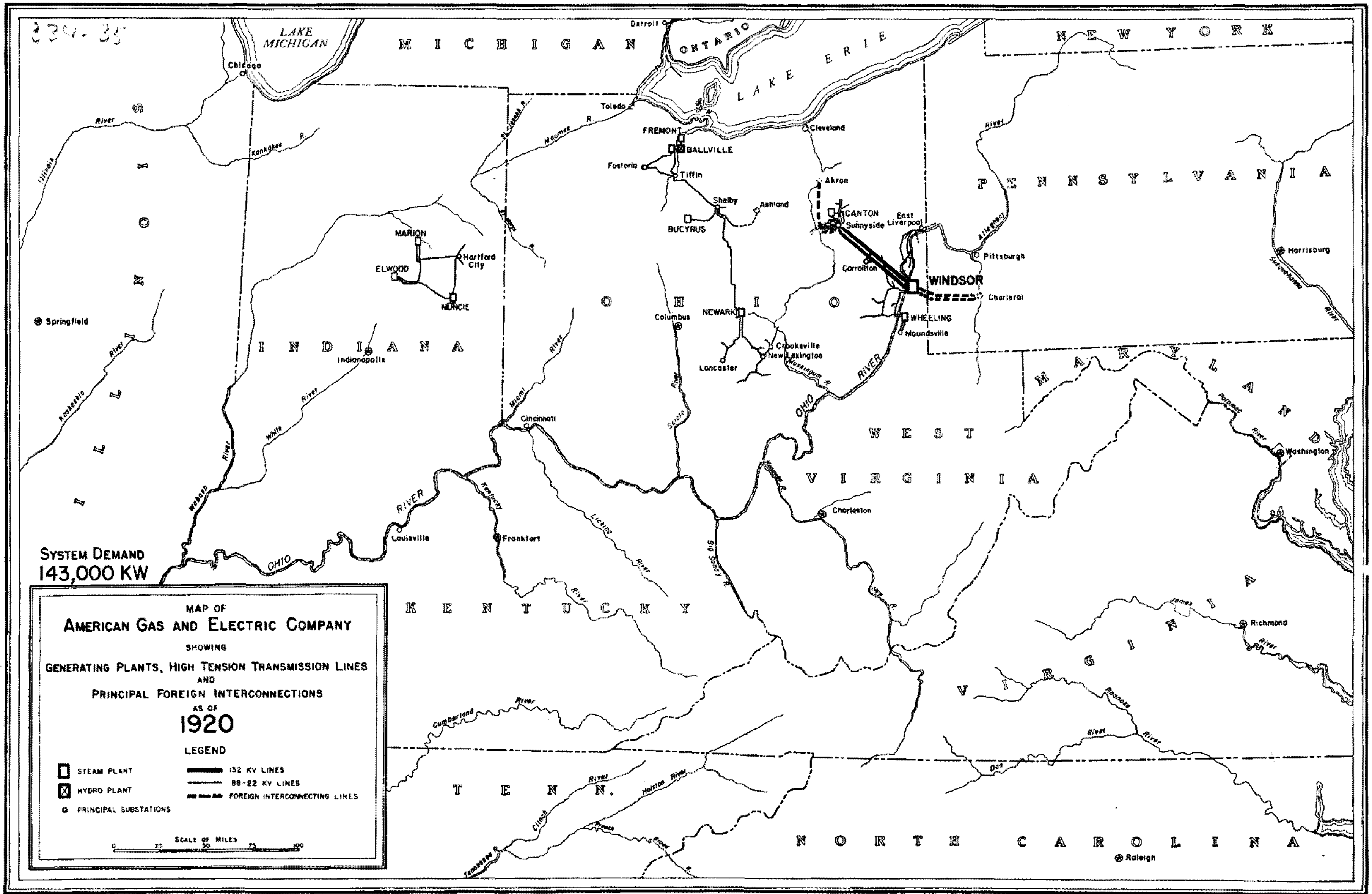

FIG. 1

For footnotes, see page 242.

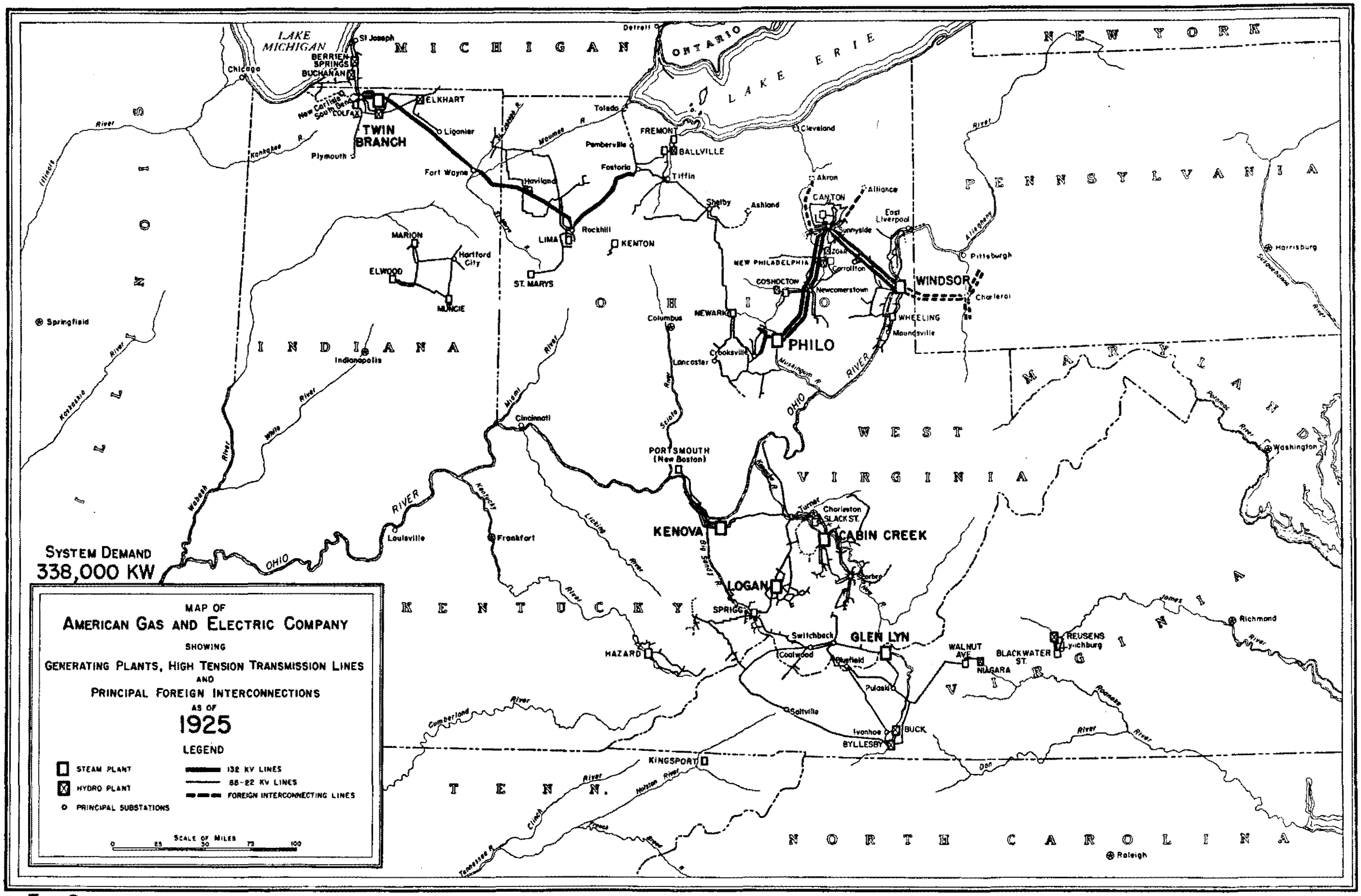

FIG. 2

For footnotes, see page 242.

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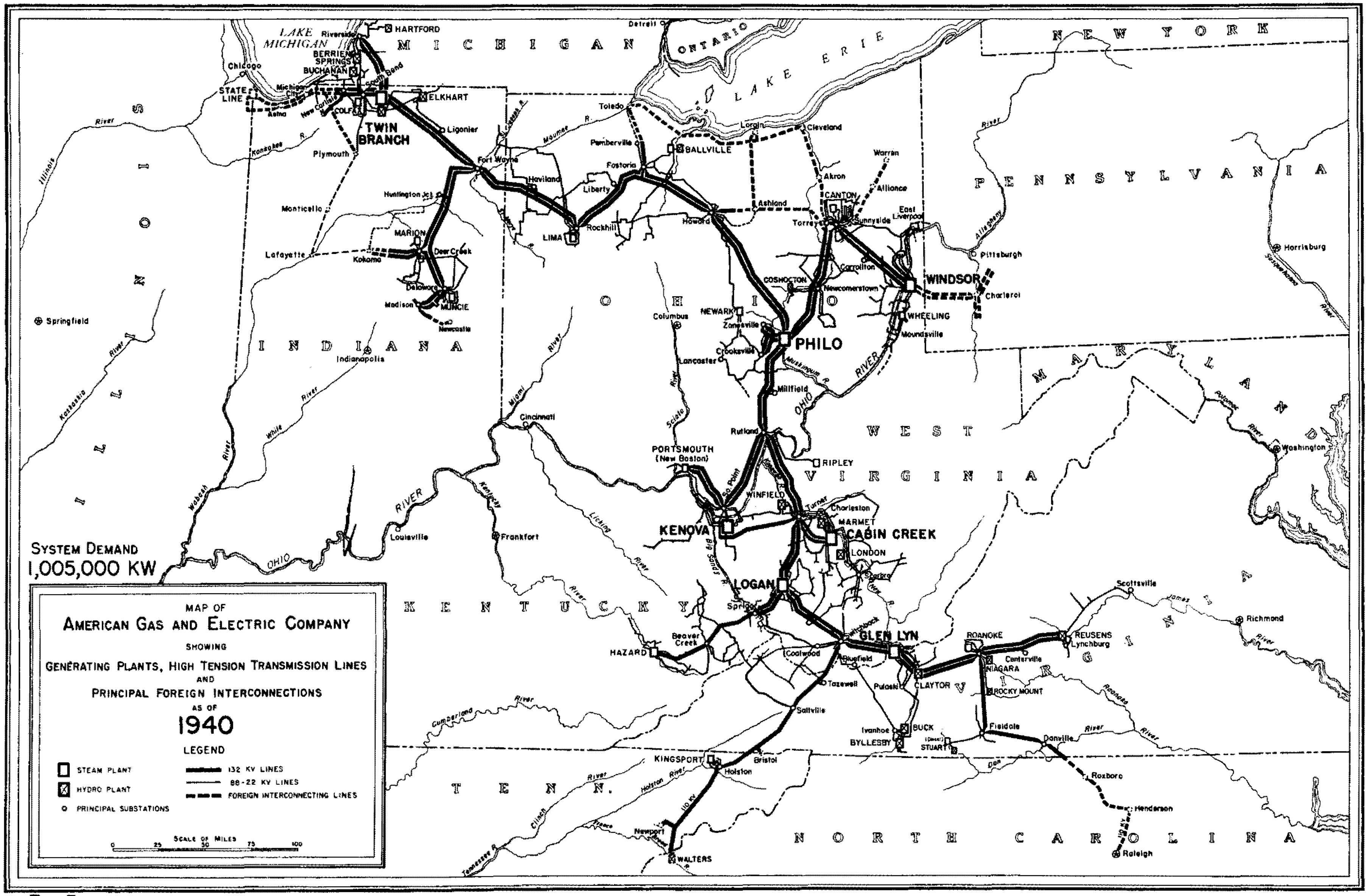

FIG. 3

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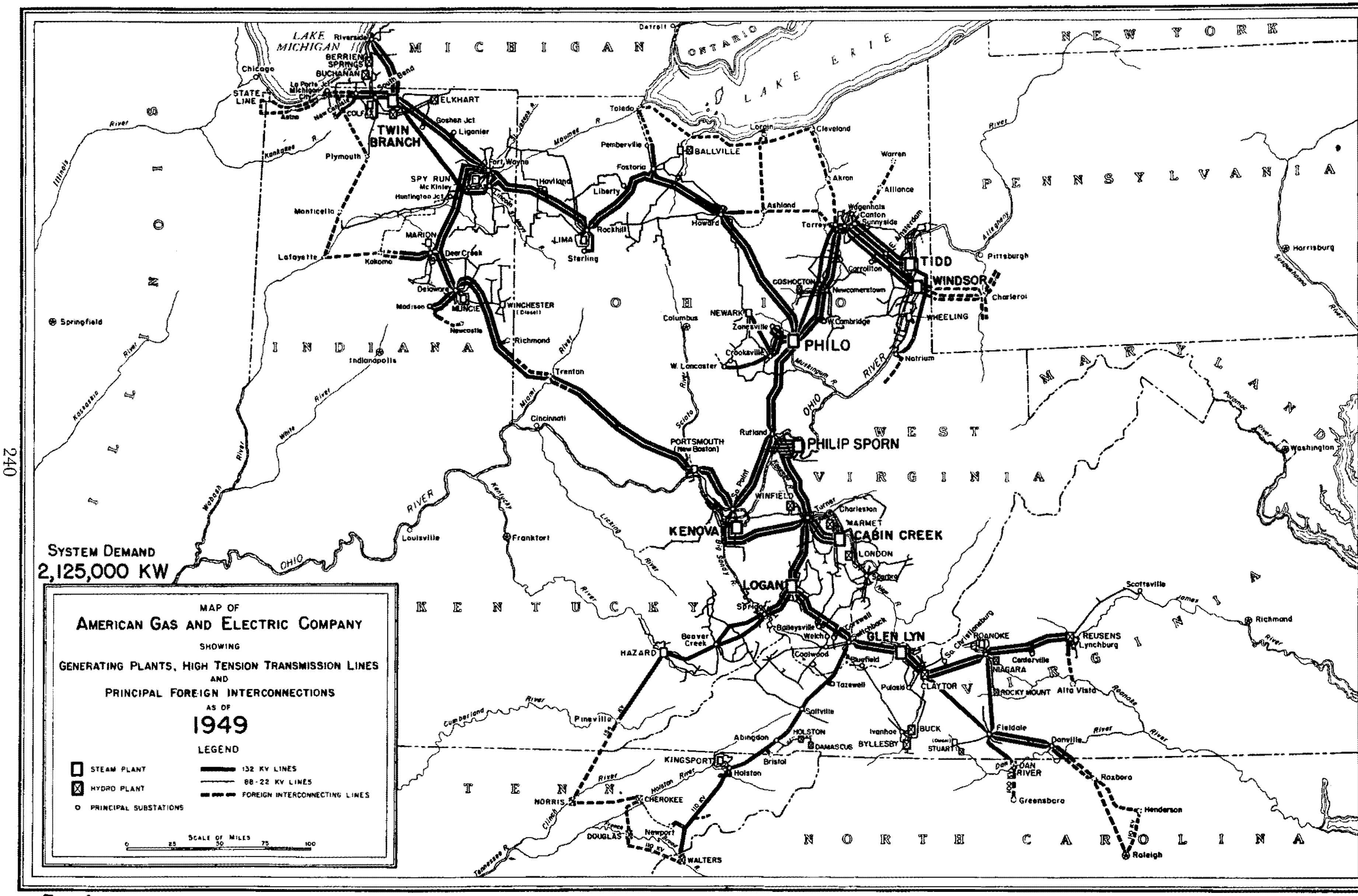

FIG. 4

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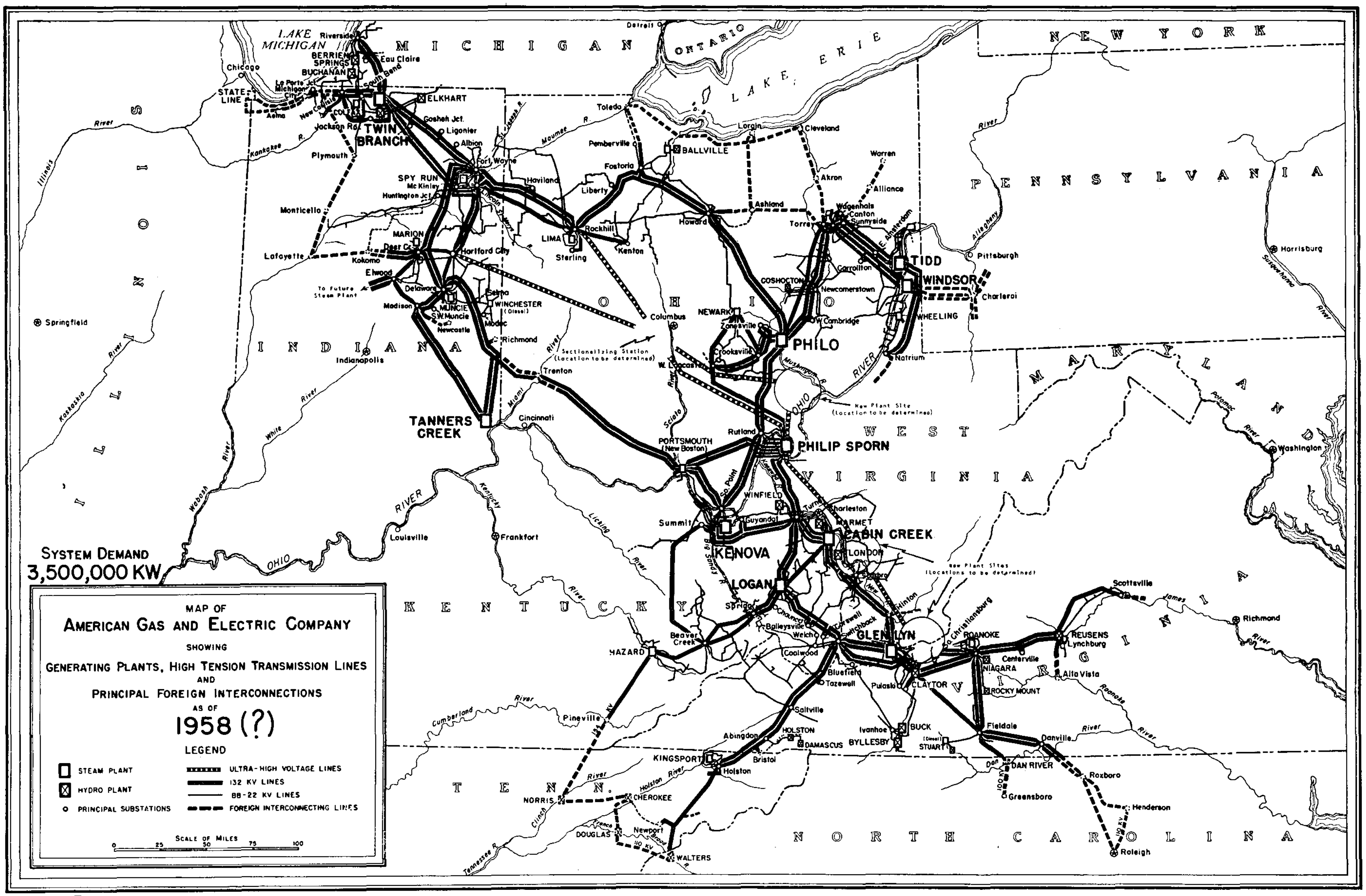


FIG. 5

For footnotes, see page 242.

FOOTNOTES TO MAPS

Map 1

The only electric power operations in 1920 that are now in the system and are still operated were located in the east-central part of Indiana, centring around Marion and Muncie; in central and eastern Ohio and in the panhandle of West Virginia in the Wheeling area.

In Indiana, the steam plants located at Marion, Muncie, and Elwood had been interconnected by 33-kv. lines. This improved service throughout the area made possible the reduction of reserves by interconnecting the three plants. It is also interesting to note that one of the first all-turbine-type prime mover plants erected anywhere in the country had been placed in service in Marion as early as 1904.

In central Ohio, the steam and hydro plants near Fremont, Ohio, had been interconnected with the Bucyrus and Newark plants by 66,000-volt transmission lines. The effect of this was similar to that already outlined for the Indiana operations.

The then modern Windsor steam electric plant had been built on the Ohio River near Wheeling. This plant strikingly illustrates one of the principles that have been consistently followed in the development of the system ever since its beginning. The use of large units (for that time), an abundant cooling water supply, and mouth-of-mine location with coal delivered from the mine to the plant by belt conveyor were the outstanding features of this plant.

There is here also shown a first major step in integration, namely, the building of the 132,000-volt double circuit line from the Windsor plant to Canton, Ohio, a line far ahead of its time in concept — to serve as the primary power supply with the fuel burning energy source 55 miles away — in magnitude of voltage chosen, and in choice of outdoor equipment. This line was to serve as the nucleus of a 132,000-volt transmission network now comprising 3,400 circuit miles.

Just prior to the building of this line the Canton area was supplied by a small plant located in Canton, but this plant could not be economically expanded due to site and cooling water limitations and was located at some distance from the coal supply. The Windsor project, including the 132,000-volt transmission lines, constituted a break with the past and inaugurated the period of integration with reliance on large-scale, properly-located generation, tied together by high-voltage transmission as the foundation for an adequate and economical power supply for the entire area.

Map 2

During the period from 1920 to 1925, additional electric power operations had been acquired in Indiana, Ohio, Eastern Kentucky, West Virginia, Virginia, and Tennessee. As fast as possible, economical generation was introduced and the integrating interconnexions developed.

In Indiana, the Twin Branch Steam Plant was placed in operation in 1925, giving an economical source of supply to this area. During this period, an interconnexion was built at 132,000 volts from the new Twin Branch Plant to Lima, Ohio, and on to Fostoria, Ohio. This modern plant and the high-voltage transmission line furnished an economical source of supply to the area around South Bend, Indiana, and to the central and western Ohio areas where existing plants could not be expanded to develop economical generation.

The Philo Plant near Zanesville, Ohio had also been constructed and placed in service and a 132,000-volt line had been built to Canton, Ohio. This plant was somewhat away from the centre of gravity of the loads served in Ohio at that time, but its location was picked because of water supply and economical coal supplies which were adjacent to the plant. However, this location having been chosen, it in turn became the focal point of an extensive integrating transmission network, which was later developed. This high-voltage transmission line interconnected the Philo and Windsor power plants through Canton, Ohio. Both the Twin Branch and Philo Plants were landmarks in efficient power generation at that time. Both plants made use of the highest pressures and temperatures available and utilizing reheat boilers to obtain a further gain in efficiency.

Relatively small operations were also acquired in Portsmouth, Ohio, in eastern Kentucky, and in West Virginia, Virginia, and Tennessee. The power plants acquired with these properties included some small hydro plants and steam plants at Portsmouth, Logan, Kenova, Cabin Creek, Glen Lyn, and Hazard. The Cabin Creek and Glen Lyn sites have since that time been expanded to several times their original size, and the Logan Plant has been expanded to the maximum extent possible with the limited water supply. All were initially well located with reference to economical coal supply, and this has in at least one case been materially improved since then.

At the end of 1925, these properties were still isolated, but plans were definitely taking shape to integrate them by a 132,000-volt network; all were located closely enough so that this could be done on an economical basis. The existence of old and relatively inefficient generation offered an additional economic support to such an operation.

Map 3

The period from 1925 to 1940 was one of intensive integration by the development and extension of the high-voltage network and the carrying forward of a programme of co-ordinated expansion of generation facilities. By 1940 all of the operation had been interconnected at 132,000 volts and for the most part by double circuit lines. This interval had also witnessed a period of intensive development of local resources. Many industries originally located in the territory were expanded, and many new industries were brought in because of favorable working conditions, availability of raw materials, transportation, and an adequate and economical supply of electric power. Coal-mining operations expanded substantially in the Appalachian region and in Ohio.

The capacity of the major power plants had been increased to meet the growing demands for power. Modernization programmes were carried out at Logan and Windsor by the installation of "topping" units. Three comparatively small hydro projects were developed on the Kanawha River at London, Winfield, and Marmet during this period. These plants were outstanding in that they were built and operated by the company at navigation dams that had been constructed and were being operated by the United States, acting through the United States Engineers Office. The availability of the integrated system made possible the economical development of these wholly non-firm hydro projects with the concomitant saving of coal this brought about.

During this period, there was also considerable expansion of system transmission facilities and building of new interconnexions with neighbouring utility systems carrying with them the many advantages to be gained by interconnecting adjacent systems.

It was also during this period that the training of personnel was carried through and the techniques and tools required for integrated system operation were developed. Typical were the development of hydrogen cooled kilovar generators, (condensers), carrier current relaying and ultra rapid reclosing and frequency and load control.

All of these problems required an enormous amount of work. The present-day integrated system functions in its highly economical and highly reliable manner only by virtue of the fact that planning has been forward-looking, that there has been proper basic engineering behind its building, and that the development of tools and techniques and the training of skilled personnel required to operate such a system have been carried through.

Map 4

The period from 1940 to 1949 was one of rapid load expansion. During this period, the system demand increased from about 1 million kw. to an estimated demand of slightly over 2 million kw. Included in this period were the war years, which placed extraordinary burdens on the system. This experience clearly demonstrated that the planning, design, construction, and operation of the integrated system was sound in that it was able to take on very heavy loads at practically any point on the system at a minimum of expense.

During this period 1,127,000 kw. of new capacity will have been installed. This includes 299,500 kw. at the Twin Branch Plant, 180,000 kw. at the Philo Plant, 180,000 kw. at the Cabin Creek Plant, 110,000 kw. at the Glen Lyn Plant, 220,000 kw. at the Tidd Plant, and 137,500 kw. at the new Sporn Plant. It is interesting to note, that in the period from 1925 to 1948 only one new steam plant site had been developed, namely, the Tidd Plant, and that except for the three hydro plants on the Kanawha River, having a total of about 50,000 kw., and the Claytor hydro plant on the New River in Virginia, with a capacity of 75,000 kw., all expansion had been carried out at existing steam plant sites.

When it became necessary to locate additional plant sites, the integrated system was utilized in a search for other sources of generation. For example, the location of the new Sporn Plant was determined entirely by the existence of the integrated system. An adequate supply of condensing water was a prerequisite. The contiguous coal supply was developed in the course of the rounding out of the project development.

During this period, the high-voltage network was strengthened, a notable example being the looping of the system between Ohio and Indiana by building lines from Portsmouth, Ohio, to Muncie, Indiana.

Ties were strengthened on the south and new ties made with large integrated predominantly hydro-electric systems, making possible the saving of fuel by absorbing dump hydro energy and making possible the creation of new capacity by delivering off-peak steam to the hydro systems, which in turn, firms up the hydro systems over peak periods. The major potentialities in this field still remain to be developed.

Map 5

During the twenty year period, 1929–1948, since all parts of the system were first integrated by the 132,000-volt backbone transmission system, the load has increased some 230 per cent. Throughout this period, the integrated system has been able to take advantage of the integrating transmission system network in expanding its sources of generation with the minimum of addition to the transmission system.

The integrating transmission system network has by now (1949) reached a point where additional backbone transmission is required, and a point where it becomes economical to superpose higher-voltage transmission on the present 132-kv. system. The proposed system is shown on the map. This is marked as a 1958 projection, but the governing condition is the system demand of 3,500,000 kw., which may or may not be reached by 1958. The development of the high-voltage system will enormously increase the load that can be transferred between sections of the system and the growth in load which can be served. During this period, there will be some additional strengthening of the 132,000-volt system, additional capacity will be installed at the Philip Sporn Plant, the new Tanners Creek Plant will be placed in service, possibly some expansion and modernization will be made at existing plants, and three new plant sites, the exact location of which has not been determined, will be developed.

It is significant to note that this great expansion of the system can be carried out without any major changes in, or obsolescing of, the existing system. The length of the new extra-high-voltage superposed, network compared with the length of the existing network is impressive: 575 circuit miles of extra-high-voltage against 5,065 circuit miles of 132,000-volt transmission. It is true that at certain points 132,000-volt oil circuit breakers will have to be changed, but this operation is almost insignificant compared to the magnitude of the whole expansion programme. Besides, all the displaced breakers will find use. This, too, is made possible by the integrated system.

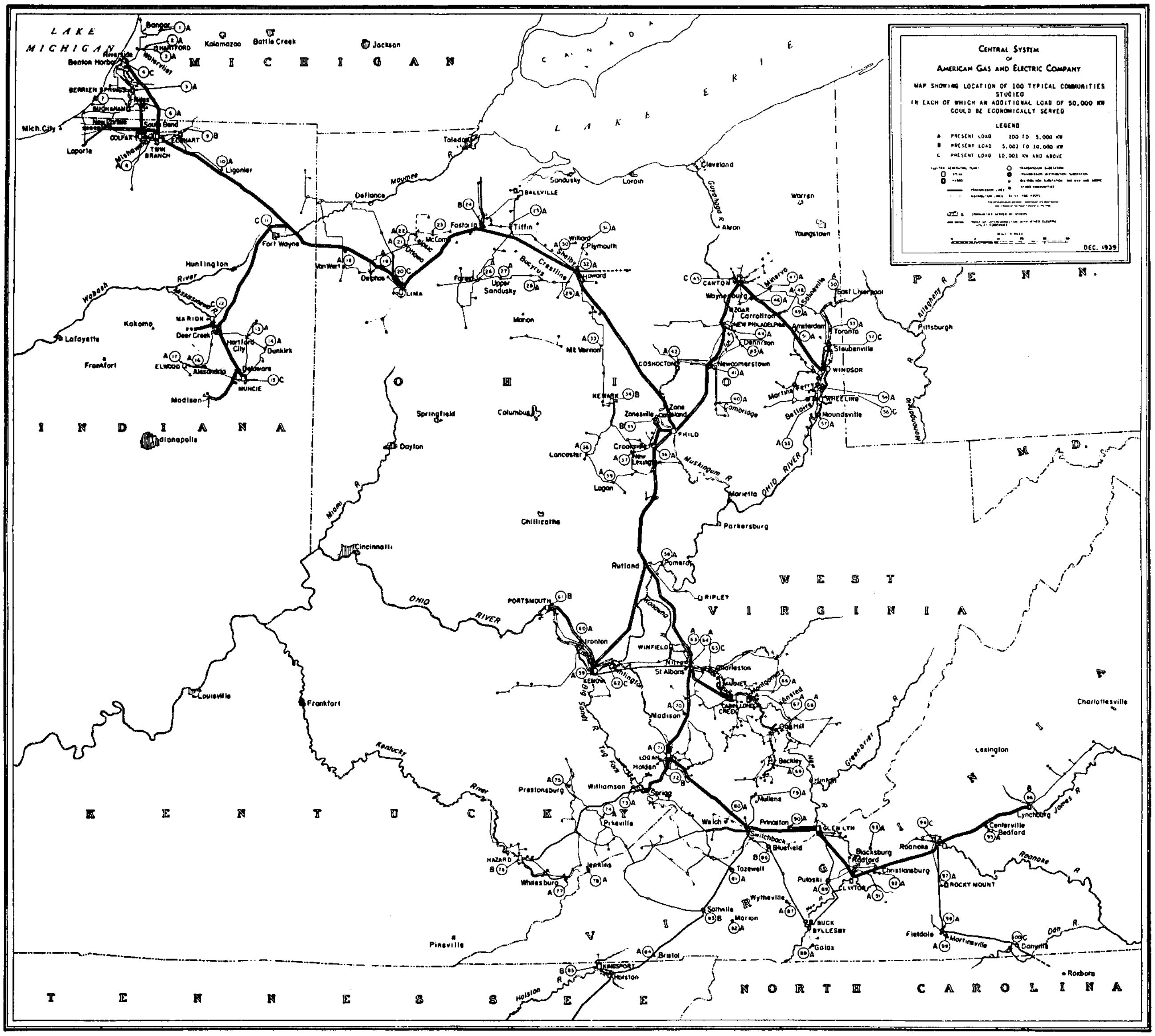

Central System
of
American Gas and Electric Company
MAP SHOWING LOCATION OF 100 TYPICAL COMMUNITIES STUDIED
IN EACH OF WHICH AN ADDITIONAL LOAD OF 50,000 KW COULD BE ECONOMICALLY SERVED
LEGEND
A PRESENT LOAD 200 TO 5,000 KW
B PRESENT LOAD 5,001 TO 10,000 KW
C PRESENT LOAD 10,001 KW AND ABOVE
DEC. 1939
LAKE MICHIGAN
MICHIGAN
LAKE ERIE
INDIANA
OHIO
WEST VIRGINIA
KENTUCKY
VIRGINIA
TENNESSEE
NORTH CAROLINA
PENN.
MD.

FIG. 6

Some Experiences of the Operation of the Electricity Grid System in Great Britain

Sir John HACKING

ABSTRACT

This paper outlines the reasons for the construction of the Grid System and reviews past operating results and future prospects. The Grid System is briefly described and the effects of the nationalization of the electricity supply industry in Great Britain on 1 April 1948, are mentioned.

The economies in capital expenditure and in operating costs, following the construction of the grid have been affected by the war, but they are substantial. Savings in capital and operating costs by the end of 1938 were 22 million pounds and 17 per cent respectively, and the relative savings are believed to be at least as great at present.

The grid enables the best sites for generating stations to be utilized, and permits the bulk transfer of energy for economic reasons.

The average thermal efficiency of generation increased from 17.1 per cent in 1932 to 20.9 per cent in 1938–1939 before war conditions caused a reduction. There has since been a recovery to a little above the pre-war figure and the upward trend should continue.

Standardization, gas-turbine generation, hydro-electric development and district heating schemes, together with the possible construction of a 275,000 volt grid give promise of further increases in thermal efficiency and reduced production costs in the future.

In reviewing the achievements of the electricity supply industry in Great Britain during the last fifteen to twenty years it is necessary to outline the conditions which existed prior to the construction of the National Grid System.

Following the 1914–1918 war, the need for integration of the electrical supply industry became apparent. Under the Act of 1919 the Electricity Commissioners were established to co-ordinate the application and to regulate the broad principles of electricity supply, and provision was made for the formation, on a voluntary basis, of Joint Electricity Authorities by the amalgamation of electricity undertakings. In fact, only four Joint Authorities were formed and the first major step towards the integration of the industry was the passing of the Act of 1926 and the establishment of the Central Electricity Board.

Before the grid was constructed some 600 municipal and company undertakings were responsible for the generation and distribution of electricity within prescribed areas and only in few instances were the systems interconnected. A multiplicity of tariffs existed and the frequency of supply was not standardized. The primary duties laid upon the Board were to co-ordinate the generation and transmission of electrical energy and to make available a cheap and abundant supply for distribution. Although the ownership of the generating stations remained in the hands of the various undertakings the Board had powers to regulate their output, to arrange for the extension or construction of new stations, to standardize frequency of supply and unify bulk supply tariffs as far as practicable.

The Grid transmission system was constructed by the Board during the period 1928–1933 and operates at 132,000 volts. It was anticipated that the interconnexion of the stations would make possible economies in fuel consumption and in the cost of production for the following reasons:

(*a*) When operating independently spare generating plant was necessary at each station to maintain supplies in the event of breakdown. By interconnexion, this spare capacity could be pooled and considerable savings in capital costs could be achieved.

(*b*) By selective loading and the shutting down of uneconomical plant when conditions permitted, considerable reductions in over-all fuel consumption and operating cost could be made.

A further advantage of the interconnexion of stations was improved reliability of supply, as supplies could be maintained, or quickly restored, from the grid in the event of serious breakdown in individual generating stations. The establishment of the grid created for the whole of Great Britain, excluding the North of Scotland, a co-ordinated system for generation and transmission.

The second major step towards integration of the supply industry was the passing of the 1947 Act, under which the ownership of all authorized electricity undertakings in Great Britain, excluding the North of Scotland, was vested in the British Electricity Authority and fourteen Area Boards, thus for the first time, co-ordinating the distributing side of the industry.

The main transmission system operated by the Authority consists of some 3,700 route miles of 132,000 volt line and 1,500 miles operating at 66,000 and lower voltages together with approximately 350 main switching and transforming stations. The Authority own and operate 302 generating stations, having an aggregate plant capacity of 12,883,000 kw. installed on 31 December 1948.

As the industry has been reorganized recently, any survey of the results which have been achieved during the past fifteen to twenty years must relate to those stations formerly controlled by the Central Electricity Board. During 1947, these stations produced 99 per cent of the electricity supplied by all authorized undertakings in the country, excluding the North of Scotland.

The results obtained and the future trend are reviewed under the following main headings.

THERMAL EFFICIENCY

The trend of percentages of thermal efficiencies on a twelve-monthly moving average basis, is shown on Figure 1. The improvement from a figure of 17.1 per cent in 1932, before

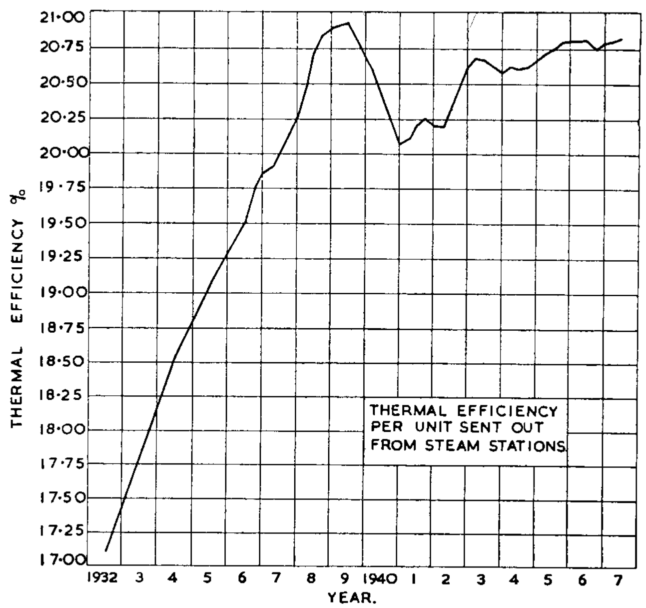


Fig. 1

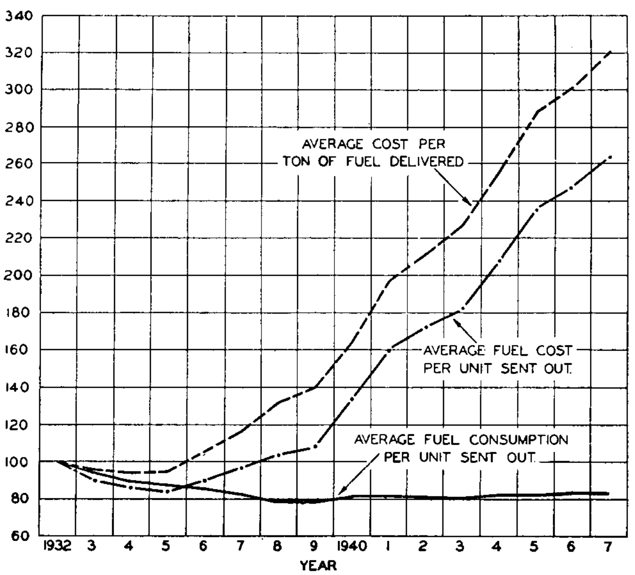


Fig. 2

the grid was in full operation, to 20.9 per cent immediately before the war, is striking. The necessity during the war to keep an abnormal amount of plant running as a safeguard against the consequences of air attack, together with the curtailment of new plant construction and the frequent enforced use of unsuitable fuels, resulted in a marked fall in thermal efficiency. Recently the effects of the commissioning of new plant, improvements in the technique of burning unsuitable fuels and greater consistency in the fuels delivered have brought about an increase in the thermal efficiency which is now slightly higher than pre-war. With the present plant shortage, relatively inefficient plant must be run longer than normally but it is confidently expected that as new plant becomes available the upward trend in thermal efficiencies will be resumed.

FUEL CONSUMPTION

The total weight of fuel burned at stations under the control of the Central Electricity Board in 1947 was 25,900,603 tons, representing an average consumption of 1.501 lb. unit sent out. The corresponding figures for 1932 and 1938 were respectively 1.794 and 1.430 lb. unit sent out. These figures do not allow for slight variations in the calorific values of the fuels. Mention must also be made of the increased ash-content of the fuels available during recent years. The average ash-content of the fuel consumed in 1939 was 11.3 per cent but by 1947 this figure had risen to 15.4 per cent. Of the fuel consumed in 1939, less than 38 per cent had a dry ash-content over 12.5 per cent but by 1947 this figure had increased to 68 per cent. Both the combustion efficiency and the ability of a boiler to steam its rated output decrease rapidly with increasing ash-content of the fuel, and this is one of the factors which have contributed to the fall in thermal efficiency during the war years and the slow rate of recovery.

COSTS

The principal item affecting the cost of production is the cost of fuel and the marked increases in the latter have been reflected in the costs of generation. The relative costs of fuel delivered, and costs and fuel consumptions per unit sent out for each year 1932—1947 are shown on Figure 2, the 1932 figures representing 100 per cent. Figure 3 illustrates the over-all costs of production per unit from steam stations controlled by the Central Electricity Board and it will be observed that, despite the improvements in thermal efficiency following the installation of new plant and the economical loading of stations, the cost of production has, in fact, risen since 1932.

Reference has been made to the deterioration in the qualities of the fuels supplied to generating stations and to increases in price which have occurred. All price increases since November 1939 have been flat-rate additions regardless of quality and the cost of the low-grade coals forming a large proportion of the deliveries to generating stations has increased by a relatively greater amount than that of better quality fuels. This inequality has been recognized by the National Coal Board and revised price scales are being negotiated.

SAVINGS IN CAPITAL AND OPERATING COSTS

By the end of 1938, the capital savings following the reduction in spare generating capacity amounted to some 22 million lb. whereas the annual saving by grid operation was estimated to represent 17 per cent of the cost of production which would otherwise have applied. Due to various factors it is impossible to derive corresponding figures for recent years, but there is no reason to suppose that the relative economies have in any way diminished.

BENEFITS RESULTING FROM THE GRID

During the war the grid played an outstanding part in the maintenance of, and provision of additional, electricity supplies. It permitted flexibility in selecting sites for new war factories, as such factories were no longer dependent on local supply services, and supplies could be made available from the grid in a much shorter time than would have been required to construct new generating stations for that purpose. The problems resulting from the evacuation of population and the consequent transfer of load were catered for by the

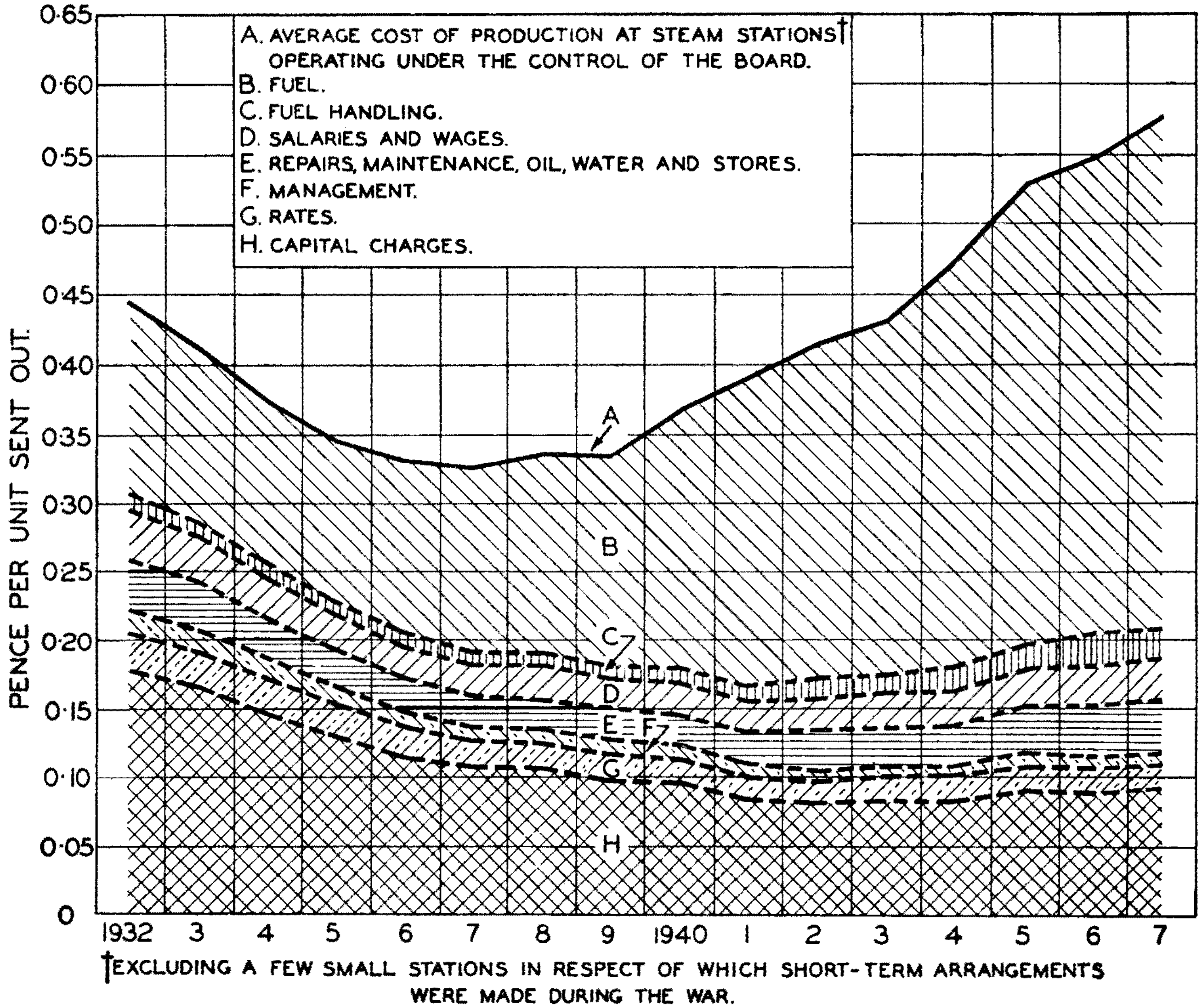


Fig. 3

grid in a manner which would otherwise have been impossible.

The grid, however, was not constructed for war purposes and it is on its peace-time record that its success must be judged. The results achieved by the grid from its inception until the outbreak of war were outstanding both in economy in fuel consumption and reduced cost of production. The grid system made possible the utilization of generating station sites which could not have been developed independently owing to their distance from the load and enabled stations to be sited on the major coal-fields, where coal transport charges are reduced, their output being distributed over the grid. During off-peak periods transfers of energy are possible from areas where the cost of production is relatively low to areas where it is high and, although such bulk transmission between separate operating areas was not originally visualized, it is of importance in the general economy of operation.

NATIONALIZATION

On 1 April 1948, the ownership of the main generating stations in Great Britain, excluding the North of Scotland, was transferred to the British Electricity Authority. The Authority are therefore able to decide not only where, and when, generating plant shall be installed but they are responsible for the design and installation of such plant. The co-ordination by one organization of the planning and design of plant extensions, whilst delegating to regional organizations the local design and construction, should result in the maximum economy and the minimum delay in the commissioning of new extensions.

Close contacts exist between the British Electricity Authority and the Area Boards. Developments of the main transmission and distribution systems are co-ordinated, duplication is avoided and arrangements can be made, within limits, for the transfer of load if desirable.

An interim tariff is in operation and the tariff to be adopted for the period commencing 1 April 1950 is being determined. The Authority have in mind instituting a uniform bulk supply tariff throughout the country subject only to coal price variations.

FUTURE DEVELOPMENT

It is possible in this paper to refer only briefly to possible future developments.

Two sizes of turbo-alternators have been standardized for new stations, i.e.: 30 mw. sets operating at 600 lb./sq. in., 850 degrees F., and 60 mw. sets with steam conditions of 900 lb./sq. in., 900 degrees F. The latter form a high proportion of the plant to be installed subsequent to 1951. Experimental machines operating at 1,500 lb./sq. in. and 1050 degrees F. are planned for completion by 1952 and the higher thermal efficiency to be expected from these new sets should materially reduce the average fuel consumption.

The Authority have under construction two 15 mw. gas-turbine sets, and are closely interested in the development of this type of plant. Owing to the high cost of oil fuel in Great Britain, however, it seems probable that the use of gas-turbine machines will be restricted to peak-load operation unless development is possible along the lines of pulverized fuel firing.

The topography of England and Wales limits the use of hydro-electric plant, but the Authority have arranged to purchase from the North of Scotland Board the surplus energy from their hydro-electric schemes. Further development of the existing hydro-electric scheme in North Wales is being examined.

Close attention is being paid by the Authority to combined electrical and thermal development for district heating and schemes are being investigated.

The construction of a grid system operating at 275,000 volts is under consideration to permit the transfer of greater quantities of energy between areas and to effect further economies in generation costs, particularly during off-peak periods.

CONCLUSION

The effects on the electricity supply industry in Great Britain of the commissioning of the grid have been distorted owing to the intervention of the war, but the results achieved have amply justified the foresight of those who planned its construction.

Although the Authority are at present severely handicapped by delays in the commissioning of new plant they are confident that, when the present difficulties have been overcome, developments on the lines indicated will make possible further substantial economies in fuel consumption and the costs of production and will result in the full achievement of one of the principal objects of the construction of the grid, i.e., to make available cheap and abundant supplies of electricity.

The Total Joint Operation of Electrical Power Systems in Sweden

GÖSTA NILSSON

ABSTRACT

Power production in Sweden is almost entirely based on hydraulic power. In normal conditions 97 to 98 per cent of the total load is provided by hydraulic power and the rest by condensing and back pressure power.

Developments have necessitated more extensive joint operation, and today stations with a total power amounting to about 95 per cent of the entire hydraulic-power production of the country are linked with a joint operation network stretching from Porjus in the north to Malmö in the south. In addition, these places are connected with Norwegian and Danish power stations.

As most of the hydraulic power is to be found in Norrland while the load is concentrated chiefly in central Sweden, joint operation between Norrland and southern and central Sweden is a quite natural consequence. The power is at present transmitted over five 200-kv. lines. By the end of 1949 another 200-kv. line is expected to be in operation and during 1951 the first 380-kv. line, which will be nearly 1,000 km. in length, will be put into service simultaneously with the completion of Harspranget, which will be the biggest power station in Sweden.

The numerous economic and technical questions arising from such extensive joint operation are settled by a voluntary organization comprising representatives of the State Power Board and of the great municipal and private power undertakings. This collaboration was started at the outbreak of the Second World War. It has been of great value for the utilization of all the power resources of the country.

ORGANIZATION OF POWER SUPPLY IN SWEDEN

The production of power in Sweden is based almost exclusively on water power, which with normal water-flow covers from 97 to 98 per cent of the total power requirements. The remaining 2 to 3 per cent consists of steam power, chiefly derived from industrial back-pressure installations and the condensing power plants of power supply undertakings.

Power supply is administered by the State, by municipal authorities and by a number of private companies. The three parties co-operate to a great extent, each having charge of the power supply in its respective area. The State is responsible for 40 per cent of the energy production, the municipal authorities for 5 per cent and the private companies for the remaining 54 per cent, 20 per cent of which is produced by industrial concerns, mainly generating power for their own requirements, and 34 per cent of which is supplied by power-distributing undertakings.

Developments in Sweden have tended to cause still more comprehensive joint operation. The first step in this direction was taken in the 1920's with the completion of a 130-kv. line more than 300 km. in length between the State power stations at Trollhättan and Västerås. This marked the establishment of what is called the central section. Little by little joint operation was extended to adjoining small power sections, until practically the whole of central and south Sweden had been gradually connected up into one joint operating unit.

Joint operation was further necessitated by the constantly growing demand for electric power, which made it impossible for some districts with small water-power resources to supply their own power requirements, while at the same time there was available a surplus of power in other districts. This situation led to the construction of a 130-kv. line from Porjus in Upper Norrland down to Middle Norrland, thus enabling the various State plants in these areas to be linked up into one great section.

The main power resources of Sweden are situated in the northern parts of the country, whereas the load is concentrated in the central and southern parts. As the water power in these last two parts became fully developed, there arose the necessity of arrangements for the transmission of power from Norrland to central Sweden. In the middle of the 1930's, the first 200-kv. power line from the centre of Norrland was put into service, this line being later connected to the abovementioned 130-kv. line from Porjus. The 200-kv. connexion constituted the last link in a great continuous transmission-line system from Porjus in the north to Malmö in the south, an air line distance of 1,300 km. There are also connexions between Porjus and Norwegian power plants and between Malmö and the Danish power plants by underwater cable in the Sound. That first 200-kv. line was soon followed by other 200-kv. lines from Norrland. Five such lines are at present in operation and a sixth will be completed by the end of 1949. In addition, a 380-kv. line is under construction from Harsprånget in Upper Norrland and a further line has been decided upon.

Taking the Central Section as the main point, the development may be seen from the following table:

Year	*Power of the water power stations in the interconnected network* — *Mw.*	*Per cent of the total water power of the country*
1922 ...	200	20
1935 ...	500	35
1948 ...	2,700	95
1953 ...	4,100	97

ECONOMY OF JOINT OPERATION

The advantages of this extensive joint operation are obvious. It has made it possible to take care of all the water power available and utilize it in the best possible manner. The linking up of the loads has reduced the demand for power generated by other means.

Joint operation also facilitates the maintenance of spare parts. The steam power plants, being made to serve as a reserve for larger areas, can be constructed of more economic size. New steam power plants may be established at appropriate points as regards geographical distribution of the load and the transport of fuel. Moreover, the total reserve power may be kept lower. Finally, the regulating reservoirs, in the first place the reservoir constituted by Lake Vänern, with a capacity to cover several years, may be better utilized when there is joint operation of the country's power supply.

An exact economic evaluation of these advantages derived from joint operation would, of course, be difficult, but there is no doubt they represent large amounts, taken absolutely and compared with the extra costs for joint operation.

As stated above, the power-line network acquired its great extent largely from the necessity to connect the producing areas with the consuming areas. In many cases, however, lines have been built for the utilization of surplus power occurring only temporarily.

With joint operation between the separate self-supporting networks for the utilization of temporary surplus power occurring with variations of water available or of load etc., there is generally no definite contract beyond what is required for the division of the cost of the interconnecting plant.

Certain rates are applied for power purchased and power sold. As a rule there are different rates for day, night and Sunday power, these being adjusted to the changes in the power balance situation. All accounting for such an interchange of power of a more temporary nature is based on hourly figures.

JOINT OPERATION OF THE 200-KV. LINES

As stated above, there are at present five 200-kv. lines, and these are operated in parallel, having a certain load compensation as a consequence. As some of these lines are owned by the State and some by private undertakings, a number of technical and economic problems arise. The parties interested have therefore set up a special trunk line delegation, to which are attached a couple of technical committees, a joint operation committee and a relay committee.

The joint operation committee is chiefly concerned with accounting questions. A general principle for settling loss has been that the total saving in power losses has been equally divided between the two parties principally interested, and the application of this principle has given rise to a number of problems, which it is the committee's business to solve.

Questions relating to the application of the relay system are handled by the relay committee and it has devised a special relay system for the 200-kv. trunk line network. This committee also deals with questions connected with the joint utilization of the Petersen coil equipment and the reliability of service etc. Special mention may be made of the automatic high speed reclosing and limitation of the effects of disengagement of a line through automatic disconnexion of a load to the network, approximately corresponding to the load on the disconnected line.

THE CENTRAL OPERATING MANAGEMENT

The common administrative organ of the power supply is constituted by the Central Operating Management. This body was established some years before the Second World War, following voluntary agreement between the State Power Administration and the large municipal and private undertakings, and it was intended to form an organization to function in the case of war.

The general work of the organization is related to its character of a central organ of the power undertakings to deal with emergency questions bearing on the electric power supply. Such work would include delays due to military action, preparedness for emergency repairs, reserving of vehicles for war service, allocation of fuel, preparation for rationing measures and building permits.

The main task of the organization, however, is to promote efficient co-ordination of power production. The work of planning required in order to derive all possible benefits from joint operation has grown more and more extensive. The number of power stations has increased and the best possible utilization of water regulating reservoirs and their augmentation must be aimed at. As more watercourses are developed, an increasing number of special factors come up for consideration, including timber floating, and continually increasing attention must be devoted to the power balance with power undertakings in joint operation, with provision for taking care of surpluses or covering deficits. Each week the organization surveys resources and the needs of the power undertakings connected, which represent practically the whole country. For long-term planning, the Central Operating Management makes balance investigations for the whole country or for certain sections of the country, basing on long-term or short-term forecasts. These investigations are of the utmost importance in arriving at reliable estimates of power balance prospects, especially on particularly critical occasions.

VIEWS ON FUTURE DEVELOPMENTS

On the outbreak of the Second World War in 1939, it was a great advantage for Sweden to have a complete organization established and ready to deal with problems relating to power supply. The experience gained with joint operation during the war has proved so favourable that the parties have decided to retain the organization even in peace-time. Of course the work since the war is limited compared with what had to be done during the war, but the recording each week of power balance conditions in the districts of the various power producers is kept up. The organization proved extremely useful for the country's power supplies in the exceptionally dry year of 1947—1948, when conditions were particularly difficult.

The more power that needs to be transmitted from Norrland to the southern parts of the country the more firmly established joint operation becomes. Up to now the principle followed has been that the State on the one hand and the private undertakings on the other hand have each constructed the transmission lines necessary for their power transmission. To continue in that way, however, would have led to difficulty as regards the establishment of an efficient system of transmission, especially in view of the necessity of limiting the number of transmission lines from Norrland by adopting transmission voltages higher than 200-kv. About two years ago, therefore, the State Power Board submitted a project for the founding of a trunk line company, which was supported by the other power undertakings. However, the project was not sanctioned by the Government and the Riksdag, which decided that all trunk lines for voltages of 200-kv. and above should be executed by the State Power Board and should be the property of the State. The accounting and estimating of charges when power is transmitted for various participants have as a result involved certain special problems.

The question of stability with the great power transmission over increasing distances, the line now being constructed from Harsprånget to central Sweden will have a length of about 1,000 km., will call for more and more attention. On the one hand, it is an economic necessity to load the line as much as possible; but on the other hand, as the proportion of long-distance transmitted power increases, the dependence on good operating reliability grows. The extent attained by Swedish joint operating so far has made calculations of load distribution and stability ever more complicated. In the planning of future lines, therefore, tests by network analysers have become necessary. Indeed, such tests have lately been made on several occasions and these have furnished most valuable results concerning the most appropriate shaping of the future trunk line system for 380-kv. and the maximum load for the different lines from the stability point of view.

When joint operation began to grow more extensive, there were fears that operation security might be less good since any faults occurring in one plant might cause disturbance over a wider area. With the standard of equipment as regards breakers and relays prevailing at that time, these fears were not altogether without foundation, and for that reason the method was applied of separating the system if there was risk of disturbance. In these days efforts are being made to maintain parallel operation in all circumstances. Rapid circuit-breakers and highly selective relay protection have been installed, and by means of these any disturbance can generally be confined to the part of the plant that is damaged. Other elements improving the stability is the particularly low reactance of the generators, the transformers and the lines, attained by installing duplex conductors and series condensers, as well as specially large flywheel mass, rapid and effective voltage regulation, and automatic high-speed reclosing.

Up to now frequency regulation has for the most part proceeded satisfactorily, without any special arrangements being necessitated by joint operation. The largest power station of the country, Trollhättan, which has very good means of regulation, is in charge of frequency regulation as a rule. Naturally the frequency regulation station has to suffer a great deal of inconvenience, such as poorer efficiency of production due to rapid load variations and the necessity of maintaining all units in operation even for low average load.

The demand for frequency regulation, however, is increasing because of the effects of the joint operating network. While it is true that a certain amount of load compensation is obtained owing to joint operation, yet on the other hand there is also increase in variation. This is principally due to the fact that stations operating to schedule are not able quite perfectly to adapt their production to the actual accumulated load. Even with the load in its present stage, power changes amounting to 200 mw. arise in only a few minutes at the frequency regulating station, i.e., almost as great as the maximum power of the station itself. The question of frequency regulation, therefore, must be dealt with in future by having several stations co-operate appropriately in regulation.

Trials have been going on for a long time with special equipment for electrical turbine regulation. This design has many advantages over the previous mechanical constructions, as it enables a more sensitive and a more rapid frequency regulation. Moreover, the electrical design can be employed for various other regulation purposes, such as automatic distribution of the production over different generators in order to ensure the best possible efficiency of a power station, conductor load regulation etc. Equipment for electrical turbine regulation has already been installed in the Norrland power station at Midskog, and similar equipment is soon to be put in service at Trollhättan.

The Integrated Power System and the Possibilities for the Development of a European Power Grid[1]

P. AILLERET

ABSTRACT

The problems connected with an "integrated power system" are important topics today, particularly in Europe where it is necessary to utilize to the best possible advantage a plant which is inadequate to cope with consumption requirements. These problems are particularly complex when power of hydraulic origin is combined with power of thermal origin. This paper brings out the conception of a hinterland to the hydro-power areas and elaborates it to take into account the irregular nature of hydro-power. The structure of the power transmission system is necessarily different inside and outside the hinterlands of the hydro-areas.

General considerations are of guidance in determining the ways in which the European power systems should be supplemented. The supplementary installations now being constructed on this system, in order to fill up gaps across State frontiers, should make it possible to explore the international traffic and to reinforce the system in step with requirements where justified by the power grid economy as a whole.

All the countries of Europe without exception are at present suffering from a shortage of electric power. Experience has shown how difficult it is to reduce consumption, even fractionally, without gravely upsetting the national economy, particularly in hydro-producing countries, where it is impossible to foresee the periods during which restrictions will be essential. Power consumption has shown itself in practice to be very unelastic and difficult to reduce.

All countries are fitting out new thermal and hydro-power stations but the manufacture of turbines and alternators is a bottleneck which threatens for some years yet to prevent production from regaining the level necessary to cope with increasing power requirements.

In view of the gravity and fear of prolongation of the power shortage, it is important to know to what extent it would be possible to improve the position of all countries by considering the power problem on the European scale: if the study of the most rational method of meeting Europe's power requirements regardless of frontiers provides a better solution than the supply of power to each individual country from its own resources, it will be possible to deduce by subtraction the changes of individual programme which will enable a benefit to be reaped and shared. If this benefit is well brought out and is substantial, it will certainly be a simple matter to find ways of reaching agreement in order to achieve and share in it.

Hence there is a general desire to work out the most advantageous plan for Europe as a whole, ignoring frontiers and profiting by the fact that today the transmission of power over the distances in question is technically possible and now merely raises problems connected with joint transmission and production economy.

This desire has manifested itself in particular by the anxiety on the part of Governments to study long-term programmes at Geneva in the Committee on Electric Power of the Economic Commission for Europe.

This has led to various studies and works either within the compass of the International Union of Electric Power Producers and Distributors, or in the form of individual publications by engineers and economists.

Engineers, moreover, are well prepared for these international studies by the contacts long established between the countries for the study of a number of technical problems and, in particular, standardization, a field in which more international work has been devoted to electricity than to any other industry.

On the economic plane, however, research in regard to electric power is particularly difficult, as it brings complicated technical factors into play and it has been easy to make gross errors of judgment either by outlining economic arguments not properly based on technical realities, or by conceiving of programmes which would be technically possible but economically wasteful.

The problems are so complicated that the Committee on Electric Power at Geneva will probably not succeed in arriving at a conclusion before the completion of a series of preliminary studies requiring very careful elaboration.

For this reason it may be useful if the author of this paper, with the lack of responsibility which is the rule at this scientific conference, reviews here and now the various aspects of the problem and the various experiences which shed light upon it, without in the least committing the responsible authorities by a somewhat premature examination of the questions they are to consider more seriously in the near future.

THE TWO PROBLEMS OF EUROPE

The countries of Europe are faced by two problems:

On the one hand, power station capacity is inadequate and the ability to manufacture both hydraulic and thermal turbines and alternators appears to be insufficient to allow of a speedy return to normal, in view of the permanent increase of power requirements and the leeway to be made up.

Secondly, there was a great shortage of coal immediately after the liberation and although it has now once more become easy to obtain coal on the world market, most countries are being forced by the lack of foreign currency to cut down the consumption of commercial coal as much as possible, and consequently to develop as far as possible the equipment of hydro-power stations or power stations burning lignite or base products.

The first of these problems is much more acute than the second in view of the profound disturbance to the economy of a country caused by even a fractional shortage of electric power. It is, therefore, simple to deduce that in order to provide for immediate needs, maximum use must be made of

[1] Original text: French.

the output capacity of plant manufacturing hydro-production equipment as well as of plant manufacturing thermal production equipment. Moreover, the new thermal equipment with a low coal consumption rate per kwh. effects a real saving in coal so long as for the greater part of the year it replaces antiquated equipment consuming twice or three times the quantity of coal per kwh.

Looking into the more distant future, it appears desirable, once the old thermal plants have been re-equipped, to push forward the production of hydro-power on the European continent in order to help in cutting down coal imports.

What, however, on the European scale, are the natural hydro-power resources and to what extent will they make it possible to cope with developments in power consumption?

FUTURE CONSUMPTION REQUIREMENTS

It is unnecessary to insist on the now well-known fact that the consumption of electric power in the various countries has always shown a long-term tendency to increase by geometrical progression, in general doubling every ten years.

In regard to this rate of increase, there is far less difference than one might have thought between poor, under-electrified countries and rich, heavily-electrified countries.

Since, moreover, this rate of increase continues to be just as high in the most heavily electrified countries, it may be inferred that there is probably no more justification today than previously for the fears of saturation which have always caused anxiety in the past.

From the point of view of the immediate present, it is likely that the effects of an industrial crisis would be counterbalanced by the fact that a certain potential demand remains unsatisfied because of restrictions imposed in recent years on the use of electricity and on the equipment of consumers.

REMAINING HYDRAULIC EQUIPMENT POSSIBILITIES IN EUROPE

An inventory of the remaining hydro-equipment possibilities in Europe has been undertaken but it is a difficult task as it is not sufficient to calculate the maximum quantity of energy theoretically available in water-flow; the quantity which can be "economically" exploited must also be determined. This requires a definition of the word "economically" or a better classification of exploitation possibilities by sections according to increasing cost.

Some figures have already been published, giving Switzerland 20 to 25 milliard kwh. (of which 12 milliards already equipped), Austria 20 to 30 milliards (of which 4 milliards already equipped) and Italy 40 to 50 milliards (of which 22 milliards already equipped). In the case of France it has been pointed out that while some 100 milliard kwh. per year may theoretically be produced, the economic maximum would be between 60 and 80 milliards, half of which would be in the Alps. These figures must be taken with every reservation but give a provisional idea of the "hinterland" which may be supplied by the hydro-power in question.

THE CONCEPTION OF A HYDRO-HINTERLAND

This "hinterland" conception dominates the whole hydro-question on the European continent. This hinterland is not determined by the technical possibilities of very high-tension transmission, possibilities which in the case of Western and Central Europe are today more than adequate, but by the relative scale of consumption and hydro-resources.

The equipment of a hydro-area must necessarily be spread over a sufficient number of years. If, for example, it was planned to exploit all the hydro-potential of Austria in only ten years, this would make it possible to meet, at the very outset, the new requirements of an enormous hinterland, but after these ten years all the new requirements of this zone would have to be met by thermal generation; the effective hinterland of a henceforth constant hydro-production would diminish with the increase in consumption and there would be a decrease in the load carried by the transmission lines constructed to supply the most distant parts of the hinterland; their economic utility would thus have been too short-lived to justify economically the effort required by their construction.

Moreover, both from the point of view of hydro-electric equipment construction and from the point of view of civil engineering undertakings, it would be a costly process to urge forward installations at such a rate only to remain idle after but ten years.

Thus there is clearly a minimum period over which the harnessing of waterfalls must be spread out; if a period of twenty years be taken provisionally, the size of the Austrian hinterland is conditional on consumption in that zone increasing steadily at the rate of one or one and a half milliard kwh. per year.

There is no need to go far away from Austria following a line parallel to its frontiers in order to include consumption at present totalling 15 to 20 milliard kwh., the annual increase in which will be from 1 to 1.5 milliard kwh. In all probability this parallel line does not go beyond Frankfurt and Nürnberg and it will be of great importance to plot it.

In order to do this, however, it is necessary first of all to elaborate the hinterland concept, since hydro-power is not available with the same seasonal distribution as consumption. In this way it is possible to distinguish several "hinterlands" around hydro-areas:

The "average" hinterland, the annual consumption in which in an average year exactly absorbs production; across its border, exchanges with outside areas balance in both directions.

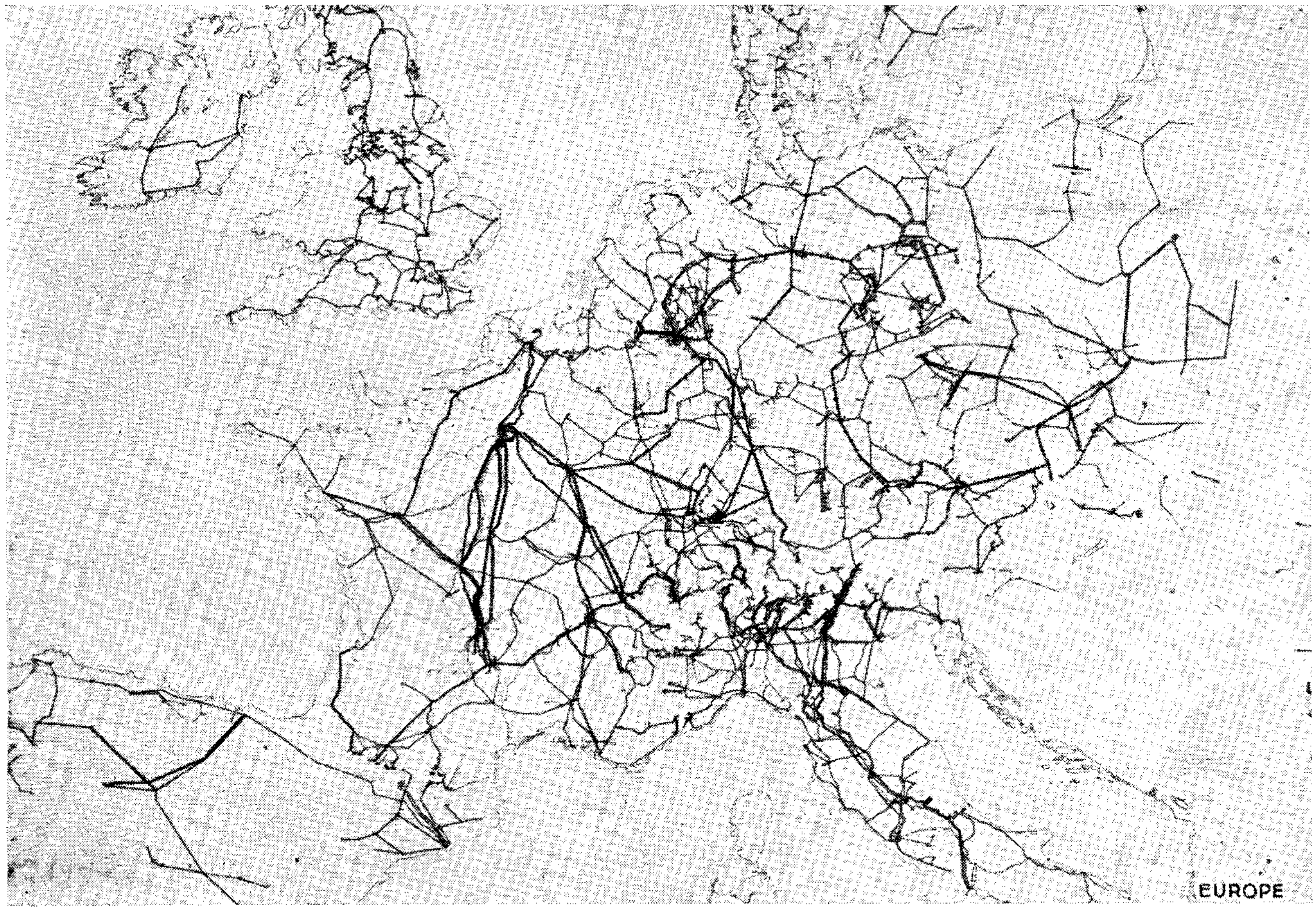
The "high-water night" hinterland; this is the zone which must be reached in order to run off at night, at high water, the electric power from the run-of-the-river plants; no hydro-power is ever exported beyond the boundary of this zone.

The "winter day" hinterland; this is the zone that the hydro-power in question can supply without outside assistance and without thermal equipment; no power is ever important by day on this side of its boundary.

If it is assumed that the various countries have specific rates of equipment, these hinterlands are necessarily governed by them and it is their location which makes possible a proper grasp of transmission requirements.

TRANSMISSION REQUIREMENTS

Up to a point a little beyond the winter-day hinterland the power loads to be transmitted are considerable and have a fairly high load factor. Distances, on the other hand, are not very great, from 100 to 300 km. Transmission capacity depends indubitably upon the installed capacity in the power stations from which it must be distributed; determination of transmission capacity is a technical and not an economic problem. A voltage of 220,000 volts (220 kv.) is suitable so long as the



Network of transmission of electric power in Europe

power to be transmitted is not very great; as soon as the number of 220,000 volt (220 kv.) lines to one and the same point exceeds 5 or 6, a voltage of 380 kv. is justified. Moreover, the use of transformable lines with pylons carrying initially two 220 kv. circuits horizontally and subsequently, by a regrouping of the conductors in pairs, a single 380 kv. circuit each phase of which is constituted by a bundle of two cables, seems to provide the best economic solution by preparing for the future without initial over-investment, as would be the case in the event of a new construction of 220 kv. lines capable of switching subsequently to 380 kv. with the same number of conductors.

Proceeding towards the average hinterland there is considerably lower consumption which affects the amount of load to be transmitted; it is chiefly a question of consuming the surplus. The transmission problem then becomes an economic problem: it would be absurd to sink unjustified sums in transmission when equivalent sums could have been used much more effectively to equip a few more power stations.

Lastly, as the high-water night hinterland is approached, it is quite normal to find thermal stations designed to supply the bulk of the power consumed. The density of the transmission lines then drops back to what it is normally in a purely thermal area.

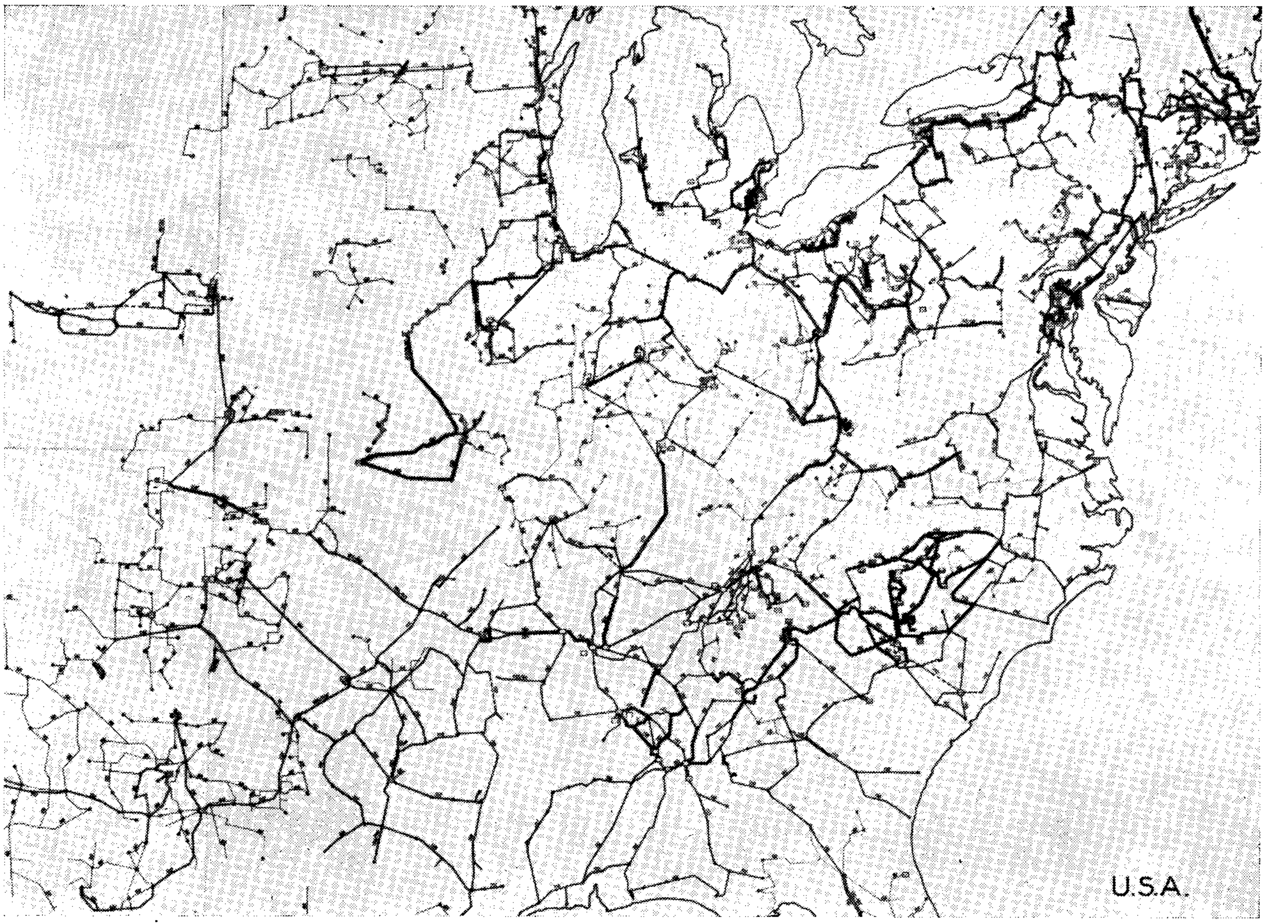
As the low coal consumption rate of a modern power station appears to make it generally more economical to transport coal than to transmit electric power, even in the case of poor quality coal, the trend is for production to become localized in the vicinity of the consumption area. The governing factors for the transmission network are then the reciprocal reserve between thermal units of ever-increasing power (100,000 kw. may be regarded as the normal power of future units), differences in consumption charts etc. This leads to considerably lower transmission capacity than when leaving hydro-production areas. It will be noted moreover that despite the extreme density of its consumption, Britain is still content with a fairly thinly laid 132 kv. network (for example, the northern and southern halves are interconnected by only three circuits of 132 kv. which can transmit only some 4 per cent of the peak load of either half). Similarly the great interconnexion between Chicago and the Gulf of Mexico, which at peak load has a maximum power of 20 million kw. is operated at a voltage not exceeding 150 kv. and the exchange power between its southern and northern halves must not exceed 3 per cent of the capacity of either half.

This shows how necessary it is not to yield to the temptation to extend too far on the map the very powerful lines required at the hydro production points themselves; real transmission requirements in the next ten years are as follows:

Adjacent to the hydro area load, governed by the installed hydro capacity;

Beyond the hydro hinterland, much lower load governed only by differences in thermal production and consumption.

As has been seen above, however, the hydro hinterlands do not extend very far: this is also brought home by the reflection that, with consumption doubling every ten years, total hydro



Network of transmission of electric power in the United States
(The European and the United States networks shown on the same scale and with the same symbols)

resources will be just sufficient to meet consumption requirements in the zones at present supplied with hydro power, within fifteen years in Switzerland, twenty years in Italy and twenty-five years in France.

THE HINTERLAND OF OTHER NATURAL RESOURCES

Hydro power is not the only natural wealth in regard to which the hinterland problem arises; it also arises in the case of the great lignite areas, particularly that of the Rhineland.

Electric power production based on lignite requires a roughly circular hinterland in which coal-burning power stations must be avoided in order to reserve an outlet for the power produced from lignite. The optimum size of this hinterland is a problem depending on the difference in price between lignite and coal. In particular, if the exhaustion of surface lignite mines were to cause all lignite to be mined from deep deposits, in which, incidentally, the quality of lignite improves, the reduction in the price variation between coal and lignite would certainly tend to make the lignite hinterland smaller.

With regard to coal waste products, their outlet will conceivably not extend very far from the mines as only the very low qualities cannot be transported and as soon as any coal reaches 5,000 calories per kg., it seems possible, thanks to the low consumption rate of modern thermal stations, to transport the coal by water or even by rail (unless this requires new track) more economically than electric power can be transported as soon as the distances become considerable.

THE SPECIAL CASE OF SCANDINAVIA

These appear to be the bases for determining the great movements of electric power appropriate to the best combined economy of the European continent.

The case of Scandinavia, however, should be considered separately: it is in that country that there is the greatest power surplus in relation to local requirements. In order, however, to estimate the possible role of Scandinavia, two difficult problems must be considered:

Transmission entails enormous distances, bearing in mind that the surplus hydro power is far to the north (Sweden is already obliged to fetch its power from the new falls situated north of the polar circle over a line almost 1,000 km. long) while the main outlets are very far to the south of the mountain passes. From the technical point of view transmission over such distances is certainly not impossible but the price at the outlet has never been well computed. Will not the figures show supply under such conditions to be uneconomical?

In Norway, a country of electro-chemical industries, it has been said that the country could be brought just as well within the framework of a European economy by using available electric power on the spot for electro-chemical manufactures, since the transportation by sea of raw materials and finished products costs much less than the transmission of the corresponding electric power. This raises problems which affect several industries at once and which are therefore much more difficult and complicated than the relatively simple problem of the utilization zones of hydro power in the most continental part of Europe, the problem to which the author intends to confine himself.

NECESSARY ADDITIONS TO THE PRESENT TRANSMISSION SYSTEM

The density of the European power transmission lines is already considerable: the two attached maps which include both existing lines and lines under construction and which are drawn to the same scale and with the same symbols for the lines show that this density is as great in Europe as in the United States.[2]

The map of Europe also shows that the system is not too artificially compartmented by political frontiers. The only frontiers immediately recognizable on the map are those which coincide with high altitude peak lines, as in the Alps. The other frontiers are no more distinguishable on the European map than are the state frontiers on the map of the United States power lines.

It is true that these maps take into account a number of interconnexions which are still under construction or are not yet finally completed (for example, the Franco-Italian interconnexion over the Little St. Bernard Pass equipped for 220 kv.; a second Franco-Belgian interconnexion equipped for 150 kv. between Gouy and Maubeuge).

This network certainly needs to be further supplemented, but in order to get a proper idea of transmission requirements the following must be clearly distinguished:

The need for channels to draw off the new hydro power towards its hinterland. The corresponding lines are strictly governed by the rate of hydro equipment.

The general need for channels for exchange on the well-known problems of production diversity, consumption diversity, pooling of reserves, etc. This requirement is suitably met within the boundaries of each country; the countries of Europe, however, are sufficiently large for the law of big numbers to operate within them. In France, for example, the operation in parallel of thermal installations producing more than 3 million kw. and of hydro installations producing 4 million kw. covers a large enough number of units to provide a statistical basis for accidental phenomena. Each production unit, even the largest thermal group or the largest hydro power station, is merely a differential in this system and the benefit of statistical averages is already being reaped by means of national interconnexions. This benefit already derived must not, therefore, be allowed for a second time when investigating the possible advantages of international interconnexions. On the other hand, the essential purpose of such interconnexions is to exploit the differences between countries already internally co-ordinated.

Transmission requirements however may be appreciated if the matter is looked at, as we have done throughout the foregoing, from the angle of the transmission network economically justified in the absence of all frontiers; the density of the lines at the point where they cross the frontiers should, *a priori*, be the same as the density inside the frontiers. This can be achieved effectively by joining up each national system to its neighbours by peripheral interconnexions. The map shows that this is already well advanced and Europe is covered with a sort of "grid" which lacks only a few links for its density at all points to be that required for the various exchanges, leaving frontiers out of consideration. It is much to be desired that the links still missing should be provided as soon as possible even if with reduced transmission capacity. European co-operation would be retarded if the required transmission capacity were over-estimated and if exaggeration were to result from a failure to see clearly.

The best plan is to build up the international interconnexions as quickly as possible, using the voltages which allow of the easiest link-up. In this way the traffic may be "tried out" and if the channel in question happens to be too often loaded to full capacity, it is possible in full awareness of the facts, to reinforce it either by doubling the line or by making the interconnexion operate at a higher voltage. The essential thing is to have a line crossing every frontier as soon as possible, as the traffic over this line provides the best basis for estimating the service that a more powerful channel could render.

To sum up, the European network is reaching a stage where it will be possible to forecast its further development directly from the load factor of its existing channels. Only a few short supplementary interconnexions across frontiers have to be added to achieve this.

POSSIBILITIES OF EXPLOITING THE EUROPEAN GRID

Sufficient experience has been acquired with existing installations to show that there are no technical difficulties in effecting all over Europe the power exchanges which will ensure the best comprehensive economy. It would be technically possible at the present time to effect a synchronous operation in parallel as is the permanent practice of Britain and France in their territories, or as is the practice of all the companies which by operation in parallel handle the distribution of some 20 million kw. between Chicago and the Gulf of Mexico. Combined power-frequency regulation makes it possible to adjust the exchanges and to adhere to the agreed exchange schedules without each country's operations losing any of their individuality and without its being necessary to subordinate them to any higher authority.

Exchanges which are economically worth while can also be handled by means of separate fractional services as is the practice in Switzerland and, above all, in Italy. Although, on a small scale, this method of separate services does not offer all the advantages provided by operation in parallel, its inferiority decreases as the scale increases, so that it will be possible, without serious disadvantage, to use it provisionally for certain international exchanges. Nevertheless, it is desirable to increase effective synchronous operation in parallel wherever possible.

Anyhow, it is not hard to find a solution to any of these problems: it is no more difficult to interconnect two electrical networks than to run railway trains through frontier stations: the flow of goods traffic alone raises difficult economic problems, but the arrangements between pointsmen or dispatchers at frontier stations have never occasioned concern. The essential thing from the technical point of view is that the railways should have the same gauge; in regard to electricity, frequency has been made uniform at 50 cycles in Europe

[2] See the two attached maps.

and very high voltages are fairly standardized. In particular, the 220 kv. voltage has already been widely developed and the 380 kv. is in process of being adopted as the standard for the future by the International Electro-Technical Commission.

EFFECTS OF INTERCONNEXION ON ELECTRICAL ECONOMIES

The development of interconnexions will undoubtedly affect the electrical economy of each country.

The use of the *electric boilers* developed for the purpose of exploiting the unusable energy at high-water periods in the hydro-power areas is already declining. Their role will become very small as the discharge of hydro power has by now become very rare, since existing interconnexions already make it possible to use surplus hydro power to cut down coal consumption in thermal stations as far away as 200 to 400 km., rather than to generate steam by dissipation of energy in industrial boilers.

Day *pumping systems* converting night energy into day energy with an efficiency which, in view of transmission losses, does not actually exceed 50 per cent, are no longer as profitable as in the days when the consumption of coal per kwh. was very much higher and when there were fewer interconnexions; it is better to put a little more power into a modern thermal plant and to concentrate coal combustion on peak hours.

It seems that pumping can no longer be considered unless the accumulation is seasonal and unless local conditions are especially favourable, in particular when it is possible to pump the water up to a height less than that from which it is run down again for use.

Interconnexion also alters the working conditions of the *electro-chemical industry:* it can no longer count on cheap local surpluses but must adapt itself to the over-all power market. It will therefore function in all periods when power is not too scanty. Moreover, this development may not be disastrous for the electro-chemical industry as the latter is already tending to work with a more concentrated utilization of power made possible by technical advances: improvements in manufacturing methods cut down the unit power consumption, but increase investments in electro-chemical plants and therefore make it feasible to operate with power that is less temporary than that from local surpluses.

CONCLUSION

It is difficult to draw conclusions in matters so complex of which, moreover, we have only made a preliminary approximate survey.

The main problems however can be summed up as follows:

For the present the principal problem is one of capacity and of bridging over dry periods. In our efforts to make up for the delays in equipment in relation to inadequately satisfied and growing requirements, the obstacle will, unless there is a serious industrial crisis, be the capacity to manufacture turbines and alternators. Hence the greatest possible number of both hydro stations and thermal stations must be built.

When it becomes apparent that the public service can be assured in the normal way and that its defects will no longer be a serious brake on the economy (because of the impossibility of compressing consumption in practice), the probable result will be that hydro equipment will be pushed ahead at full speed in order to avoid the purchase of coal from abroad. If at that time, however, the thermal equipment has been sufficiently renewed to eliminate very inefficient stations, and if pit-head thermal stations absorb all the very low-quality coal, it will be possible to restrict thermal equipment to the minimum necessary to supplement the maximum possible hydro-equipment.

However, as natural resources are limited, the maximum hydro equipment can only supply a limited hinterland around the hydro areas (apparently from 200 to 400 km. around such areas, depending on the site).

In the hinterlands transmission is directly governed by the size of the installed hydro powers; it will reach very high capacity (similar to the transmission to the Californian coast of hydro power from the interior). Outside the hydro hinterlands the transmission required to take advantage of the differences in production and consumption involves only much smaller capacities (to be compared with the relatively low capacities involved in the British network or in that between Chicago and the Gulf of Mexico).

The European network already crosses the political frontiers fairly satisfactorily but wherever this is inadequate, it must be supplemented as quickly as possible by interconnexions across the frontiers which make it possible to *try out the traffic.* If exchanges profitable to the two countries thus interconnected develop, these interconnexions will be quickly doubled or reinforced at a higher voltage.

Exchanges between neighbouring countries must not, of course, be impeded by Customs or excessively lengthy procedures. The position is already fairly satisfactory in this regard but, above all, producers engaged in this work must be empowered everywhere to carry out short-term exchange operations immediately, without any suspensive formalities. Otherwise there would be the risk of losing the advantage of unexpected exchanges for which schedules cannot be arranged far in advance. Given this, operating difficulties can be easily solved and are of minor importance as compared with the great problem of determining the nature of new equipment.

The structure of the European network must conform to actual requirements, whether the aim is to supply the hinterland of the great hydro areas or to provide a general interconnexion, so as to benefit by the differences of production and consumption. That structure must be based either on very exact study or on statistical records of the congestion of certain lines, but care must be taken to avoid the mistakes which might be caused by arbitrary plottings on the map as the result of over-generalized or over-brief surveys not sufficiently grounded on physical realities.

French Mine-Mouth Power Stations (1952 Programme)[1]
Features due to the high ash content of the fuels burned

M. GEORGES and M. GIBRAT

ABSTRACT

The note begins with an estimate of French coal production in 1952, out of which 6 million tons of low-grade coal (3,300 to 4,500 calories) will be allocated to power stations.

Fifteen power stations (1,100 mw.) are planned with 27 3,000 r.p.m. sets of capacities ranging between 25 and 110 m.w. and 58 boilers of the smaller capacities (vaporization between 32 and 170 t.h.). Because of the high ash content of the fuel, the maximum output of the boilers is limited to 170 t. h.

(A) The power stations are situated in the immediate vicinity of the mine and almost all have special cooling installations: in view of the high ash content of the coal, it is uneconomic to use the water of a river more than 35 km. away. Moreover, a mine-mouth station consumes half its production on the spot while the choice of the site is also governed by considerations of mining safety.

(B) The choice of the steam cycle is not influenced by the heating value of the coal when the main factor is the annual output of low-grade coal all of which must be consumed. Advanced cycles are therefore used in mine-mouth stations, as in plants using good coal.

(C) In view of the large interconnected power capacity of the French grid (10,000 mw.) the author recommends that the low-grade output of each coal-field should be consumed in one or two sets each forming a unit with a boiler (maximum capacity of the sets 110 mw.).

However, with present techniques, the high ash content imposes strict limits on the unit capacity of the boilers; for this reason the Lorraine field has limited itself to 150 t h. (4 boilers per set).

(D) It is planned to hold large stocks so as to permit optimum use of the nation's hydraulic plants: Carling for example will have a stock of 200,000 tons.

Further, with a view to the systematic use of tailings with a 28 per cent water content, it is planned to transport millions of tons of a mixture of fuel and water with an approximate density of 300 gr./litre for a long distance (10 km.) through pipes. The mixture will be dried in the immediate neighbourhood of the power station.

French coal production (excluding the Saar) for 1952 is estimated at 64 million tons, of which 20 million tons will be low-grade.

Whatever the various outlets (concessionary coal, colliery use, briquettes) that may be found for these coals, a substantial portion can be used for no other purpose than the production of electricity. In the current programme, it is proposed to allocate 6½ million tons for the production of electricity, as follows:

3,500,000 tons in the Nord and Pas de Calais coal-field;
1,750,000 tons in Lorraine;
1,250,000 tons in the small coal fields in the Centre and South.

In view of the uncertainty of commercial programmes, it is difficult to define exactly the average heating power of these coals, but it will be small, varying from 3,300 to 4,500 cal. per kg. owing to the very high ash content of 35, 40 or even 45 per cent.

The French coal industry has therefore had to set on foot in 1945 a programme making it possible to convert 24 thousand million large calories into electric power annually from 1952 onwards, representing 7 to 8 thousand million kwh. from a useful power of approximately 2,000 mw. In 1938 the useful power available was approximately 900 mw., producing 2,670 million kwh.

The gap is being filled by the opening between 1948 and 1952 of 15 stations of 1100 mw., 400 mw. in the Nord, 300 mw. in Lorraine and 300 mw. in the Centre and South. After 1952 a supplementary programme will be required as some of the old power stations are on their last legs.

Some of the features of this programme (see attached table) are immediately striking:

(*a*) 800 mw. and 10 power-stations have special cooling installations, 300 mw. and 5 stations are on river sites; no station is more than 10 km. from the mine mouth;

(*b*) The steam cycle adopted in 9 stations gives 65 kg. per sq. cm at 500 degrees at the throttle; in 4 others the figures vary between 45 and 61 kg. per sq. cm and between 450 degrees and 482 degrees; in Lorraine (2 stations totalling 300 mw. in the first state) it is as high as 88 kg. per sq. cm at 520 degrees. There is no re-superheating;

(*c*) Of 27 sets, all at 3,000 r.p.m.:
2 have a unit power of 7.5 mw. (Ljungstrom);
11 have a unit power of 25 mw.;
9 have a unit power of 40 mw.;
2 have a unit power of 55 mw.;
3 have a unit power of 110 mw. (Lorraine).
thus attaining the highest powers at present possible at 3,000 r.p.m.;

(*d*) On the other hand, the boiler capacities are not very large; of 58 boilers:
2 have a capacity in steady full operation of 32.5 t./h. (grate);
3 have a capacity in steady full operation of 50 t./h. (grate);
22 have a capacity in steady full operation of 70 to 80 t./h.;
15 have a capacity in steady full operation of 100 to 115 pulverized coal;

[1] Original text: French.

16 have a capacity in steady full operation of 150 to 170 pulverized coal.

Here we are lagging far behind the 500 t./h. of some American boilers;

(*e*) Lastly we have:
One station with 1 set and 1 boiler (25 mw., 115 t./h.);
One station with 2 sets and 2 boilers;
Two stations with 1 set and 2 boilers;
Six stations with 2 sets and 4 boilers;
Two stations with 2 sets and 6 boilers;
each of the three 110 mw. sets in Lorraine being coupled with four boilers.

These features are the result of the peculiar geographical situation of the coal-fields and the high ash content of the fuels to be used.

(A) The distance at which it is more economic to transport the coal rather than to transmit the electricity decreases as the ash content increases. Thus, at the end of his important work[2] on he subject, Mr. Ricard, comparing a mine-mouth station with special cooling installation and a riverside station, both connected to the general grid system, demonstrates that the mine-mouth station is the more economic if:

$$u\,c\,TL > m\,(u\,c + R)$$

Where

m = increased consumption for a station with special cooling installation;

u = coefficient of utilization of the power installed;

c = average consumption in calories/kwh.

$1000.T = \frac{p}{P\,f_c}$ ratio of the cost of transportation per kilometre ton to the cost of the fuel, or to the product of the heating power P and the price f_c per calory at the mine.

L = distance to be transported in kilometres.

$R = \frac{a\,f}{8760\,f_c}$ ratio of financial charges (product of the investment cost per kw, f, and the rate a of financial charges) to operating expenses calculated per calory per hour for the 8,760 hours in a year.

Where $m = 5$ per cent; $u = 0.6$; $c = 3{,}000$; $\frac{p}{f_c} = 0.1$;

$a = 0.1$;

$$\frac{f}{f_c} = 10^8,\ R = 1300$$

giving the numerical relation $L > 8.6\,\frac{P}{1{,}000}$

hence $L > 60$ km. if $P = 7{,}000$ cal. per kg.
$L > 35$ km. if $P = 4{,}000$ cal. per kg.

It is therefore uneconomic to look for a river at a distance of more than 35 km. in the case of low-grade coal. In the two great coal-fields of the North and Lorraine, the only rivers on which mine-mouth power stations can be installed are the Scheldt and Saar respectively, which explains the predominance of stations with special cooling installations.

If electricity transmission losses and the initial outlay on lines and transport are charged to the mine-mouth station, the formulae become more complex and the distances become respectively 140 and 400 km.

In fact, since a mine-mouth station consumes at least half its production on the spot, the distance over which low-grade coal is transported should not exceed 70 km.

The Paris region lies 200 km. from the Nord coal-field, 400 km. from the Lorraine field and an average distance of 500 km. from the other fields. It is therefore obvious why stations using low-grade coal are all situated in the immediate vicinity of the mines.

Considerations of mine safety, while still extremely important, are gradually losing their significance as the interconnexion of the French grid improves year by year.

(B) On the other hand, contrary to a widely held opinion, the calorific power of the coal has no bearing on the choice of the steam cycle. It is true[3] that in the case of an isolated plant the utilization of which is determined by the customers to be served, the higher the price of the fuel the greater the output that must be attained and therefore the more advanced the cycle that must be aimed at. But for a mine-mouth station where the basic factor is the annual production of low-grade coal, all of which must be burnt, the bookkeeping cost of the fuel has no influence on the choice of the cycle, and the optimum depends only on the ratio of the initial cost to the price of the power sold, the latter being determined by the price of high-grade coal burnt in competing stations. The result is the adoption of cycles practically identical with those used in stations using high-grade coal.

The cost of a power-station of given capacity being independent of the temperature chosen for the cycle, it is advantageous to use the highest temperature compatible with the metallurgical possibilities, whence the 500 degrees of 1946 and the 520 degrees in Lorraine (565 degrees is now being considered for a station in Auvergne). In the absence of re-superheating, the pressure will be determined by the maximum admissible theoretical humidity in the last stage of the turbine. In some cases the search for efficiency has been pushed very far; mention may be made of the 110 mw. set in Lorraine on the Saar river which includes 1 high-power, 1 medium-power and 2 low-power units each with two exhausts; this set will almost certainly hold the world length record for sets operating at 3,000 r.p.m.

(C) The unit power of the sets or of the boilers depends theoretically on the one hand on the rapid lowering of the cost per kw. or of the installed t./h. when the power increases, and on the other hand on the seriousness of any breakdown that may occur in a set or boiler; breakdowns being the more serious in proportion as the unit power increases. Comprehensive studies have been made in France on the basis of the rather high probability in Europe of stoppage through breakdown (10 per cent for a boiler, 5 per cent for an average set as against 1 and 3 per cent in the United States).

It might therefore be expected that unit powers would be lower in France than in the United States. However in our opinion, in view of the large interconnected power capacity of the French grid (10,000 mw.) and the constructional possibilities, the ideal solution is to consume the low-grade output of a coal-field in one or two sets each forming a unit with a

[2] See annexed bibliography (item 1).

[3] See annexed bibliography (items 1 and 2).

Principal Features of Mine-Mouth Power-Stations under Construction

(a) Turbo-alternator sets

Coal-field	Power-station	Installed power in MW.	Turbo-alternator sets: Supplier or type	Pressure and Superheat at throttle bars. (degrees	Cooling system	Turbo-Alternator: MVA.	Terminal voltage kv.
Nord and Pas de Calais	Labuissière	2 × 40	Schneider	65–500	Special cooling	50	15
	Beuvry	2 × 40	C.E.M.	45–450	Special cooling	50	15
	Vendin	1 × 40	Alsthom	35–425	Special cooling	50	15
	Harnes	2 × 55	Westinghouse	61–482	Special cooling	68.5	16.2
	Dourges	2 × 25	C.E.M.	66–500	Special cooling	31.5	15
	Thiers	2 × 40	Alsthom	66–500	Scheldt	50	15
		2 × 25	Oerlikon	66–500	Scheldt	31.5	15
Lorraine	Carling	2 × 100/110	Alsthom	88–520	Special cooling	135	14.5
	G. Stroff	1 × 100/110	Brown Boveri	88–520	Saar	135	14.5
Loire	Le Bec	2 × 25	C.E.M.	66–500	Special cooling	33.5	11.5
Cévennes	Le Fesc	2 × 25	Schneider	65–500	Special cooling	31.5	10.5
Blanzy	Lucy	2 × 40	Alsthom	65–500	Special cooling	50	5.5
Aquitaine	Carmaux	1,25	Alsthom	65–500	Special cooling	31.5	10
	Penchot	1,25	Alsthom	65–500	River	31.5	10
Auvergne	Saint-Eloy	1,25	Schneider	65–500	La Sioule	31.5	10.5
	Brassac	2,7.5	Ljünström	45–475	Allier	9.4	10.5

(b) Boilers

Coal-field	Power-station	Boilers: Number	Builder or type	Capacity in t/h.	Pressure and superheat bars.	Combustion chamber
Nord and Pas de Calais	Labuissière	6	F. L. Stirling	60/80	80–510	Pulverized coal
	Beuvry	4	Benson Penh.	80/100	57–475	Pulverized coal
	Vendin	2	F. L. Stirling	85/100	42–450	Pulverized coal
	Harnes	4	C. Engineering	90/170	62–485	Pulverized coal
	Dourges	4	F. L. Stirling	57/78	80–510	Pulverized coal
	Thiers	6	B.W.	90/110	80–510	Pulverized coal
Lorraine	Carling	8	B.W.	120/150	105–530	Pulverized coal
	G. Stroff	4	Stein Roubaix	120/150	105–530	Pulverized coal
Loire	Le Pec	4	Stein Roubaix	50/70	80–510	Pulverized coal
Cévennes	Le Fesc	4	Cail	50/70	75–510	Pulverized coal
Blanzy	Lucy	2	F. L. Stirling	90/110	85–510	Pulverized coal
		3	B.W.	40/50	80–510	grate
Aquitaine	Carmaux	2	Stein Roubaix	50/70	80–510	Pulverized coal
	Penchot	2	Stein Roubaix	50/70	80–510	Pulverized coal
Auvergne	Saint-Eloy	1	Alsthom	90/115	80–510	Pulverized coal
	Brassac	2	Cail	32.5	60–485	grate

boiler. In fact 3,000 r.p.m. sets must be limited to approximately 110 mw. because of the alternator rotor, as hydrogen cooling must be used to attain this capacity.

The Nord or Lorraine coal-fields would therefore have 4 to 8 sets. Some authors[4] consider that capacity should be less concentrated in the case of mine-mouth stations than in the case of stations using high-grade coal. The question deserves further consideration.

In some coal-fields, water must be obtained by drilling, and it has been argued that the total power of the stations should be limited to approximately 100 mw.; in our opinion this is not so, as the cost of transporting water over a distance of a few kilometres is negligible. Moreover, a station with four 110 mw. sets, supplied by wells, is being planned at Carling in Lorraine: two of the sets will be in operation in 1951 each with a hyperbolic cooling plant with a capacity of 21,000 cub. m./h. (a world record so far as we know).

On the other hand the high ash content imposes severe limits, with our present techniques, on the unit capacity of the boilers. Thus after much study and to our great regret, the Lorraine field has had to limit itself to boilers of 150 t./h., or 4 per 110 mw. set, which would be unthinkable in the United States. A boiler of the "Springdale" type might perhaps have been suitable but the risk of stoppages through clinkering seemed too great.

[4] See annexed bibliography (item 3).

(D) Before concluding this review of the features of mine-mouth power stations in France, mention may be made of two innovations in the handling of low-grade coals. The first mine-mouth stations had practically no stocks but the Monet Plan Commission required the maintenance of large stocks in the more recent stations with a view to the optimum utilization of the nation's hydraulic stations. In the first stage, the Carling station in Lorraine will therefore have a stock of 200,000 tons. Further the systematic use of coal with a 28 per cent water content (tailings) has led to a complete change in the means of transport from the mine to the plant. As a result of tests on scale models, it has been decided to transport several millions of tons annually through pipes for a distance of over 10 km. in the form of a mixture of coal and water with an approximate density of 300 gr./litre, about the same as that furnished by coal-washing plants. The drying of the various materials takes place on arrival near the power station. It is hoped that the cost of transport and of drying will be substantially reduced in this way.

Bibliography

(1) J. Ricard, *Equipement thermique des usines génératrices d'énergie électrique*, 2nd edition, Dunod, 1948.

(2) L. Musil, *Die Gesamtplanung von Dampfkraftwerken*, Springer Verlag, Berlin, 1942.

(3) J. Ricard, *Conséquence des interconnexions dans le choix du matériel des usines génératrices thermiques*, Congrès de l'Unipède Brussels, 1949.

Summary of Discussion

The Chairman announced that the meeting would deal with the question of conservation and utilization of energy. In the past, the power generated by individual power stations had not been utilized during periods of low consumption because of lack of co-operation among power-stations. The resulting loss of energy, however, had been considerably reduced in the course of the previous fifteen to twenty years through the integrated power system which made it possible for idle electric power to be transmitted to areas where it was needed most. The system was important not only for countries of limited energy resources but also, in view of the rising demand for power, for countries with larger power reserves. In Norway, for instance, the consumption of power had increased by 90 per cent during the previous nineteen years. At the same time, 65 per cent of the total installed capacity had been interconnected in the integrated power system. The system was still limited to certain regions, but it would be extended to other parts of the country as the unutilized hydro-electric power was further developed.

The integrated power system was connected with many technical, economic, social and, to some extent, political problems some of which would be considered during the first part of the meeting. The second part of the meeting would be devoted to the question of conservation and better utilization of fuel for power generation.

Mr. Sporn introduced and summarized his paper on "The Integrated Power System as the Basic Mechanism for Power Supply". In his paper he had endeavoured to present, in condensed and organized form, a discussion of the philosophy, the component parts, the potentialities and the limitations of the integrated and co-ordinated power system as a mechanism for achieving the specific social-economic objective of an adequate and economical power supply. He had sought to cover every important point which should be taken into account in the planning and operation of an integrated and co-ordinated power system.

After reviewing the nine principal headings into which his paper was divided, Mr. Sporn read out the conclusions of his paper.

He wished, finally, to stress the following points: since the objective is the furnishing of an adequate supply of electric energy of the proper quality at the lowest practicable cost, the development of an integrated power system depended neither on the amount or source of energy, nor the political and economic situation of the country and it could be set up under government, private, or mixed ownership. Furthermore, the integrated system can be established gradually.

Sir Harold Hartley presented Sir John Hacking's paper on "Some Experiences of the Operation of the Electricity Grid System in Great Britain". After a brief review of the conditions existing prior to the construction of the national grid system, the author indicated the results of the integration of the power supply industry in his country, which were:

(1) Thermal efficiency had risen from 17.1 per cent in 1932 to 20.9 per cent immediately before the Second World War. Conditions during the war had resulted in a marked fall in thermal efficiency, while recent construction of new plant and improvements in the technique of burning unsuitable fuels and greater consistency in the fuels delivered had brought about an increase in thermal efficiency which was slightly above the pre-war level. A further upward trend in thermal efficiencies was expected.

(2) Fuel consumption had fallen from 1.794 lb./unit in 1932 to 1.430 lb./unit in 1938. Increasing ash content of the fuel, however, caused decreased combustion efficiency; it was one of the factors which had contributed to the fall in thermal efficiency during the war years and to the slow rate of recovery.

(3) The cost of fuel had a direct effect on the cost of generation.

(4) By the end of 1938, capital savings resulting from reduction of spare generating capacity had amounted to approximately 22 million pounds, whereas the annual saving by grid operation had been estimated at 17 per cent of the cost of production which would otherwise have applied. While figures for recent years were not available, there was no reason to suppose that the relative economies had in any way diminished.

(5) The grid system made it possible to effect considerable economy in fuel consumption and to reduce production costs,

and opened the way to the utilization of generating station sites which could not have been developed independently owing to their distance from the load. During off-peak periods, transfers of energy were possible from areas where the cost of production was relatively low to areas where it was high, thus providing general economy of operation.

Sir Harold then drew attention to the future developments outlined by Sir John Hacking and to the latter's conclusion, namely, that when present difficulties had been overcome, developments on the lines indicated would make possible further substantial economies in fuel consumption and in the cost of production, and would result in the full achievement of the objective of providing cheap and abundant supplies of electricity.

Mr. Malmström introduced Mr. Nilsson's paper on the "Total Joint Operation of Electrical Power Systems in Sweden".

Mr. Nilsson's paper gave the technical background of the joint operation of hydraulic power and condensing and back pressure power in Sweden.

Joint operation of electric power systems had become necessary in Sweden for a number of reasons. First, certain districts with small resources of water power, which had been unable to meet the steadily growing demand for power, had been forced to supplement their own supply with surplus power from other districts. Secondly, the main power resources were situated in the northern regions, whereas the load was concentrated in the central and southern parts, thus necessitating a transmission system of a number of trunk lines covering distances of approximately 1,300 km.

The previous year, hydro-electric stations with a capacity of 2.7 million kw., representing over 95 per cent of the total water power of the country, had been interconnected in one network. By 1953 the capacity of the system would be 4.1 million kw.

Since some of the power lines in Sweden were owned by the State, while others were in the hands of private enterprise, certain committees had been set up to deal with the resultant technical and economic problems. The Central Operating Management was in charge of promoting efficient co-ordination of power production and of ensuring power balance on the basis of short-term or long-term forecasts. The author gave a detailed account of the nature and task of that body which, set up during the war, has proved to be of utmost value even in peace time.

In conclusion, the author stated his views on future developments. In accordance with a new law, all trunk lines for voltages of 220 kv. and above must be built by the State Power Board and must be the property of the State. The question of stability in great power transmission over increasing distances would call for tests by network analysers; such tests had yielded valuable results on previous occasions. Attention was also drawn to the technical means of maintaining parallel operation of trunk lines in all circumstances, to frequency regulation and to the advantages of electrical turbine regulation.

Mr. Aubert introduced Mr. Ailleret's paper on "The Integrated Power System and the Possibilities for the Development of a European Power Grid".

In order to meet the existing power shortage in European countries, it was recommended that the problem should be considered on a general European scale. Numerous studies had been carried out in that regard by the International Union of Electric Power Producers and Distributors as well as by individual engineers and economists.

The countries of Europe were faced with two problems; first, power station capacity was inadequate and the ability to manufacture both hydraulic and thermal turbines and alternators appeared to be insufficient to allow a speedy return to normal in view of the persistent increase in power requirements. Secondly, lack of foreign currency forced most countries to cut down the consumption of commercial coal and hence to develop, as far as possible, the equipment of hydro-power stations or power stations burning lignite or base products. Consequently, once the old thermal plants had been re-equipped, production of hydro-power on the European continent should be pushed forward as quickly as possible in order to cut down coal imports.

The author then explained his theory of a hinterland to the hydro-power areas of Europe, which should be so planned as to take into account the irregular nature of hydro-power. The structure of the power transmission system would necessarily be different inside and outside the hinterlands of the hydro-areas.

In conclusion, the author considered various means of supplementing the European power system.

Mr. Thomas congratulated Mr. Sporn on his paper and on the important part he had played in the development of the system described therein. Figure 3 in Mr. Sporn's paper showed a network made up of short links from point to point, while figure 5 showed the first longer link, which provided greater stability but had its own disadvantages. Mr. Thomas emphasized the need for avoiding very extended systems with heavy concentrations of power and suggested that each large system should be regarded as a group of smaller systems, each one of which should be nearly self-supporting. In that way a general breakdown of the whole system would be less disastrous, because the smaller systems would be able to start again on their own without necessarily waiting for the neighbouring ones to be repaired.

He emphasized the advantages of using wind power as an auxiliary to steam power. Wind power units were much smaller than steam power units and if they were located at the ends of the feeder transmission lines, away from the main generators, they would not add to the concentration of power to be handled by the circuit breakers. They would act as line stabilizers and would provide an extremely helpful adjunct to the system as a whole. If they were placed in the way he had indicated, there would necessarily be a favourable wind at one or other of them all the time.

Mr. Crary emphasized the progress which was being made in the field of power transmission and, to illustrate his point, enumerated the various tools which had gradually been put into use. One point of particular interest was that the steps required for moderate distance transmission were also required for longer distance transmission and should therefore be universal in their application.

Mr. Hannum congratulated Mr. Sporn on his paper and described some of the advantages which had accompanied the voluntary integration of the various power systems in the area of the Columbia river basin.

The whole development of the river basin was being carried out under an integrated plan in order to obtain the maximum advantages for all purposes.

Integrated operation of the hydro-electric plants, made possible by the 230 kv. transmission network interconnecting the hydro-electric plants and delivering to load centres, enables the Hungry Horse project to add 590,000 kw. to the Pacific North-west, in place of adding only 190,000 kw. which would be the maximum without the 230 kv. network and integrated operation.

Mr. LINDEMANN asked why the sizes recommended for turbo-alternators with a view to ensuring the highest thermal efficiency differed in the three papers which had been submitted.

Referring to the statement in Mr. Ailleret's paper that consumption of electric power doubled approximately every ten years, he said that in Norway it had taken twenty years for consumption to double. However, if electric heating of houses became more general, consumption of power was likely to double every ten years.

Mr. KARPOV commented on Mr. Sporn's highly interesting paper and particularly on the integrated system which he had given as an example. Referring to Figure 5, Mr. Karpov pointed out that the backbone of the system described was the area rich in coal deposits. The basic economic justification of the system lay in the fact that the bulk of the energy was generated in the coal belt, where plenty of coal was available at low cost. The availability of cooling water had been another deciding factor. This low cost energy was transmitted to the surrounding highly industrialized regions.

The system was extremely important in relation to the neighbouring power systems, and each system was very valuable to the others in times of emergency. The relationship between the system described by Mr. Sporn and the TVA system was particularly important, since the former was predominantly thermal, while the latter was based primarily on water power.

In Mr. Karpov's opinion, the system described by Mr. Sporn might be called a luxury system, since the concentrated demand and the financial resources required for its establishment would not readily be found outside of the United States. Nevertheless, the various elements of the system would provide a valuable model to countries where industrialization was just beginning. He suggested that it might be advisable, in such countries, contrary to Mr. Sporn's system to take a calculated risk of having a few short interruptions in service if a considerable part of the cost could thereby be saved. For some time to come, frequency control would be far less important in such countries than it was in the United States.

In conclusion, he emphasized that the less-developed countries, while making the utmost use of the wealth of experience gained by the United States, should nevertheless remember to apply that experience in the way best suited to their economic and other local conditions and the financial resources available.

Mr. HALS described the manner in which the Norwegian integrated system had come into being. There were two kinds of water-power stations in Norway: the first were located in the valleys of large rivers and could store only a limited part of the water-flow of the rivers concerned; the second were located in the mountainous region, where there was ample opportunity for storing surplus water. Moreover, owing to the topographical features of the country, there were differences between the precipitation conditions obtaining at those water-power stations. The two types of power stations had therefore been connected and were operated under central control; it was thus possible to derive the maximum production from both.

The Norwegian integrated system included power systems owned by private companies, municipal bodies and the State. Mr. Hals felt that the combination of high-head and low-head power stations, and also thermal stations along the same lines might be of interest to some other countries, for instance to those in central Europe.

Mr. SPORN, in reply to Mr. Lindemann, said that the main point to be remembered in connexion with any grid system was that whenever a certain tightness of capacity occurred, thermal efficiency suffered because the highest available efficiency did not become available as rapidly as was required. It was necessary, therefore, to consider a system which would provide both an average and an optimum efficiency. The most efficient unit of the system he had described had an efficiency of 36.8 per cent. Five such additional units were expected to come into operation by 1952, when the average performance of the system would be approximately 31 per cent.

Replying to Mr. Karpov, he agreed that it was impossible, overnight, to create an integrated power system in the less developed countries. He could not agree, however, with the view that there was any element of luxury in providing continuous service and frequency. Indeed, any reduction in frequency reduced everybody's load and, whereas some operations could stand reductions when the system was short of capacity, others could not. It was essential, therefore, to maintain a sound frequency throughout.

Mr. ANGUS asked Mr. Sporn to confirm that the development of the integrated power system in the United States had been brought about by co-operation between various companies and undertakings. Similar negotiations in Europe between one State and another were often hampered by security and policy considerations, as no country wished to become too dependent on another.

Secondly, he wished to know whether there was any minute to minute control of frequency of the system.

Mr. SPORN replied that integration had been brought about in the United States by a very slow process. The first high-tension transmission line in the United States had been constructed in 1916. Since then, the high voltage transmission system had been extended more and more, the usual voltage being of the order of 132,000 volts.

Minute to minute control is assured by a group which watches the system constantly. It is a small but highly centralized and technically capable group.

Mr. AUBERT, in reply to Mr. Angus, said that the French integrated system had been developed slowly. One of the determining factors in the transmission of energy was that transport of power was more expensive than transport of coal. A European network was currently being developed. Exchanges of power would be small at first but might increase in the future.

Mr. DE MERIT gave details of the connexions existing between the TVA system and the adjacent power systems.

He referred to Mr. Karpov's statement that the predominantly hydro stations of TVA and the large predominantly steam-generating system of the American Gas and Electric Company could very well be co-ordinated. He said that these two systems had been publicized and it was not a matter of general knowledge that other predominantly steam-generating systems having some 2 million kva. of steam capacity were contiguous or closer to TVA and its load requirements; that TVA had interconnexions of a total capacity of about 600,000 kw. with these companies which consist of the Alabama Power Company, the Georgia Power Company, the Mississippi Power Company, the Carolina Power & Light, the Mississippi Power & Light, the Arkansas Power & Light, the Kentucky Utilities Company, and the Louisville Gas & Electric Company; that the hydro generation of the TVA system had been co-ordinated with the steam generating stations of these other companies to develop the greatest combined capacity and economy of such co-ordinated operation; that such co-ordination was initiated prior to the war; and that as the installed hydro capacity of the TVA increases, added interconnexions or interconnexion capacity is installed to the extent that it is economical to continue and to augment the co-ordinated operation of TVA's predominantly hydro-electric system with that of predominantly steam-electric systems. Interconnexions also exist between the American Gas and Electric Company and the TVA system to the extent that is economical, taking all factors into consideration. Further co-ordination of the American Gas and Electric Company system is not as great as generally believed by the public because the large steam generating stations of the first were some 400 to 500 miles from the point of power requirements of TVA, which, at the moment, centre in the proposed New Johnsonville Steam Plant area. Nevertheless, studies of the advisability of increasing the interconnexion capacity between these two systems are continually in progress.

Mr. Aubert presented and summarized the experience paper prepared by Mr. Georges and Mr. Gibrat on the "French Mine-Mouth Power Stations". The paper dealt with the use of low grade coal for the production of electricity at power stations situated in the immediate vicinity of the mine and outlined developments which were taking place in France in that field.

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New Developments in Production and Utilization of Energy

31 August 1949

Chairman:

F. PICARD, Director, Engineering Department, National Renault Works, Billancourt, France

Contributed Papers:

Future Trends in Fuel Utilization
H. ROXBEE COX, Chief Scientist, and
F. A. WILLIAMS, Fuels Technologist, Ministry of Fuel and Power, London, England

Future Outlook on Fuel Utilization
J. J. BROEZE, *Koninklijke Shell Laboratorium,* Broekmolenweg 20/22, Delft, Holland

Future Trends in Fuel Utilization and Conservation
JOHN I. YELLOTT, Director of Research, Locomotive Development Committee, Bituminous Coal Research Inc., Baltimore, Maryland, U.S.A.

Progress in Thermal Power Generation
ANDREW K. BUSHMAN, Manager, Application and Service Engineering Division, General Electric Company, Schenectady, New York, U.S.A.

Future Outlook on Fuel Utilization
F. PICARD, Director, Engineering Department, National Renault Works, Billancourt, France

Utilization of By-Products Gases Produced in an Iron and Steel Works
F. KENNEDY, Chief Heat & Fuel Engineer, Dorman, Long & Co., Ltd., Middlesbrough, England

New Developments in Electric Energy Production
R. GIGUET, *Directeur de l'Equipement de l'Electricité de France*, Paris, France

Power for Industrial and Agricultural Development
PAUL J. RAVER, Administrator, Bonneville Power Administration, United States Department of the Interior, Portland, Oregon, U.S.A.

Power for Industrial and Agricultural Development in Finland
E. K. SARAOJA, Head of Research Department, Finnish Association of Electricity Supply Enterprises, Helsinki, Finland

Harnessing the Wind for Electric Power
PERCY H. THOMAS, Federal Power Commission, Washington, D.C., U.S.A.

Report on the Utilization of Windpower in The Netherlands
De Hollandsche Molen (Society for the Preservation of Windmills in The Netherlands), Amsterdam, The Netherlands

Windpower: Its Interest and Possibilities
R. FARDIN, Paris, France

Summary of Discussion:

Discussants:

Messrs. MACFARLANE, UYTENBOGAART, ROSE, BUSHMAN, RETTALIATA, HANSEN, FIELDNER, AUBERT, RAVER, DAHLGREN, VELANDER, THOMAS, RINGERS, KARPOV, DE LUCCIA

Programme Officer:

MR. W. A. MACFARLANE

Future Trends in Fuel Utilization

H. ROXBEE COX

F. A. WILLIAMS

ABSTRACT

The paper surveys the present and future consumption trends for oil, solid fuel, electric power and gas, and proceeds to discuss the influence on them of technical developments. In road transport, attention is drawn to means of improving the efficiency of the petrol engine for lighter transport in order that it may bear more favourable comparison with the diesel engine. Gas turbines are not thought to have an immediate future in road transport, although in the air they are ousting piston engines. The need is for gas turbines which can burn coal or heavy residual oil for rail and marine use and for small power stations. Complete gasification of coal is of great interest not only for synthetic oil but also for towns, gas, power gas and the chemical industry. The use of lower grade coal for power generation has come to stay. Improvements in domestic space heating appliances burning solid fuel will assist in reduction of atmospheric pollution, but the use of oil for this purpose is an extravagance. It is pointed out that in order to delay the need to produce oil by synthetic means, which probably entails considerable cost and effort, conservation of oil should be more extensively practised. The convenience and cleanliness of oil should not be allowed to override considerations of conservation and result in its use for purposes which coal can serve.

PRESENT AND FUTURE CONSUMPTION TRENDS

OIL

United States production of oil now represents a decreasing proportion of the world total and at the same time United States domestic consumption has risen considerably, and is still rising, with the result that the United States of America is no longer an exporter but an importer of petroleum.

Whilst world-wide shortages, due to tanker and refinery deficiencies, are well on the way to being overcome, it is evident that the increase in consumption in the United States of America will continue and although there are signs of a slackening in the rate of increase, American consumption will, to a considerable extent, influence the use of petroleum in the rest of the world. The most spectacular increase in United States of America demand is for distillate fuel oil largely used for domestic heating but there are also substantial increases in gasoline and kerosene consumption. Residual oil demand has remained roughly constant. American demand has produced a world shortage of distillate oils and there was indeed a distinct tightness developing inside the United States of America towards the end of 1947, relieved only by prodigious effort by the oil industry and a voluntary curtailment of new domestic heating appliances.

As development of transport, industry and agriculture proceeds, apprehension must ultimately be felt about oil resources, and, despite extensive oil shales and oil sands, the world may be forced to turn some of its substantially greater resources of coal into oil.

A notable recent feature has been the spread, particularly in European countries, of the American custom of refining oil near consumption centres rather than at the production source. The future may, therefore, see the establishment in these countries of synthetic chemical industries based on petroleum. Liquified petroleum gas will also be more freely available.

SOLID FUEL

In Western European countries the war has produced marked decreases in the output and quality of coal and steeply rising prices have focussed urgent attention on fuel economy. Some improvement in coal quality may be expected, but as a result of the increasing mechanisation of mining, coupled with the development of inferior seams, the coal reaching the surface will continue to be dirtier than pre-war and to contain more smalls. In Europe all useful combustible material will, in the future, have to be recovered and suitable techniques developed to ensure the utilization of low grade small coal, an essential condition for which will be consistency in quality.

ELECTRIC POWER

Post-war production of electricity in most European countries has increased substantially partly owing to domestic consumers short of solid fuel turning to electricity; in Great Britain there has resulted an exaggerated daily peak load, particularly in cold weather. Not until 1953 will the gap between capacity and peak demand be closed, despite improvement in the load factor from 34.6 in 1938 to 42.4 in 1947. Further action is being taken to improve the load factor.

In the United States of America electricity production fell immediately after the war due to decreased industrial demand but is now increasing again. Although some 30 per cent of the electricity is generated by water power virtually no space heating is carried out electrically. Projected new generating stations are almost invariably coal-fired.

GAS

In Great Britain industrial demands for gas decreased at the end of the war but nevertheless there has been continuous increase in the total demand due to the domestic load resulting from general tightness in the fuel situation. The chief problems of the industry are the mid-day cooking load on Sundays and the demands arising from prolonged cold. Peak loads are, at present, largely met by the use of carburetted water-gas employing imported gas oil.

In most countries towns gas is manufactured from bituminous coal, although in Germany considerable progress has been made with the use of brown coal, and these methods will find extension in other countries e.g., Australia. In the United States of America, however, the distribution of natural gas by pipeline has been developed on a scale equivalent in thermal value to half that of the petroleum there produced. Some 80 per cent of the gas goes to industry. Coal carbonization is practised on a minor scale and the coke produced is consumed in water-gas plant using either gas oil or residual oils for carburetting in the proportions roughly 1 to 3. This use of residual oil is in marked contrast to the employment of gas oil in Great Britain. The industry has a tremendous winter peak load and to meet this methods such as storage of liquid methane above ground and of coke oven gas in partially depleted gas fields have been employed. These methods seem capable of extension to other countries.

INFLUENCE OF TECHNICAL DEVELOPMENTS ON FUTURE TRENDS

TRANSPORT

Road: The petroleum industry has been largely geared to the production of gasoline for the spark ignition engine. The demand for greater and greater power output has led to the use of higher compression ratios with consequent more severe demands on the anti-knock qualities of the fuel. American engine design may well call for high octane fuel in view of the tendency to achieve more miles per gallon by the use of higher compression ratios. The manufacture of such high-grade fuels involves, however, a decreased yield per barrel of crude. For road purposes where an engine is running for the greater part of its time under much less than full load it is extravagant to supply a high-grade fuel except under those conditions likely to give rise to detonation, i.e., full throttle and low speeds. There is, therefore, particularly in Europe, a tendency towards conservation by manufacture of a grade of gasoline of about 70 octane number which is obtainable in substantially greater yield per barrel of crude. Economy in consumption is also sought by attention to stratification of the charge in the cylinders. To cover conditions of detonation produced by large throttle openings, it is possible that an auxiliary supply will be brought automatically into use giving either a high octane gasoline or an injection of a special anti-knock additive. Mechanical devices such as the hydraulic torque converter will also assist in avoiding the neccessity for high-grade fuel.

It is recognized that the present day gasoline engine has on the road a thermal efficiency which may be as low as 10 to 15 per cent. The engine is, however, cheap to manufacture and light in weight. The diesel engine for road purposes has at least 25 per cent efficiency in operation but is substantially heavier and in general more costly largely because of the injection equipment. For the heavier classes of vehicles, the saving in fuel costs of the diesel engine soon offsets the extra capital cost. Direct injection would improve the gasoline engine efficiency but it is unlikely to replace the carburettor system. In the larger private car engines, say, 25 to 50 h.p. the diesel engine may begin to oust the gasoline engine. Such a trend will reduce the fuel used per vehicle per mile by possibly 25 per cent. Unfortunately, any such saving in fuel will soon be swallowed up by the increasing output of vehicles consequent upon a rise in the standard of living. At present, some 1 million tons in the United States of America and 800,000 tons in Great Britain of kerosene are used for agricultural tractors with an efficiency estimated to be as low as 8 per cent. With diesels the fuel saving of 33 to 50 per cent has to be offset against increased capital cost.

Several designers have seriously considered the gas turbine for road transport and at least two experimental engines have been constructed in England. For road vehicles, however, the gas turbine is well below the size for optimum efficiency and any attempt to achieve acceptable thermal performance by conventional heat exchangers is apt to produce an awkward layout. If a good rotary heat exchanger is developed there is a brighter future for the road gas turbine, but the gas turbine has probably further to go to get on level terms with its competitors in this field than in any other application. In any case, the effect of fuel conservation would be small as the tendency would be to compete in the fuel range of the diesel engine.

Air: The future course of fuel utilization in aircraft engines is more clearly cut than for any other form of engine. A definite swing away from the piston engine towards the gas turbine is evident, both in military and civil aviation. This means a change from gasoline to kerosene with an attendant reduction in fire risk. So long as there is a sufficient supply of kerosene, it can be presumed to be the fuel for aircraft turbines. The turbine could use heavier fuels, but the higher pour points would make them operationally unsuitable.

A great increase in military aviation might render the supply of kerosene inadequate, in which case the tendency would be for the aircraft gas turbine to burn gasoline.

Rail: A most remarkable post-war development has been the celerity of the change in the United States of America from steam locomotives to diesel traction. Whereas, the best steam locomotives have efficiencies of 8 to 11 per cent, the diesel regularly yields 25 per cent at the draw bar. Despite the difference in fuel prices the diesel has the advantage over steam in fuel costs and also in labour and costs of refuelling facilities. The capital cost of diesel locomotives may, however, be 2.5 times that of the steam locomotive. In a country like the United States of America, where traffic density is generally low, diesel traction has the advantage over electrification, which involves high capital costs in permanent way equipment. In Great Britan where diesel fuel is more costly relative to coal on a thermal basis, the diesel engine will not score so heavily and with a higher traffic density electrification may be more advantageous. British Railways have recently experimented with diesel-electric locomotives drawing ordinary rolling-stock on main lines. Oil-fired gas turbine locomotives are also on order in Great Britain and operating results are awaited with interest. It is unlikely, however, that the gas-turbine will be widely used in Great Britain unless it can be adapted to burn coal.

In the United States of America the Locomotive Development Committee is developing a coal-fired gas-turbine locomotive which, if successful, may give coal a new lease of life for rail traction. It is clear, however, that considerable difficulties are being encountered which will require the expenditure of much effort to overcome.

Marine: At present the diesel engine is finding favour for new ocean-going shipping in powers up to 8,000 s.h.p. because of its low fuel consumption. Marine diesel oil is the normal fuel but some engines as large as 8,000 s.h.p. are also being operated continuously on gas oil. A notable experiment has recently been made in running the diesel engines of a British tanker on residual boiler fuels. Minor alterations were made in the engine and the boiler fuel oil was carefully centrifuged. Although the experiments are not yet completed, there is reason to hope that ultimately complete success will be attained and the way opened to conservation of some of the distillate oil at present used for marine purposes.

Progress is being made with the adaptation of the gas turbine to marine work for which long life, reliability and flexibility to permit of manoeuvring are required. Engines designed with these points in view are being manufactured in Great Britain for trial in an oil tanker and also in a naval frigate. In both cases, the object is to gain operating experience and to experiment with fuels. In general for marine purposes, the potentiality of the gas turbine in competition with steam and diesel engines will depend upon the extent to which it can be developed to burn heavy grades of oil.

SYNTHETIC OIL

Estimates (1946) of prices for petrol production from bituminous coal in Great Britain based on commercial operation of the hydrogenation process in Great Britain and Germany and of the Fischer-Tropsch process in Germany show that these processes are uneconomic. Both processes would yield petrol at about 2/6d. per imperial gallon. Tar hydrogenation is rather more favourable at about 1/10d. per gallon. The current price for imported petrol is about 1/6d. per imperial gallon, inclusive of tax. The cost of hydrogen in the hydrogenation process represents about 40 per cent, and the cost of synthesis gas in the Fischer-Tropsch process, about 60 per cent to 70 per cent of the cost of the finished petrol.

The German hydrogenation process had an average thermal efficiency of only 29 per cent, but by close attention to details, particularly of heat conservation and by raising the efficiency of hydrogen production, the United States Bureau of Mines is hopeful of realizing a figure of 56 per cent.

The conventional German Fischer-Tropsch process has undergone radical post-war development in America where, employing the fluidized catalyst technique and based on natural gas, synthetic petrol has been estimated to be competitive with natural petrol. Two large-scale plants are projected but involve very high investment costs, and rising prices have led to one being abandoned. Natural-gas reserves, moreover, are far from unlimited and are being increasingly exploited for other purposes so that ultimately the future of synthetic oil will have to depend upon coal. At present prices production is not economic, except in those parts of the world where exceedingly cheap coal is available and oil is relatively expensive. As scarcity of oil develops, and prices rise, the position for synthetic oil will become more favourable. At the time of writing oil prices tend to decline.

Even after allowance is made for developments, both the hydrogenation and the Fischer-Tropsch process will not require much less than 5 tons of coal per ton of oil and must, therefore, be regarded as extravagant of coal reserves as well as of steel, technical skill and labour. Synthetic processes cannot, therefore, be contemplated as potential suppliers of oil for purposes, such as oil firing, for which direct coal firing can provide a satisfactory alternative. It is to be concluded that better utilization and conservation of the existing oil resources should be practised so as to defer as long as possible the necessity to turn to synthetic oil.

COMPLETE GASIFICATION

The development of cheaper continuous processes less selective in fuel than the conventional water-gas process has become of world-wide interest, for towns gas distribution, for power gas production, and as raw material for oil synthesis and the chemical industry.

The German developments of complete gasification for water-gas production employed internal heating by combustion in oxygen of part of the fuel and one of these, a modified Koppers process, is favoured in the United States of America. The use of oxygen is, however, not a necessity. In Britain a process is under development for the chemical industry in which in successive fluidized stages bituminous coal is first carbonized, then undergoes partial combustion in air, and is finally gasified in steam to water-gas.

All the German processes give a gas of much the same C.V. as water-gas except the Lurgi which with brown coal yields a gas of about 450 B.T.U./c.ft. and is therefore of interest to the towns gas industry. Unfortunately, the Lurgi process requires a reactive fuel such as brown coal. With less reactive bituminous coals, the C.V. of the gas falls to 350-400 B.T.U./c.ft. The process is however undergoing development for bituminous coals.

The lower reactivity of bituminous coals may lead to the development of processes in which the scrubbing action between the coal particles and the reacting steam-oxygen mixture is intense, as in a vortex arrangement. It may be that one can envisage a vortex gasification process operating under pressure and producing a gas of high C.V. from bituminous coal. If a high C.V. gas is not obtainable by such processes the towns gas industry may need to carburett with oil as at present, or upgrade the C.V. of the water-gas by catalytic conversion to methane.

POWER GENERATION

One of the most important trends in power generation by steam is towards the use of lower grades of fuel. In the United States of America this has led to the development of the Cyclone burner now being extensively adopted by one company.

In Great Britain there will be a continuing necessity to burn high ash small coal at power stations and appropriate methods of burning are being developed. Whilst such fuel can be burnt as pulverized fuel there is obviously an upper limit of ash beyond which the fuel is uneconomic to grind. Mechanical stokers are being redesigned to give better combustion with these fuels and special artifices employed to ensure earlier ignition. One consists of injecting as a spray 5 per cent of oil and another method employs steam jets (the Courtauld system) to assist ignition by drawing hot combustion gases back over the unignited fuel. Such methods enable the rated capacity of the boiler to be maintained on fuels up to 40 per cent ash.

In Great Britain, two 15,000 kw. open cycle and one 12,500 kw. closed cycle gas-turbine power stations are being built. These will run, at any rate to begin with, on middle distillate fuels. On such fuels these plants are not economic propositions for load factors greater than about 15 per cent. Nevertheless, there is no strong tendency to use the gas turbine for peak load generation. Research is rather in the direction of developing it as a base load plant using residual oil or coal. The principles developed in complete gasification of coal may be applicable to producing a cheaper power gas from coal as an alternative to the direct use of coal.

The high capital cost of meeting peak load demands emphasizes the importance of considering afresh the possibilities of all methods of meeting these loads, such as pumped water storage which has, under favourable circumstances, been developed on the European continent.

NON-INDUSTRIAL AND DOMESTIC UTILIZATION

A marked conversion from coal to oil firing for non-industrial and domestic heating is evident in the United States of America. The fuel employed is largely distillate. This change results from convenience and cleanliness and to some extent from steps to reduce atmospheric pollution. Does not this represent an extravagant use of the expendable resources of oil since when oil becomes short and prices rise, there will have to be reconversion to coal?

In Great Britain, the desirability of improving the efficiency of solid-fuel domestic heating and the heat insulation of buildings has at last been realized. It is, however, thought that the saving of solid fuel resulting from the use of the new improved appliances will not be in direct proportion to their increased efficiency, but a much better heat service will result.

In Britain, the domestic consumer as a result of solid fuel shortage as well as for convenience, has tended to turn to space-heating by electricity and gas and these services are usually used in a manner which accentuates peak loads. It can clearly be argued that neither is as efficient from the point of view of coal conservation as solid fuel in modern appliances. Utilization of waste heat from power stations and adoption of complete gasification by the gas industry would render electricity and gas for space heating less open to criticism.

ATMOSPHERIC POLLUTION

The world is agreed on the social and economic evils of atmospheric pollution and certain cities in the United States of America and Great Britain have taken legislative powers to restrict the use of bituminous coal and of unsuitable appliances. Attention has, therefore, been devoted to appliances burning bituminous coal smokelessly and several promising designs have been developed. Such legislation is in the United States of America partly responsible for conversion to oil and it has also stimulated the production of smokeless fuel by low-temperature carbonization.

In Great Britain, the newer, more efficient, domestic solid-fuel appliances are designed to burn smokeless fuels and also bituminous coal with much reduced smoke emission, but the difficulty of the many millions of existing open fires still remains. If these are not replaced by newer appliances can the gas industry supply for them a coke which has the necessary combustion properties? Technically, this can be done but the supply of such fuel in the quantities required will call for considerable expansion of the carbonizing industry. The problem of atmospheric pollution appears to be one calling for attack from a number of directions. Low temperature carbonization which can provide suitable smokeless fuel at some extra cost can assist. Is complete gasification possibly the ultimate solution of the problem?

In Great Britain, the increasing use of low-grade high ash coal at power stations is undoubtedly adding to the grit nuisance and increasing attention is being paid to the combined removal of grit and oxides of sulphur by washing.

In ordinary industrial plants, pollution by smoke is a more amenable problem since economy demands its reduction and the training of personnel can do much to help. Conversion of railroads to diesel traction and electrification are already making an important contribution.

INDUSTRIAL FUEL UTILIZATION

Furnaces. With oil in most countries a more expensive fuel than coal, it is in general only more economic for furnace work where its physical properties or its particular combustion characteristics result in special benefits which more than offset its added cost. Such a property is flame luminosity resulting in higher rates of heating than for solid fuel or gas. In many cases, however, the necessary luminosity may be imparted by carburetting producer gas flames with a small quantity of oil and this practice is capable of more extended use. Oil assisted combustion of low-grade high ash fuels is another example of the same effect.

The combustion of oil is generally thermally slightly more efficient than of coal because of the better control, particularly over excess air. No general conclusions regarding the economies of oil versus coal or gas can safely be reached since each application must be considered on its merits. It is perhaps pertinent to ask why stable colloidal coal oil mixtures have not found greater use.

Diesel engines and gas turbines. For many purposes for which stationary diesel engines are employed, the recent tendency has been to install engines of comparatively small cylinder diameter running at more than 700 r.p.m. In Great Britain, the fuel employed is invariably gas oil but in the United States of America may be gas oil or kerosene. For many of these purposes, such as pumping water, where the load is steady and continuous, high-grade fuel is unnecessary, and a fuel consisting partly of residual oil would probably be satisfactory, particularly if the engines are supercharged. Should not engine manufacturers be encouraged to develop their engines to use heavier fuels?

The gas turbine is potentially omnivorous as regards fuel. At present, however, the fuel has to be free of substances giving a plastic or bondable ash at turbine operating temperatures and this restriction naturally applies to attempts to burn coal.

It cannot be predicted whether the solution to the ash deposit problem with heavy oils and coal will be the simple one of cleaning the hot combustion gases or the more complex one of cheapened supplies of clean gas for combustion.

The gas turbine is particularly adapted to use in the chemical industry, in which hot gases are frequently available under pressure.

The Future Outlook on Fuel Utilization

J. J. BROEZE

ABSTRACT

Considering that the present phase of civilization based on the utilization of stored energy deposits is a passing one, in uneasy confidence of finding further ways, the most economical use must be made of fuels.

Fuel is used for domestic and technological purposes (the latter including power and transport). Fuel economy must be weighed against other factors: capitalization of equipment, ease of handling and control and cleanliness.

Domestic fuel utilization covers the following applications:

Heating: The trend is towards compactness and ease of handling, automatic control, community heating schemes. Stress is laid on smokeless fuels.

Cooking: With controllability in the foreground the battle is between gas and electricity, with some activity in light petroleum distillates. Radiant heating is getting more attention.

Lighting: Domestic lighting is overwhelmingly electric but there is a new development in gas-discharge lamps. This commodity has caused secondary comforts to follow; outside public utilities these will raise a continued demand for small individual power units.

For technological purposes fuel is used for:

Heat: Here the trend is for streamlining and unitizing of technological processes for better thermal efficiency through recuperation of waste heat, and for combination with power processes. Close control of temperature and sometimes of atmosphere is required. Radiant heat transfer is assuming importance.

Power: There is great variation in heat engines for various purposes. In stationary plants, the emphasis is on fuel economy and cheap grades of coal with steam turbines for big units, while in peak load plants the emphasis is on gas turbines or diesel engines. With respect to movable installations, liquid fuel is indicated for ships, steam turbines for big power units and diesel engines for smaller power units. A possibility is the use of low-grade fuels and of interchangeable high-speed engines in order to avoid delay to the ship for repairs. The future of the gas turbine is uncertain. For trains, the diesel engine is the general solution with electrification wherever traffic is sufficiently dense. Gas turbines for big units are likely. In road transport, the emphasis is on diesel engines where the intensity of usage is great and on gasoline engines where it is smaller. The prospect of increasing octane numbers is practically at an end, but the use of separate anti-detonants is a possibility. The use of the diesel engine has been greatly promoted by additive type lubricating oils. Air transport in the future is likely to depend on gas turbines and a combination of propeller and jet. Among the unorthodox possibilities are the hot-air cycle engine and the thermo-electric pile.

INTRODUCTION

We people of the twentieth century are living in the grandest and most precariously founded civilized society the world has ever seen, the apotheosis of the Promethean era. Fire is its life-breath, man-made fire. The invention of fire is truly the main source of human civilization in its technical sense, and who can doubt its equal significance for the spiritual development of mankind? Fire has thus become one of the most prominent basic needs of man, first for food preparation and for giving warmth in the inhospitable climate with which much of the earth is endowed, then for technological purposes and lately, what a short stretch of time a century is!, for the conquering of terrestrial space.

Yet this very prominence makes us take notice and worry, since in a toss-ball game the development of controlled fire has enabled the world's population to grow out of all proportions and, at the same time, its need of fuel to grow again disproportionally with it. The critical point in this game came when the fuels which nature provided from its contemporary resources, wood, vegetable or animal fats, and which by their relative rareness or by the man-power required to procure them limited the pace of development, were first supplemented and later replaced by fuels from stored deposits, accumulated during aeons, which we are now using up at an alarming rate as viewed in a historical time scale.

It is clear that this cannot go on for ever and that other bases for human civilization must be found, of which we know wind and water power already from experience, and nuclear fission energy as a nearby probability. Yet in a somewhat uneasy confidence that man will find ways of safeguarding his own future there is every reason to consider carefully how we stand on this vital issue and what are the prospects for the near future, the next generation or so.

Others will give that part of the prospects that shows the estimated magnitude of the stored energy deposits; we shall deal now with the part that indicates what man hopes or expects to do with these. In doing so, the historical sequence may best be followed: domestic uses, technological purposes, including power production and transportation. However, attention must be given to some aspects common to all these fields of application: the importance of the fuel cost factor with regard to other cost factors of the process, whether this be the running of a household or of a ship; the question whether the process requires continuous operation or includes important periods of idling or low heat or power requirements; the questions of cleanliness and ease of operation; and last but by no means least whether or not close control is required. The balance of all these factors differs from country to country, as, for instance, the cost of various fuels per heat unit may differ and is differently related to the cost of labour. The balance also differs between spacious rural conditions where, for instance, smoke is not troublesome, and congested city conditions, and so on. Furthermore, and but partly as a consequence of the foregoing, the difference in advancement of techniques is staggeringly great. We shall look more particularly at the advanced stages of Western industrial development for leads.

DOMESTIC FUEL UTILIZATION

Heating

With the trend in housing pointing to increasing compactness and simplicity, both because the house building industries are unable to produce inexpensively and because of the domestic help problem, indications are for heating systems requiring at most only a small fuel storage and little care.

In closely built-up areas, community, block or apartment house schemes for general heat provision will develop more and more, based on efficient and usually automatic boilers, utilizing, wherever possible, waste heat from power plants. In the case of existing property in such areas, electric or gas heating may best answer the purpose. This would leave, however, the majority of homes to be provided for by automatic or semi-automatic plant employing smokeless fuel: anthracite, coke, oil, gas. There is a strong tendency to prefer the easiest type of fuel requiring the cheapest appliance: a light distillate oil or gas. Very satisfactory solutions have been worked out also for heavier oils and for coal, to be applied where fuel cost is being considered more carefully or the demand for the best qualities outruns the supply.

In soft-coal countries with mild to temperate climates, the open soft coal fire still holds its own, notwithstanding damning evidence of its inefficiency and its contribution to smog and corrosion. The cleaner aspect of a hard-coal country is always being remarked upon. The trend is towards segregating activated coke and gas, and making use of the valuable by-products.

Low-temperature radiant heat is being appreciated as more comfortable and more economical in fuel, although requiring more capital outlay than its counterpart, hot air heating. The latter allows of a direct combination with that recent addition to domestic improvement: air conditioning.

Cooking

The battle is mostly between gas (coal, natural and bottled) and electricity, with controllability, if possible by thermostat and clock, as the main weapon. Great progress has also been made in the control of solid-fuel furnaces and in their efficiency, which has long been of a very low order owing to a combination of idling losses and bad heat-recovery when on load. Combinations with heating plant are among the most advanced domestic constructions.

In oil appliances, where very light distillates are used, there is a steady development, also with a view to obtaining closer control and avoiding sooting through improved burning conditions. Also in this case the tendency is not to consider, for the future, appliances with their own individual fuel containers, causing a daily refill nuisance, but to aim at a centralized storage outside the house and to lay out fuel lines to serve the necessary points.

Radiant heating of the cooking vessels is being given increased attention by all designers, whether interested in electricity, gas or oil.

Lighting

Real improvements in this field, to wit, gas discharge lighting augmented by the conversion of ultra-violet rays into light rays by fluorescence, do not change the already overpowering superiority of electricity for light production. So strong is this superiority that together with other attractive possibilities: radio, refrigerator, oil firing, water pumping, it has created a strong demand for electrification and where this cannot be performed economically by means of public utilities, small automatic gasoline or oil engines step in. It is for this market that the revival of the hot-air cycle and of other long-known but discarded processes may be of extreme interest.

TECHNOLOGICAL USES OF FUEL

Heat

Most technological processes require heat in some form: reduction of ores, melting of metals, distilling, baking, drying; the differences are in the relative importance of fuel cost, in the temperature and in the degree of control required. Sometimes efficiency is still very low owing to bad process layout, which occasionally necessitates several reheats, to bad heater design causing undue direct losses, and to intermittent operation. Great progress is due to streamlined operations such as now lead to the production of sheet steel from the steel furnace without reheat. This line of development ends in a concentration of all phases of operation within one plant, from ore reduction to finish rolling, and will be followed more and more as thermal economy of technological processes gets more attention. An even wider notion of thermal economy is also being more widely understood; its significance is to evaluate heat by the temperature at which it is required, and to provide low-temperature (low-grade) heat only as a waste product of the high-grade heat provided by combustion (always well over 1000 degrees C) after making use of the valuable high-temperature levels, for instance for power production or high-temperature furnace operation. This development leads to more highly organized, complex, technological units combining greater fuel economy possibilities with greatly increased capitalization and decreased flexibility, hence demanding more knowledge and foresight as well as the promise of stable conditions.

Typical of the trend is the requirement of close control both of temperature and, in some metallurgical cases, of atmosphere, which requirement has favoured gas and even electricity, the only case worth mentioning where heat may be produced without even initial combustion if the power is derived from water. This heat may be obtained in many ways: from the arc, the induction or the eddy current and by radiation. Great strides have, however, been made in obtaining closer control of gas, oil and (powdered) coal combustion, which latter, by providing strongly radiant flames, furnish their heat in a very concentrated way most suitable for high-temperature processes. An interesting feature here is that cheap residual and cracked oil fuels, owing to their lower hydrogen content, are more favourable than lighter oils with a view to obtaining radiant flames. Of course, over some 1500 degrees C. one is practically limited to electric heat; this limit may be raised as inexpensive oxygen becomes available. In specific instances, to be sure, the use of oxy-acetylene and oxy-propane is well known.

Power

In the world at present a wide variety of heat engines is available, based on coal and on petroleum derivatives, and fitted to suit many requirements. Decisive factors in the evolution of types are requirements of weight, cost, reliability and ease of control or maintenance, besides pure fuel economy, the last dominating the scene only in a few cases. The most striking feature of power technology is the mutual adaptation between heat-engine concept and design on the one hand and fuel characteristics on the other, an adaptation groping for optimal results out of the manifold contributing and often conflicting factors. Continually changing techniques and prospects on both sides often make it hard for engine designers, as well as fuel technologists, to see clearly ahead, and the result is, of necessity, a progress involving halting and stumbling, often with mistakes and regrets. But such is all the progress of mankind, and this field, where progress is not made by a few chosen ones but by the multitude, each seeking for the best solution to his own problem, in his light and within his means, should be no exception.

In order to attempt a projection of the lines of development it is, perhaps, profitable to make a general distinction according to main applications. Thus, following a general scale of specific engine weights, stationary, marine, rail, portable, road and air units will be found. A further rough cross-distinction according to intensity of usage, providing a certain indication of the balance between capital cost and direct cost of operation, will then allow a more precise charting of the roads to be followed. The extremes of the chart thus obtained give at the same time the extreme of adaptation of power plant to fuel one way, and of fuel to power plant the other.

In a big stationary plant built for mass production of electrical power, the usual layout is the solid fuel-fired boiler with steam turbine plant in big units. This is partly so because the turbine is the only type of heat engine suitable to really big powers, and because the general cheapness of solid fuels prescribes their use, which, so far, has only been possible with external combustion. The necessity, again, to obtain high efficiency has primarily resulted in high temperatures and pressures. Boiling liquids of which, of course, water is the most obvious but thermo-dynamically not the most advantageous, give very high rates of heat transfer, which enables the designer to build his heater, the boiler, with a relatively small heating area, whilst adjusting the design of its combustion chamber to the cheapest possible fuels, such as very lean coal or high-ash brown coal. It is, therefore, probable that this line of development will be pursued further, to the exclusion of other possibilities, such as the internal or external combustion air cycle turbine. Everything possible will, of course, be done to make use of heat at lower temperature levels for increasing the economy, the waste heat being finally exploited for technological or space-heating purposes wherever possible.

The emergency or peak-load plant is an entirely different proposition. These plants may be extremely valuable for maintaining or extending the capacity of a power system by being able to replace or complement this system for short periods. Here, the balance between capital investment and operating cost points towards simpler, less expensive machinery, which may be less economical in fuel, either quantitatively or qualitatively. Simple steam turbines with compact, quick-acting boilers, and also oil engines have been used, the latter particularly on account of their immediate response. Now, the internal combustion turbine also presents itself for these purposes, possessing in simple form a moderate efficiency, on a reasonable range of oil fuels, together with attractive features of compactness and ease of operation.

For all movable installations liquid fuels have, of course, much to recommend them, and although steamships and locomotives were developed before oil fuel was available, the influence of the attractive features — high specific energy content, easy bunkering, good control, aided also by the development of specific oil-burning machinery, such as oil engines — has been to drive inroads into this field of coal utilization.

For ships, the easy disposal of bunker space for liquid fuel and the saving of space, weight and man-power have decided entirely in favour of oil fuel. The battle is between the steam turbine and the diesel engine. The steam plant is predominant in big powers and is also favoured where personnel of the special type necessary to coax big diesel engines along is not available, and where heavy boiler fuel is really cheap.

The oil engine has proved to be equally reliable in many cases and scores where better fuels are available at little extra cost, and on long runs where its low consumption rate counts. It is becoming appreciated that, given suitable design and auxiliary equipment, the oil engine may also use low-grade fuels, and future development will certainly be directed in many cases towards this end. Conversely, for lighter duties where the power demand is temporarily great, the recent progress in diesel engine lubricating oils has made high-speed oil engines attractive. These can solve a question of vital interest to shipowners, namely that of replacement instead of repair *in situ*.

It is as yet too early to predict any big future for the internal combustion turbine, apart from lightweight military plant; one of the great difficulties in gas turbine development is the bigness of the object, when it is built for economy, making it cumbersome for experimentation.

For trains, the days of the steam locomotive are numbered. Intense traffic is being handled by means of electrification; for individual traction, either by locomotive or by rail-car unit, the oil engine is the solution at present aimed at by every railroad in the world. It is foreseen, however, that the internal combustion turbine may become very attractive because of its compactness in big powers. The task to make this type of engine burn powdered coal, undertaken in the United States, would appear to be a tremendous one and against the general trend for transport engines. So probably oil will be the principle fuel.

In road transport, as well as in portable power units, the internal combustion piston engine reigns supreme, in the shape of the inexpensive gasoline engine, where intensity of usage is relatively small, and of the more expensive but also more efficient diesel engine, where it is greater. It is, of course, too well known to stress it that the attractiveness of the gasoline-driven road vehicle has stimulated the oil industry to its present height, but outside the industries concerned it is not always realized to what extent mutual adaptation of engine and fuel has been driven, with the biggest efforts doubtless on the side of the fuel technologist, which is as it should be. The cracking process has served to bring more material within the volatility range that the gasoline engine can consume. At the same time this process assists other chemical conversion processes to adapt the hydrocarbons to the combustion process described, which is a curious one inasmuch as good burning is required and, on the other hand, a certain resistance against premature reactions between fuel and oxygen, which would lead to untimely explosions known as detonation or knocking. There are signs that the oil industry, sensing that it has reached at least for the present the limit of its possibilities, and fearing a reduction in yield per barrel of crude that would offset gains in performance or economy, will not contribute to the same extent to further adaptation and that other possibilities must be investigated first. One of these, based on the fact that detonating conditions are only met with during a small fraction of the total time of operation, is the introduction of a special antidetonant fluid during that fraction. Such a fluid may be based on petroleum or on water-methanol, with tetra-ethyl-lead added, and the principle may become very important in this field.

The progress made possible in high-speed diesel engines through improved lubricants promotes wider application of this type of engine and further development characterized by the pass-words: supercharging and two-stroke cycle. The requirements in the way of fuel characteristics are much less sharply defined than those for gasoline engines, and, it is of interest to note, tend to become less so as dimensions and loads increase. There is great competition for the type of fuel required here by the very big domestic heating business, resulting in a tendency towards decreased over-all quality. Further development of this type of engine, the characteristics of which are only gradually becoming understood, in conjunction with still better lubricants, will do much to cope with this situation.

High above these everyday problems soars the airplane, which, by virtue of its ethereal being, is a law unto itself, but a law drawn up by the soldiers. Civil aviation makes grateful use of what is developed for war purposes, but it has never been able to insist on what it would like to demand: a safe fuel. Requirements of power and speedy possibilities of development have long helped to maintain the gasoline engine in its leading position, to which end fuel technologists have worked out miraculous formulae and intricate processes. The oil engine has missed its day in this field, being always a little behind; it still has a chance, however, since it can show in compounded form, that is, in combination with high supercharge and full utilization of exhaust energy, the lowest possible consumption figures.

But more likely is the victory of the internal combustion turbine, already at the top as regards performance, and soon also, no doubt, acceptable for economy. Although stringent military requirements cannot be met by other than volatile fuels, it is very likely that the persistent cry for increased safety in civil flying could be answered satisfactorily by the use of inexpensive fuels of low volatility. This safety, with the luxury of smooth noiseless motion, would add greatly to the attractions and the usefulness of flying.

A few final remarks about unorthodox ideas for power production. It may seem from the foregoing paragraphs that the problems of power production by combustion have been solved by time-tried thermodynamical processes, and that apart from gradual development and improvement nothing basically new may be expected. The recent rise to fame of the internal combustion turbine should be warning enough to dispel this idea, albeit that this possibility was known in principle and awaited suitable materials and patient development work to materialize. In a somewhat similar position, but less advanced, is the revival of the Stirling hot-air cycle piston engine, which may, for certain applications, show attractive possibilities. So far, we have not gone beyond the limits of classical air-cycle thermodynamics.

There are, however, in principle entirely different ways of converting combustion energy into power, notably electric power. Recently, great advances have been made in small power plants based on thermo-electric potential differences between two metals or half-conductors, thus converting heat into electric power without moving parts. Direct utilization of electro-chemical phenomena at high temperatures, possible in principle, has so far failed owing to the lack of suitable materials, but these possibilities are always in the minds of men impressed by the complications and hazards of the present methods.

What shall we see of new methods in the next ten to twenty years? Nobody can tell, since, apart from much hard work, so much depends on some sudden flash of genius which may light up in any unexpected corner of this world.

Future Trends in Fuel Utilization and Conservation

JOHN I. YELLOTT

ABSTRACT

Utilization of fuel is increasing throughout the world at a rapid rate. The need for energy will continue to increase in the foreseeable future, thus necessitating a more efficient use of the hydrocarbon fuels now available, and an ultimate return to the non-expendable energy sources, such as solar radiation and plant growth. Methods of reducing fuel consumption include improvement of prime mover efficiency; utilization of prime mover exhaust heat for space and process heating requirements; use of abundant solid fuels wherever possible, in place of liquid fuels.

The development of the gas turbine is described, and particular importance is attached to the fact that its exhaust heat is available as hot air in relatively large quantities and at high temperature. This makes possible the generation of steam at pressures high enough to be useful industrially. The prospects of using solid fuels in the gas turbine are mentioned, and a brief report is given of the recent work of the Locomotive Development Committee.

INTRODUCTION

In the industrialized nations of the world, utilization of fuels is increasing at an amazingly rapid rate. In the decade between 1935 and 1945, the population of the United States increased by 10 per cent, but the total energy consumption rose by 70 per cent. If present trends continue, the United States will by 1955 have more than 150 million inhabitants, who will need more energy than could be supplied by 1,500 million tons of bituminous coal. The reasons for this increase from an annual consumption equivalent to 6.0 tons *per capita* to a probable requirement in excess of 10.0 tons lie in the province of the sociologist rather than the engineer. The fact remains that in all parts of the world, populations are increasing, and their demands for fuel are growing even more rapidly. These demands are already taxing the available supplies of fuels to such an extent that a new version of the Malthusian Law may well be promulgated. The world's population will, in the future, be limited not only by the rate at which food can be produced upon the surface of the earth, but also by the rate at which fuels can be withdrawn from beneath that surface.

The only two sources of energy which can today be converted in useful quantities to power and heat are the diversion through turbines of water flowing towards the sea and the burning of hydrocarbon fuels. Nuclear fission, now fearfully practical for military purposes, must await the maturing of its new technology before it becomes a commercial reality. Other energy sources, wind and sun, wave and tide, are not likely in the immediate future to be used in significant amounts.[1]

The number of places where falling water can be effectively harnessed is so limited that only a few major new developments of hydro-electric power will take place in the near future. The world's rapidly increasing demands for power must therefore be met primarily by fuel-burning installations.

Any attempt to evaluate the earth's resources of hydrocarbons, coal, oil, gas, shale or tar sands, can at best be only a rough approximation. The most recent and authoritative estimate for the United States (2)[2] is shown in Figure 3. Future exploration will reveal new reserves of the fluid fuels, but the passage of the five decades remaining in this century will result in virtually complete exhaustion of our petroleum and natural gas. Only coal is known to exist in quantities sufficient for the needs of the next century.

ANALYSIS OF FUEL UTILIZATION

A study of United States fuel consumption statistics for 1947 has been summarized in Table 1. Approximately 11 per cent of the total was used for the generation of electricity in public utility stations. Twenty-three per cent was used for transportation. Coke and other industrial chemical uses accounted for approximately 13 per cent, while general industrial use required 33 per cent. Retail consumption was approximately 20 per cent.

To express these figures in another way, approximately 35 per cent of the fuel was consumed in the generation of power, with little or no recovery of waste heat. Thirteen per cent of the fuel was used for its carbon content, while 52 per cent, used by general industrial and retail consumers, went primarily to the production of heat.

From a consideration of these statistics, it may be concluded that major reductions in fuel consumption can be accomplished by the following measures.

Table 1. Fuel Utilization in the United States in 1947
(Total bituminous coal equivalet, 1,244 million tons)

Use	Coal	Petroleum products		Natural gas	
	Million tons	*Million barrels*	*Coal equivalent, million tons*	*1,000 million cu. ft.*	*Coal equivalent million tons*
Electric utilities	89.5	45.3	10.4	373.1	15.3
Gas	6.3	29.5	6.8	0	0
Transportation					
Railroad	100.5	107.7	25.5	0	0
Highway	0	594.3	136.0	0	0
Marine (foreign trade)	1.7	72.1	16.5	0	0
Air	0	21.6	4.2	0	0
Coke, steel etc. (including carbon black)	119.0	47.6	10.9	735.0	30.2
General industrial	152.3	762.8	173.3	2,224.3	92.3
Retail	136.9	308.9	70.7	1,087,3	44.6
Totals	606.2	1,989.8	455.3	4,444.7	182.4
Percentage of total coal equivalent	48.6		36.5		14.9

[1] Numbers within parentheses refer to items in the bibliography.

[2] Ayres, in reference 1, gives a comprehensive survey of the sources and utilization of energy at the present time. He states that solar rays could conceivably yield about fifty times as much energy as is now being used.

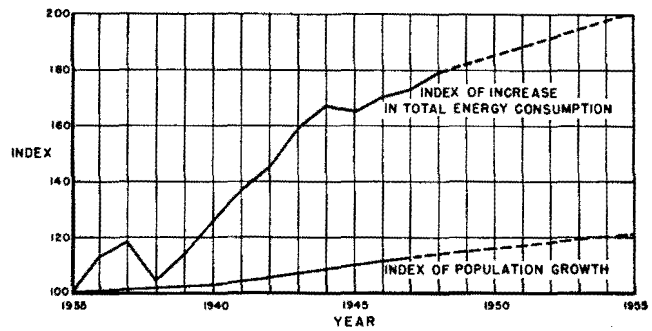


Figure 1. Indices of population growth and total energy consumption in the United States, 1935–1955

Improvement of prime mover efficiency

The 23 per cent of the fuel consumption which goes to transportation is used in millions of small, individual prime movers. A major reduction in fuel consumption could be accomplished if the efficiency of these units could be raised substantially. This can be done by increasing their full-load efficiency, as by replacing inefficient steam locomotives with diesel or gas turbine-electric locomotives, or by increasing the load factor, as by using far smaller engines in the millions of automobiles which now operate at a load factor of less than 5 per cent. In the generation of electricity, fuel is consumed by a relatively small number of very large plants. Increasing the already high thermal efficiency of these plants will result in only a small decrease in the over-all fuel consumption picture.

Utilization of prime mover exhaust heat for space and process requirements

The requirements for energy in the form of heat could largely be met without consumption of additional fuel, if the heat rejected by large individual prime movers, such as industrial and utility steam turbines, could be turned to useful purposes.

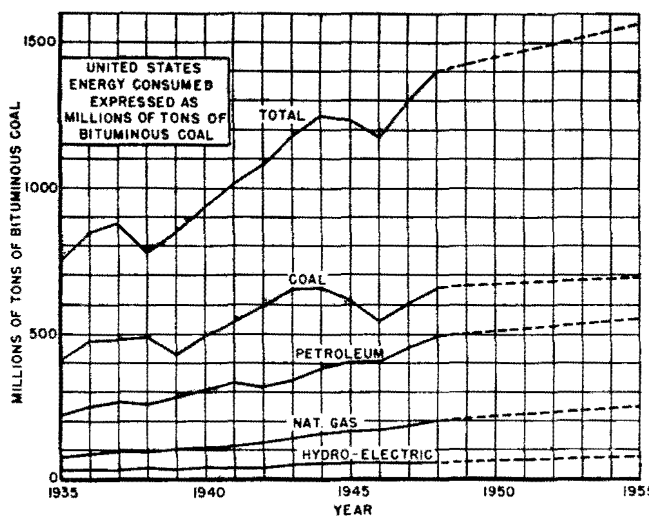


Figure 2. Energy consumption statistics for the United States, 1935–1948, with anticipated growth to 1955

There is little chance of recovering waste heat from the mobile prime movers, but much can and probably will be done in the near future to avoid the tremendous waste of energy which is represented by condenser cooling water from utility power plants.

Many economic studies in the past have shown that, with the prices of fuel then prevailing, it was not expedient to utilize exhaust heat for space heating, particularly when there was no use for the exhaust steam in the summer. It should be pointed out, therefore, that the waste-heat utilization will change appreciably as fuels become more costly.

Use of more abundant solid fuels where now fluid fuels are being used

The rising cost of oil and gas will automatically cause the owners of large stationary plants to convert their equipment to coal. The mobile users must continue to use oil, because of its convenience, until a coal-burning prime mover is developed which can offer, particularly to the railroad industry, the advantages which are now given by internal combustion engines. Industrial and retail users of oil and gas will find it necessary to balance convenience against cost, and an increasing trend to coal will develop when the prices of oil and gas begin to rise again.

Although the conversion of coal to liquid fuels is now technologically possible, it is undesirable because of the tremendous loss in energy which is inherent in this conversion. Approximately 50 per cent of the energy in the fuel must be dissipated in the form of waste heat when coal is converted to oil. The cost of the conversion in dollars is certain to be very high, and the amount of steel and other vital materials required to establish an industry of adequate size would be extremely large.

Of these three methods, the most significant would be an increasing use of prime mover waste heat to supply the low-temperature heating needs of industry and retail consumers. Already a number of industries and public utilities are jointly solving their problems by generating electricity in large central

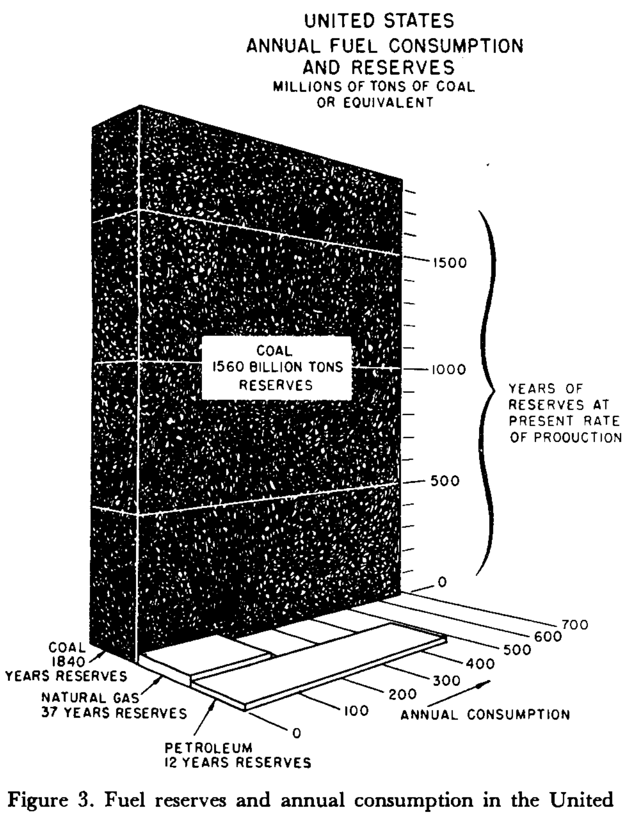


Figure 3. Fuel reserves and annual consumption in the United States

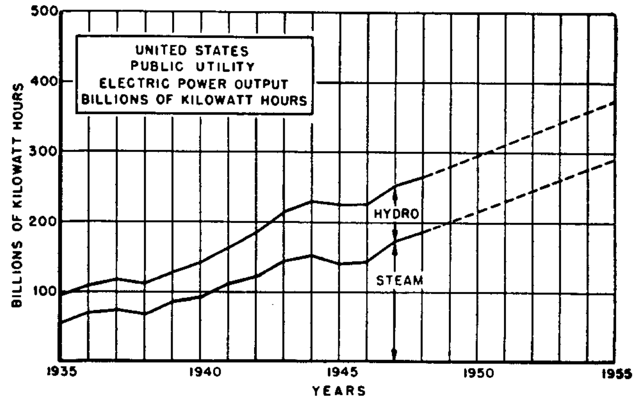


Figure 4. Public utility electric power output in the United States, 1935–1955

stations, and utilizing the latent heat of the turbine exhaust for industrial processes in adjacent plants. In future years, the present practice of throwing away two-thirds of the heating value of the fuel in condenser cooling water will be looked upon as an inexcusable waste, and fuel-burning stations are likely to be planned as much with utilization of exhaust heat in mind, as with the distribution of electrical energy.

TRENDS IN PRIME MOVER DEVELOPMENT

A survey of the existing means of generating power from fuels is given in Figure 5. Here, each prime mover is classified as to its attainable heat rate, its maximum unit size, its present applications, and its ability to use the various fuels. The senior member of the prime mover family, the steam plant, offers the widest extremes in unit size, thermal efficiency, and fuel flexibility. The condensing steam plant will continue to dominate the field of large-scale stationary power generation and marine propulsion. By exacting refinements in cycle arrangement, its losses are gradually approaching an irreducible minimum. The use of the binary vapour cycle seems to offer the principal hope for future improvement in cycle efficiency in cases where exhaust steam cannot be used for space heating or process needs.

At the other end of the efficiency scale, the non-condensing steam plant, in which the exhaust is wasted, is the last efficient of all prime movers. The justification for the existence of non-condensing steam plants lies in the fact that they are cheap, simple, reliable and compact. However, as the cost of fuels increases, the importance of high thermal efficiency will become greater, and the non-condensing steam engine, now surviving principally in the locomotive, will be relegated to a position of diminishing importance.

Two major sources of heat loss exist in the steam cycle. (See Figure 7.) They are the moderately hot gases emerging from the stack, and the relatively cold circulating water coming from the condenser. The stack loss is small in amount and, because of corrosion problems resulting from sulphur-bearing fuels, difficult to reduce. The condenser circulating water is too low in temperature to be of further use. Central station heat rates, now as low as 10,000 B.T.U. per kwh., will not be subject to major reduction until the latent heat in the exhaust steam can be used for industrial processes or space heating. It is in this field that the major reduction in utility fuel consumption must be expected.

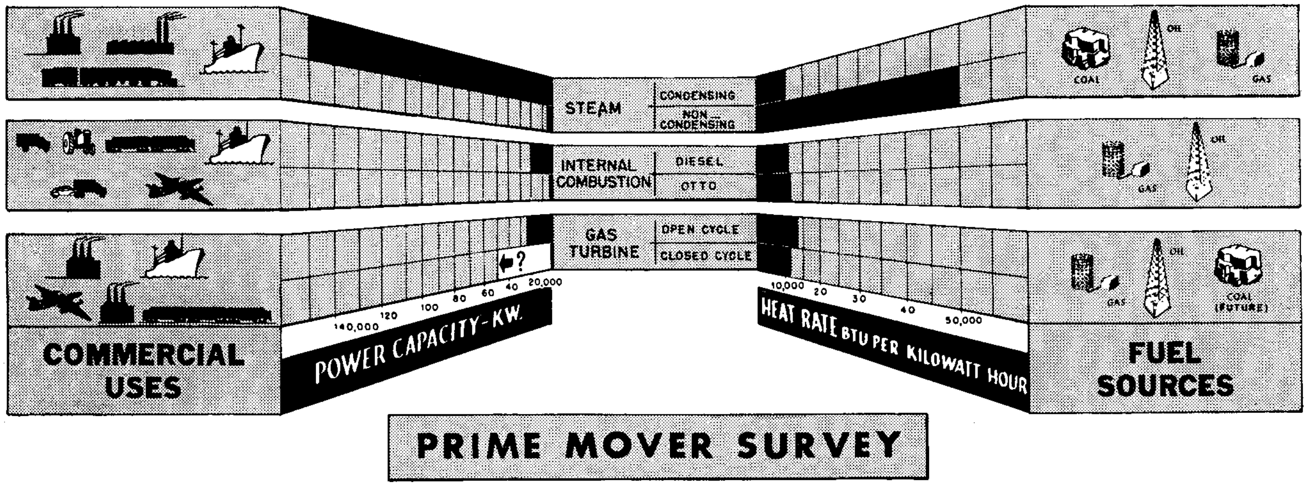
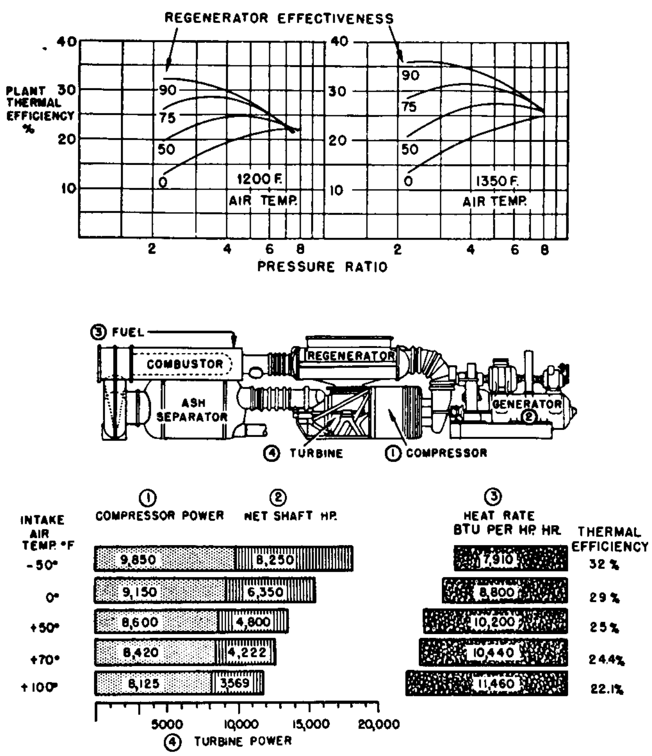


Figure 5. Prime mover survey

INTERNAL COMBUSTION ENGINE ADVANCES

Piston engines far surpass all other forms of prime movers both in numbers — in the United States alone, there are some 35 million motor vehicles — and in fuel consumption. Improvements in the over-all thermal efficiency of these small, load-factor plants are not likely to be rapid or significant, until the price of gasoline increases greatly. To paraphrase Ayres, (1), improved automotive-engine efficiencies are announced from time to time, but motorists have realized little increase in mileage, since the potential efficiency increase has been taken up in running more powerful engines under lower partial loads. It is quite probable that the principal development which will result from the increasing price of motor fuels will be the reduction in unit engine size.

Diesel engines will be more widely used in trucks and buses, because their higher thermal efficiency and their ability to use distillate fuel oil instead of gasoline will result in lower operating costs. The increasing demand for this type of fuel for domestic heating purposes, however, is likely to increase its price so that the present differential between gasoline and diesel fuel will be narrowed.



EFFECT OF AIR TEMPERATURE UPON
PERFORMANCE OF GAS TURBINE POWER PLANT
RATED AT 4,000 HP FOR 70 F. AIR

FIG. 6 GAS TURBINE CYCLE EFFICIENCIES

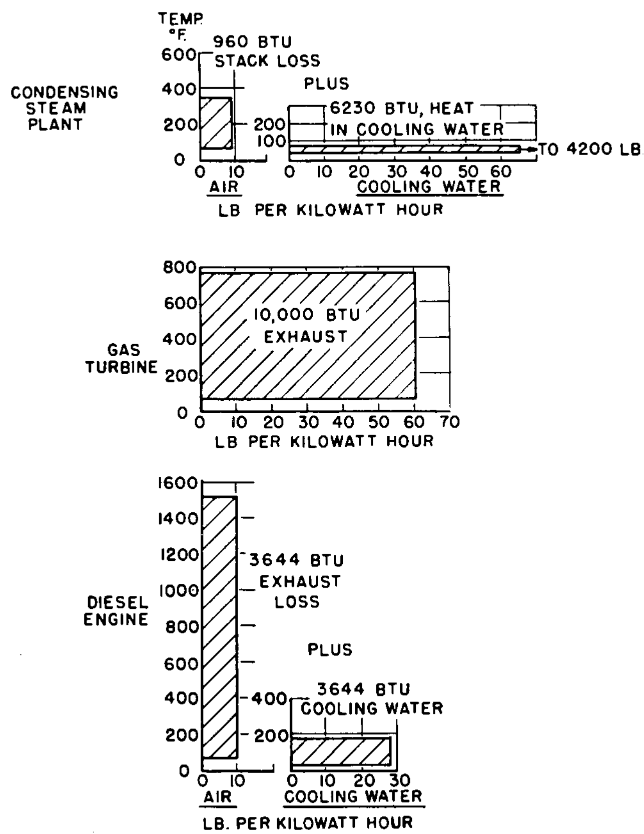


Figure 7. Prime mover waste heat analysis

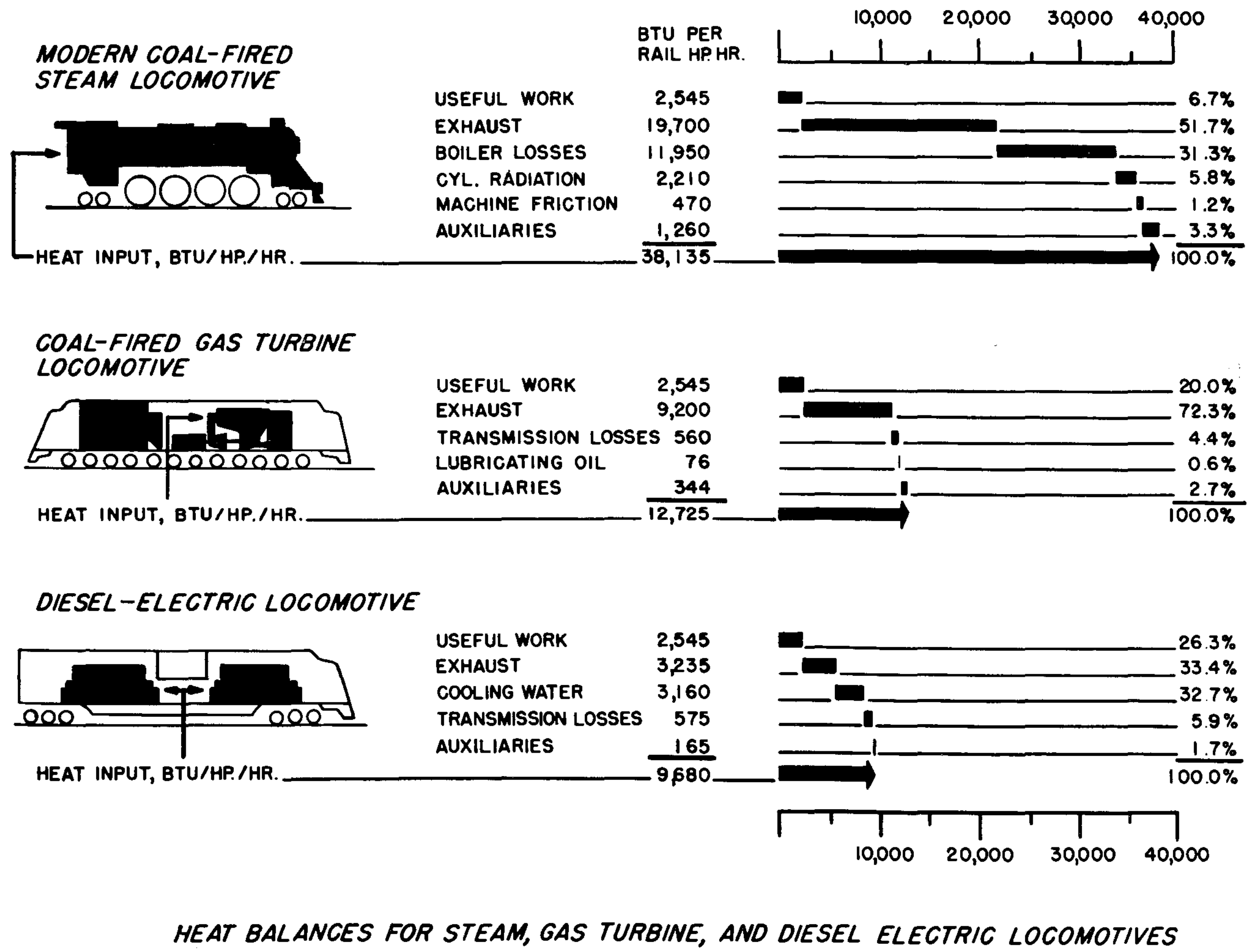


Figure 8. Locomotive heat balances

GAS TURBINE DEVELOPMENTS

The most recent addition to the family of prime movers is the continuous-combustion gas turbine. Although the concept is almost as old as the steam engine, practical gas-turbine power plants could not be constructed until the simultaneous introduction of highly efficient compressors and alloys which retain their strength at high temperatures.

The rapid development of the gas turbine in the past ten years has been due primarily to its suitability for high-speed aircraft propulsion. The invention by Whittle of the turbo-jet, followed by the practical application of this system in both Germany and Great Britain, made it necessary for these nations, and the United States as well, to devote prodigious efforts to perfecting the components necessary for successful aircraft propulsion. Even earlier, the Swiss firm of Brown Boveri had made strides of the greatest importance in developing both gas turbines and axial-flow air compressors. Their first applications, in the field of industrial processes and supercharged boilers, did not require highly efficient components. As the components were improved, however, the gas turbine rapidly assumed importance for both stationary and mobile power generation.

The gas turbine is of importance in fuel conservation, primarily because it appears to be the first power plant where relatively high thermal efficiency can be combined, in installations of moderate size, with fuel flexibility and freedom from water requirements. Piston engines are limited to fluid fuels, but the problems still remaining before coal can be used as gas-turbine fuel do not appear to be insurmountable.

The cycle efficiencies which can be attained today by simple gas turbine power plants are shown in Figure 6. The gas turbine has already invaded a realm of efficiency which hitherto had been the exclusive property of the diesel engine and condensing steam plants.

The gas turbine offers hope of fuel conservation, because it will allow the substitution of lower-grade fuels in services where now only the higher grades can be used. This is likely to be of particular significance in the railroad field. At the present time, the only way in which railroads can utilize heavy oil and coal is with steam locomotives. As Figure 8 indicates, the thermal efficiency of even the best non-condensing steam locomotives is very low, and their heat rate is at least 38,000 B.T.U. per rail-horsepower-hour. The diesel-electric locomotive makes a fourfold reduction in heat rate, but it requires a distillate fuel, the price of which is, in the United States, approaching 90 cents per million B.T.U. The gas-turbine locomotive, burning oil now but to be powered in the future by coal, can have a heat rate as low as 13,000 B.T.U. per horsepower-hour, and the cost of coal, at the present time, is approximately 20 cents per million B.T.U. for railroads with on-line mines.

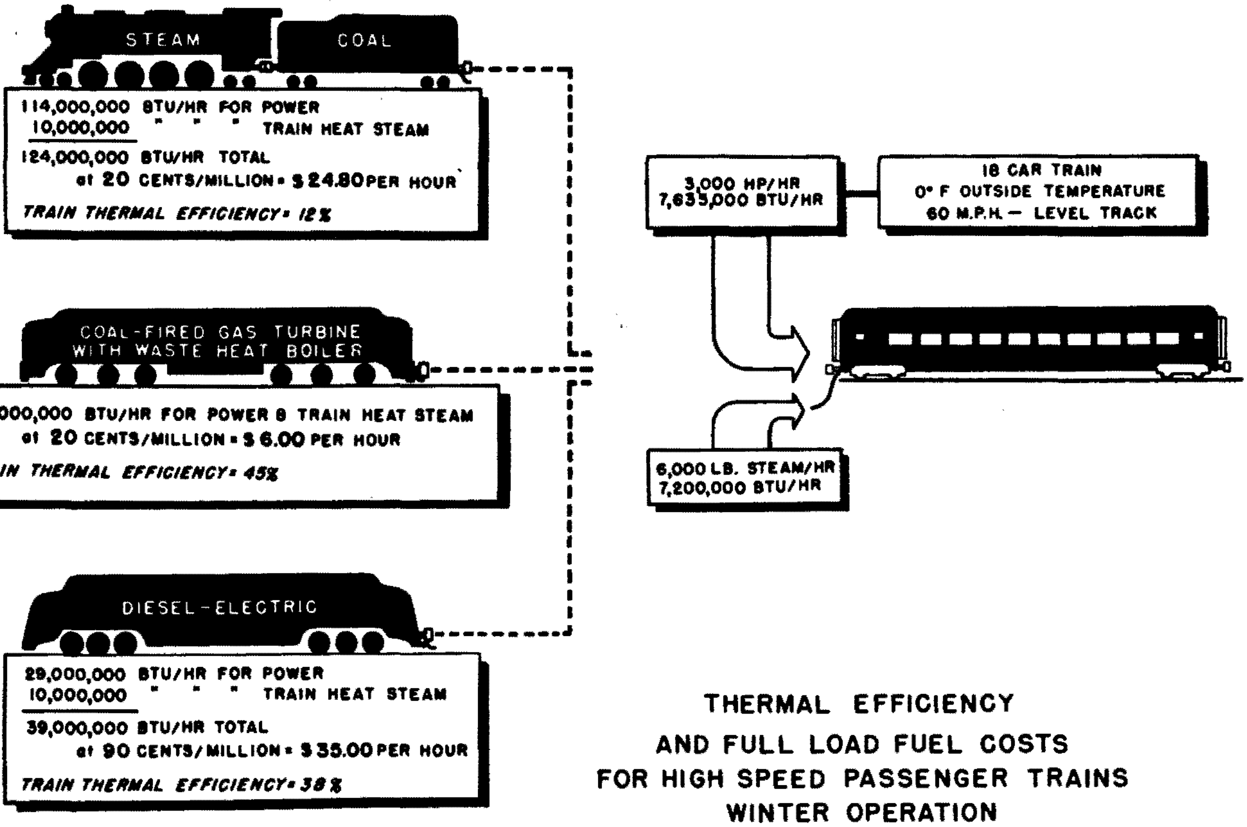


Figure 9. Train thermal efficiency

The ability of the gas turbine to turn its exhaust heat to useful purposes is also significant. As Figure 7 shows, the heat which is rejected by the gas turbine is in the form of relatively high temperature air, from which steam can be generated at pressures up to at least 100 lb. per sq. in. The diesel engine is so efficient that it rejects less heat than any other type of prime mover, except the mercury-vapour steam plant. The heat which is rejected is in the form of relatively low-temperature jacket-cooling water, and a small quantity of high-temperature exhaust gases. While certain applications exist for waste heat under these circumstances, they are by no means as large as those which exist for heat at the level produced by the gas turbine.

One particularly pertinent application for the utilization of waste heat is in the heating of passenger trains. Figure 9 shows that an 18-car train, travelling at 60 miles per hour through a 0 degrees F air temperature, requires almost as much energy for heating the cars as is used to pull the train. With a conventional steam locomotive, this heat can be readily supplied, although at the expense of burning additional coal. In the diesel-electric locomotive, it can be supplied only by the burning of high-grade fuel in small boilers. The gas turbine, if equipped with a waste-heat boiler, can produce this heat requirement without burning additional fuel. It is by similar processes of waste-heat recovery that major reductions in fuel consumption can be accomplished.

The outlook for the use of coal as gas-turbine fuel may be summarized as follows. One obvious way of accomplishing this purpose is by the gasification of the coal, and the burning of the gas in conventional turbines. In the United States, the General Electric Company is pursuing a programme of research in this direction. The Locomotive Development Committee of Bituminous Coal Research, Inc. has, for the past four years, been working on the problem of burning coal directly in the open-cycle gas turbine. While it is premature to say that an early solution may be expected to all of the problems involved in this project, it can be said that a full-size gas-turbine plant is now being erected at the Committee's Dunkirk, New York, laboratory. Full-scale combustion and ash-removal equipment has been developed as the result of a co-opèrative programme sponsored and financed by the Committee, and carried out at a number of locations in the United States.

It has been found that pulverized coal can be pressurized and burned under gas-turbine conditions, with efficiencies ranging from 93 per cent in all-metal combustors, to 99 per cent in refractory tubes. The removal of the solid residue from the

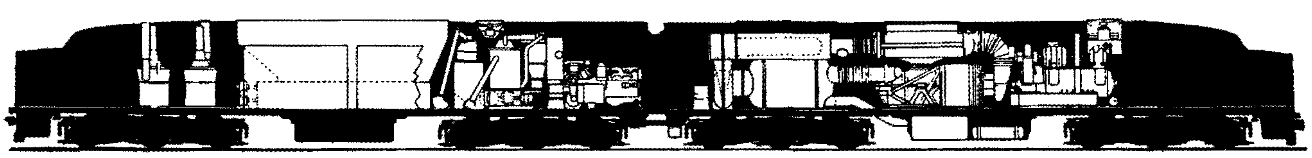


Figure 10. Proposed coal-burning gas turbine locomotive

products of combustion has been accomplished by the use of two-stage ash separation equipment. At the first stage, a louvre-type separator is used to remove the larger ash fragments; cyclone separators are used as a second stage to eliminate as far as possible the finer particles. The work now progressing at Dunkirk is intended to show whether the cleaning which can thus be accomplished is adequate for gas turbine operation. Major problems of control, ash disposal etc., still lie ahead, but the results accomplished up to the present time are encouraging.

The principal problem which is encountered in the use of either residual oil fuel or coal is, of course, the removal of ash from the heated air. Users of heavy oil have, under certain circumstances, encountered serious problems from ash deposits, and from sludge formation which has fouled the fuel distribution equipment. In the use of coal, the extremely abrasive nature of the ash, and the inflammability of the carbon which remains when combustion is not complete, have presented problems of the greatest difficulty. However, it appears possible to remove the larger fragments of ash as well as the finer constituents, and to overcome the problem of the burning of the residual carbon. The major problem which still confronts the Locomotive Development Committee is to determine the effect upon turbine blades of the ultra-fine ash which cannot be removed with conventional equipment. This same problem, however, confronts the users of heavy oils which contain high percentages of ash. Certain forms of oil ash apparently cause serious building up of solids on gas turbine components. Other types of oil ash, however, do not cause this trouble. Much wider experience is necessary before the cause and cure of this difficulty can be specified.

The closed-cycle gas turbine has frequently been suggested as a remedy for the ash disposal problem. A number of equally serious problems exist, however, in designing a closed-cycle plant. Large steam generators have often encountered difficulties from ash deposition, and this same problem will probably confront those who endeavour to burn heavy oil or coal in the air-heater section of closed-cycle gas turbines. A compromise exhaust-heated cycle is now under development in Canada and the United States. This cycle, in which all of the heat is transferred through a heat exchanger, and the turbine exhaust is used as the air supply to a combustion chamber, appears to be suited to relatively small applications, and it is not limited to fluid fuels.

In summary, it can be stated that the gas turbine appears to offer a major reduction in fuel consumption, because of its ability to use relatively low-grade fluid fuels in service for which high grade fuels have hitherto been necessary. When the problems associated with the burning of coal are solved, a tremendous stride will have been made in this direction. It will then be possible for railroads, one of the major users of fuel, to rely upon coal for most of their needs, rather than upon distillate fuels. The ability of the gas turbine to reject its heat in useful form, at a temperature level high enough to generate steam at useful pressures, is also of the greatest significance.

The major reduction in energy consumption which may be anticipated in the future will almost certainly come from wider utilization of exhaust heat which is now being wasted rather than from startling improvements in thermal efficiency as such. It is in this field that the gas turbine is likely to make a particularly important contribution.

Eventually, we must turn to the continuous sources of energy, of which solar heat is by far the most important. Hydrocarbons can be produced, at a price, in virtually unlimited quantities for the indefinite future from air and water, but the energy which will be required for this conversion, and for all other needs of mankind, must ultimately come again from the sun. When the secret of photosynthesis has been learned, we may well find that vegetation can become the source not only of food for mankind, but also for the fuel which he will need to maintain his standard of existence.

ACKNOWLEDGEMENTS

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Bibliography

. EUGENE P. AYRES, *Major Sources of Energy*, American Petroleum Institute, 1948.

2. ARNO C. FIELDNER, "Solid Fuel Reserves", *Oil and Gas Journal*, 17 March 1949

Progress in Thermal Power Generation

A. K. BUSHMAN

ABSTRACT

Increasing investment and operation costs have focused attention on improvement in generating station efficiency and design and construction changes which will give lower unit costs of power produced. The present status of various forms of thermal generation is outlined and the following methods of obtaining improved efficiency and lower production costs are cited as offering the most attractive possibilities.

1. The development of materials capable of withstanding higher temperatures at high pressures.

2. Further application of re-superheating cycles, particularly where fuel costs are high.

3. Modernization of present low-pressure, low-temperature steam plants by installation of new high-pressure, high-temperature boilers and superposed steam turbines.

4. Utilization of the efficient mercury-steam cycle where economically feasible, either in completely new installations or superposed on existing steam stations.

5. Reduction of unit cost of steam stations by use of one boiler per turbine, larger units, simplified auxiliary power systems, simplified buildings and, in some cases, outdoor installations.

6. Reduction of operating costs by use of centralized control, automatic controls and other labour-saving devices.

7. Further development of the gas turbine toward the use of higher temperatures, higher efficiency components and coal-burning which will make the gas turbine a very efficient prime mover and particularly attractive in areas where water is not plentiful.

8. Further utilization of steam stations capable of providing process steam required by industries and also generating power for distribution by public utilities.

INTRODUCTION

In recent years power system investment and fuel costs have increased rapidly without a corresponding increase in load factor. This fact, together with the ever-present resistance to higher rates emphasizes the need for continuing improvement in generating station efficiency to reduce the cost of power.

The largest part of the electrical energy supplied by central stations in the United States is generated by steam turbines. As of 1 November 1948, out of a total installed capacity of approximately 55 million kw., about 69 per cent was in steam stations, 28 per cent hydro-electric and less than 3 per cent internal combustion. New construction during the past three years and that planned for the next few years is at least 80 per cent in steam with a corresponding decrease in hydro-electric generation. This increased emphasis on thermal generation has resulted from the fact that many of the most readily available hydro sites which can be most economically utilized have already been developed and also because the cost of developing new hydro sites has greatly increased. Continued improvement in the efficiency of steam power plants has made power generation by this means more economical.

Of the power generated in thermal stations in 1948, approximately 77½ per cent was from coal, 8 per cent from oil and 14½ per cent from natural gas. The use of natural gas as a fuel has increased rapidly in recent years but is largely confined to the south-western part of the United States.

CONDENSING STEAM STATIONS

Practically all recent steam-turbine installations in central stations have been condensing units operating at back pressures of from 1 in. to 2½ in. Hg, depending upon the condenser cooling water available. The designers have made every effort to obtain greater efficiency and lower unit costs of power produced, in spite of higher construction and operating costs.

INCREASE IN STEAM TEMPERATURE AND PRESSURE

Maximum steam conditions at present in use commercially are 1050 degrees F. at a pressure of 2,000 lb. per sq. in. and 940 degrees F. at a pressure of 2,400 lb. per sq. in. Increases in efficiency obtainable by the use of higher temperatures and pressures are shown in the tables below.

Effect of increase in steam temperature at 1,250 lb. per sq. in.

From (degrees F)	*To (degrees F)*	*Per cent gain in heat rate over 900 degrees F*
900	950	1.8
950	1,000	1.45
1,000	1,050	1.33
1,050	1,100	1.25

Effect of increase in steam pressure at constant temperature

From lb. per sq. in.	*To lb. per sq. in.*	*Per cent gain in heat rate over 850 lb. per sq. in.*
850	1,050	1.6
1,050	1,250	1.3
1,250	1,450	1.0
1,450	1,650	0.9
1,650	1,850	0.6
1,850	2,050	0.5

From these data it is apparent that increases in pressure give a rapidly decreasing gain but that there is a still appreciable gain to be made by increasing steam temperatures above the present limit.

It therefore seems probable that in the future it will not be economical further to increase steam pressures, but with the continued urge for increased economy, steam temperatures will be increased as rapidly as new materials and manufacturing methods are developed.

USE OF RE-SUPERHEATING

The limitation on initial steam temperature and pressure imposed by available materials has led to the use of the re-superheating cycle to increase station efficiency. At an initial steam temperature of 1000 degrees F. with re-superheating to 1000 degrees F., the optimum gain in heat rate over a non-re-superheating cycle with the same initial conditions, is approximately 5.5 per cent to 6.5 per cent depending upon the initial steam pressure. Re-superheater pressures for optimum efficiency gain are approximately 150 lb. per sq. in. Hg for an initial pressure of 850 lb. per sq. in. Hg, and 225 lb. per sq. in. Hg for an initial pressure of 2,000 lb. per sq. in. Hg. However, in order to reduce the size of piping to the re-superheater and to obtain greater efficiency at reduced loads, re-superheater pressure of about 400 lb. per sq. in. Hg are commonly used and hence the gain in heat rate obtained at full load is reduced to about 4 to 5 per cent. This gain is approximately that which would be obtained by increasing the initial temperature of a non-re-superheating cycle by 150 degrees F.

Only about one-half of the gain in heat rate obtained by the use of re-superheating is pure thermodynamic gain, the remainder resulting from increased efficiency of the low-pressure turbine due to reduction of moisture in the last stages and the smaller exhaust loss due to the lower steam flow.

Even when metallurgical advances permit the use of higher temperatures, it is expected that the use of the re-superheating cycle will be retained particularly for applications where fuel costs and anticipated load factor are high. Simplicity and reliability of boilers and turbines for the re-superheating cycle, resulting from recent advances in design, will continue to make this cycle attractive wherever applicable.

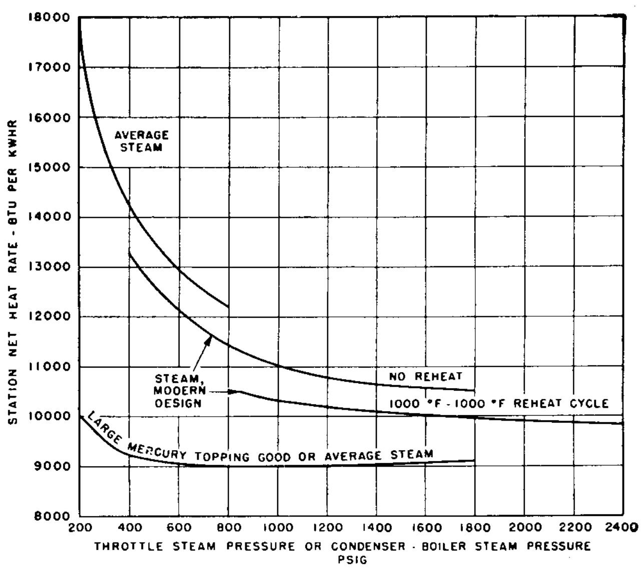

Figure 1. Typical station net heat rates for various thermal cycles.

USE OF REGENERATIVE FEEDWATER HEATING

By extracting steam at several stages of the turbine for boiler feedwater heating a very considerable gain in efficiency can be obtained, partly by the increased thermodynamic efficiency of the steam cycle and partly by the reduction in exhaust loss of the steam turbine due to reduction in condenser steam flow. Theoretically, the greater the number of extraction points, the greater the gain in thermal efficiency but at the expense of greater investment in heaters and piping. In practice it has been found economical to use from 4 to 6 stages of feedwater heating resulting in a decrease of from 10 per cent to 15 per cent in the non-extraction heat rate, depending on the initial steam conditions.

If feedwater heating by extraction steam is carried too far, the increased thermodynamic gain in the turbine cycle may be more than offset by the decrease in boiler efficiency caused by less heat being recovered by the economizer from the boiler flue gases.

USE OF HYDROGEN COOLING OF GENERATORS

The full load efficiency of a hydrogen-cooled generator is from 0.6 to 1.0 per cent better than that of an air-cooled generator of equal rating, and at part loads the improvement is considerably greater. The gain in efficiency makes hydrogen cooling economical for generators above 15,000 kw. at 3,600 r.p.m. and above 40,000 kw. at 1,800 r.p.m. Hydrogen cooling in addition to its effect on efficiency permits a reduction in weight and size of the generator for a given output, and gives reduced maintenance due to exclusion of dirt and moisture from the generator casing, besides eliminating corona damage and the fire hazard.

USE OF ELECTRICALLY-DRIVEN AUXILIARIES

A decrease in station heat-rate of at least 1 per cent has been obtained by using electric motors in place of steam turbines for driving station auxiliaries. Electric motors have also proved to be more reliable and lower in first cost since modern steam temperatures and pressures have greatly increased the cost of auxiliary turbines.

IMPROVEMENT IN BOILER EFFICIENCY

Improvements in detail design of boilers, the use of water walls, improved methods of firing, improved combustion control and the almost universal use of economizers or air heaters, or both, have all contributed to greatly increased boiler efficiency. Pulverized-coal-fired boilers are now being built with an efficiency of 88 to 90 per cent, based on the higher heating value of the fuel, or 91 to 93 per cent based on the lower heating value.

The only possibility of making any further large gain in boiler efficiency is in the reduction in temperature of the flue gases leaving the air preheater. This would require the use of an extremely large air preheater, made of materials capable of withstanding the corrosive effect of the flue gases, as it has not been found economically feasible to reduce the flue gas temperature below approximately 275 degrees F. with materials presently available. Development of new materials may make it practicable to go to lower temperatures with a resulting gain in boiler efficiency.

SUPERPOSED UNITS

The availability of steam turbines and boilers capable of operating at high temperatures and pressures has made it economical to apply superposed turbines to many existing low-pressure, low-temperature steam stations. Replacement of existing low-pressure boilers with new high-pressure boilers, supplying a non-condensing turbine which in turn supplies steam to existing low-pressure turbines, has made it possible to increase capacity at minimum cost with an over-all net heat-rate comparable to new high-pressure, high-temperature installations.

The boilers in many existing stations, operating at moderate temperatures and pressures will probably reach the end of their useful life while the turbines are still in good operating condition. It therefore can be expected that superposed units, operating at high temperatures and pressures, will be applied to these stations with excellent economic results.

TYPICAL STATION HEAT-RATES

Figure 1 shows typical but conservative net station heat-rates for various initial steam pressures. As steam pressure is increased, there is a corresponding increase in steam temperature from 575 degrees F. at 200 lb. per sq. in. Hg to 1000 degrees F. at 1,800 lb. per sq. in. Hg. All heat-rates shown on the curves are based on the higher heating value of the fuel.

As an example of the heat-rate that can be obtained by taking full advantage of all the recent advances in design, a large station is now under construction for initial steam conditions of 2,000 lb. per sq. in. Hg and 1050 degrees F. with reheat to 1000 degrees F., which is expected to have a net station heat-rate of 9,300 B.T.U. per kwh.

STEAM STATION COST

Obviously, the advantages of increased efficiency must be balanced against the increased investment required.

While the increased cost of turbines, boilers and piping as steam temperatures and pressures are raised is to some extent offset by the reduction in the size of the boiler, condenser, cooling water system, feedwater heating system and coal-handling equipment due to the lower steam-flow required by the more efficient station, nevertheless each successive increment in steam temperature and pressure results in a greater net increment in station cost. Thus the future trend in station economy must necessarily depend on future cost of high temperature and pressure materials and the price of fuel.

Re-superheating adds about 3 to 5 per cent to the cost of a station but with present high fuel prices can often be justified, for larger units, by the increased efficiency obtained.

The intial cost of steam generating stations can be reduced by the following design features:

(1) By using only one boiler for each turbine. Boilers are now available capable of supplying all the steam required by a 125,000-kw. turbine on a non-reheat cycle or a 150,000-kw. turbine on a reheat cycle, and it has been indicated that considerably larger boilers could be built if required. For a 100,000-kw. unit, using one boiler instead of two, will reduce the station cost by $ 5 to $ 10 per kw.

(2) By using larger turbine-generator units. Because of the reduced investment per installed kw., including both equipment and buildings, the lower operating cost and the slight gain in efficiency, there has been a continued demand for an increase in the size of units. The largest 1,800-r.p.m. set in operation, or being considered at present, has a capability of approximately 165,000 kw. The lower cost of high-speed turbines and the problems associated with designing the larger diameter 1,800-r.p.m. turbines for higher pressures and temperatures has resulted in a demand for larger 3,600 r.p.m. machines. The largest 3,600-r.p.m. set being designed has a maximum turbine capability of 121,000 kw. and a generator rating of approximately 150,000 kva., 0.85 power factor at 15 lb. per sq. in. hydrogen pressure. By taking full advantage of the steam flow permitted by a 3,600-r.p.m. tandem compound, triple flow turbine, a maximum turbine capability of 150,000 kw. can be realized. Developments that are well along will permit a corresponding increase in rating of 3,600-r.p.m. generators.

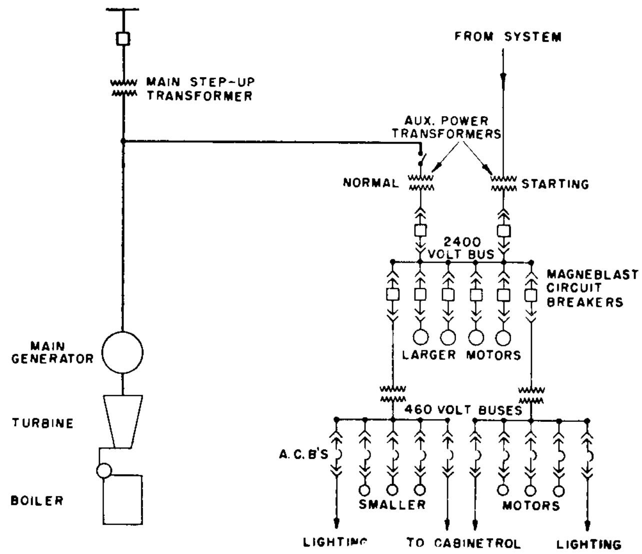

Figure 2. One line diagram of generating unit showing main power connexions and unit type radial auxiliary power system.

A combination of units already available, operated as cross-compound sets, makes available single blocks of generation that are larger than can be economically justified on present day systems.

(3) By simplification of the steam and electrical layout of the station. Important cost reduction can be obtained by use of the unit system for both steam and electrical connexions with elimination of all steam and electrical interconnexion between units, by use of a simple radial system of auxiliary power supply (Figure 2) and by elimination of unnecessary features in buildings, such as dividing walls between boilers and turbines.

(4) By placing a large part of the equipment outdoors, where climate permits, saving amounting to $3 to $10 per kw. can be realized.

Operating cost: Recent rapid increases in the cost of operating labour in steam stations has directed more attention to designing stations which can be operated by less personnel. One of the outstanding developments has been the introduction of centralized control rooms (Figure 3) from which several turbines and boilers can be controlled by a few men. Other features which reduce operating labour are automatic combustion control, supervisory instruments, automatic voltage regulators, automatic load control, hydraulic handling of ashes and automatic soot blowing. The trend to larger turbines with only one boiler per turbine has further decreased operating labour costs.

MERCURY-STEAM PLANTS

Binary cycles, particularly the mercury-steam cycle (Figure 4) offer possibilities of obtaining greater plant efficiency than is possible with straight steam cycles. Figure 1 showing mercury-steam net station heat-rates compared with straight steam cycles, indicates that the mercury cycle shows gains of from 1,000 to 3,000 B.T.U. per kwh.

In many cases, mercury turbines can be superposed on existing steam cycles to obtain increased capacity with a large reduction in over-all station heat-rate. The following table, comparing mercury topping with steam topping using 2,400 lb.

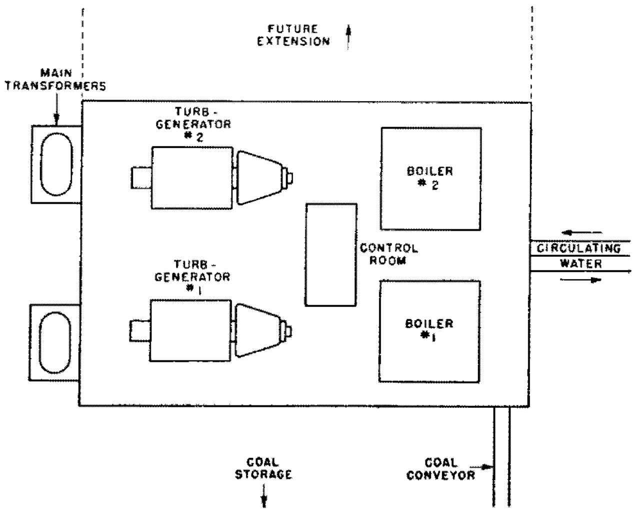

Figure 3. Plan view of a generating station showing location of major equipment and control room.

per sq. in. steam, shows the amounts of topping power obtainable per kw. of existing low-pressure condensing plant capacity and the gain in heat-rate by using mercury topping instead of steam topping.

Low-pressure steam Lb. per sq. in. Hg.	*Topping power per kw. of low pressure capacity*		*B.T.U. per kw-hr. gain in heat-rate over steam by using mercury*
	Using 2,400 lb. per sq. in. Hg steam	*Using mercury*	
200	0.65	0.90	1,100
400	0.40	0.78	1,800
600	0.25	0.65	1,800
800	0.14	0.55	1,800

Mercury-cycle installations are most attractive where fuel cost and load factor are high or where there is a limited amount of cooling water available. In general, mercury-steam plants may be expected to have a slightly higher first cost than a straight steam plant of the same capacity, however, since the mercury cycle makes possible large gains in efficiency over a straight steam cycle, particularly in the medium and small size plants, it will undoubtedly receive increasing attention.

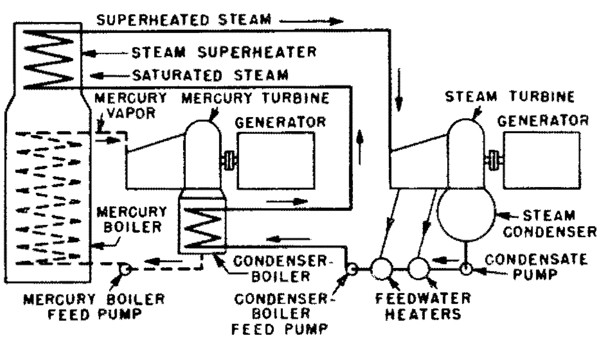

Figure 4. Schematic diagram of the mercury-steam cycle.

GAS TURBINES

The gas turbine is rapidly reaching a state of development where it can soon be considered a competitor with the older established prime movers in the field of power generation. Simple-cycle gas turbines with no exhaust heat recovery can be built with a thermal efficiency of 17 per cent and more complex units using intercooling between stages of compression and exhaust heat recovery in the gas-turbine cycle can be built with a thermal efficiency of at least 28 per cent (Figure 5). These units can be operated on either heavy fuel oil or natural gas and compare favourably in efficiency with the smaller sizes of steam turbines. It is reasonable to expect that, as new materials capable of withstanding higher temperatures become available and with further refinements in the design of compressors and turbines, the efficiency of the gas turbine may be increased to the point where it is at least as efficient as the largest high-pressure, high-temperature steam turbines.

It is apparent that the development of a satisfactory coal-burning gas turbine would greatly increase the economic field of application of this prime mover and this matter is receiving considerable attention at present. At least two methods of burning coal are being investigated; first, direct combustion of pulverized coal with the subsequent removal of the ash by mechanical or other means before the hot gases pass through the turbine and, second, the use of a coal-fired gas producer, operating under pressure, with the coal gas thus obtained being burned in the gas-turbine combustion chambers. It can be expected that either one or both of these methods will be in successful operation within the next few years.

In certain cases the gas turbine can be used to advantage in conjunction with a steam plant by utilizing the exhaust heat from the gas turbine for boiler feedwater heating or direct production of steam.

DIESEL AND GAS ENGINES

The maximum economical size of diesel and gas engines is of the order of 5,000 kw., hence these prime movers are usually applied only in small central station installations. In this field they may prove more economical than comparable sizes of steam stations due to their lower first cost, higher efficiency and smaller cooling-water requirements.

Where large amounts of power are required, however, the multiplicity of units in a diesel installation makes it uneconomical as compared with a steam station, both on the basis of first cost and of operating and maintenance cost. Also the present high cost of diesel oil detracts from the attractiveness of this prime mover.

While the efficiency of diesel and gas engines will probably be somewhat improved by further development, the gas turbine appears to offer greater possibilities for future gains so that with its adaptability to cheaper forms of fuel it will probably become a serious competitor of the diesel engine in the small power generation field.

ATOMIC POWER

Nuclear energy, or atomic energy as it is commonly called, cannot be eliminated from a discussion of power generation in the future. Cost data are not available, however, and commercial installations of this type are still some years ahead. It seems sufficient therefore, to point out that at present development work is based on using the heat of nuclear fission in conventional turbines, either using straight steam or binary cycles, and therefore any advances in the art of steam station design or in turbine and generator design will apply directly to nuclear power plants.

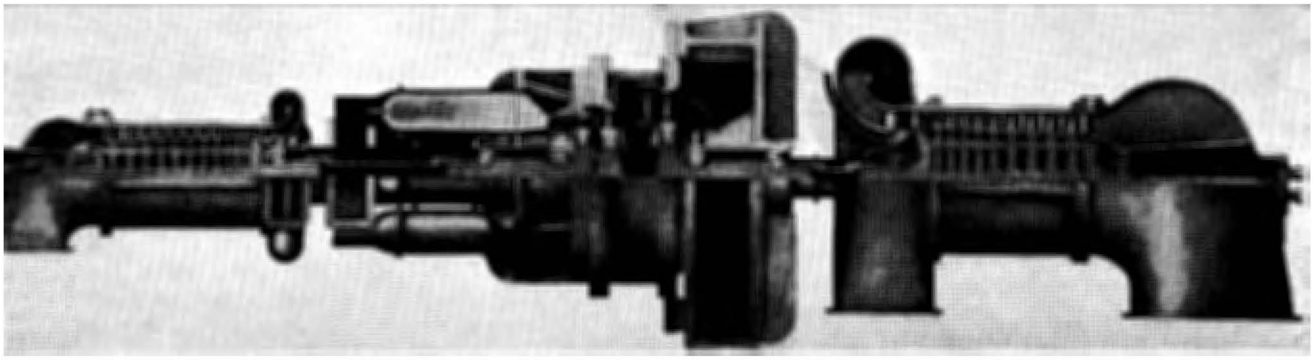

Figure 5. Longitudinal semi-section of gas turbine for 5,000 Kw. turbine-generation set.

BY-PRODUCT POWER FROM PROCESS STEAM

Industries often require large quantities of process steam in addition to electrical power. Usually this process steam is provided either by separate boiler plants or by using higher pressure boilers and non-condensing or automatic extraction turbines generating the electrical power required.

Electrical power produced as a by-product of process steam is generated essentially at boiler efficiency and consequently at a heat-rate of approximately 4,200 to 4,500 B.T.U. per kwh. as compared with 10,000 to 14,000 B.T.U. per kwh. in a condensing steam plant. The major loss in producing by-product electrical power occurs in the boiler but there are also minor losses such as electrical, mechanical and radiation losses in the turbine-generator set. The amount of electrical power that can be generated for a fixed quantity of process steam can be greatly increased by using higher initial steam pressures or by using the mercury-steam cycle.

Another method of producing process steam is to utilize the hot exhaust gases from a gas turbine in a waste-heat boiler. Simple-cycle gas turbines with no heat recovery in the cycle operate with higher exhaust gas temperatures than do the higher-efficiency gas turbines in which some of the exhaust heat is recovered, and are therefore capable of producing more steam. The heat-rate at which by-product electrical power can be produced in a gas turbine varies, depending on the extent to which it is economically feasible to lower the exhaust gas temperature and, while not as low as that obtained by steam or mercury turbines, nevertheless is very attractive compared to condensing steam plants.

The low heat-rate at which power can be derived from process steam opens up a broad but often unappreciated field foi co-operation between industries and public utilities in the production of steam and electricity with the further advantages of reduced total investment and lower operating costs.

CONCLUSION

An attempt has been made to outline the present status of various forms of thermal generation and to indicate some of the developments that contribute to higher efficiency, lower first cost and lower operating costs. In brief, the following are some of the factors that will result in the still more efficient production of electrical power at lower cost:

(1) The development of materials capable of withstanding higher temperatures at high pressures.

(2) Further application of re-superheating cycles, particularly where fuel costs are high.

(3) Modernization of present low-pressure, low-temperature steam plants by installation of new high-pressure, high-temperature boilers and superposed steam turbines.

(4) Utilization of the efficient mercury-steam cycle where economically feasible, either in completely new installations or superposed on existing steam stations.

(5) Reduction of unit cost of steam stations by use of one boiler per turbine, larger units, simplified auxiliary power systems, simplified buildings and, in some cases, outdoor installations.

(6) Reduction of operating costs by use of centralized control, automatic controls and other labour saving devices.

(7) Further development of the gas turbine toward the use of higher temperatures, higher efficiency components and coal burning which will make the gas turbine a very efficient prime mover and particularly attractive in areas where water is not plentiful.

(8) Further utilization of steam stations capable of providing process steam required by industries and also generating power for distribution by public utilities.

Bibliography

G. B. Warren and P. H. Knowlton, "Relative Engine Efficiencies Realizable from Large Modern Steam-Turbine Generator Units", *Transactions A.S.M.E.*, 1940.

G. B. Warren, "Progress in Design and Performance of Modern Large Steam Turbines for Generator Drive", *op. cit.*, vol. 63 (1941), pages 49–79.

J. K. Salisbury, "The Steam Turbine Regenerative Cycle—An Analytical Approach", *ibid.*, 1941.

E. E. Parker, "Steam Turbines for Re-Superheat Cycle", Presented at Annual Meeting A.S.M.E., New York, December 1948.

E. E. Harris and A. O. White, "Developments in Re-Superheating in Steam Power Plants", *ibid.*

D. S. Snell and L. P. Grobel, "Nine Years Operating Experience with Hydrogen Cooled Generators", *Power Plant Engineering*, May–June 1947.

W. H. Rowand, A. E. Raynor and F. X. Gilg, "High Pressure Boilers with Reheaters", Presented at Annual Meeting A.S.M.E., New York, December 1948.

W. S. Patterson, "Modern Reheat Boilers", *ibid.*

Martin Frisch, "Steam Generating Equipment for Re-Superheating Cycles", *ibid.*

Philip Sporn, "The 2000 PSIG, 1050° F. and 1000° F. Reheat Cycle at Philip Sporn and Twin Branch Steam Electric Stations", *Transactions* A.S.M.E., vol. 70, no. 4, pages 287–294.

J. B. McClure and S. I. Whittlesey, "Power Systems for Auxiliary Drives in Steam Electric Stations", *Transactions* A.I.E.E., vol. 14 (1945), pages 844–851.

A. R. Smith and E. S. Thompson, "The Mercury Vapor Process", *Transactions* A.S.M.E., vol. 64 (1942), pages 625–646.

C. G. Adams and J. B. McClure, "For Greater Topping Power Use Efficient Mercury-Steam Cycle", *Power*, January 1947.

H. N. HACKETT, "Mercury for the Generation of Light, Heat and Power", *Transactions* A.S.M.E., vol. 64 (1942), pages 647–656.

ALAN HOWARD, "Design Features of a 4800 hp. Locomotive Gas Turbine Power Plant", *Mechanical Engineering*, vol. 70 (April 1948), pages 301–6.

ALAN HOWARD and C. J. WALKER, "A 5000 kw. Gas Turbine for Power Generation", Presented at Annual Meeting, A.S.M.E., New York, December 1948.

G. R. FUSNER, "The Gas Turbine with a Waste Heat Boiler", *Mechanical Engineering*, June 1948, pages 515–518.

Future Outlook on Fuel Utilization[1]

F. PICARD

ABSTRACT

A process of evolution is taking place in the techniques of fuel utilization. The choice of fuels and engines is governed by the performance desired, the efficiency of the transformation process from the point of view of both power output and cost and, lastly, facility of use.

Developments in the spark ignition engine, which up to now have been aimed chiefly at performance, will now be directed primarily towards increasing efficiency by improving the anti-knock properties of fuel, and engine design. The aircraft industry has extracted the maximum performance from this type of engine, at the cost of reducing the efficiency of fuel production.

Turbo-jet engines have developed rapidly because they improved high-altitude performance and used a simple fuel-oil obtained by simple methods. Both techniques, however, will continue to be used in aviation in the future.

The trend in compression ignition engine design has been chiefly towards improved efficiency; their high weight-to-power ratio renders such engines unsuitable for the traction of light vehicles. Their development is assured wherever they compete with steam engines.

The gas turbine which is arousing great hopes has not yet been put to much industrial use. The prospects for its development depend chiefly on the operation costs realized.

The steam turbine is still the engine for high powers, heavy oil tending to take the place of coal for heating boilers where the plants are remote from the mining centres.

The over-all trend of industry is towards the utilization of the heaviest components of petroleum.

GENERAL

Utilization techniques are characterized by the variety of fuels at the disposal of industry (gasoline, petroleum, diesel oil, fuel oil, benzol, alcohols, acetyles, natural gases, gas derived from distillation and gasification) and by the variety of engines transforming their potential energy into mechanical energy.

A double choice has therefore to be made.

For this purpose three basic factors have to be considered: performance, efficiency, and facility of use.

The *performance factor* is essential for all means of transport. The relative weight of the engine is more important in the case of a land vehicle than in the case of a ship, and still more important in the case of an aircraft than in that of an automobile. The weight-to-power ratio of the engine expressed in kilogrammes per horse-power will be the decisive factor, the most suitable fuel corresponding to the minimum of that ratio.

However, in the case of engines which can run for a long period without refueling, the governing factor should be not the weight of the engine alone, but the sum of the weight-to-power ratio and the specific consumption (g./h.p.h.) representing the fuel transformation efficiency.

This factor, however, is of no account in the case of fixed installations.

The *efficiency factor* is more complicated and brings in various conflicting scientific and economic considerations.

The need to economize natural resources necessitates the minimum consumption of raw materials to obtain the desired result, displacement of a ton-kilometre or production of a kilowatt-hour. The efficiency factor is purely physical in character and its unit of measurement is the calorie. This *total efficiency* is the product of our component efficiences (Figure 1):

Production efficiency, which depends on transformation techniques, expresses the number of raw material calories required to obtain a given number of fuel calories. It thus reflects all advances made in the field of manufacture.

Transport efficiency where high-power fuels of high calorific efficiency clearly have the advantage. The farther away the utilization points are, geographically, from the centres of production, the more necessary it will be to choose these fuels.

Efficiency of transformation:

Of the fuel's potential energy into *mechanical energy,* reflecting advances made in engine design and construction;

Of mechanical energy available on the crank-shaft into *movement* of the transportation unit or into *electric power* in the case of a power plant.

The user's interest may not coincide with the economical use of natural resources. For industrialists and businessmen the dominant factor is that of price, which is equally essential from the economic point of view because of its influence on the general price level. Computation of this cost price is a complicated operation inasmuch as it includes not only technical and financial elements but also human elements such as wages and overhead expenses. The operation costs of an engine therefore include the following:

Fuel cost which depends upon the cost of production of the fuel plus taxation, the initial cost being added to by Governments in varying proportions;

Depreciation of equipments and interest on capital invested; operational labour costs: wages and social charges;

Maintenance of equipment including both wages and materials.

These factors will vary in relative importance according to the economic conditions of the country under consideration

[1] Original text: French.

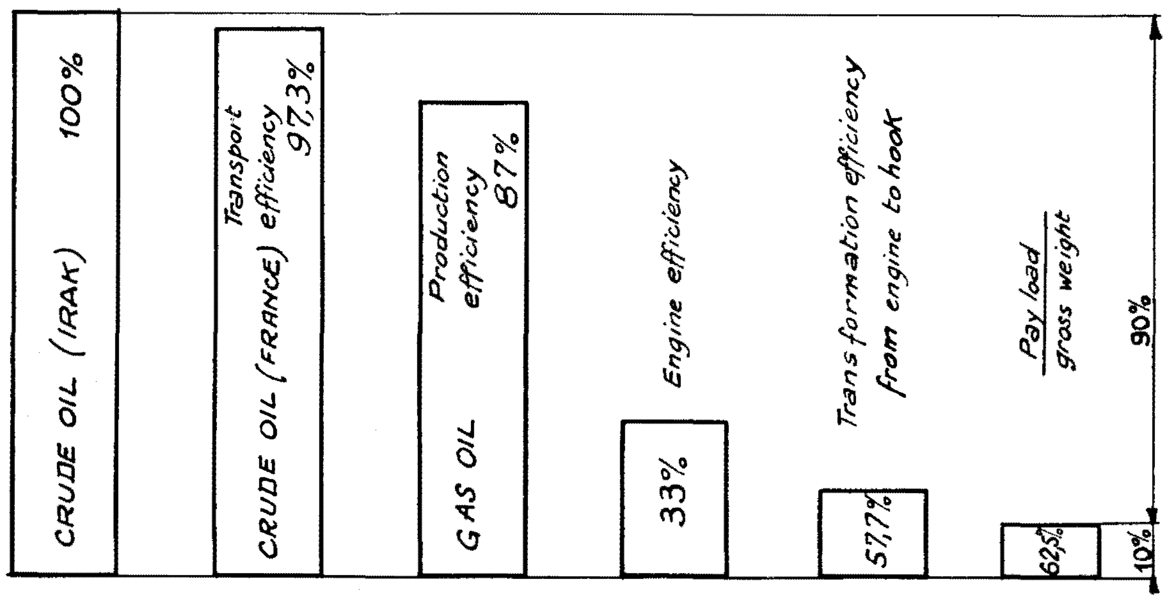

Fig.1 - *Total efficiency of diesel traction on railroads*.

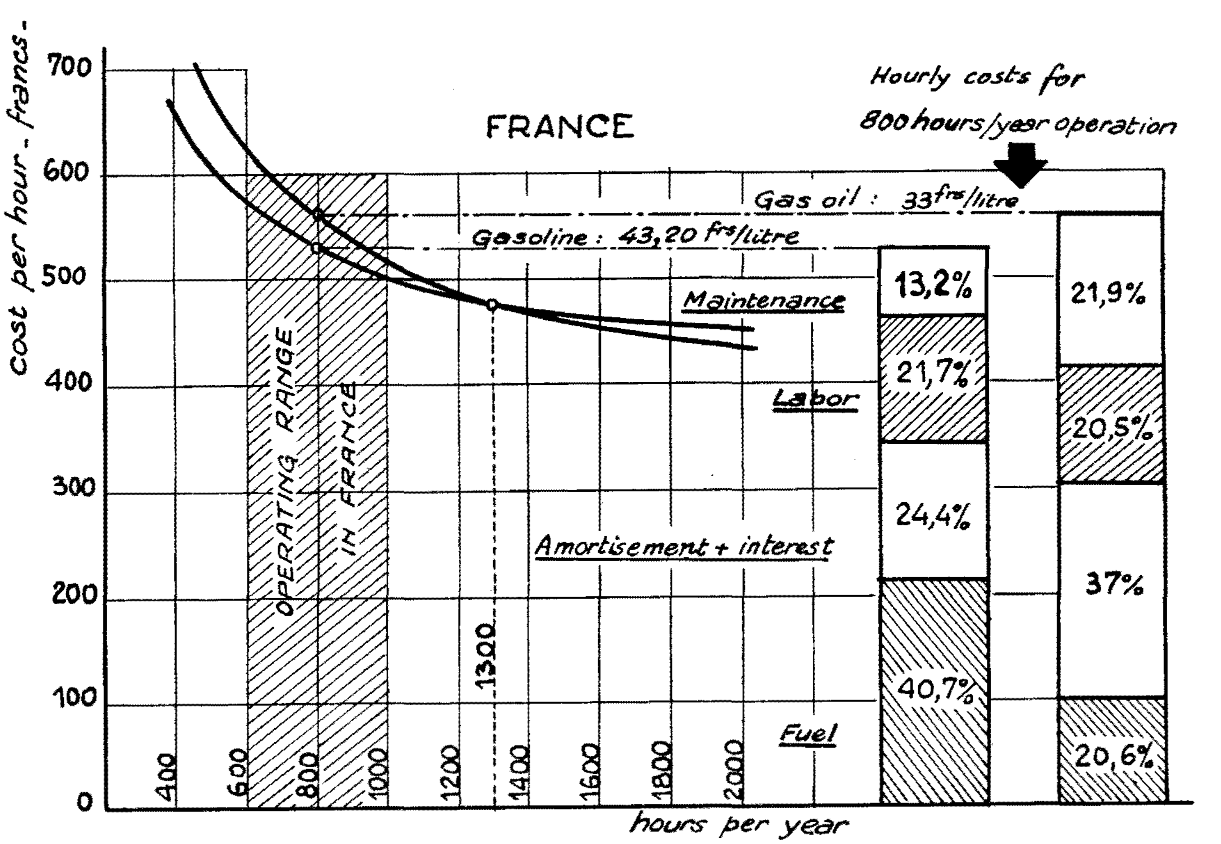

Fig.2 - *Compared operation costs per hour of diesel and gasoline engined tractors*

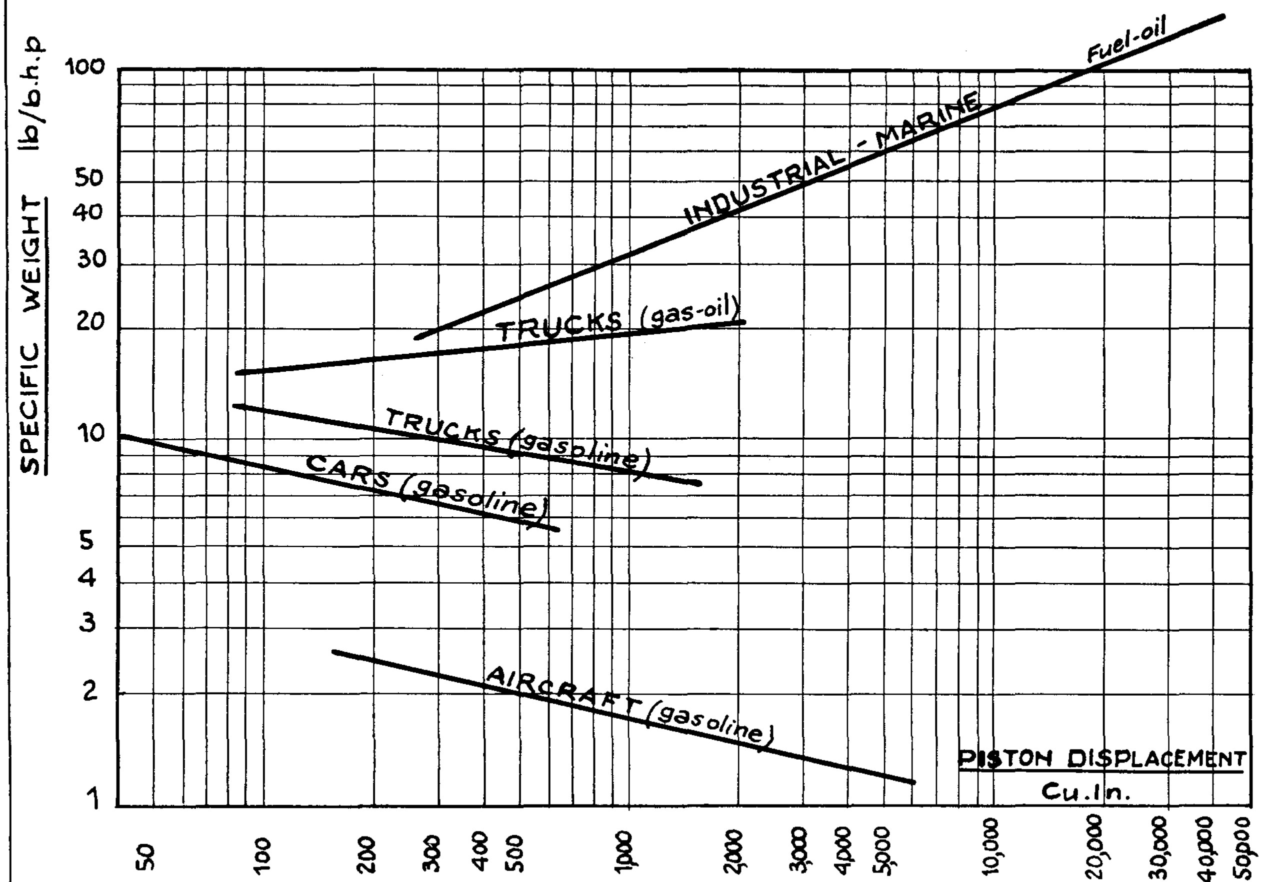

Fig. 3 – *SPECIFIC WEIGHT OF ENGINES*

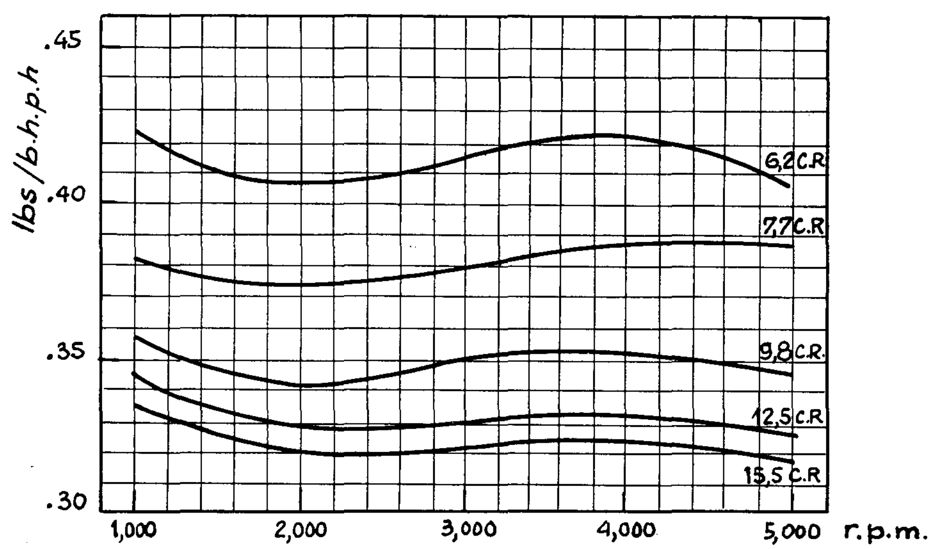

Fig. 4 – *SPECIFIC CONSUMPTION OF A HIGH-COMPRESSION SINGLE CYLINDER ENGINE (C.F. Kettering (3).)*

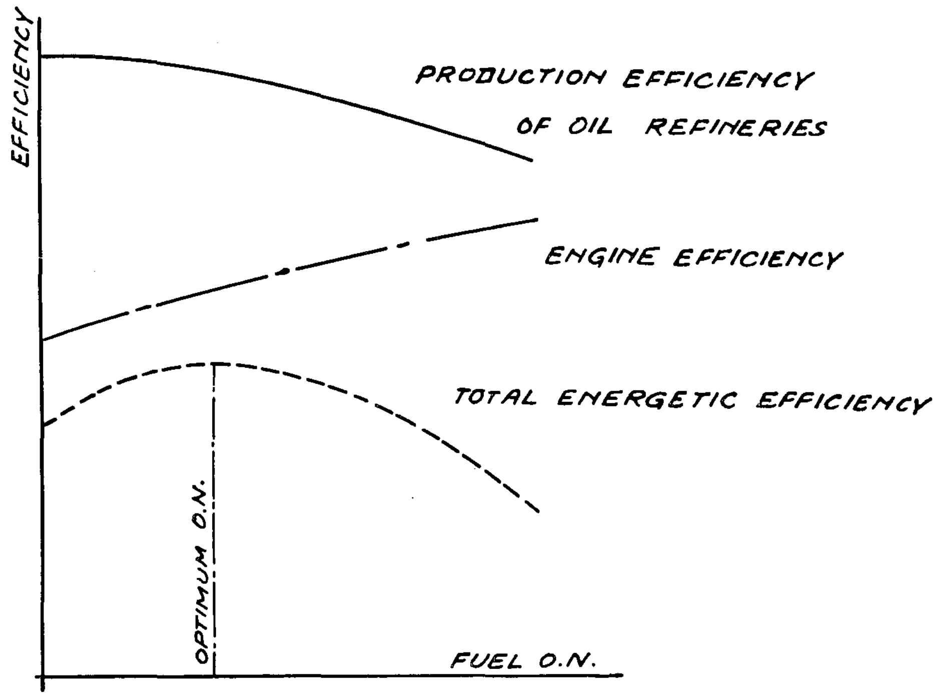

Fig. 5 - RESEARCH OF OPTIMUM O.N.

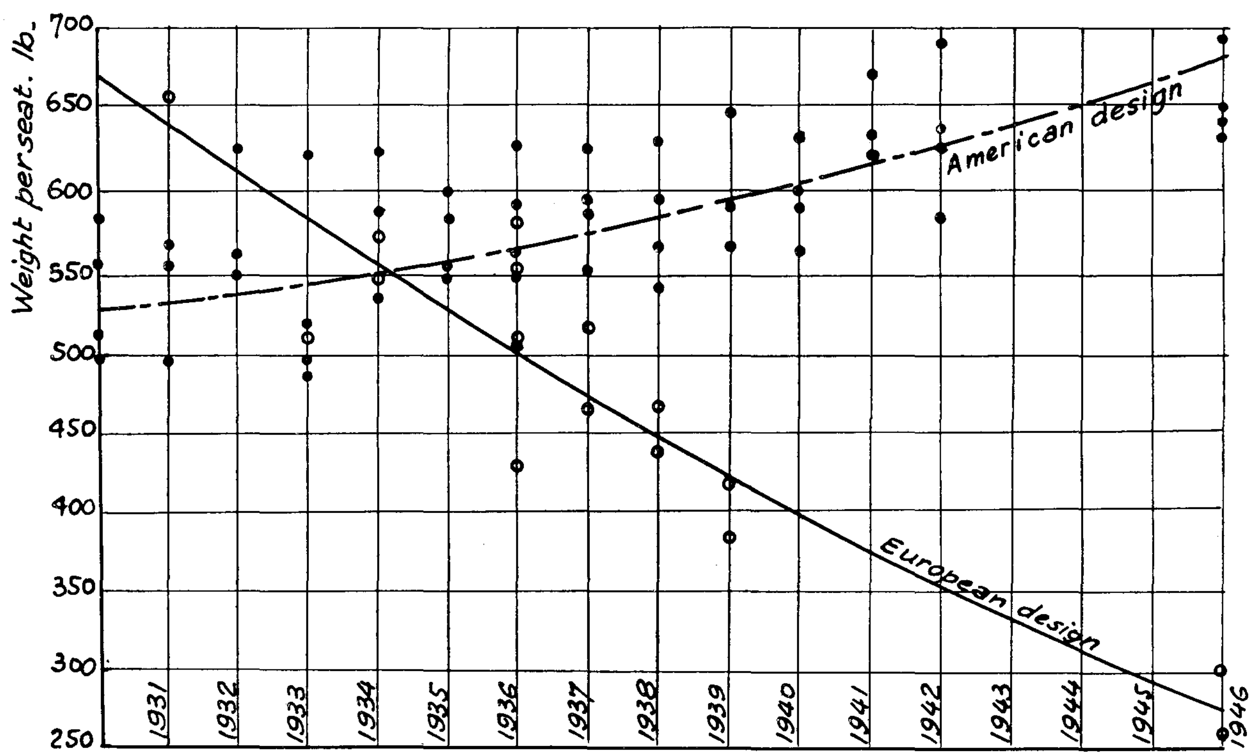

Fig. 6 - Trend of car weights.

and may decide the choice. Figure 2 shows for example that in France, despite the prices prevailing, gasoline is more economical than heavy oil for agricultural tractors operated less than 1,300 hours per year, owing to the depreciation and maintenance factors.

Facility of use, which it is difficult to evaluate, takes into account the ease with which the fuel can be stored and handled, the starting, running and operation of the engine, and the sounds and smells which may result from its use.

Let us examine fuels and engines from these various aspects.

UTILIZATION IN RELATION TO THE ENGINE

1. *The spark-ignition engine,* the most widely used (58 million in the world representing approximately 5½ milliards horse-power) has as its main advantage a low weight-to-power ratio (Figure 3):

0.500 to 1 kg./h.p., for aircraft, according to power.

2.500 to 4.500 kg./h.p., for passenger cars.

3.500 to 5.500 kg./h.p., for commercial vehicles.

The transformation efficiency varies:

In the case of aircraft, between 24 and 32 per cent (180 to 240 g./h.p.h. of gasoline).

In the case of automobiles, between 21.5 and 26 per cent (220 to 270 g./h.p.h. of gasoline).

Table 1 shows that gasoline gives the highest use efficiency.

Despite the very large amount of attention already devoted to improving both the efficiency and the design of this engine, further progress is anticipated:

Improved thermo-dynamic efficiency will be obtained by increasing the compression ratio in the following ways:

Improvement in the *anti-knock properties* of the fuel (2, 3)[2] represented at present by the octane number (Figure 4). As this cannot be achieved by adding tetra-ethyl-lead in quantities much larger than those used hitherto, the trend is towards manufacturing processes which allow of the selection of the hydrocarbon components of the fuel (4, 5). The aim is not the highest octane number but the maximum product of production efficiency and utilization efficiency (6) (Figure 5).

Improved engine design (7) so as to obtain the highest possible compression ratio for a given fuel. With this object, research is being made into:

Internal cylinder cooling by the injection of water or alcohol, as this vaporization causes good heat absorption (8).

Replacement of the carburation process by injection of the fuel, improving distribution among the cylinders and restricting hydrocarbon transformation during compression (9, 10).

Adaptation of ignition timing to the speed of rotation and to the load, so as to obtain minimum consumption at each utilization point (11).

In addition to these engine studies, research is being made into the utilization of the energy produced so as to:

Cut down the passive resistances of the engine,

Reduce friction by lightening the weight of land vehicles as much as possible (6) (Figure 6),

Improve the streamlining of aircraft, cars and ships to reduce resistance (6) (Figure 7).

Increase transmission efficiency and improve adaptation of engines to the power needed for propulsion, by the use of hydraulic transformers and automatic transmissions.

All these are improvements which should allow of a reduction in the fuel consumption required to obtain the desired result.

2. *Turbo-jet engines.* These considerations do not apply to the aircraft industry which, during the Second World War, exhausted all the technical possibilities of obtaining maximum performances: two-stage compressor supercharging, variable pitch propellors, fuels with better anti-knock properties than iso-octane and so on. As the efficiency factor has become a secondary consideration, the production of the special fuels requires a large consumption of crude oil and the installation of expensive plant.

Since propellor efficiency is considerably reduced at high altitudes and speeds (12) (Figure 8), turbo-jet engines have rapidly come to the front in this field because of their theoretical advantages. Today a jet plane flying at 800 km./h. at a height of 6,000 metres consumes only 600 grammes of oil per kilometre while a piston-engined aircraft would, in the same conditions, consume 1,200 g./km. of 120/130 gasoline, the weight of the engine being 137 g./h.p. in the first case as against 600 g./h.p. in the second case.

Figure 9 (13) shows the effect of the speed of the machine on efficiency; it does not, however, bring out the fact that the fuel used in turbo-jet engines is a common type of oil obtained by simple, high-production methods.

Tests made with turboprop engines are also very encouraging (21) for speeds between 500 and 900 km./h. and long-distance flights. Certain researches even suggest that in this field their operation costs will be less than that of a piston-engine, while passengers will appreciate the absence of vibration and noise.

The relative development of the three techniques is bound up with that of trans-continental and trans-oceanic air transport and military requirements, which depend far more on political and psychological than on technical conditions; it is therefore difficult to make any predictions.

3. *The compression-ignition engine,* less common than the spark-ignition engine (1,400,000 with 100 million h.p.) covers a wider power range extending from a few horse-power in the case of industrial single-cylinder engines to 30,000 h.p. in the case of marine engines.

Its particular features are its high efficiency — 29 to 37 per cent (160 to 200 g./h.p.h.) — and its relatively high weight-to-power ratio (from 6 to 60 kg./h.p.).

As the only method of increasing the speed of rotation is a considerable reduction in the cylinder bore (Figure 10), and as the number of cylinders is limited by the torque vibrations of the crankshaft, high powers require wide bores and low running-speeds which rapidly increases the weight-to-power ratio (14, 15) (Figure 2).

Despite the fuel saving it permits, its use in motor vehicles is limited by the high maintenance and depreciation expenses due to the cost of construction. Figure 1 shows that in France it is only profitable for medium agricultural tractors when their annual utilization exceeds the normal and Figure 11 shows that in the case of a commercial vehicle carrying a load of four tons, over 14,000 km. per year must be run before the compression-ignition engine becomes preferable to the gasoline engine (16). This is not so in the case of marine engines, vehicles on rails (17) (Figure 12) and small power plants where the amount of power involved brings it into competition with steam. Its efficiency and running costs are definitely superior. However, in the case of warships in which low weight-to-power ratios are

[2] The figures in parentheses refer to works listed in the bibliography.

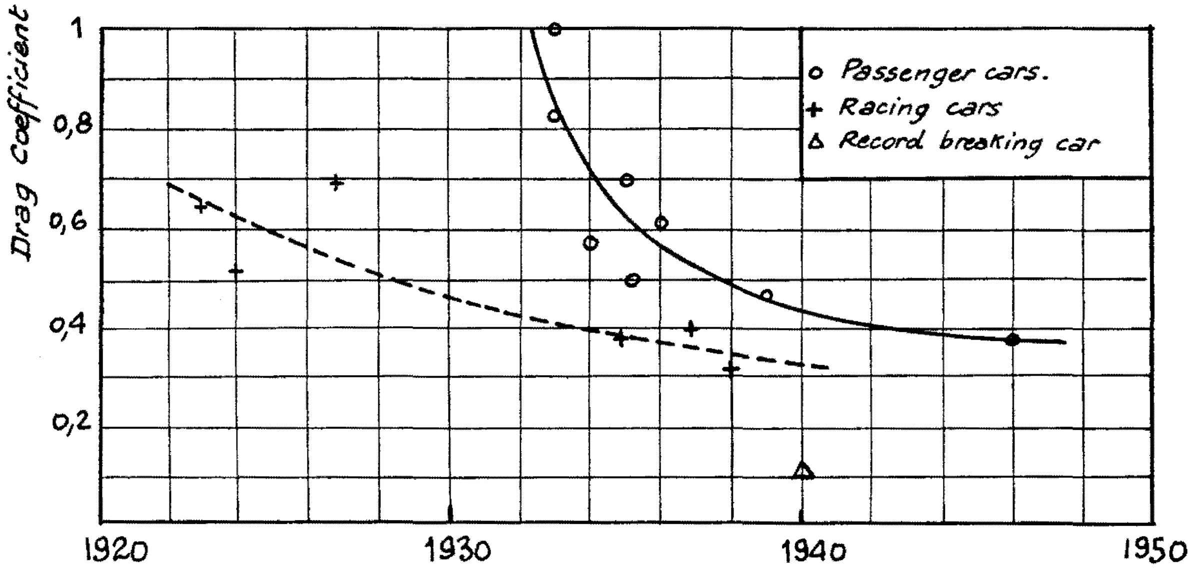

Fig. 7. *Improvement in streamlining of automobiles* (6)

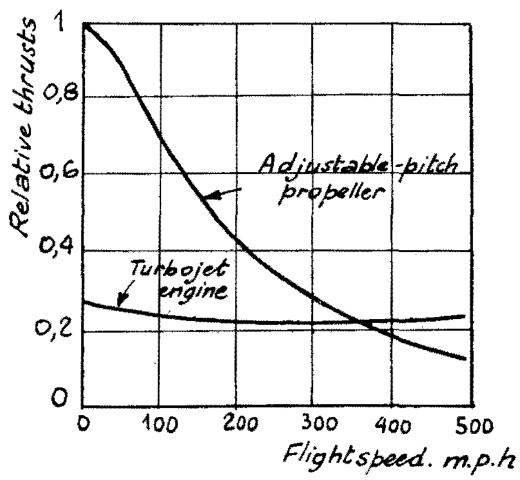

Fig. 8 - *Comparison of the thrust characteristics of adjustable-pitch propeller and turbojet engine.*

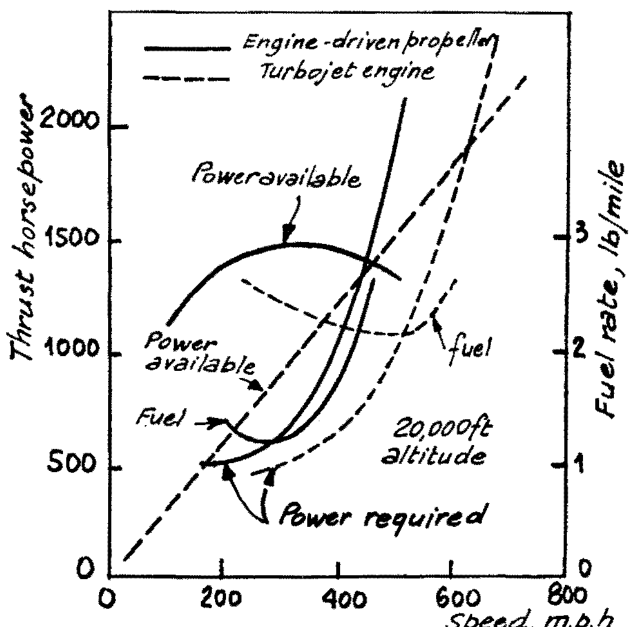

Fig. 9 - *Comparison of performance of engine-driven propeller and turbojet engine propulsion systems.*

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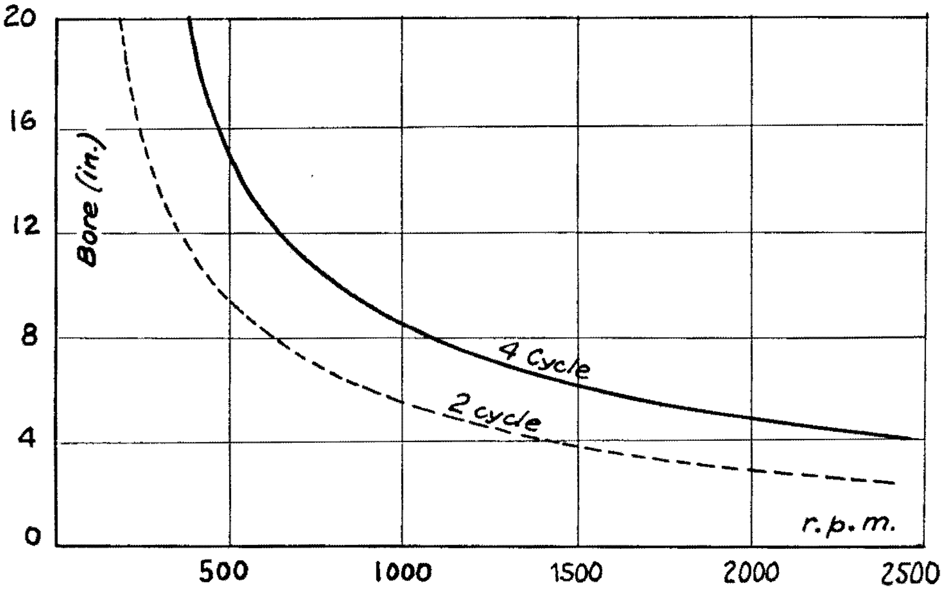

Fig. 10 - Compression-ignition engines.
Bore versus r.p.m

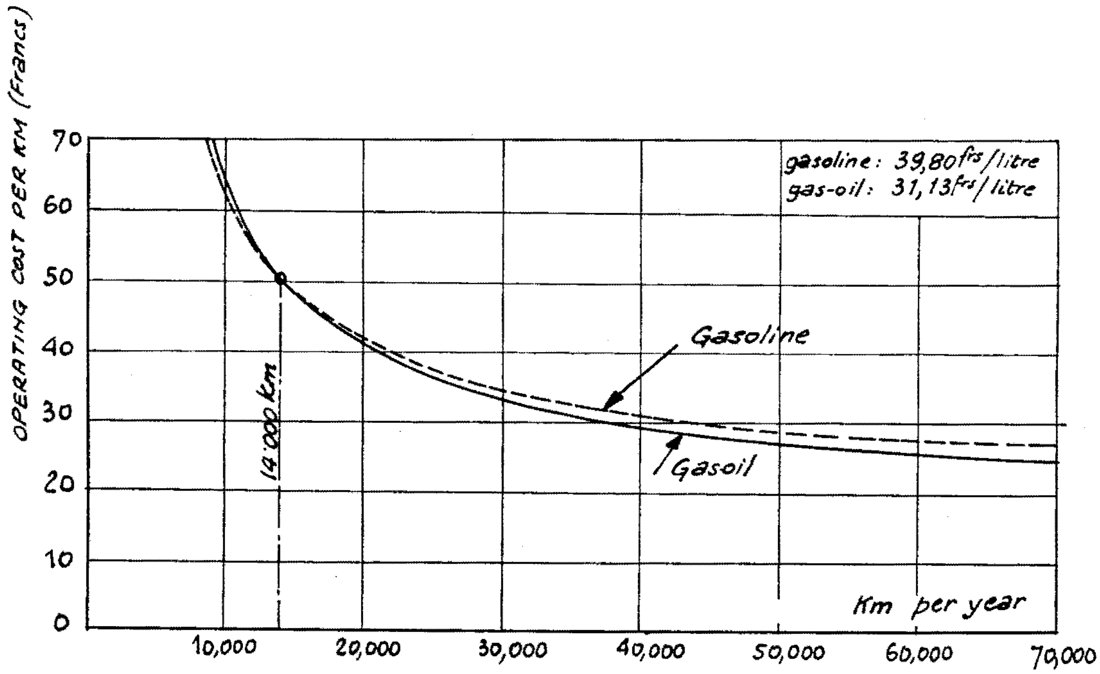

Fig. 11 - Comparison of operating cost per Km of 4 T (pay load) gasoline and diesel trucks in France - (31-12-48)

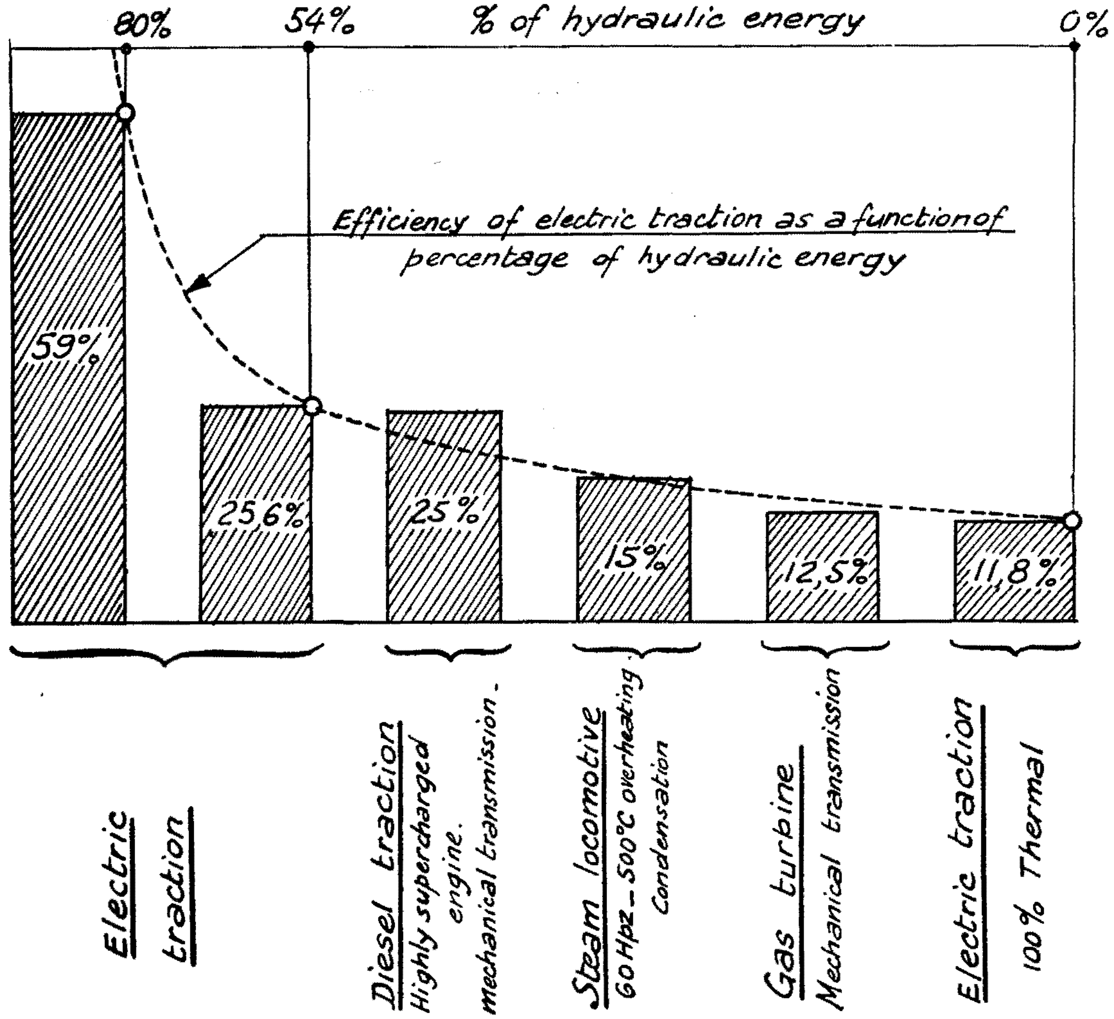

Fig. 12. Average hook efficiency of various systems of traction with improved technique, (Dugas (17))

required in order to obtain high performance, it is inferior to steam turbines with oil-heated boilers.

During the last two decades, most mechanical problems have been solved by the advances made in lubrication and metallurgy. Thus the chamber-type engine is giving way to the direct injection-type, which is more efficient but requires superior quality diesel oils (high cetane index). The higher the speed the more exacting must be the requirement in this regard. Slow engines manage with heavy fuel oils, coal oils and even vegetable oils.

Limited but appreciable advances are being made on the basis of:

The extended use, with high powers, of the two-stroke cycle which makes it possible to reduce the weight-to-power ratio without an excessive loss of efficiency.

Supercharging by means of turbo-blowers recovering the potential energy of the exhaust gases, thus reducing the weight per horse-power by approximately 30 per cent and improving efficiency by 5 to 10 per cent;

The use of doped lubricating oils, which cuts down maintenance costs by eliminating the sticking of piston rings and reducing wear through sludge or deposits;

The improvement of diesel oils both by increasing the cetane number and by reducing the sulphur content.

4. *The gas turbine*. A few years ago it was thought that the development of piston engines would soon be stopped by the application of gas turbines (12), the principal advantage of which lay in the use of heavy fuel oil.

Despite the extensive study and research devoted to this technique outside the field of aviation, little has yet been achieved industrially, and it is difficult to say at present how it will develop (18).

The open-cycle units which have been built both for rail traction and for ships and power stations lie between 1,000 and 20,000 h.p. Their weight-to-power ratio is 15 kg./h.p. and their efficiency from 17 to 20 per cent (290 to 350 g./h.p.h. of heavy fuel oil).

Their construction is relatively simple but such efficiency

Table I

FUEL	Upper Calorific value	Production efficiency f (1)	Mean fuel consumption per b.h.ph	Utilization efficiency u	Efficiency u × f	Specific weight* lb/b.h.p	Classification according to facility of use
NATURAL GASOLINE (O.N. 70)	19'800 Btu/lb	0,85	.56 lb	0,230	0,195	10,4	1
SYNTHETIC GASOLINE	19'800 —	0,28	.56 -	0,230	0,065	10,4	1
BENZOL	18'130 —	0,776	.605 -	0,232	0,180	10,45	3
ETHYL ALCOHOL 95 deg. Bé (beetroot)	12'150 —	0,474	.85 -	0,247	0,117	10,45	4
METHYL ALCOHOL (coal)	9'580 —	0,256	1.03 —	0,258	0,066	10,45	4
COAL GAS	35'600 Btu/cu. ft	0,776	26.6 cu.ft	0,214	0,166	11,72	6
WOOD (humidity: 20%)	6'740 Btu/lb.	0,887	2.35 lb	0,161	0,143	31,7	9
CHARCOAL	13'500 —	0,438	1.16 —	0,162	0,071	30	8
CHARCOAL BRIQUETTE	14'000 —	0,562	1.06 —	0,171	0,096	30	7
LEAN COAL	14'000 —	0,948	1.03 —	0,176	0,167	31,7	10

* *Specific weights of approximately 65 b.h.p truck engines.*

Table II

		Turbojet engine	Reciprocating engine: spark ignition	Reciprocating engine: compression ignition	Free piston generator	Gas turbine	Burner
AIRCRAFT	> 435 miles/hour	Kerosene				fuel-oil	
	< 435 miles/hour		O.N > 90			fuel-oil	
AUTOMOBILE	Cars - Motorcycles		$60 < O.N < 90$				
	Trucks: pay load < 11000 lb		$60 < O.N < 90$				
	Trucks: pay load > 11000 lb		$60 < O.N < 90$	gas-oil			
AGRICULTURAL TRACTORS	Wheel Type < 40 h.p		$60 < O.N < 90$				
	Track laying type > 40 h.p			gas-oil			
RAILROADS	Railcars			gas-oil			
	Locomotives			gas-oil	gas-oil	fuel-oil	fuel-oil
MARINE	River boats			gas-oil			
	Merchant ships			fuel-oil	gas-oil	fuel-oil	
	Passenger ships				gas-oil	fuel-oil	fuel-oil
POWER PLANTS	< 20'000 KW			fuel-oil	gas-oil	fuel-oil	
	> 20'000 KW						fuel-oil

figures require the use of high temperatures (700 to 750 degrees C.) which can only be maintained if very high quality metals are used. Not all the metallurgical problems have been solved and only lengthy experience of this type of installation will make it possible to determine the operation cost, as depreciation and maintenance cannot at present be calculated.

In order to improve efficiency (30 to 32 per cent) it will probably be necessary to have closed-cycle turbines with air coolers between the various compression stages and exchange-recuperators to heat the air admitted (19), but, as regards the fuel, there will be the urgent question of eliminating sulphur which is dangerous to recuperators.

None of these difficulties is near solution, and so a technique is being developed which combines the advantages of both the compression-ignition engine and the low temperature turbine, namely the free-piston gas generator (20). The results being achieved at present are encouraging. For high powers the weight (12.5 kg./h.p.) is much lower than that of the two-stroke diesel engine, fuel consumption being much the same—175 g./h.p.h. of diesel oil (efficiency 33 per cent).

It is very likely that the next few years will see a development in this technique both for railway traction and for shipping and small isolated power plants.

5. *Power Plants.* All these solutions to the problem of energy transformation concern powers under 25,000 h.p. The steam turbine will probably continue for many years to be the best adapted to very high-power units. The problem here is the choice between coal and heavy oil for heating boilers, both solutions having their advocates. Powdered coal will certainly continue to be employed in mine power-stations so as to utilize types of coal which, until recently, were ruled out because of their high ash content (30 to 40 per cent). The advantages of heavy oil are greater in proportion as the power stations are further away from the coal production centres. These advantages are undeniable—convenience of storage, flexibility of installation, smaller capital expenditure, regularity of combustion and ease of control. It is not yet known how to utilize processes for the transmission of heat by flame radiation.

In the final analysis, however, the choice depends strictly on the cost per kw./h. produced, which itself depends rather on the relative prices of coal and heavy oil than on the other more or less equivalent factors.

At one time it was thought that the use of heavy oils would improve combustion efficiency. Experience has shown that this can be achieved only by using oils with a sulphur content difficult to obtain without operations greatly increasing their price. Any advance made in this respect would definitely tilt the balance in their favour.

CONCLUSIONS

Table II, which sums up the considerations set forth above, shows that logically the utilization of the various engines and fuels is clearly determined by performance, efficiency and facility of use.

These, however, are scientific conclusions which, in many cases, are overruled by economic or political factors because of:

Past events which have led to the construction of equipment that is now out of date but not financially amortized;

The financial situation of countries with a small export trade which, in order to cut down their foreign currency requirements, artificially stimulate the consumption of national products often less advantageous as regards power produced and cost, or refrain from developing means of transport which they appreciate;

The desirability of balancing the consumption of the various products, because the transformation plants do not provide the whole range of fuels with the optimum efficiency and qualities at all times.

Engineers and economists are endeavouring to solve these temporary difficulties. Their efforts will be the more effective if they are accompanied by a policy which takes into account both technical progress and the development of reserves.

Bibliography

(1) Rimbaud, *Conf. du 17 Mai 1941, Association des Techniciens Français du Pétrole,* Paris.

(2) T. H. Risk and J. F. Jordan, "Motor-fuel trends in relation to anti-knock requirements", *Oil and Gas Journal,* 5 April 1947, page 78.

(3) Ch. F. Kettering, "More efficient utilization of fuels provided by new high-compression automobile engines", *ibid.,* 12 July 1947, no. 10.

(4) A. T. Colwell, "Fuel developments. Their effect upon post-war automobiles", *The Automobile Engineer,* May 1944, pages 194–202.

(5) E. V. Murphree, A. J. Blackwood and A. C. Patterson, *Advances in motor fuel manufacturing processes leading to better fuel economy,* Fuel Economy Conference of the World Power Conference, The Hague, 1947, Sect. C2, paper no. 4.

(6) F. Picard, *Les problèmes immédiats de la technique automobile française, Congrès Technique International de l'Automobile,* Paris, 1947, Publ. S.I.A. Paris.

(7) Earl Bartholomew, *Potentialities of the new fuels in the design of passenger car engines,* Meeting S.A.E., June 1946.

(8) E. F. Obert, "Detonation and internal coolants", S.A.E. *Trans.,* January 1948, page 52.

(9) Jalbert, *Préparation du mélange carburé par injection directe, Congrès Technique International de l'Automobile,* Paris 1947, Publ. S.I.A. Paris.

(10) J. Prévost, *Carburation dans les moteurs à injection et à allumage commandé, Congrès Technique International de l'Automobile,* Paris, 1947. Publ. S.I.A. Paris.

(11) Everett M. Barber, "Knock-limited performance of several automobile engines", S.A.E. *Trans.,* vol. 2, no. 3 (July 1948).

(12) M. J. Zucrow, *Principles of jet propulsion and gas turbines,* John Wiley and Sons, Inc., New York, 1948.

(13) F. W. Godsey and C. D. Flagle, "The place of the gas turbine in aviation", *Westinghouse Engineer,* June 1945.

(14) *British Diesel Engine Catalogue,* Temple Press Limited, Bowling Green Lane, London E.C.I., 1947.

(15) *Diesel Engine Catalog,* Diesel Engines, Inc., New York, 19, 1946.

(16) W. E. Turner, "Calculations point up Diesel fuel economy", S.A.E. *Journal,* September 1948, page 76.

(17) R. Dugas, *Comparaison des différentes formes d'énergie utilisées dans les transports par chemin de fer,* Fuel Economy Conference of the World Power Conference, The Hague, 1947, Sect. C4, paper no. 2.

(18) M. Roy, *Prochains emplois de la turbine à gaz en France,* Fuel Economy Conference of the World Power Conference, The Hague, 1947, Sect. C2, paper no. 5.

(19) Cox H. Rowbee, A. R. Howell and A. G. Smith, "The Dependence of Gas Turbine Economy on Internal Aerodynamic Design", Fuel Economy Conference of the World Power Conference, The Hague, 1947, Sect. C2, paper no. 7.

(20) G. Eichelberg, *Les générateurs de gaz à pistons libres, Le Génie Civil,* 15 Nov. and 15 Dec. 1948, Paris.

(21) E. L. Bass, "L'avenir de la turbine à gaz dans l'aviation civile", *Shell Aviation News,* no. 126, Dec. 1948.

Utilization of By-Product Gases Produced in an Iron and Steel Works

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ABSTRACT

The need for the efficient utilization of the large quantities of by-product gases produced in a modern iron and steel works is stressed and there is discussion of the general economic and technical considerations which determine how this is best achieved to suit local conditions. An indication is given of the fundamentals in any good gas-distribution system, i.e., the provision of adequate gas-storage capacity and the existence of a "buffer" unit fired with alternative fuel in the event of gas shortage. Various potential gas-consuming units, i.e., coke ovens, hot blast stoves, soaking pits, mill reheating furnaces, open-hearth furnaces and gas engines, are examined to determine what particular fuels are most suitable to their needs and their subsequent effect upon the over-all gas balance of the works. The degree of gas cleanliness required and some methods of achieving it are mentioned, and the paper concludes with a brief summary of the functions of a typical works fuel control department. A line diagram is appended, showing the distribution in a typical works of the fuel and energy required at each stage of manufacture of a ton of finished steel.

The manufacture of coke and pig-iron is accompanied by the production of large volumes of by-product gases, the heat content of which is equivalent to approximately half that originally present in the coal initially charged into the coke ovens, i.e.:

Plant	*Volume of gas produced*	*Calorific value B.T.U. per cub. ft.*
Coke oven ...	10,000 to 12,000 cub. ft. per ton of coal	480/560
Blast furnace..	135,000 to 150,000 cub. ft. per ton of coke	85/105

To attain the most economic utilization of these gases, the coke ovens and blast-furnaces should form part of an integrated steel-works so that the available by-product gases can be used to supply the heat and power requirements of the steel plants and mills.

In such an integrated steel-works the principal purposes for which fuel and power are required are:

(1) Heating coke-ovens.
(2) Heating blast-furnace stoves.
(3) Provision of blast for blast-furnaces and Bessemer converters.
(4) Firing open-hearth furnaces.
(5) Firing soaking pits, reheating and heat-treatment furnaces.
(6) Provision of steam and electric power.

Various factors must be taken into consideration before deciding how the available by-product gases should be allocated to these different consumers; as local conditions vary considerably, it is not possible to recommend rigidly any one set of procedures, but certain fundamental considerations which are generally applicable are tabulated below:

(1) Blast-furnaces and coke-ovens are continuous processes which operate for the complete 168 hours of the week and therefore, as far as possible, the units to which the by-product gases are allocated should also work similar hours.

(2) The by-product gases should primarily be used to replace gas made from coal in a producer with its inherent irrecoverable losses.

(3) The efficient utilization of the by-product gases is very important, but it is nevertheless of secondary consequence to the main processes producing coke, iron and steel, and therefore, the utilization of the by-product fuel must not interfere with the smooth rate of production and efficiency of the main processes.

(4) The rates of gas production are related to the main process and normally cannot be adjusted to suit gas-consumption requirements; therefore, it is necessary to have gas-storage capacity, and also, and even more important, a "buffer" which can be fired with an alternative fuel whenever gas demand exceeds rate of gas production.

(5) As coke-oven gas is capable of developing a much higher flame temperature than blast-furnace gas, it should be reserved primarily for processes requiring high temperatures.

It is proposed to discuss briefly the general application of these ideals to each of the possible consuming units.

COKE OVENS

Providing the ovens are suitably designed initially, they can be fired with either coke-oven or blast-furnace gas; owing to the different characteristics of the two gases, the thermal efficiency is better with coke-oven gas than with blast-furnace gas firing, but even so, it is preferable to fire the ovens with blast-furnace gas as the coke-oven gas thus freed can be much more profitably used in the steel-works. Given suitably designed plant with ample gas-regenerator capacity, the principal practical detail to be watched is the maintenance of a high standard of gas cleanliness in the blast-furnace gas used for underfiring; otherwise, troubles will develop in the regenerator system.

HOT BLAST STOVES

Blast-furnace gas is invariably the only fuel considered for this operation, unless a very abnormal set of conditions is encountered; with well-designed equipment efficiencies of the order of 90 per cent can regularly be attained. The maximum blast temperature which still permits smooth operation of the furnace should be carried, particularly on furnaces producing ferro-alloy.

PROVISION OF BLAST

Blast-furnace gas-driven blowing engines were formerly popular for this service, but steam-driven turbo blowers are now more in evidence and their use increases the flexibility of gas supply as gas engines are a preferential gas consumer whose gas require-

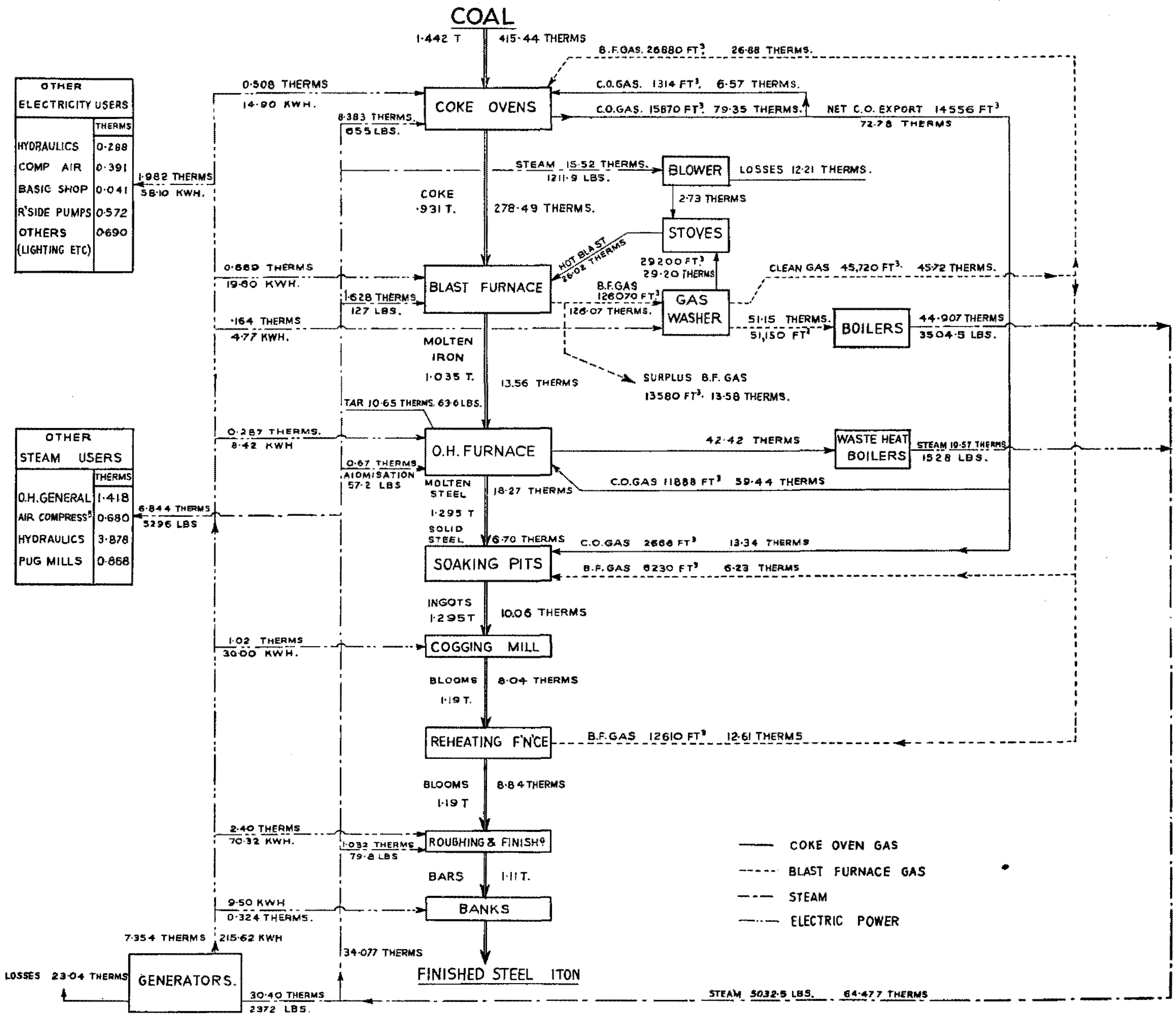


Figure 1. Utilization of Byproduct gas in Iron and Steel manufacture

Table 1. Tabulation Showing Gas, Steam and Power Requirements for Production of one Ton of Steel Sections

Plant	*Material required*		*Power required*		*Heat used*					*Gas made*		*Steam raised*
						Fuel used						
			Elect.	*Steam*	*Total heat*	*B.F. Gas*	*C.O. Gas*	*Tar*	*Coal*	*C.O.*	*B.F.*	
		Tons	*Units*	*Lb.*	*Therms*	*cub. ft.*	*cub. ft.*	*Lb.*	*Tons*	*cub. ft.*	*cub. ft.*	*Lb.*
Coke ovens	Coal	1.442	14.90	655	33.45	26,880	1,314			15,870		
Blast furnace	Coke	0.931	19.60	1,338.9	29.20	29,200					139,650	
Gas cleaning			4.77									
Steel plant	Molten Iron	1.035	8.42	57.2	70.76		11,888	63.6				
Cogging mill	Ingots	1.295	30.00		19.57	6,230	2,668					
Roughing & finishing mills	Blooms	1.190	70.32	79.8	12.61	12,610						
Finishing banks	Bars	1.110	9.50									
Waste heat boilers												1,528
Fuel-fired boilers					51.15	51,150						3,504.5
Power station				2,372								
Others			58.10	529.6								
	Finished steel	1.00	215.61	5,032.5	216.74	126,070	15,870	63.6	Nil	15,870	139,650	5,032.5

ments must always be met, whereas steam required by a steam turbine can be obtained from blast-furnace gas when available and at times of gas shortage from cheap, low-grade fuels.

FIRING OPEN-HEARTH FURNACES

Open-hearth furnaces can be fired with either coke-oven gas alone or a blast-furnace/coke-oven gas mixture; the author's preference, where gas balance permits, is for coke-oven gas with a carburetting agent such as pitch/creosote mixture, crude tar etc.; with such a system a shortage of coke-oven gas can be made up by increasing the proportion of the carburetting agent.

The most successful furnace designs are similar to those which give good results on oil firing and similar furnace efficiencies should be obtained.

SOAKING PITS, REHEATING AND HEAT TREATMENT FURNACES

As far as possible, blast-furnace gas should be used for these furnaces. Given ample regenerative or recuperative devices, blast-furnace gas gives good results on soaking pits, but owing to its low flame temperature, it gives a slower rate of heating than the higher calorific value coke-oven gas, or mixtures containing it. The final choice depends upon the relative quantities of the two gases available and the proportion of cold ingots required to be heated. In addition, the blast-furnace gas-fired pit is more expensive to erect owing to the additional heat-recovery equipment necessary. The high temperatures required in the mill reheating furnaces make the use of blast-furnace/coke-oven gas mixtures of 150/200 B.T.U.'s per cubic foot preferable, and as these furnaces are frequently erected in locations where floor space is at a premium, the more compact arrangements possible with the higher calorific value gas have many advantages.

Small heat-treatment furnaces etc., are suitable in many respects, particularly temperature conditions, for blast-furnace gas firing, but, owing to their small size etc., and space considerations, it is frequently the practice to equip them for rich gas firing.

PROVISION OF STEAM AND ELECTRIC POWER

The efficiency of the modern steam turbine when using steam at medium pressure and superheat makes it preferable for electric-power generation as compared with gas-engine generation, and, provided that the available by-product gases can all be utilized efficiently elsewhere in the steel-works, this tendency facilitates the organization of the gas distribution. The boiler makes an ideal "buffer consumer", as a suitably designed unit will give the rated output on greatly differing fuels, even cheap low-grade fuel, and this provision of ample "buffer" capacity to ensure availability of gas supply to the essential consumers is of vital consequence.

The accompanying Figure 1 and tables 1 and 2 indicate gas, steam and power distribution for a works operated on the lines indicated.

The distribution shown in table 2 is based on ideal conditions when all parts of the plant are in balance; under normal operating conditions such a plant will probably require additionally each week some 600 tons of coke breeze or coal for boiler firing and an additional 200/300 tons of liquid fuel at the open-hearth furnaces to ensure continuity of operations during periods of gas shortage.

The consumptions quoted in tables 1 and 2 are influenced by the local operating conditions, particularly the types of ores available for the blast-furnaces and the quantity and price of scrap available for the open-hearth furnaces producing steel, but the data shown indicate the ideal for a given set of operating conditions. Operators whose conditions differ from these must modify the individual items where necessary.

GAS CLEANING

In order to obtain the highest efficiency of heat transfer at gas-consuming units, it is imperative that all suspended dust be removed from the gases. Coke-oven gas, after by-product recovery, is sufficiently clean for works purposes, but blast-furnace gas, on leaving the furnace, contains large quantities of suspended solids.

This foreign matter may be removed by repeated washing with water, by filtration through bags, or by electrostatic precipitation methods, the latter method being favoured in modern plants. This cleaning of blast-furnace gas is an expensive process and it is essential that the closest control of the process be maintained in order to keep the cost of cleaning as low as possible.

WORKS OPERATION

The efficient distribution and utilization of the large quantities of by-product gases available can only be attained by the extensive use of measuring, controlling and regulating instruments. The efficient gas distribution system such as is required for a large works involves the installation of hundreds of instruments—pressure and volume recorders, regulators, controllers. Additionally, the obtaining and maintaining of high efficiency at the individual consuming units necessitates similar instrumentation at those points. The interpretation and maintenance of these instruments must be followed up by a keen, live, fuel-efficiency organization and the calibre of this staff is the keystone to the quality of the results. In many cases the extensive utilization of the by-product gases has been grafted on to old equipment. Only in very few cases have integrated works been designed initially to permit of the most efficient and economic utilization of the by-product gases and it is thus the exception to find all units designed initially for operating on the general lines postulate. It is imperative, therefore, that in all cases there should be an active, live organization whose prime objective is the attaining of the utmost efficiency in this sphere. There are no set rules applicable in all cases. Under some conditions it may be found advantageous to link up with public utilities to export or interchange gas or electric power; this arrangement has much to recommend it from the technical aspect of conserving fuel and power resources, but it is the exception to find that the agreements give a reasonable economic return to the steel-works.

The whole question must always be kept under very close inspection and be constantly reviewed to ensure that the most economic value of the by-product gases is being obtained.

Table 2. Fuel Balance for Composite Iron and Steelworks Making 15,000 tons of Finished Sections per Week

Average operating conditions

Coke ovens. Coal consumption 159 tons/hour; coke make 102.7 tons/hour.

Blast-furnaces. Coke consumption 102.7 tons/hour; basic iron make 114.2 tons/hour.

Steel furnaces. Molten iron consumption 114.2 tons/hour; ingot make 142.8 tons/hour.

Mills. Ingot consumption 142.8 tons/hour; rolled section make 131.3 tons/hour; finished sections 110.3 tons/hour or 15,000 tons/week.

Gas distribution

	Blast-furnace gas cub. ft./hr.	*Coke-oven gas cub. ft./hr.*	*Tar and P-C min lbs. per hr.*
Blast-furnace stoves	3,221,000	—	—
Coke ovens...........	2,965,100	144,500	—
Steel plant	—	1,310,500	7,105
Mill soaking Pits and reheating Furnaces	2,078,800	294,000	—
Boilers................	5,642,200	—	—
	13,907,100	1,749,000	7,015

New Developments in Electric Energy Production[1]

R. GIGUET

ABSTRACT

Sources of power, which are worked in accordance with the laws of thermodynamics, appear to us chronologically in order of decreasing efficiency as regards cost and of increasing efficiency as regards quantities.

The progress of technical processes has reduced the difference between the costs of successive quanta and contributed simultaneously with the constant increase in demand for power, to bring new sources under exploitation. Only rarely does it reverse the order of succession of the quanta.

Despite the enormous diversity in kind of the potential sources of power, certain natural phenomena as they develop recapitulate, as it were, the general evolution of power economy.

This applies to the harnessing of certain rivers, which, depending on the point where their course is regarded, show characteristics so different that the various sections into which they can be divided may justifiably be considered as essentially different sources of power.

In France, the Rhône fulfils these conditions. Its course may reasonably be divided into three sections.

It has been possible to harness the upper section, from the Swiss frontier to Génissiat, by means of a single installation of 65 metres drop at Génissiat. Here five Francis turbines of 70,000 kw. each supply in an average year 1,700 million kwh. at a price between 11 and 12 francs per kwh./year. The Génissiat plant was put into operation in 1948.

The second section stretches from Valence to Mondragon. The fall here is only 0.77 metres per km. The section will be divided into three works of about 25 metres drop, constructed on long by-passes. The total production of this section will be about 6,000 million kwh. The downstream installation is under construction at Bollène and will supply 2,000 million kwh. per year at a price of 35 francs per kwh./year. The installation of this section of the river was made economically possible by the invention of the Kaplan wheel, or, at least, of the helical wheel.

The third section, over which the fall is only 0.50 metres per km., will comprise 17 works of variable drop (between 4.5 and 17.5 metres). It will be capable of producing 9,000 million kwh. per year, but at a price of more than 40 francs per kwh./year, which exceeds the economic limit.

It would appear, however, that the time is near when plans will include the working of this section. This development will undoubtedly have been made possible by the invention of the Kaplan turbine.

It is only just, however, to give due weight to the part played by recent technical progress in the construction of low dams and in high-tension power transmission.

[1] Original text: French.

In proportion as the human population increases, and as men, striving to satisfy new needs, learn to utilize natural agencies for this purpose with more efficiency, engineers are called upon to divert towards the centres of population an ever increasing (though still infinitesimal) proportion of the enormous quantities of energy ceaselessly interchanged in the course of the natural chemical and mechanical processes of which our part of the universe is the scene, and in the reproduction and utilization of which we shall not in all likelihood have any fundamental difficulty.

I. THE GENERAL EVOLUTION OF POWER

If it had been possible to draw up a complete inventory of such sources of power, and if reason only and considerations of yield guided human beings in their choice, it can be imagined that plans for providing power would be taken from this list in which operations would be classified in order of decreasing attractiveness, due account being taken of their cost, their geographical situation and their adaptability to consumption needs. It will readily be understood, for example, that while the exploitation of a waterfall of 70 metres drop with a rate of flow at lowest water of 30,000 cusecs would represent an operation of the highest possible utility in Europe, it could be accorded only a very low priority if Nature had placed the necessary conditions in Africa, far from any centre of consumption. Of course matters are not and have never been decided in so simple and naive a manner, yet if we consider all the energy sources worked at present and those it is hoped to utilize in the near future, it will be noted that they fall into groups following more or less the law of decreasing yield just outlined and this point merits some consideration.

It will be noted in the first place that the principle holds good only in macroscopic physics, which is governed by the principle of Clausius, and where there are basically no truly new sources of power, which explains why engineers have had the time to classify phenomena, more or less deliberately, in order of efficiency. In nuclear physics, on the contrary, where phenomena which are normally extremely infrequent bring into play relatively enormous quantities of energy, and where research, in the true sense of the term, was begun only a very few decades ago, it would be rash to hazard any rule.

Since, in any case, it is not my task to deal with these difficult problems, I shall content myself by saying that even where (as in the case of chain fission reactions) it has been possible to eliminate the basic infrequency of a nuclear process, it is difficult to believe that it will be possible to find any industrial application without returning to the field of macroscopic phenomena, to which we will confine ourselves for the rest of this paper.

A second point which arises is that the idea of decreasing efficiency applies to the chronological order of the quanta of exploitation by man of the natural reservoir of power on which he draws only if, as hitherto, we are considering the prime cost of the equipment concerned and its adaptability to demand. If, however, we consider the *amounts* of power which each quantum places at our disposal, it will be noted that the relevant law is one of *increasing* efficiency; i.e., each time we make an identical additional sacrifice on the price we are prepared to pay per marginal kilowatt, nature credits us, as it were, with a greater number of kilowatts, a rather encouraging fact for the even distant future of humanity. Even more encouraging is the fact that from the point of view of power pure and simple the credit balance of investment at our present stage is so amazingly good that we run no risk of error in affirming that we have before us practically unlimited prospects of enrichment. We are aware, of course, that it is extremely difficult to compute the power balance of an investment accurately, and we are equally aware that in itself such a computation is incomplete and unsatisfactory since it neglects the inherent quality of human labour, which is essentially irreducible to computation in terms of power (the fundamental reason for the discrepancy always found between power balances and financial balances); nevertheless, it remains true that hydroelectric installations — high quality installations of course, but these are fairly numerous — produce in four or five months more energy than was invested in their construction; and there is thus no danger that men will refuse to undertake such investments, or even others of much lower productivity.

If, however, it can legitimately be maintained that power sources, whether old or ostensibly new, arrange themselves in a list according to decreasing efficiency, whence the human mind summons them to service only when human needs so require, that is not to say that the engineer's art should be confined to opening the next drawer when the top drawer is empty.

The conditions under which natural sources impinge on human life, so to speak, are imposed (and constantly modified) by technical knowledge; and though it may be rare for the engineer's discoveries to modify the order in which sources of power become available, nevertheless it is those discoveries which transform potentiality into practical workings and very often reduce the gap between the cost of the most recent acquisitions of humanity and those which preceded them. The progress in metallurgy which made possible the internal combustion engine and the gas turbine did not thereby cancel the intrinsic superiority of the steam engine, and even, in fact, helped to improve its operation. The construction of turbines having efficiency varying little according to load, down to the smallest units of load, might make it possible tomorrow to build a tidal energy factory, but the prime cost of the power produced by such a factory would nevertheless remain higher than the price of the power obtainable from high waterfalls still remaining to be harnessed. Many similar examples could be cited in the various branches of energetics, and the only result would be to confirm the proposition that in view of the advanced state of industrial macroscopic physics all that can reasonably be anticipated from technical progress is quanta of power of increasing prime cost per unit, but also of increasing magnitude. Generally speaking, the order and nature of these quanta are known even before it is possible or necessary to draw upon them; but the invention of new mechanical processes serving the required purpose may, in exceptional cases, alter the order of the quanta and, frequently, diminish the gap between the prime cost of two consecutive quanta.

But if the various sources of power range themselves before us, as it were spontaneously, in the very order of their thermodynamic and economic efficiency, it may be asked whether there do not exist in nature phenomena recapitulating, within a limited series, the past and future evolution of human action on the sources of power.

To put the matter differently: what we are seeking is a system of power sources which, while essentially similar, can be classified on the basis of their exploitation by man (for the actual *nature* of sources has not yet been dealt with in our analysis) into a natural order following the same rules as the system of power sources existing in the macroscopic universe.

Such systems do in fact exist; namely, the rivers, or at least those rivers embracing in their courses a variety of conditions of hydraulic production the extremes of which are so diverse, and so dissimilar from the technical standpoint, that they may quite justifiably be considered as independent "sources" of power. The exploitation of a few cusecs under several hundred metres of head is as different from the exploitation of several hundred cusecs under a few metres of head as the construction of an aero-motor from that of a tidal energy factory; in fact, it might be claimed that for all the apparently greater dissimilarities the real similarities in the latter case are greater than in the former.

II. A TYPICAL CASE: THE RHONE

Only a few such rivers exist in France; it may indeed be said that there is only one: the Rhône. Even then it would be necessary, if we wished to reconstitute a more or less complete gamut of power qualities with the various types of installation possible in this geographical region, to go beyond the French part of the river and extend the study to the whole catchment area, including the Alpine tributaries, the only ones which provide examples of extremely cheap exploitation, by Pelton wheel, of high waterfalls with low rate of flow. These tributaries are also unique in lending themselves to the exploitation of the vast reserves of power stored in the lakes in their upper reaches. The prime costs connected with these lakes are doubtless relatively high, owing to the difficulty of keeping them regularly fed by diverting torrents from their natural courses; but they provide high-quality power in every way comparable with that obtainable from thermal stations.

Finally, the Rhône basin offers on another plan the possibility of constructing installations which may be considered as new sources of power, since they are based not on the principle of diverting streams from their natural courses over a distance of a few kilometres, without changing their catchment area, but on taking water from the Loire basin and diverting it into that of the Rhône. It should be said in passing that the reasons which make it possible to describe projects of this kind, in France at least, as new sources of power, are much less technical than political or moral, for while it is true that such works do violence to nature, as it were, and usually require more extensive cutting and greater efficiency than installations which respect the natural conditions of water flow, it is nevertheless most often respect for ancient customs and the acquired rights of the riparian populations which, in countries of ancient civilization, retard work on the diversion of streams from basin to basin and sometimes increase its cost and difficulty out of all proportion.

But whatever the causes, the phenomenon itself does in fact present the characteristics which we tried to describe when we analysed the notion of "new sources" of energy.

Even if we confine ourselves to the course of the river itself, however, we may distinguish four main regions in it from the moment it enters France and begins, almost at once, to traverse the folds of the Jura through deep gorges:

The upper course, where the gradient exceeds 2.50 metres per kilometre, and the mean flow reaches 340 cusecs. This is a fairly short section, covering hardly more than a score of kilometres, and ending near Génissiat, where the first plant of the *Compagnie Nationale du Rhône* (C.N.R.) was built;

The second region, which does not immediately follow the first, extends from Valence to Mondragon. It therefore begins about 100 km. below Lyons (whereas the first section ends about 160 km. above Lyons) and covers a distance of about 100 km. The surface gradient does not exceed 0.77 metres per kilometre, but the mean flow is more than 1500 cusecs;

The third region is far less homogenous than the first two, comprising two somewhat different sections, one extending over a distance of about 260 km. from Génissiat to Valence in the course of which the mean flow increases as we go downstream from 340 cusecs to 1,500 cusecs, and the other beginning at Mondragon and ending near Tarascon, with a mean flow of 1,800 cusecs. These two sections, however, both have a gradient of about 0,50 metres per kilometre, which is a good enough reason, in a brief analysis, for grouping them together;

Below Tarascon extends the fourth region, in which the flow continues to increase slightly but the gradient is so slight that the river meanders through a series of bends to empty finally through numerous branches into the Mediterranean.

Despite the steep gradient of the zone between Valence and Mondragon, the river between the sea and Lyons has served for navigation from the earliest times, and could be opened for navigation, though, it is true, large works would be needed above Lyons as far as Switzerland. In its middle and particularly its lower reaches, the waters of the Rhône, when they can be used for irrigation, constitute the supreme wealth of the surrounding land, which is fertile but parched. But it is above all for purposes of power production that the exploitation of the Rhône has assumed its present prominence in the plans of those responsible for the French economy. It should in any case be noted that there is no inherent incompatibility in the planning of a river for power production, for navigation and, finally, for irrigation. This point was well understood by the French parliament, when, in 1921 (long before the brilliant success of the Tennessee Valley project, therefore), it laid down the principle of the technical unity of exploitation of the Rhône valley for the triple purpose defined above, and provided for the establishment of an organ embodying this unity and responsible for the construction and exploitation of the works required for this triple plan.

In actual fact, it was not until 1934 that the *Compagnie Nationale du Rhône* was founded thanks to the persevering efforts of Léon Perrier and Prime Minister Edouard Herriot; and the tempo of its work compares unfavourably with the astounding speed of the Tennessee Valley Administration (TVA), a delay and relative slowness deriving from the difference between the industrial power of the United States and that of France, from the different population densities of the Rhône and Tennessee valleys, and, finally, from the structure of the two organizations, based as they were on the almost diametrically opposed conceptions prevalent in the two countries, with their different characters. Thus, while the TVA was vested by President Roosevelt and by Congress with the broadest powers and equipped with the most efficient means of curtailing investigation formalities and acting without delay, the *Compagnie Nationale du Rhône* was modelled in the image of a limited liability company, and remained subject to all the restrictions by means of which the French Government has aimed to protect the public welfare against the incursions of private interest.

But whatever the reasons which so easily explain the discrepancy between the speed of work of the TVA and that of the C.N.R., and the difference between their objectives, the very facts of the problem with which the C.N.R. was faced suffice to demonstrate the necessity of the order in which that organization set out to solve the elementary terms.

We have said enough above, and in any case the fact is obvious of itself, to show that the plan of work was governed primarily by the requirements of power production, the secondary objectives being capable of fulfilment only in so far as the principal objective supplied the means necessary for the others, particularly the dams, for regulating the depth of water, without which no river can be considered permanently navigable.

At the outset there seemed to be a number of solutions to the general problem of planning the river for power production. In actual fact, however, in view of the company's subsidiary objectives and, particularly, of the conditions under which this region with such an ancient culture as the Rhône valley had become populated, the solution appeared practically determined in advance and it was only rarely necessary to resort to the criterion of prime cost in order to choose between a number of layouts which were, in any case, very similar.

Thus, towards 1936, when the Company's first studies reached their conclusion, the general Rhône plan took the following lines, which it still retains, for there is reason to believe that the studies being conducted by the Company will lead only to modifications of detail.

The first of the sections into which we have divided the course of the Rhône could be equipped with a single installation with a variable drop, between 65 and 70 metres according to the flow, producing 1,700 million kwh. in an average year for a power of 325,000 kw., supplemented by a reservoir of 13 million cub. metres capacity, which would be sufficient for 24 hour regulation, and improved by the proximity of the Lake of Geneva, which, for all its lack of exact regulation, cannot fail to contribute to stabilizing the river's flow. Together, all these elements constituted a system of high economic value with which, as we have already said, the C.N.R. began its work. In view, for Europe, of its quite exceptional size and of the unfortunate consequences of the war, which complicated and prolonged the construction from 1937 to 1948, the Génissiat plant deserves the reputation won for it by French engineers; but it involved no important technical problem, and the very characteristics of the Francis turbine for falls of average and fairly constant load made the choice of this type of plant inevitable.

As for the prime cost (which, expressed in francs of early 1949 parity, would be between 11 and 12 francs per kw./year), this justifies the company's decision to begin its work with this project and at the same time automatically gives it first place in the list of decreasing efficiency outlined above for the exploitation of this great French river.

In the second section, between Valence and Mondragon, conditions are less favourable, the physical and human geography of the region making it impossible to construct sluice works even for much lower heads than at Génissiat. It has therefore been necessary to divide the section into three, each part comprising a by-pass canal which is capable of taking a flow of some 1,500 cusecs, and may therefore without exaggeration be called an artificial river.

Constructed across these canals there will be three waterworks of about 23 metres head, each possessing 300,000 kw. capacity and producing about 2,000 million kwh. per year. The nature of the ground and the necessity of crossing affluents of considerable flood water make the construction of the two upper waterworks a complicated matter, and may make it necessary to divide the median head into two works, constructed in series along the same canal.

The *Compagnie Nationale du Rhône* therefore began work on this section with the downstream works, at Bolléne. This plant, begun in 1947 with very large-scale resources, is to produce power by 1952.

The relatively high prime cost of this plant is explained by the length of the by-pass canal, which covers a distance of 28 km. between Donzére and Mondragon, and by the magnitude of the subsidiary works (headrace and storage dams, lock coupled with the waterworks etc.), some of the characteristics of which (segmental sluices of 45 metres free radius, lock of 25 metres head) would in themselves alone arrest the attention of the technical world. It would seem that the cost cannot be much less than 35 francs per kwh./year (something between a fifth and a sixth of which figure may legitimately be attributed to navigation); i.e., the very limit of reasonable investment for water power.

It is important to note that in 1921, when the French parliament voted the Rhône law, the operation of the central third (our second section) of the river represented the extreme limit of what was then technically possible, and perhaps even exceeded that limit. With the Francis turbine, the only type then available, the enormous flow of the river (itself one of the elements contributing to the site's high value) would have necessitated the installation of a large number of units of very great dimensions, and consequently have augmented the size of the works excessively; whereas the invention of the Kaplan turbine has made it possible to reduce the number of units, which can easily be installed, with their accessory works, in one section across the canal. But even if we assume that it would have been possible to construct the works in 1921, the cost of the power obtained (much higher than at present, other things being equal) would have rendered the project quite impracticable, even if technically possible. It may be, in any case, that the considerable advances made by the hydroelectric industry between 1925 and 1930 as a result of the invention of the helical turbine would have sufficed to bring the price of power in the central third of the Lower Rhône down to those prevalent at other sources of power; for the helical turbine is cheaper for equal power than the Kaplan turbine and the variations in head according to flow would certainly not have been high enough to cause losses of efficiency constituting an intolerable burden on production.

It is therefore clear that the mass of energy latent in the second section of the Rhône, while much greater than that contained in the first section, can be worked only at a much higher cost. The increase in demand and the fall in price which followed the invention of the helical turbine and the Kaplan turbine are now bringing this source of power out of the sphere of theory into that of practice; but while the latter invention has reduced the price discrepancy, the general tendency, at least, remains unchanged.

Let us now pass to the third section.

This will contain seventeen stations which, according to the geographical conditions are either coupled to the dam providing the head on the river, or installed on navigable by-passes. The total power with which these stations could be equipped is very little less than 1,500,000 kw., and their production per mean year would be nearly 9,000 million kwh. Only five, however, would have heads of more than 10 metres, with a maximum of 17.5 metres in the case of the St. Rambert works; and the six lowest heads would be between 7.5 and 4.5 metres. Before the invention of the Kaplan turbine the cost of a project of this kind would have been impossibly high for the general power market; for in view of the high relative effect of variations in the heads of small falls, only the very highest falls of this section, of which there are but few, could be worked by the helical wheel process. But even today, in spite of the advances made in turbine construction, it is doubtful whether the quantum of power corresponding to the third section can find a place in any industrial investment plan intended for the immediate future.

It is true, of course, that the *Compagnie Nationale du Rhône* is at present constructing the Seyssel works, the first units of which may be put into operation in 1951; but the 8 metre dam to which this plant is coupled provides partial compensation for the effect of the locks attached to the Génissiat station, and its cost is therefore rightly charged to that station, since the latter could not use its reserves in a durable manner if the river flow was not regulated downstream.

Thus relieved of the cost of its dam, the Seyssel station produces energy at a lower price than the corresponding thermal equivalent. This, however, is clearly a very special case, and the other stations in this third section studied by the *Compagnie National du Rhône*, either upstream (Sault Brenaz), where navigation charges are at present low, or downstream (Lyon Pierre Bénite), where they are high, show prime costs of 40 or 45 francs per kw.-year, which has made it impossible hitherto to include them in construction programmes. It would appear, however, that in view of the depletion of the best sources the time may now be near when the *Compagnie Nationale du Rhône* will be able to construct the least unfavourable stations of the third section of the river, even if no new technical advance supervenes to reduce the gap between the prices of the second and third sections.

It is difficult to conceive of such progress being made in the fields of hydraulics or electricity; but on the other hand the conception of the sluice works, which originated in Germany in the Lech waterworks, may, once experience has perfected it and, if this should ever be possible, solved the problems connected with its construction, lead to a considerable decrease in civil engineering costs.

There is no need to labour the point that here we have come back to the principal features of the classification of sources of power in decreasing order of efficiency, and of the role of technical progress, which we tried to outline at the outset of this study.

III. THE IMPORTANCE OF RECENT TECHNICAL ADVANCES

Before closing this study it remains for us to complete in two respects our analysis of the technical advances which have made the harnessing of the Rhône, if not physically, at least technically possible.

We have stressed the importance of the stride forward in the harnessing of the river constituted by the invention of the Kaplan turbine. This indeed, has been the most important development of recent years; and what we said in connexion with the second section of the river applies with still more force to the third, where the very highest heads could have been equipped with helical or, perhaps, Francis turbines, but where it would be quite impossible to harness the lowest falls of variable head, were it not for the Kaplan turbine.

It is only just, however, to point out that the progress made simultaneously in the construction of variable low head dams has had the most beneficial effects on the Rhône waterworks projects, all of which, with the exception of the Génissiat station, include such dams, either close to the works or at the origin of the headrace.

For heads of more than 8 metres the metal framework system now makes it possible to construct sectoral sluices of 45 metres radius, which leave abundant room for navigation. For lower heads the Chanoine dams with hoists, skilfully adapted by Mr. J. Aubert, offer a solution which, while extremely effective entails little initial outlay.

The second technical advance without which it would have been impossible to build this series of works, some of which will be among the most powerful in Western Europe, is the transmission of power over long distances. It is true that the Rhône region is fairly densely populated; but by far the largest industrial centre it contains is Lyons, and the increase in power production which will follow the harnessing of the Rhône will greatly exceed the increase in power consumption by Lyons, which now lags far behind regional production.

Economically, therefore, the tremendous operation represented by the Rhône works demands large-scale exportation of power from the South-East to the other regions of France. Under present conditions only the increase of the standard transmission voltage to 220 kv. has made it possible to export the power of the plants already in operation, and it will be necessary to increase the voltage to 400 kv. before the entire production can be exported. Nevertheless it would have been impossible to increase the voltage from 150 to 200 kv., and subsequently to 400 kv., without the technical progress made in transmission equipment, and particularly in switching and transformer apparatus.

We have now reached the end of our study, and the care with which we have consistently followed the plan proposed and outlined at the outset makes any further conclusions unnecessary.

Clearly, there are few such rivers as the Rhône which, in the diversity of their equipment, recapitulate the progress made by man in the conversion of natural power resources. All the more interesting is it for us to study that river which Nature has placed in our country; a river whose long, civilized and glorious past has by no means exhausted its fertility, since it is now called upon to supply us with a great proportion of the power France may draw from its hydraulic resources.

Power for Industrial and Agricultural Development

PAUL J. RAVER

ABSTRACT

The Pacific Northwest offers an excellent practical example of the use of hydro-electric power as a tool in the conservation and development of valuable and exhaustible natural resources. The construction of large multiple-purpose dams on the Columbia River, in the north-west corner of the United States, has given this region a large new energy base, the lack of which had handicapped industrial growth in the past and forced the growing population to exert an increasing pressure on exhaustible forest and agricultural resources. Low-cost electric power, available in large blocks, brought electro-process industries to the region. Some of these made use of imported raw materials such as bauxite for aluminium; others made use of the region's complex, refractory ores, some of which could be refined feasibly only by means of an electrolytic or electrothermic process. In other instances, the availability of electric power for industry has greatly extended the resource base. An example is to be found in the lumber industry where the substitution of central station electric power for power generated locally in sawdust-fired steam plants has released an important new raw material to form the basis of several new manufacturing processes. An extensive transmission grid system, connecting all the multiple-purpose projects and extending to the various load centres, facilitates the integrated operation of both the hydraulic and electrical features of the project. Along with a uniform rate, it is also encouraging the decentralization of both industry and community development. This tendency, along with a greatly increased consumption of electric power in the home, is doing much to increase standards of living and to improve the general well-being of all the citizens in the region.

The United States has earned an unenviable reputation as a wastrel in the utilization of natural resources. While the allegation cannot be denied, it is probably true that our actions have not been much different from those which usually take place in a frontier economy where natural resources are plentiful and man-power scarce. It is true that we are still too much engaged in utilizing only prime resources, discarding much of Nature's scarce irreplaceable products. However, it is also true that these situations are generally becoming the exception rather than the rule. The evidence is unmistakable that this country is emerging into a mature economy characterized by a more careful husbandry of our natural resources and the fullest utilization of those resources that known technical methods will allow. In every phase of modern industry a prominent expression today is the word "by-product". We have a common expression in the United States with respect to the meat industry, that it "uses every part of the hog except the squeal". This trend toward a higher degree of utilization is evolving in each of our major industries.

My specific assignment is in the field of power and the ways in which power has been effective in the development of industry and the more complete utilization of natural resources. Two of the best examples that I know of in my country are to be found in government. Specifically, they are found in the experience of the Tennessee Valley Authority and the Bonneville Power Administration. The former is active in the Tennessee Valley in the south-eastern part of this country. The Bonneville Power Administration operates in the Columbia River Valley of the Pacific Northwest. In the observations that follow I shall restrict my remarks to the latter where in the last ten years I have had the experience of seeing the hydroelectric development of this country's greatest power stream initiate a significant transformation of industry and resource utilization.

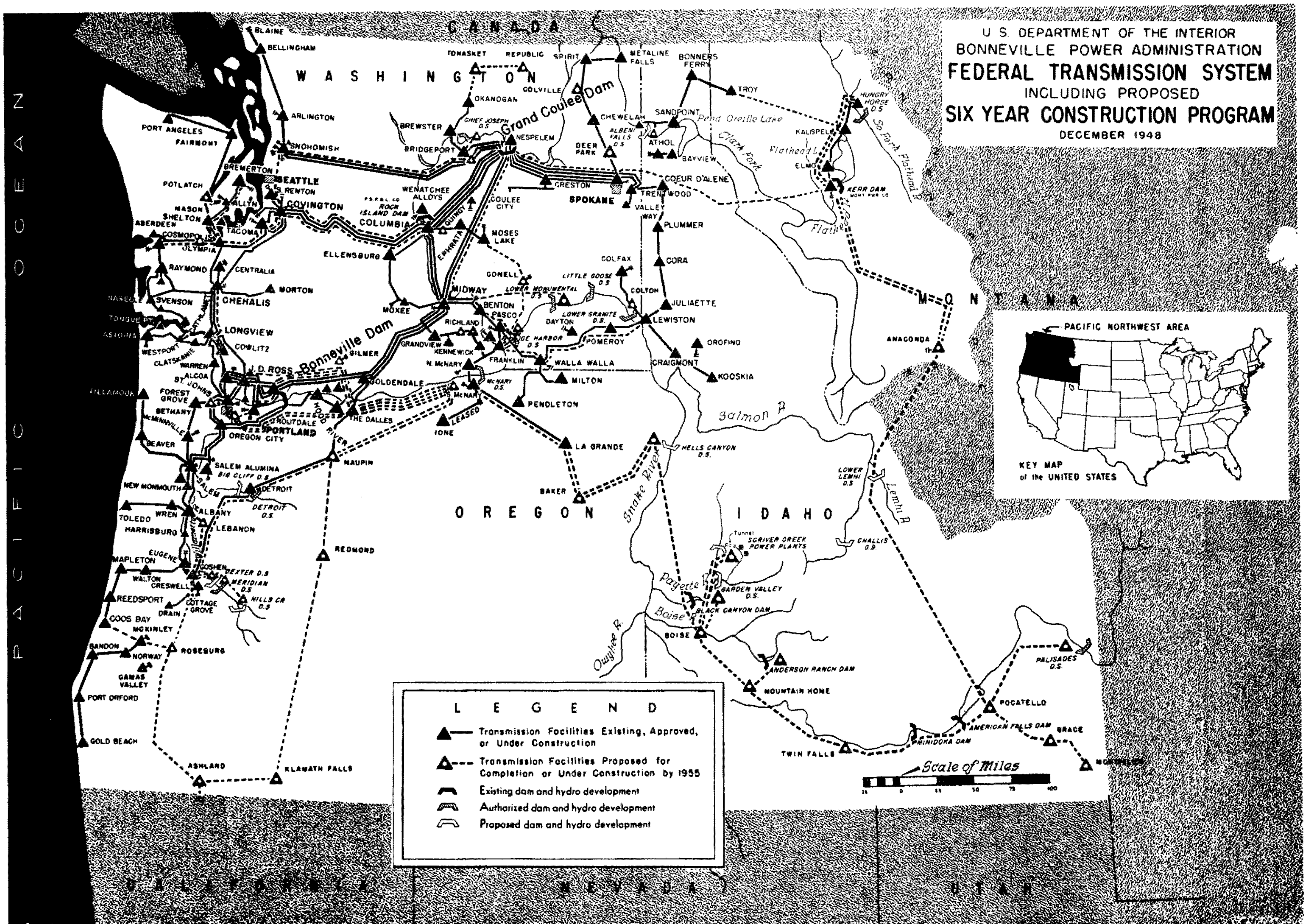
To understand fully what has taken place in the Pacific Northwest, it is necessary to describe briefly a few of the outstanding physical characteristics of this region. In the first place the region has a most unusual "energy base". Unlike most other parts of the United States, the Northwest is deficient in all three of the principal industrial fuels: coal, petroleum, and natural gas. But in another respect we exceed all other sections of our country. Forty per cent, or 30 million kw., of the total undeveloped hydroelectric energy in the country is to be found in the United States portion of the Columbia River and its tributaries. Heavy rainfall and snowfall in the higher altitudes that fringe a large drainage area are responsible for this great hydroelectric power potential.

A similarly high precipitation along the coastal area is also responsible for the region's great timber assets. The Pacific Northwest is the home of the great Douglas fir, lumber from which is utilized extensively in all parts of the world. Although our great stands of Douglas fir and Ponderosa pine have been cut at a rate far in excess of their rate of growth, we are beginning to make progress in stabilizing this industry on a perpetual sustained yield basis.

Agriculture, another important activity, is also greatly influenced by precipitation. Large portions of our fertile soils are in areas deficient in rainfall, and other areas, in spite of a heavy winter rainfall, have a period of summer drought that requires supplemental irrigation. Thus any expansion in agriculture will require the wise utilization of water resources.

The region is known to be well mineralized, but its mine development has not been outstanding with the exception of copper mining in western Montana and the silver-lead-zinc mining activities of northern Idaho. Many of the known ore deposits are of complex, refractory minerals for which treatment techniques have emerged only during recent years. By and large these new techniques call for either electrolytic cell or electric-furnace methods of refining.

Into this situation, which I realize I have described much too briefly, has been introduced the availability of large blocks of low-cost electric energy. This came about with the construction by the federal Government of Bonneville Dam, completed in 1938, and Grand Coulee Dam, completed in 1940. The completion of these multiple-purpose dams, for navigation-power and irrigation-power respectively, made available very large blocks of electric power at prices that definitely made it a competing form of industrial energy. Already this


U. S. DEPARTMENT OF THE INTERIOR
BONNEVILLE POWER ADMINISTRATION
FEDERAL TRANSMISSION SYSTEM
INCLUDING PROPOSED
SIX YEAR CONSTRUCTION PROGRAM
DECEMBER 1948
LEGEND
Transmission Facilities Existing, Approved, or Under Construction
Transmission Facilities Proposed for Completion or Under Construction by 1955
Existing dam and hydro development
Authorized dam and hydro development
Proposed dam and hydro development
Scale of Miles
PACIFIC NORTHWEST AREA
KEY MAP of the UNITED STATES
CANADA
WASHINGTON
OREGON
IDAHO
MONTANA
CALIFORNIA
NEVADA
UTAH
PACIFIC OCEAN
Grand Coulee Dam
Bonneville Dam
BLAINE
BELLINGHAM
ARLINGTON
PORT ANGELES
FAIRMONT
SNOHOMISH
BREMERTON
SEATTLE
RENTON
POTLATCH
MASON
SHELTON
ABERDEEN
COSMOPOLIS
OLYMPIA
TACOMA
COVINGTON
RAYMOND
CENTRALIA
CHEHALIS
MORTON
LONGVIEW
COWLITZ
WESTPORT
CLATSKANIE
J.D. ROSS
FOREST GROVE
BETHANY
TROUTDALE
PORTLAND
OREGON CITY
BEAVER
SALEM ALUMINA
BIG CLIFF D.S.
DETROIT
DETROIT D.S.
NEW MONMOUTH
TOLEDO
WREN
ALBANY
HARRISBURG
LEBANON
MAPLETON
EUGENE
WALTON
CRESWELL
GOSHEN
DEXTER D.S.
MERIDIAN D.S.
HILLS CR D.S.
REEDSPORT
DRAIN
COTTAGE GROVE
COOS BAY
MCKINLEY
BANDON
NORWAY
ROSEBURG
CAMAS VALLEY
PORT ORFORD
GOLD BEACH
ASHLAND
KLAMATH FALLS
REDMOND
MAUPIN
THE DALLES
HOOD RIVER
GOLDENDALE
GILMER
IONE
LEASED
McNARY
McNARY D.S.
N. McNARY
PENDLETON
LA GRANDE
BAKER
HELLS CANYON D.S.
TONASKET
REPUBLIC
SPIRIT
METALINE FALLS
BONNERS FERRY
TROY
COLVILLE
OKANOGAN
CHIEF JOSEPH D.S.
BREWSTER
BRIDGEPORT
NESPELEM
CHEWELAH
ALBENI FALLS D.S.
SANDPOINT
Pend Oreille Lake
ATHOL
BAYVIEW
DEER PARK
GRESTON
SPOKANE
TRENTWOOD
COEUR D'ALENE
VALLEY WAY
PLUMMER
CORA
COLFAX
COLTON
JULIAETTE
LEWISTON
OROFINO
CRAIGMONT
KOOSKIA
WENATCHEE
ALLOYS
ROCK ISLAND DAM
COLUMBIA
COULEE CITY
QUINCY
EPHRATA
MOSES LAKE
ELLENSBURG
MOXEE
MIDWAY
CONELL
LITTLE GOOSE D.S.
LOWER MONUMENTAL D.S.
LOWER GRANITE D.S.
BENTON
PASCO
RICHLAND
DAYTON
POMEROY
GRANDVIEW
KENNEWICK
FRANKLIN
WALLA WALLA
MILTON
Salmon R.
Snake River
Clark Fork
Flathead L.
HUNGRY HORSE D.S.
So. Fork Flathead R.
KALISPELL
ELMO
KERR DAM
ANACONDA
LOWER LEMHI D.S.
Lemhi R.
CHALLIS D.S.
SCRIVER CREEK POWER PLANTS
Payette R.
GARDEN VALLEY D.S.
BLACK CANYON DAM
Boise R.
BOISE
Owyhee R.
ANDERSON RANCH DAM
MOUNTAIN HOME
TWIN FALLS
MINIDOKA DAM
AMERICAN FALLS DAM
POCATELLO
PALISADES D.S.
GRACE

low-cost electric power has attracted several electro-process industries, and today the region produces half of all aluminium ingots produced in the United States. Other industries in this electro-process group already attracted to the region include the manufacture of ferro-alloys, calcium carbide, powdered iron, hydrogen peroxide, abrasives, chlorine, caustic soda, and electrolytic zinc. Thus, for the first time in its one hundred years of economic activity, there has been introduced into the Pacific Northwest a type of industry distinctly different from, and independent of, the traditional stand-bys of lumbering and agriculture which placed such great emphasis on the rapid liquidation and export of irreplaceable natural resources.

In the absence of cheap coal and oil and natural gas this region, in former years, placed heavy emphasis on the generation of steam electric power by burning waste wood. The proportion of saw-log cut that has been available for this lower economic use is truly staggering. The Forest Service estimates that less than half of the volume of logs felled in the forest are finally processed into a marketable product. But here, too, progress is being made and hydroelectric power is playing an important part. Several new processes for utilizing these "wastes" in the manufacture of pulp, wallboard, Kraft paper, and wood-derived chemicals, have been perfected in recent years. They are being adopted extensively and represent perhaps the best example that the region has to offer of the growth of new industries based on raw materials that formerly were largely wasted. Columbia River power is playing a significant role in this development, because all of these new processes require considerable amounts of electric power. Furthermore, the sawmills which formerly used waste wood to generate their own electric power now purchase central station electric power not only for these new processes but for their entire integrated manufacturing operations.

Prior to the construction of the large federal projects on the Columbia River, steam plants were already shifting from the use of sawdust to oil. This change to oil was necessary because of the inability to depend on wood waste in those communities that had lost or were losing sawmills, the industry having moved on to areas with a more abundant and easily accessible supply of logs.

With the construction of the large federal projects it has been possible to shift again, this time from oil to hydro, thus placing a greater dependence on a continually rechargeable resource and saving our irreplaceable oil supply for other uses. At the same time, this development harnesses the great river to obtain for the people other benefits such as irrigation, navigation, recreation and control of floods.

In another instance low-cost power makes possible the practical utilization of a very important natural resource, namely, the large phosphate rock deposits of the states of Montana, Wyoming, Utah, and Idaho. A large proportion of these deposits are of such grade that their most economic beneficiation is possible only by means of electrothermal processes. As soon as additional dams and adequate transmission lines to the mining areas are constructed, low-cost electric power will release a great natural resource for the manufacture of a product sorely needed by agriculture and industry in all parts of the world. Here again the relation of various resources is apparent. The fertilizer which results from processing the phosphate rock by use of hydroelectric power will maintain the fertility of the soil in a large portion of the nation.

In another completely different way, the development of the large multiple-purpose projects on the Columbia River has aided resource development without encouraging undesirable exploitation. They have done this by aiding greatly in financing the largest irrigation project in this country. The Columbia Basin irrigation project in the State of Washington will eventually transform about a million acres of semi-arid but fertile soil into a highly productive agricultural area of diversified farms and small manufacturing establishments. This is made possible by the fact that even with the lowest rate for electric power in the country it is still possible to earn a sufficient surplus to pay approximately three-fourths of the irrigation construction costs on this large project.

In the past, the Pacific Northwest has been characterized by very sparse population. It has lacked the density of population that is ordinarily necessary to justify the establishment of small manufacturers. Partly as a result of the developments described above, the situation has changed dramatically in recent years. In fact, the population of the Pacific Northwest since 1940 has increased by 36 per cent, faster than that experienced by any other regional group of states in the country, and well above the national average, which was 11 per cent. As a result of this growth, it is now possible for more of our population to find their employment in one of the service industries or in small manufacturing, thus relieving the pressure for the rapid exploitation of timber and other scarce resources. Where formerly the choice of occupation was narrowly limited to the field of resource exploitation, today that field is considerably expanded and will continue to expand at an even greater rate as time goes on.

There is another group of important benefits for which low-cost electric power can take much responsibility. Some of these are non-economic in character, but nevertheless they are of great importance in the orderly development of a new region. In developing the Columbia River by construction of multiple-purpose projects, it has been obvious that maximum benefits can be obtained only by designing the facilities for an integrated operation of the various facilities on the river. To secure this integration, we have constructed a 3,393 mile high-voltage transmission grid connecting the power plants at the dams and extending to the various load centres in the region. This electrical interconnexion not only has resulted in important net additions to prime power but also has provided an indispensable tool for the management of the river itself from its headwater to its tidewater. This will become increasingly important as additional projects are constructed. The transmission system has made it possible to adopt the policy of what we call the postage-stamp rate for electric power. This means that our rate is the same in all parts of the region whether use of the power is made within a few miles of the dams or in the farthest corner of the area accessible by our transmission lines. As a result we have introduced an important factor in the direction of decentralization of industry and, therefore, also of population and community development. Thus, electric power is helping to avoid one of the principal objections to modern industrial civilization — the inordinately heavy concentration of people in large industrial centres which in-

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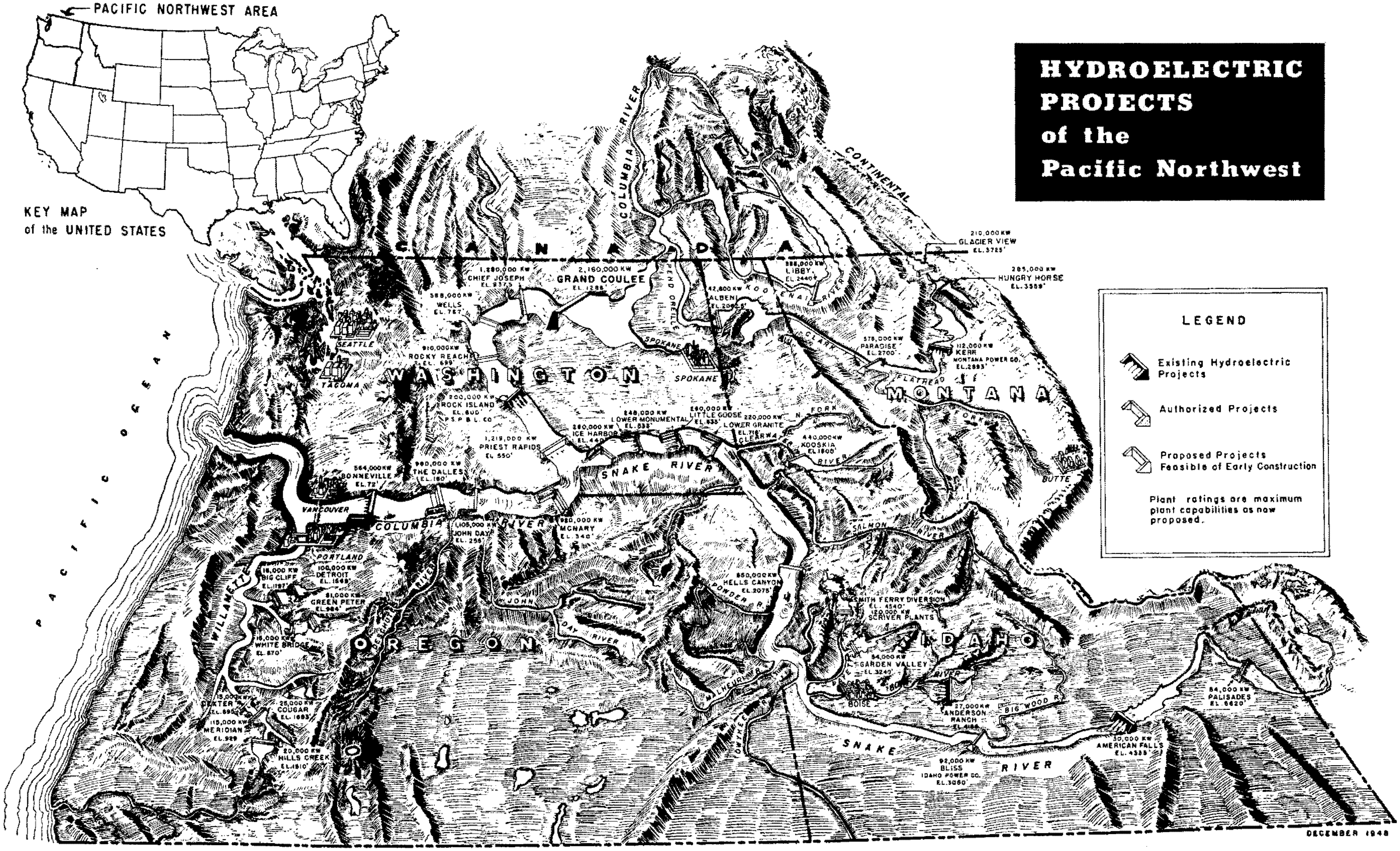


PACIFIC NORTHWEST AREA
KEY MAP of the UNITED STATES
HYDROELECTRIC PROJECTS of the Pacific Northwest
LEGEND
Existing Hydroelectric Projects
Authorized Projects
Proposed Projects Feasible of Early Construction
Plant ratings are maximum plant capabilities as now proposed.
CANADA
WASHINGTON
OREGON
IDAHO
MONTANA
PACIFIC OCEAN
CONTINENTAL
COLUMBIA RIVER
SNAKE RIVER
SALMON RIVER
SEATTLE
TACOMA
SPOKANE
VANCOUVER
PORTLAND
BOISE
BUTTE
210,000 KW GLACIER VIEW EL. 3725'
285,000 KW HUNGRY HORSE EL. 3559'
112,000 KW KERR MONTANA POWER CO. EL. 2893'
1,280,000 KW CHIEF JOSEPH
2,160,000 KW GRAND COULEE EL. 1288'
KOOTENAI RIVER
LIBBY
ALBENI
PARADISE EL. 2700'
WELLS
ROCKY REACH
ROCK ISLAND P.S.P.&L. CO.
1,219,000 KW PRIEST RAPIDS EL. 550'
ICE HARBOR
LOWER MONUMENTAL
LITTLE GOOSE
LOWER GRANITE
KOOSKIA EL. 1600'
564,000 KW BONNEVILLE EL. 72'
980,000 KW THE DALLES
1,105,000 KW JOHN DAY
980,000 KW MCNARY EL. 340'
DETROIT
BIG CLIFF
GREEN PETER
WHITE BRIDGE
DEXTER
COUGAR
MERIDIAN
HILLS CREEK
WILLAMETTE
JOHN DAY RIVER
850,000 KW HELLS CANYON EL. 2075'
SMITH FERRY DIVERSION
SCRIVER PLANTS
GARDEN VALLEY
ANDERSON RANCH
BIG WOOD R.
84,000 KW PALISADES EL. 5620'
AMERICAN FALLS
92,000 KW BLISS IDAHO POWER CO. EL. 3060'
DECEMBER 1948

variably brings with it the evils of congestion, ugliness, uncomfortable living, and social strains.

In the rural areas lower-cost power is also responsible for a very significant change. Today in the Pacific Northwest, 96 per cent of our farms are electrified. I have no way of measuring but shall leave it to your imagination to assess the amount of drudgery that has been eliminated and the improvement in living standards that has been made possible by this widespread utilization of electricity by rural people. We have found that standards of living in our rural areas are improving more rapidly, principally because of the availability of electric power, than in any other segment of our population. The heaviest utilization of energy by domestic customers is on the farm, and it is growing at a more rapid rate than domestic consumption in the city. Already the consumption by all domestic users is two and one-half times the average rate of consumption for the United States as a whole, and that rate, too, is continuing to rise very rapidly, having doubled since the end of the war.

In the preceding remarks I have described how the development of a particular resource, in this case hydroelectric power, has played an important part in the conservation and development of valuable and exhaustible natural resources. I have cited the example of the Columbia River power development programme of the federal Government in the Pacific Northwest. In this relatively new region, where the exploitation of lumber and agricultural resources has been going on at an excessive rate, the introduction of large blocks of low-cost electric energy has done much to reverse the trend. It has substituted the power of falling water where formerly there was a heavy dependence on other fuels, including wood waste. I have pointed out that this so-called wood waste, partly because of the availability of hydroelectric power, is fast becoming the basis of new industries that formerly did not exist in the region. But low-cost electric power has done even more. It has introduced completely new industrial processes into the region. Some are making use of low-grade ores that were formerly considered not feasible for exploitation. The availability of employment in these occupations has lessened the pressure on the rapid liquidation of our forest and agricultural resources, a pressure which is increasing as more and more people come into the region.

Finally, our method of marketing electric power in the Pacific Northwest has introduced a strong motive for the decentralization of industrial activities, and such decentralization, along with a greatly increased domestic consumption of electric power, is doing much to increase standards of living and to improve the general well-being of all the people in the region.

Power for Industrial and Agricultural Development in Finland

E. K. SARAOJA

ABSTRACT

The article first gives statistical data of energy production during the years 1930 to 1948, and explains the reasons for the set-back during the Second World War.

The different power resources utilized in the country are then scrutinized. Water-power is the chief resource, and an account is given of its present scope, of the plans for future expansion and of the ultimate potential possibilities.

Lastly the different uses of electricity are described. The industries take the biggest share, but the use of electricity for domestic purposes is rapidly increasing, and rural electrification especially is making great progress since the war.

PRODUCTION OF ENERGY

The gross production of electrical energy during the years 1930 to 1948 is given in Figure 1, sub-divided into water-power, back-pressure steam power and condensed steam power. The water-power includes also the directly coupled mechanically used water-power, converted to electrical units.

The figure gives the amounts of energy in logarithmic scale, so that the trend of the percentage yearly increase can easily be seen. In the years 1930 to 1938 the average yearly increase was 13 per cent, which corresponds to a redoubling in six years. After that the production declined abruptly, mainly for the following reasons:

During the years 1940–1943 and 1947–1948 exceptional droughts prevailed, which were worse than any encountered during the 100 years from which exact statistics are available, and which caused severe restrictions and rationing in the use of electricity;

During the war years very limited amounts of foreign fuels (coal and oil) were obtainable, and industrial activities were slack;

In the peace treaties about one-fourth of Finland's established water-power was ceded.

UTILIZATION OF DIFFERENT POWER RESOURCES

WATER-POWER

Potential resources: In order to give an idea of the theoretical total amount of water-power in Finland, Figure 2 shows the altitude contours of the country, Figure 3 the approximate resulting height characteristic.

The average yearly precipitation is 59 centimetres, and of this amount slightly over half flows to the sea, while the rest evaporates. Thus the average water-flow is about 1 cub. metre per second for each 100 sq. km. of a drainage area. The corresponding theoretical value of the mean water-power in the whole country would be about 3,500 mw. and the yearly amount of energy about 30×10^6 mwh.

The actual amount of energy which it would be technically and economically possible to obtain by a mean flow has been estimated at about 10×10^6 mwh. yearly. In the future when power-station techniques have developed and the demand for power increases this estimation can perhaps be somewhat extended.

Production of Electrical Energy During 1930–1948

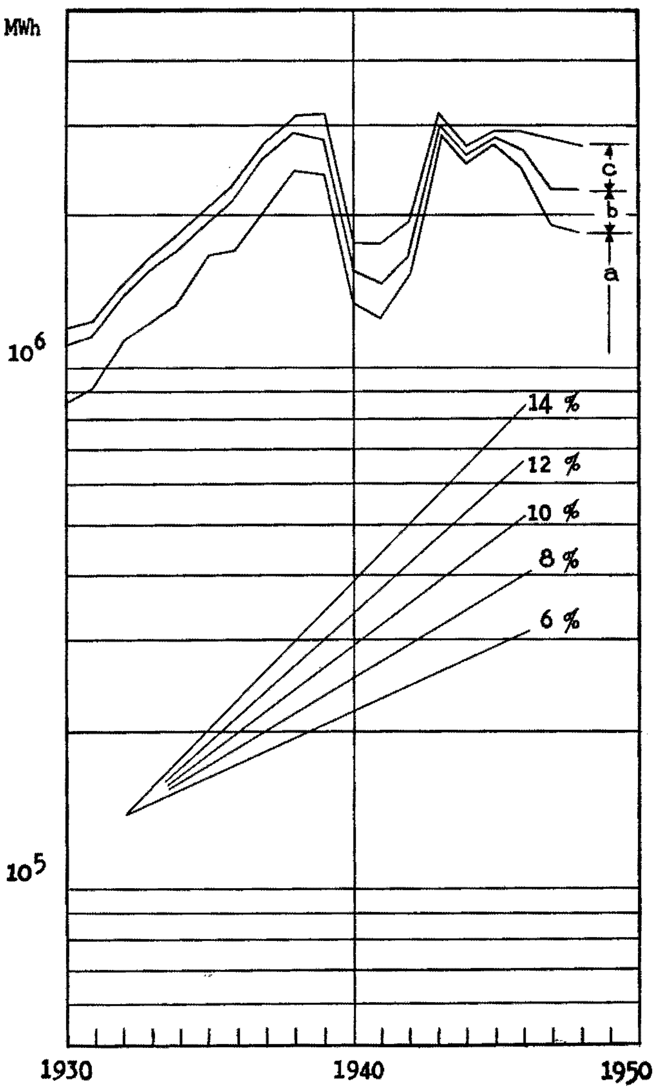


Figure 1

a = water power
b = back-pressure steam power
c = condensed steam power

Figure 4 shows the lakes and watercourses in Finland.[1] The five main rivers, which comprise two-thirds of the total potential water-power of the country, are named in the figure and are shown as thick lines.

Utilization of resources. After the wars the water-power installations totalled 440 mw., and the yearly energy by a mean flow would have been about 2.5×10^6 mwh. The power stations were situated mainly in the south of Finland, because the consumption of electricity is concentrated there, and the waterfalls could be built very favourably as the flow in the rivers is made fairly even by the great lakes in the centre of the country.

So as to compensate for the great set-back suffered by the power industry during the war, drastic measures were taken in 1945–1946 to finish certain water-power stations that were under construction, and to start the building of eleven large new power stations which eventually will have twenty-six generators. The first of these stations went into operation in 1948, most of them will be running by 1950, and by 1952 they will all be completed. The total amount of installed water-power will then be increased to 800 mw., and the yearly amount of energy will be by mean flow about 4.5×10^6 mwh.

Altitude Contours of Finland

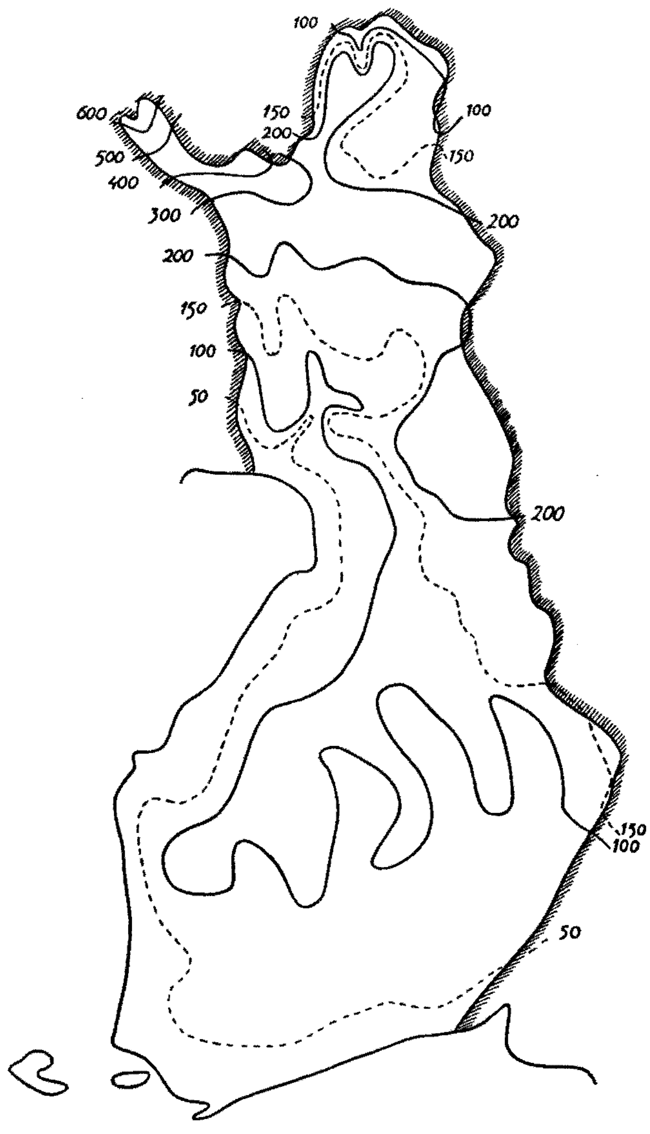


Figure 2

[1] Figure 4 owing to technical difficulties is not being reproduced. The five rivers referred to are the Kemi, Oulu, Kokemäki, Kymi and Vuoksi.

Of these eleven water-power stations six are in the south of Finland, and with their completion practically all available water-power in the southern part of the country will be harnessed. Thereafter additional water-power stations can be built only in the north.

Technical design. The height of the water-fall in most power stations is very moderate, usually 10 to 20 metres. The stations generally have three vertical generators, the turbines being mostly of the Kaplan type with adjustable runner blades, and the generators are directly coupled to the turbines. Only in two pre-war stations with exceptionally low heads have gearings been used.

The total capacity of the generators corresponds usually to 1.5 times the mean flow. A basin above the power station is arranged by damming so that at lower-water flow an effective regulation can be attained at least within every twenty-four hours.

No yearly regulation has yet been arranged except at the top lakes of Kokemäki River, but very soon it will be possible to regulate also the rivers Vuoksi and Oulu, when the corresponding power stations at the river heads will be completed.

The questions of log floating and fishing are usually interconnected with the building of a new water-power station, and because of obsolete water legislation complicated legal disputes have often occurred. The present solution for log-floating is that the builder of the power station also constructs a by-pass trough for log-floating and compensates the log-floating concerns for 1.5 times their direct material losses caused by damming the river, but pays no other compensation.

So-called fish-steps (small basins in series) or fish lifts have been constructed to enable migrating fish to by-pass power stations on their yearly trips upstream. These devices have nevertheless been rather ineffective or they have wasted too much water. Attempts have also been made to rear fish and plant them above the power stations, but even this has not succeeded very well. The whole question of fishing versus power stations has now been taken up for a thorough investigation so as to find the best solution.

Future developments. Although the critical power shortage will end when all the power stations started in 1945—1946 will have been finished, yet a sound economic development would require a steady increase of power resources, such as occurred before 1939. For the time being the building of two new power stations should be started every year. Because of lack of funds, however, no new stations were started in 1947—1948, but quite recently the decision was made to start two new ones.

Although the building of new stations thus tends to be an uneven development, all the main potential water-power resources in Finland will be harnessed at least within the next twenty years. After that additional water-power might perhaps be obtained from Norway. The potential water-power resources in the different countries of Fenno-Scandia are as follows:

			Per cent.
Norway ..	120×10^6 mwh./year	=	67
Sweden ..	50×10^6 mwh./year	=	28
Finland ..	10×10^6 mwh./year	=	5
Denmark .	0×10^6 mwh./year	=	0
Total =	180×10^6 mwh./year	=	100

Power transmission. At first the transmission voltage in the Finnish trunk lines was 110 kv., a voltage that was quite adequate so long as the main power stations and consumer centres were in the south of the country. Simultaneously with the building of the first big water-power stations in the north of Finland, a 220 kv. transmission line was built for connecting with the south, and a second 220 kv. line is projected. Later a transmission voltage of 380 kv. may have to be adopted as in Sweden. The voltage depends on future industrial developments — whether additional water-power will have to be transmitted mainly to the south of Finland, or whether new power-consuming industries will appear in the north.

The transmission of water-power from Norway to Finland in the future will probably be technically and economically feasible as soon as high-voltage, direct-current transmission has been developed in a practical way. Then water-power could be transmitted directly from the south of Norway to the south of Finland, perhaps by using the sea as one conductor.

Approximate Height Characteristics of Finland

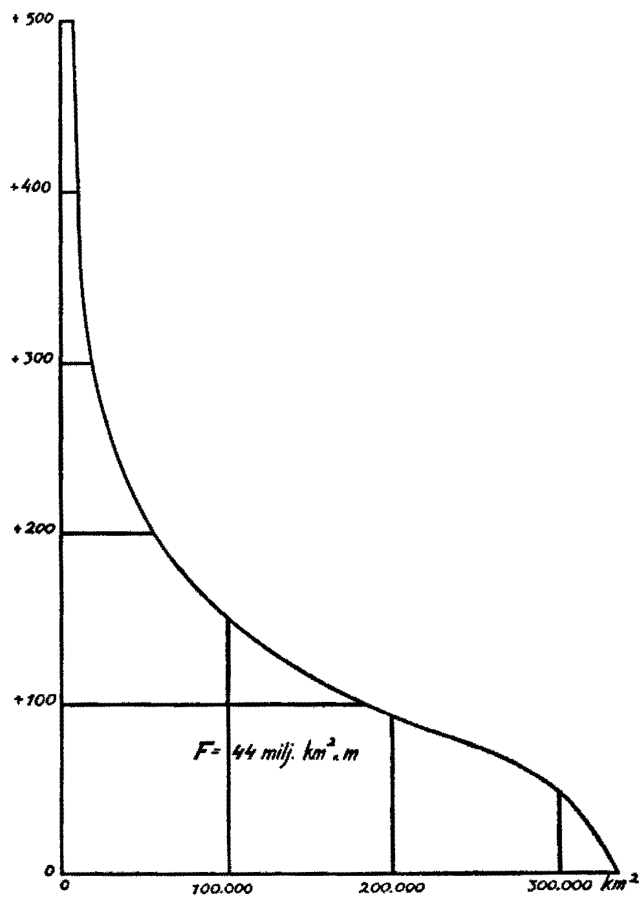


Figure 3

STEAM POWER

The capacity of back-pressure and condensed steam plants was about 474 mw. in 1946, i.e., somewhat more than the

Electrical Energy Used For Different Industrial Purposes

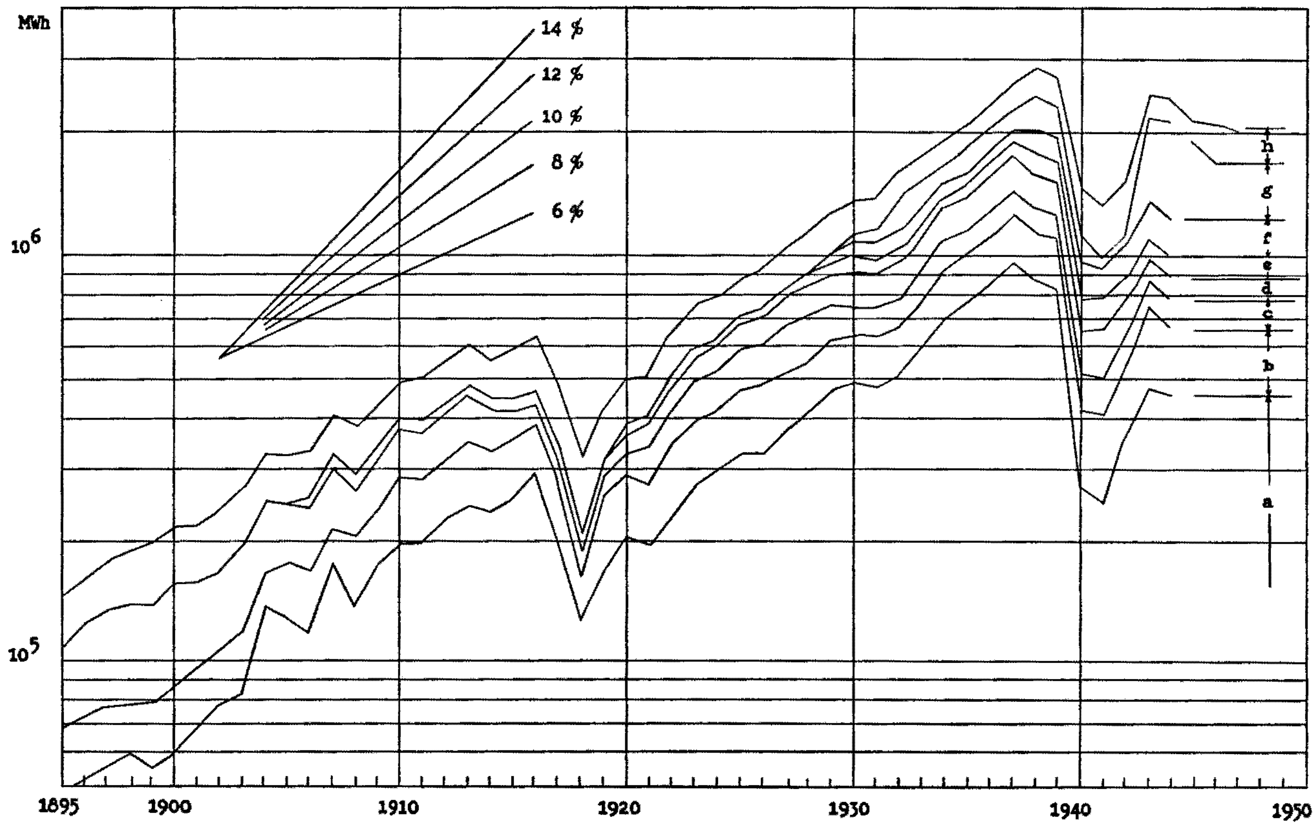


Figure 4

a = pulp and wallboard industries
b = paper industry
c = timber industry
d = sulphite cellulose industry
e = sulphate cellulose industry
f = electrical furnaces
g = electrical boilers
h = other industries

capacity of the water-power plants (440 mw.). In the near future this ratio will be reversed.

Before the war the yearly amount of energy developed by steam was about one-fourth of the total energy production, as shown in Figure 1, and the major part of the steam energy was produced by back-pressure plants. During the exceptional war conditions the steam energy was in some years even less than one-tenth of the total energy production.

Back-pressure steam power. Back-pressure steam-power is developed mainly in conjunction with process steam in wood industries. Thus many paper and cellulose factories obtain nearly all their energy as back-pressure power, and only small quantities of additional power are needed. Machine capacities are usually 1 to 5 mw. though in a few cases they amount to 10 mw. As fuel, in addition to waste wood, coal is mainly used (except during the war), and smaller quantities of wood and peat. The sulphate cellulose factories have also a considerable fuel resource in the waste lye. The corresponding problem in the sulphite cellulose industry is yet to be solved.

Condensed-steam power. Condensed-steam power is used in industries in addition to water-power and back-pressure power, and also in municipal power stations and the State-owned central steam-power station for public consumption. The biggest units are two 30-mw. units at two stations, and last year two additional 30-mw. units were ordered for these same stations. As nearly all the large industrial and municipal plants are now connected to the main 110-kv. transmission net, the trend is for adding condensed-steam power mainly at central stations in as large units as possible.

In connexion with the condensed-steam power station of the capital, Helsinki, district heating has been contemplated in order to increase the thermal efficiency.

INTERNAL COMBUSTION ENGINES AND GAS TURBINES

Internal combustion engines are used in small power stations as additional and stand-by power, but their total capacity is only about 2 per cent, and their yearly energy output
No gas turbines are yet in use in Finland, but they have
only about 0.2 per cent of water and steam power.
been contemplated in connexion with certain blast-furnaces, and their possible use in other connexions also has roused considerable interest.

ATOMIC POWER

There are in Finland no known sources of heavy elements, which now are considered necessary for atomic power generation. Consequently if this is at some time developed to a practical and economical level, Finland will be completely dependent on foreign imports, as it is also on imports of coal and oil at present.

It might be mentioned that there is in Finland a fairly rich find of titanium ore, which might become of significance if titanium should prove to be a suitable building material in future atomic power-station constructions.

USES OF ELECTRICAL ENERGY

The following table gives the amount of electrical energy used for different purposes in 1946, and the consumption per inhabitant:

	Mwh.	*Per cent*	*Inhabitants*	*Kwh./inh.*
For industrial purposes	2.13×10^6	82	—	—
For domestic purposes:				
In urban areas ..	0.31×10^6	12	1.2×10^6	260
In electrified rural areas ...	0.15×10^6	6	1.7×10^6	90
In non-electrified rural areas ...	—	—	3.9×10^6	—
Total	2.59×10^6	100	3.9×10^6	660

INDUSTRIAL USE

The table above indicates that the main part of all electricity generated is used for industrial purposes. In fact, the development of power generation has always been closely connected with industrial development.

Figure 5 shows the amounts of electrical energy used for different industrial purposes from 1890 to 1948, all directly-coupled mechanical energy being included. The scales in Figure 5 are the same as in Figure 1.

It can be seen that the biggest consumer of energy has been the wood-grinding industry, i.e., the pulp industry. It is based solely on water-power, and even now uses a large amount directly coupled. As the available water-power undergoes yearly variations, this industry has become seasonal in part. As the energy consumed per unit of production is very high, it is not economically possible to fill in with steam-power.

Other industries based on water-power and hence partly seasonal are some metallurgical industries, e.g., the silicon-steel industry.

Most of the so-called tertiary water energy, which is only available on random occasions, is now used in electrical boilers by those industries that need process-steam. The electrical boilers are cheap to install, and the use of surplus energy in the boilers permits the saving of a corresponding amount of fuel, chiefly coal.

Since the war many projects have been suggested for increasing the use of electricity in industries within the possibilities of modern techniques, but the lack of funds and the shortage of power have greatly restricted these efforts.

DOMESTIC USE

Practically all households in urban areas are provided with electricity. The higher *per capita* consumption of electricity in urban areas is chiefly the result of the use of electricity for cooking. This use increased fairly rapidly at the end of the last decade, but was greatly hampered during the war years. In Finland the use of electricity for cooking has great potential possibilities, as there are gas works in only two towns.

Rural electrification was restricted before the war mainly to the more densely populated parts of the country (average 18 inhabitants per sq. km.). In the non-electrified areas (average 5 inhabitants per sq. km.) paraffin oil was used for lighting and small steam locomobiles and internal combustion or horse-driven engines for power. During the war only very restricted quantities of oil were available, a shortage that gave strong impetus to rural electrification. Six large electrification companies were formed for this purpose. Their plans will be fulfilled within the next two years, and the number of electrified households in rural areas will be increased from 50 to 80 per cent.

Without doubt the *per capita* consumption will also increase in rural areas. Recently, electricity rates have been modernized and standardized, and research work has been carried out concerning the possible uses of electricity in the improvement of living conditions in the countryside.

With respect to technical details it may be mentioned that the consumer voltage throughout the country has been standardized at 220/380v., 3-phase A.C.; 6 kv., 10 kv. or 20 kv. are used as the distribution voltage in urban areas, but only 20 kv. in rural areas.

Bibliography

1. *Teknillinen Aikakauslehti (Technical Journal,* a Finnish periodical), 1947, pages 102–107, 363. List of literature concerning water-power and water-power stations in Finland, containing 266 references.
2. *Sahkotarkastuslaitos (Electrical Inspection Commission), Sahkolaitostilasto,* 1946 *(Statistics of electricity supply undertakings in 1946),* Helsinki (English summary).
3. *Voima ja Valo (Power and Lighting,* a Finnish periodical), various articles.

Harnessing the Wind for Electric Power

PERCY H. THOMAS

ABSTRACT

Giant turbines can now be constructed. This engineering accomplishment follows from the highly specialized research in the aerodynamics of the airplane and from the successful operation of the 1,250 kw. Smith-Putnam turbine in Vermont, U.S.A. While the delivery of wind energy is intermittent, low-cost firm wind-power can be secured by operation as an auxiliary in a large utility network containing sufficient hydro storage. Energy from the reservoirs is borrowed and returned at relatively short intervals. On account of the leanness of the energy in the wind, structures of very large dimensions are required.

By accepting somewhat higher power cost, wind-power may be utilized in many areas where fuel and hydro are limited or are not available at satisfactory costs.

The selection of the most favourable turbine sites, which should have high average wind-velocities, requires careful investigation.

Weather bureau observations indicate that annual and monthly averages of the hourly wind-velocities at their stations are surprisingly constant; thus promising long-time stability in the wind energy. The diversity between the patterns of the wind at different stations appears to be very helpful in firming wind-power.

The author outlines a complete study-design for a 7,500 kw. aerogenerator, together with an estimate of its cost.

Among Nature's many generous sources of energy, the wind stands unique. It is delivered free, and in all countries; it is unlimited in extent; when utilized it leaves no ashes or poison gases; it is not subject to interruption, and its price does not change. But Providence has teased would-be users by making the energy content of the wind exceedingly lean and the supply uneven. Thus Nature's offer of wind-power is a challenge to the engineer, and has been for some thousands of years.

It is necessary on this occasion to resist the temptation to recount the many ingenious and often surprisingly successful wind-power projects of the past; implementing the world's commerce on the seas for thousands of years and even to our time; driving Holland's famous drainage pumps until the advent of cheap electric-power; also Britain's ten thousand windmills, grinding grain and doing chores for Englishmen, even grinding sugar-cane on a large scale in Barbados. The outstanding present fact is that now, at long last, engineers are ready to harness the wind and to force it to contribute its due share to the supply of electric-power for all.

Few achievements of research in solving the many and varied riddles offered by Nature to engineers are more intriguing than that of securing for man the mastery of this familiar but illusive agent. We may be thankful that the new supply of energy has become available at a time when our mounting demands for power promise, within the foreseeable future, to absorb all of our most available hydro-power, and when our reserves of petroleum and natural gas may be needed for preferential uses.

Countries not favoured with an abundance of coal or other fuel may well look hopefully to this source of low-cost energy to build up their supplies of industrial power. This situation is found in many important areas, notably in the southern hemisphere.

The purpose of this paper is to present a realistic view of the ways and means by which bulk electric-power may be obtained from the wind. It is believed that engineers other than aerodynamic experts will be interested to have some understanding of this new development.

At the outset, the author would like to point out that the statement that wind energy is now available for electric utility service is intended to be taken literally, the only reservation being the allowance of a reasonable amount of time and of a sufficient preliminary design effort to produce the first full-sized physical structures. The appropriate design procedures, both aerodynamic and constructional, are now known. There remains, however, for designing and operating engineers, the inevitable educational stage so characteristic of all new developments. No untried types of structures or mysterious aerodynamic principles are involved.

Three principal significant steps have led to the feasibility of the designing of wind turbines for electric utility supply, all previously familiar to engineers in other fields of activity.

First, the use of the principle of impact is essential to the effective operation of the wind turbine. This principle makes use of the same force of inertia that enables the hammer to drive the nail, the projectile to pierce the armour plate, and that enables the hydraulic ram to pump water higher than its source.

To get a concept of the nature of this inertia action in a wind turbine, picture the wind as made up of many, many small parallel filaments of moving air, taken together constituting the complete wind-stream. These filaments would be somewhat similar to the straws in a sheaf of wheat, or to individual rods lying side by side in a bundle. Each filament moves in its own path and has its own inertia. The wind turbine wheel is rimless and consists of a hub and two or three spokes spaced wide apart, known as "blades", similar in form to the familiar airplane propeller. With this wheel revolving at very high speed, a blade cuts across the path of one of these filaments in a small fraction of a second and the filament is brought to an abrupt stop, its inertia simultaneously developing a high momentary shock pressure on the blade.

As the blade proceeds, it cuts across the paths of other filaments at a uniform rate and so has a steady, high pressure impressed upon it. A component of this pressure in the direction of the blade motion drives the wheel. When the blade has passed completely across the path of any filament of air, that filament is stagnated, but the unlimited stream of oncoming air immediately proceeds to re-establish its velocity, ready for the next blade. The time required for this re-establishment of the filament velocity explains the wide spaces provided between blades.

The second step relates to the intermittency and other vagaries of the wind. The difficulty with this unevenness of velocity is overcome by treating wind energy as an auxiliary to the power supply of the present far-flung, highly developed, mixed steam and hydro systems. In such systems difficulties with failing supply are no novelty, for example, in the very familiar case of hydro plants, where dry years are proverbial. This difficulty with dry years is overcome, wherever feasible, by installing seasonal storage reservoirs in the rivers, as is well understood. Energy from these storages is available for bridging low-wind periods, as well as low-water periods. Naturally, such use of its storage to firm wind-power would limit the capacity of a reservoir for supporting hydro. On examination, however, the surprising and very favourable situation develops that the vagaries of the wind are of much shorter duration than those of river stream flow, so that by setting up the "effective" capacity of an aerogenerator as the average output, whatever energy is borrowed from the reservoir in one period to firm the wind, is paid back by the taking over of a portion of the hydro load by the wind turbine at periods of supply above the average. This is not the place to enter into a study of this operation, but an analysis will show that when wind energy is used as an auxiliary in a large, mixed system of steam and hydro, the use of seasonal hydro storage to firm the wind energy puts only a very slight limitation on the ability of the reservoir to serve its normal function.

These large systems have many other difficulties with local supply failure, and reserves of appropriate types are provided. This is routine. Such reserves will often be available for assistance also to the wind supply in emergencies and with little detriment to its other functions. Naturally, this superimposed use of hydro and other reserves is not without its costs and these must be added to the cost of wind-power. According to the studies of the author, they will not ordinarily be found burdensome.

The third step in advance, paving the way for an effective design of the aerogenerator, is based upon the painstaking and exhaustive study of the aerodynamics of the airfoil and of the airplane propeller. The impact nature of the turbine action has already been pointed out, and the fact that the reaction of this shock on the blade, set at an angle to the plane of the wheel, causes the rotary torque force which delivers the power to the wheel shaft. This impact action is characteristic of only the high speed turbine with wide spaces between the blades, leading to the intermittent stagnation and respeeding of the air filaments. It is dominating in the design of effective wind turbines.

It does not take an engineer to understand that the determination of the effect upon the impact forces on the blade produced by the many variable factors, the blade speed, the wind velocity, the shape, thickness and width of blade, its angular setting, the width of the open space between blades, etc., is too complicated for any purely mathematical analyses to solve. There further must be included as disturbing factors uncertain air friction and other wastages. To bring the performance of the wind turbine within the control of the designer required not only careful analysis but also a vast accumulation of adequate, empirical test material.

The long series of experimental and analytical researches on this subject matter during the last twenty or thirty years has finally provided sufficient data so that, with the now available laboratory techniques for tests on model airfoils and turbine wheels in wind tunnels, a definite turbine design may be made with assurance that the result will conform reasonably to expectation, subject only to this model test of the wheel. As a word of caution it may be stated that while there is much in common between the two, the optimum designs of turbine and propeller wheels are far apart.

Economical and ready installation of the huge constructions required for tower and wind wheels to secure effective wind-turbine performance has been greatly forwarded by the development in recent years of notably improved construction equipments.

The somewhat startling dimensions of these large capacity turbines are rendered necessary by the leanness of the energy in the wind. Obviously the wind-turbine profits greatly from its capacity to tap a cylinder of air far larger than its own diameter.

With few exceptions, each of the highly specialized technical advances that have contributed so conspicuously to the high standards of our modern life, has had to deal with some unique and difficult design problems, representing the "price" to be paid for their high efficiency. The hydro plant has its vast bulk, uncertain foundations, and 1,000-year floods; the steam boiler, exceedingly high temperatures and pressures, as well as feed water corrosion and combustion difficulties; the steam turbine, very high speeds, uneven expansion and vibration troubles; the gas engine, high speed, high temperature, low natural efficiency, combustion air and so on. The special "price" to be paid for an effective wind-turbine seems to be limited to the problem of economically constructing giant wheels set on a turntable supported on a high tower, certainly not a staggering task.

By their personal experiences inventors and promoters are well aware of the inborn skepticism of engineers toward new technical ideas. This attitude on the part of engineers is proper and normal enough, in view of the great predominance of impracticable and "crack-pot" schemes that are pressed upon them. But once in a long while a sound innovation comes along and it usually receives the same cold shoulder treatment and may be held back until long overdue. There are many such examples, not always without justification, however. This gives an opportunity for some keen and foresighted engineer to recognize the value of the new project and do the industry a favour by giving it a demonstration.

Something of this sort seems to have happened in the case of the wind turbine. After one or two expensive and conspicuous failures with experimental large capacity wind devices within the last generation, interest seemed to die down, until some ten years ago, when Mr. Palmer Cosslett Putnam of Boston, Massachusetts, determined to build a large-capacity wind-turbine adapted for utility power. He was able to interest several of the best known of our large engineering concerns, under the sponsorship of the S. Morgan Smith Company, to build a wind turbine of 1,000 to 1,250 kw. capacity on a small mountain in Vermont, USA, called Grandpa's Knob. The services of well-known experts in several related lines were obtained — aerodynamic, meteorological, structural, etc. — and the installation was completed in 1941. This was known as the Smith-Putnam turbine and was connected to an operating utility as a source of auxiliary power. It is reported to have been able easily to supply 1,000 kw. to the utility system at the rated wind velocity of thirty miles per hour, and to generate even up to 1,400 kw. in favourable winds.

However, this unit was unfortunate, and had a checkered career. Completed during the war, certain necessary repair parts could be obtained only after extraordinarily long delay, and finally certain fatigue cracks developed in the blade shell and in the internal framing, as reported, leading to structural failure. This unit was then abandoned, apparently as the feasibility of the operation had been established and redesign of the structure to eliminate the defective parts of the original unit would have been unreasonably expensive.

Mr. Putnam reports that this unit was turned over to the utility staff for regular operation early in March 1945, and that it ran continuously on load, night and day, whenever the velocity of the wind permitted, for three weeks, and that it ran uneventfully until the occurrence of this fatigue failure, under a light load, closed its career.

Space will not permit further discussion of this very notable experiment, but the fact that a wind-turbine could be designed and built to successfully deliver 1,000 kw. and operate continuously for hundreds of hours in routine service seems to establish at least the feasibility of wind-power for utility supply. It has served to break the ice and pave the way for further development.

If, thus, large capacity aerogenerators are feasible, it is pertinent to ask, "What are they like?" As engineers are wont to say, "That depends". It is too early to state with finality what type of structure or what regime of operation will in the end be found most effective. Two distinct designs have so far been proposed: (*a*) The Smith-Putnam turbine offers one model; a single 30-ton, 175-foot wheel with two blades, mounted on a slightly inclined shaft on the top of a 125-foot tower, and adapted to be revolved automatically to face the wind. On the same revolving platform with the wheel are the generator and all auxiliaries. Gears are required to speed up the slow wheel rotation to a proper speed for the generator which runs in synchronism with the utility. The blades feather to the wind, under governor control, to vary the load. This turbine installation is shown in Figure I, supplied by the S. Morgan Smith Company. (*b*) After studying this Smith-Putnam turbine and its performance, the author undertook to make a study-design for an aerogenerator of very much larger capacity (7,500 kw.) and one that would avoid some of the difficulties shown by the experience of Grandpa's Knob. The work by the author was done as a member of the staff of the Federal Power Commission of the United States of America and for its information. A photograph of a model of this aerogenerator is shown in Figure 2, reproduced from reference 3. The artist's concept of a battery of three in open country is illustrated in Figure 3, from the same reference.

A brief description of this layout will be given. To tap as large a body of wind as possible, two wheels are provided, each 200 ft. in diameter, located on the two ends of a 235-ft. bridge, revolving on a turntable located on the top of a 475-ft. tower. These wheels have three blades each, fixed in position in the hub, but without the feathering feature. On account of the terrific aerodynamic thrust upon these blades, due to their very high speed, 550 feet per second at the tip, a tension brace leading from the hub is provided for each blade to give it sufficient strength.

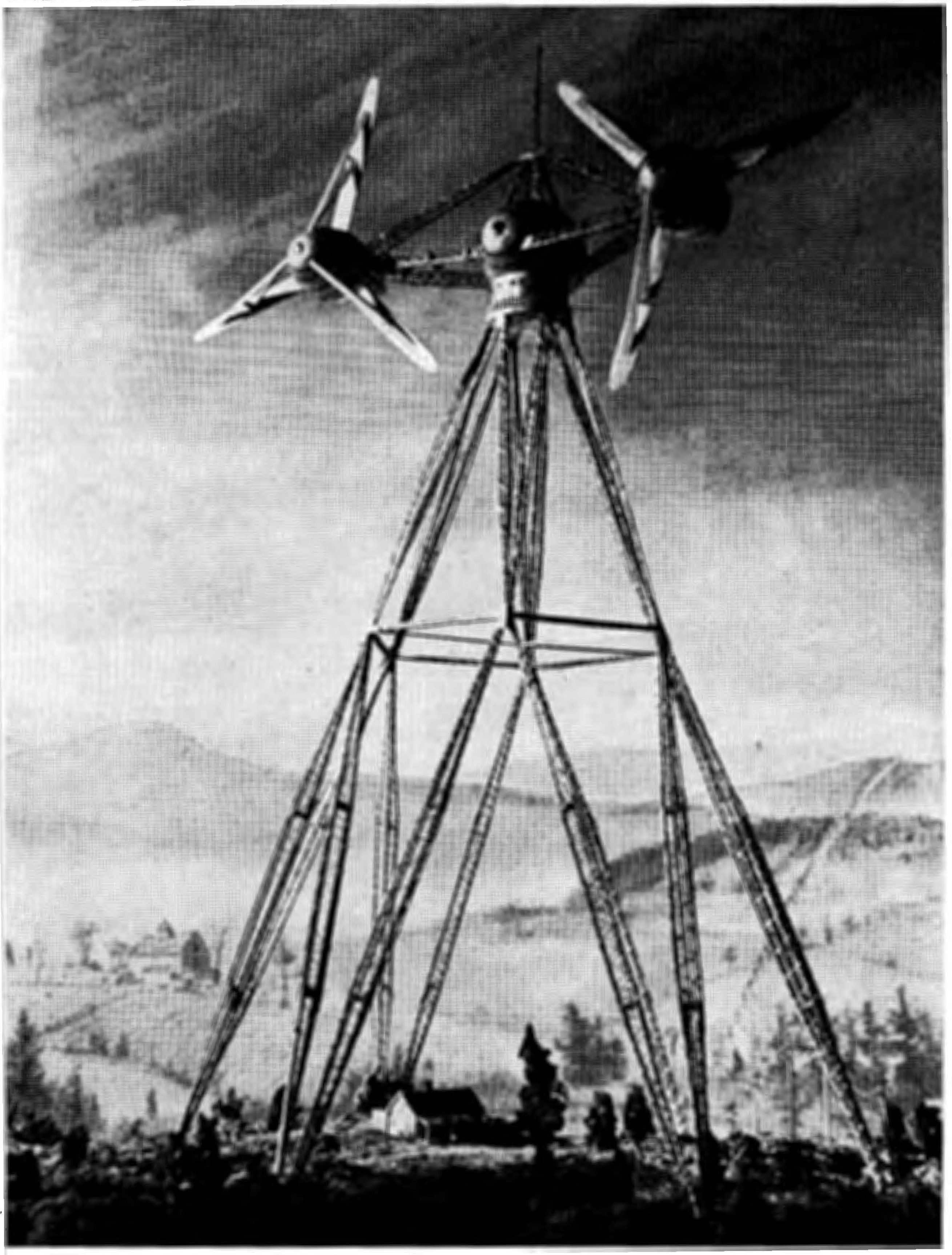
This very high tower is desirable for two principal reasons: First, the wheel of a high speed, impact-type turbine like this,

Federal Power Commission

Figure 1

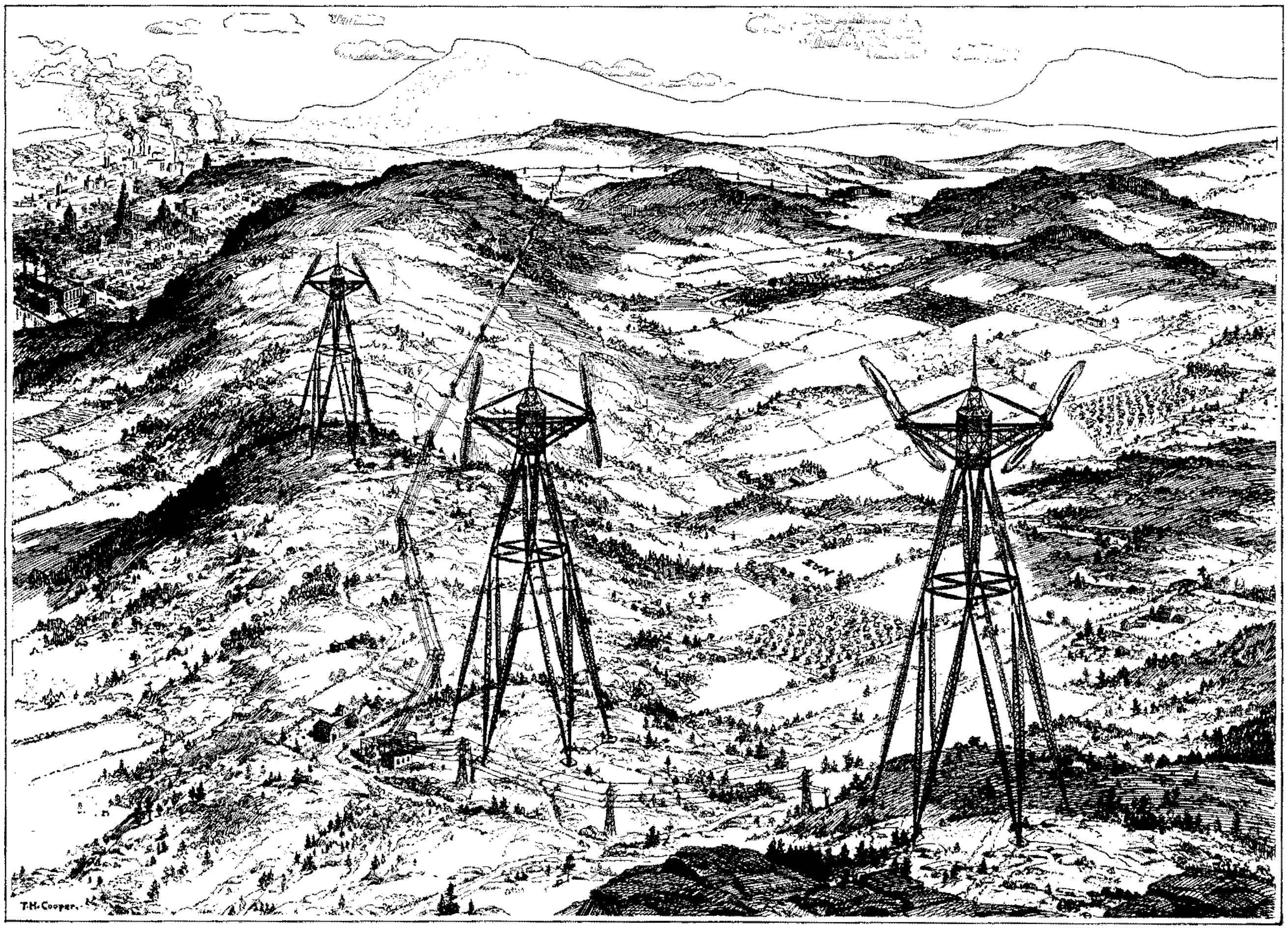
draws upon a cylinder of the wind several times as great in diameter as the wheel itself, and so should be given a sufficient clearance from the ground for this air cylinder. Second, the velocity of the wind and its smooth streamline character are definitely more favourable several hundred feet above the surface. As a sufficiently high average wind velocity is very important for economy in the wind turbine, the more favourable velocity high above the ground assumes an almost dominating importance. This will be realized when it is remembered that, while over level ground, the wind velocity may increase some 40 per cent in the first 500-ft. rise in elevation, the energy content of the wind would then increase as the cube of this velocity, that is, by 275 per cent. It is surprising to note that according to estimates, the cost of this 500-ft. tower is less than 25 per cent of the whole aerogenerator cost.

In this study-design, the two wind-wheels are connected to a single shaft through step-up gears and jointly drive a direct-current generator. This generator thus runs synchronously with the turbine which operates at a speed proportional to the wind velocity. The direct-current energy is transformed to alternating in an inverted rotary converter, which runs in synchronism with the delivery power circuit. This flexible arrangement permits the most favourable extraction of the wind energy and offers an opportunity for a very simple



Federal Power Commission

Figure 2. 7,500 kw. twin wheel turbine model



Designed by Percy H, Thomas

Figure 3. Federal power commission, Battery of Wind Turbines in an electric power system (An Artists' Conception)

automatic control of the wheel speed. It has the obvious disadvantage of a double conversion of energy and the addition of the cost of the inverted rotary.

Time will not permit descriptive detail of this carefully prepared study-design, but additional information may be obtained in reference 4.

Of greatest interest to prospective exploiters of wind-power is the choice and availability of wind-turbine sites, since the low cost and abundant wind energy is of no value without a suitable site. Looking at the problem from a realistic and practical point of view, the present position at first sight seems quite disappointing. It is not that suitable and adequate sites are not believed to be available, but that so little research has been done as to their characteristics and the locale. As far as the author knows, with the exception of certain local research work by the Smith-Putnam experts, there are no adequate studies made of the patterns of the wind at points suitable for the location of a large capacity turbine. The main researches and conclusions from the studies of these Smith-Putnam experts are fully described in reference I, but are of interest to the meteorologist rather than to the utility engineer.

As it is incumbent on somebody to offer the best information available on this all-important subject, the author will outline the results of his own studies.

Some assistance in the search for turbine sites may be obtained by studying the physiographic characteristics of the area selected, which should be one in which there is an observed tendency to windiness. It is helpful to imagine the wind as a vast stream of water flowing over the surface of the country like a river. Looking at a brook or rapid river, the "fast water" is seen to run between stones and over obstructions on the bottom, and where the slope is the steepest. It is the same way with the wind. It may be assumed that several of the following tendencies may be acting simultaneously.

1. The highest average wind will occur when there is the least surface obstruction, considered over a wide area, as the ocean or a large lake.

2. Velocity of wind will tend to be high on down slopes due to gravity, as with water.

3. Where there are many houses, trees and unevennesses in the ground surface, the wind will tend to be slowed down, this effect extending to elevations above the ground many times the height of the obstruction.

4. A single isolated obstruction tends to cause an increase in the velocity of the air locally without greatly affecting the over-all stream velocity. Such isolated obstructions are favourable to fringes of high wind-velocities. If the obstruction be narrow and high, the wind will go around both sides of it. If it be long and low, like a rolling hill, the wind will speed up over the top.

5. Streamline flow, as distinguished from turbulence, is very important and difficult to find in the wind near the ground.

6. On account of the resistance at the surface of the ground, the velocity of the wind is greater at higher and higher levels, more or less in what is known as a "logarithmic" ratio. In open, flat country, balloon measurements in the United States of America have shown an average increase in velocity of some 40 per cent at about 500 ft. above the ground, with further increase still higher.

Reference 6 gives the results of extensive studies of air currents in Germany as affecting glider operation.

Even if no field data is available for individual turbine sites, some valuable conclusions may be drawn from the patterns of the wind at other points where adequate observations have been systematically made. With the reasonable assumption that the most general of these patterns will apply also at favourable turbine sites, this data will be seen to be very helpful and of real value to utility engineers.

In a number of the larger countries regular wind velocity measurements have been made at many selected stations for long periods of time. Several millions of such readings have been recorded by the Weather Bureau of the United States of America and carefully analysed. An examination of data from some of the most important of these Weather Bureau stations shows the following characteristics covering the observations for thirty consecutive years and for fifty stations scattered over the United States of America.

At least for the United States of America, the *annual* average of the hourly wind-velocities at any station is quite constant, with the minimum annual average of hourly readings never dropping more than 20 per cent below the long-time annual average.

In the same way the monthly averages of the hourly velocities are found to be surprisingly constant, never dropping below half the annual average for that station. Even the weekly averages have a rather stable value .

The variations of the monthly averages within the year show velocities in the months of July to September some 15 per cent lower, on the average, than the annual average, as shown in Figure 5, from reference 3.

Figure 4, also from reference 3, shows charts of the variations through the years of the annual averages of the hourly velocities and, also, the maximum and minimum monthly averages of the hourly velocities for the same years. The gaps in these curves occur when the location of the measuring instrument was changed, breaking the continuity of the record. The monthly incidence of the minima is found at the right of the chart.

In appraising these values of velocity it must be remembered that the energy in the wind varies much more widely than the velocity, since the energy is proportional to the cube of the velocity. There are important compensating considerations, however, which cannot be covered here.

Based on the examination of some 7,000 hourly readings, selected to cover typical days of the year 1941 and some twenty separated stations, there was a very important diversity value in the wind energy. The lowest hourly total energy value of the group as a whole was nearly half the average hourly energy of the whole. When the fact that this diversity minimum holds through the 24 hours of the day, while peak loads are limited to from 6 to 10 hours a day, the potentialities of diversity in firming the wind are obvious. These diversity figures are for energy, not velocity. Further studies covering many more stations and far more readings, and for other countries, are required before any definite general conclusions can be drawn.

While this glimpse at the patterns of the wind is informative and, it may be said, quite favourable, they are no substitute to the designer for exact data applying definitely to the particular site chosen. The designer's requirements are few and simple, but very specific. The information he requires is reliable values for the range of wind velocities at the actual location of the wind-wheel circle, extending over one or more years, and the aggregate number of hours per month, or other convenient unit of time, during which each such value of the wind velocity may be expected to exist. The designer himself will set the minimum useful value of wind-velocity which will no doubt lie between one-third and one-half of the rated wind-velocity with units of the type of the study-design.

The nominal rated velocity for the wind-turbine is that value at which the generator will be fully loaded by the energy in the wind. The turbine will be expected to operate at higher wind-velocities, up to "half a gale", but means will be provided to prevent overloading of the generator. In the Smith-Putnam turbine this was accomplished by feathering the blades; in the study-design, by slowing down the wind-wheel.

The curve showing the aggregate time of the continuance of each value of wind-velocity as a per cent of any period of time under consideration, as for example, a month, is called a "duration" curve. Such curves are commonly used in hydro and other studies. The designer will accept velocity values in such a curve for his design work only because he can derive corresponding energy quantities therefrom by the cubing operation. Three typical duration curves are shown in Figure VI, reproduced from reference 3.

It may be pointed out that duration curve data for the turbine designer can be gotten at any elevation chosen by means of a suitable anemometer supported by a balloon and sending electric impulses representing the momentary wind-velocity down to the ground to a suitable impulse distributing and summating instrument. Such an anemometer should measure only horizontal components of the wind, not the actual wind-velocity where up-currents are involved.

The prosaic and stubborn matter of cost must arise in the study of the economics of any new undertaking. If there were a successful full-sized windmill in operation, its cost could be determined, but without one, reliance must be upon estimate. For the purpose of furnishing as useful a guide as was feasible, the author turned designer and made structural drawings of all the essential elements of a 7,500 kw. twin-wheel aerogenerator, with the stresses for each element computed and a suitable cross section selected for each structural member. From this was made up an installation cost estimate covering all features, electrical and mechanical, with allowances for contingencies, interest, overhead, profit, etc. This study-design has already been referred to and, together with this cost estimate, is found in reference 4. This estimate was based on pre-war costs to have a reasonably basis of comparison.

These pre-war costs are of course now too low, but the general conclusion was drawn that the installation cost of such an aerogenerator, when constructed as routine, would be somewhat below that of a low-cost steam plant. Presumably the comparison is now still at least as favourable to the aerogenerator. As its operating costs are very low, both in labour

FEDERAL POWER COMMISSION

TRENDS OF ANNUAL AVERAGE WIND VELOCITIES

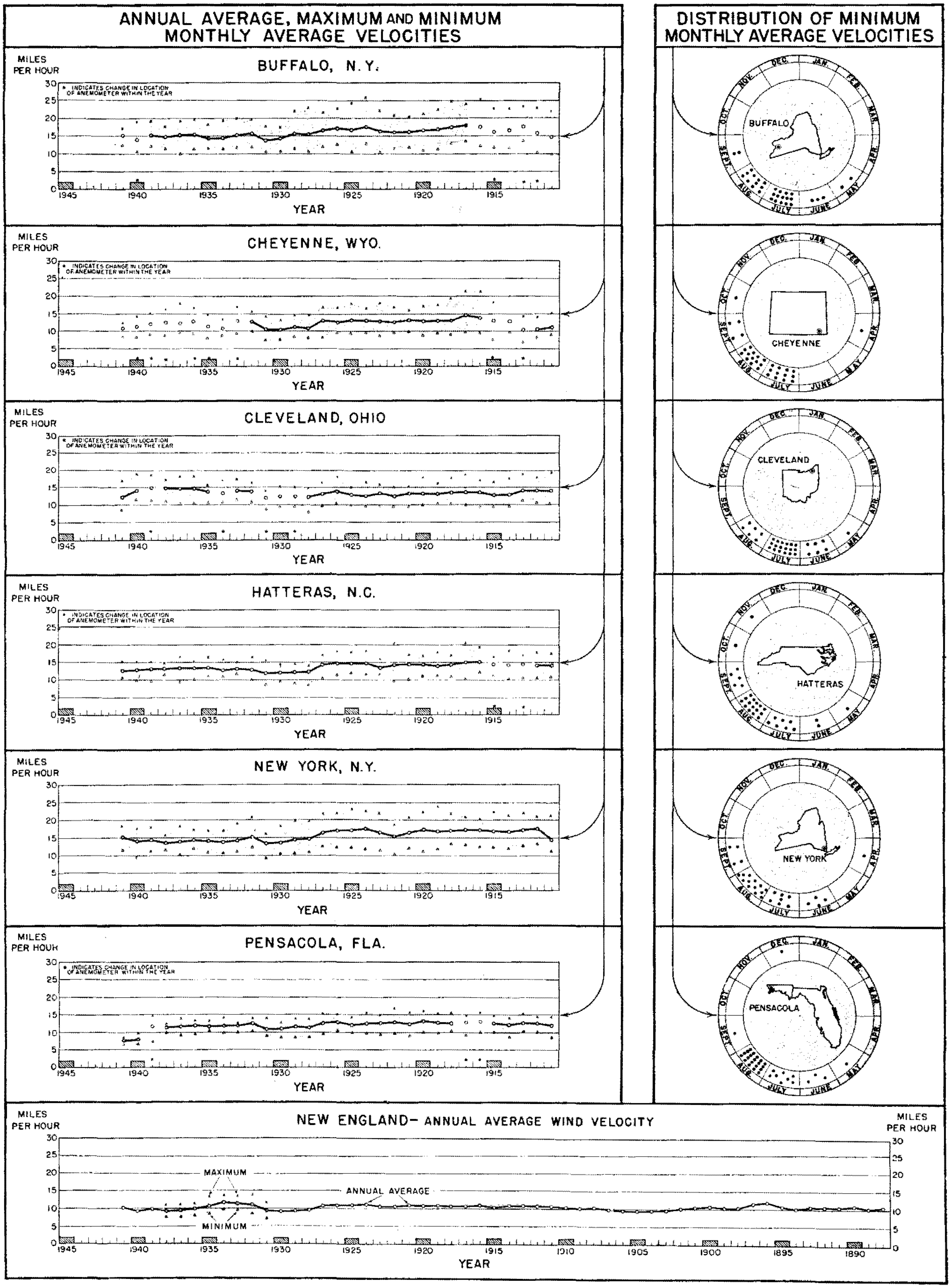


Figure 4

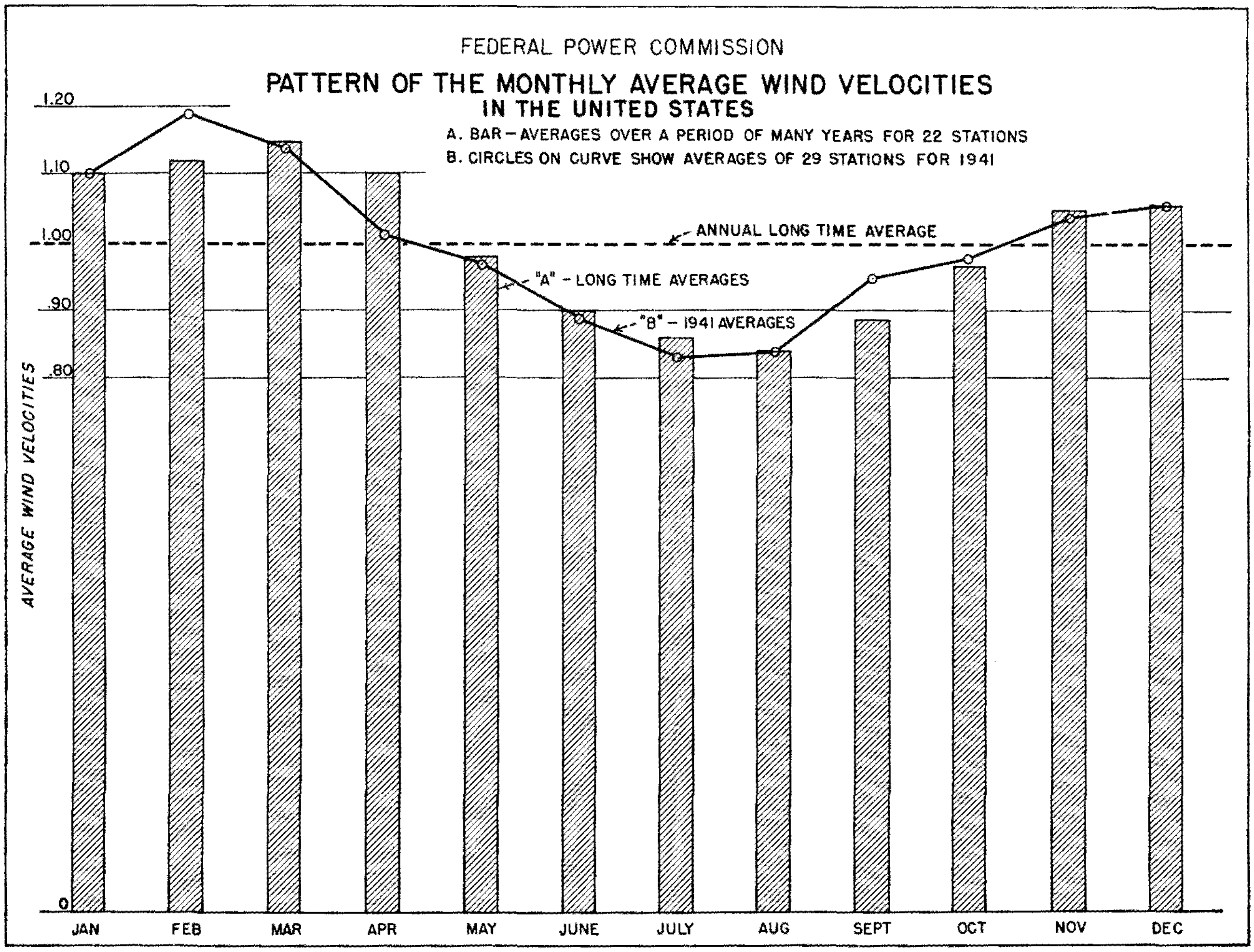


Figure 5

and maintenance, they compare with the operating costs of installed hydro. Under pre-war conditions, the total annual costs, including all fixed charges, were estimated at from 1.34 mills to 2.04 mills per kwh. according to the rate of interest allowed on capital. These costs would be higher now, but the cost of the wind energy *per se* will be unchanged.

For reasons of space, it is not feasible to go into the highly important and very interesting subject of the aerodynamics of the wind turbine, a field at present practically untreated in any form useful to the power engineer. The writer has prepared a monograph covering this subject in a manner especially adapted to such engineers (see reference 5). The aerogenerator should be considered from still another point of view. What is the aerogenerator to the engineer operating an extensive electric utility system? What are its characteristics? How does it fit into present operation? What does he get from it? Here are some of the answers.

The aerogenerator will be a source of energy at whatever point it may be installed. It will also be a line stabilizing point. The power will be accepted by the system as it is provided by nature, intermittently. No one unit can be counted upon for energy at any particular moment. On the other hand, as has been elsewhere explained briefly, and as may be seen by careful examination of the possibilities of the large network system, the average wind-power delivery over the system can be made firm for the system as a whole at a reasonable cost by relying upon temporary support from hydro storage.

With the wide dispersion of wind units and their small individual capacity, the shifting of local supply from place to place with the vagaries of the wind is not likely to be important.

The limitation imposed upon operation by the reliance upon hydro storage for firm capacity from wind-power means that not more than a certain optimum portion of the total energy and capacity of the system can be expected to be conveniently obtained from wind energy. It is the impression of the author, after consideration of this question for some years, that between 25 per cent and 40 per cent of the system energy and between 20 and 30 per cent of the firm capacity in the peak may well turn out ultimately to be this optimum utilization in a large, wide-spread utility network. This statement is made on an economic and operational basis, and applies only to such large interconnected utilities for the general supply of electric power. When used in other situations, wind-power may still be very useful, but careful study must be given to its special application.

The English technical magazines in January 1948 announced the formation of a new section of the British Electrical and Allied Industries Research Association under Mr. T. G. N. Haldane, to study the technical and economic problems of large-scale aerodynamic generation in Great Britain. Notes on the organization and activities of the body have been reported

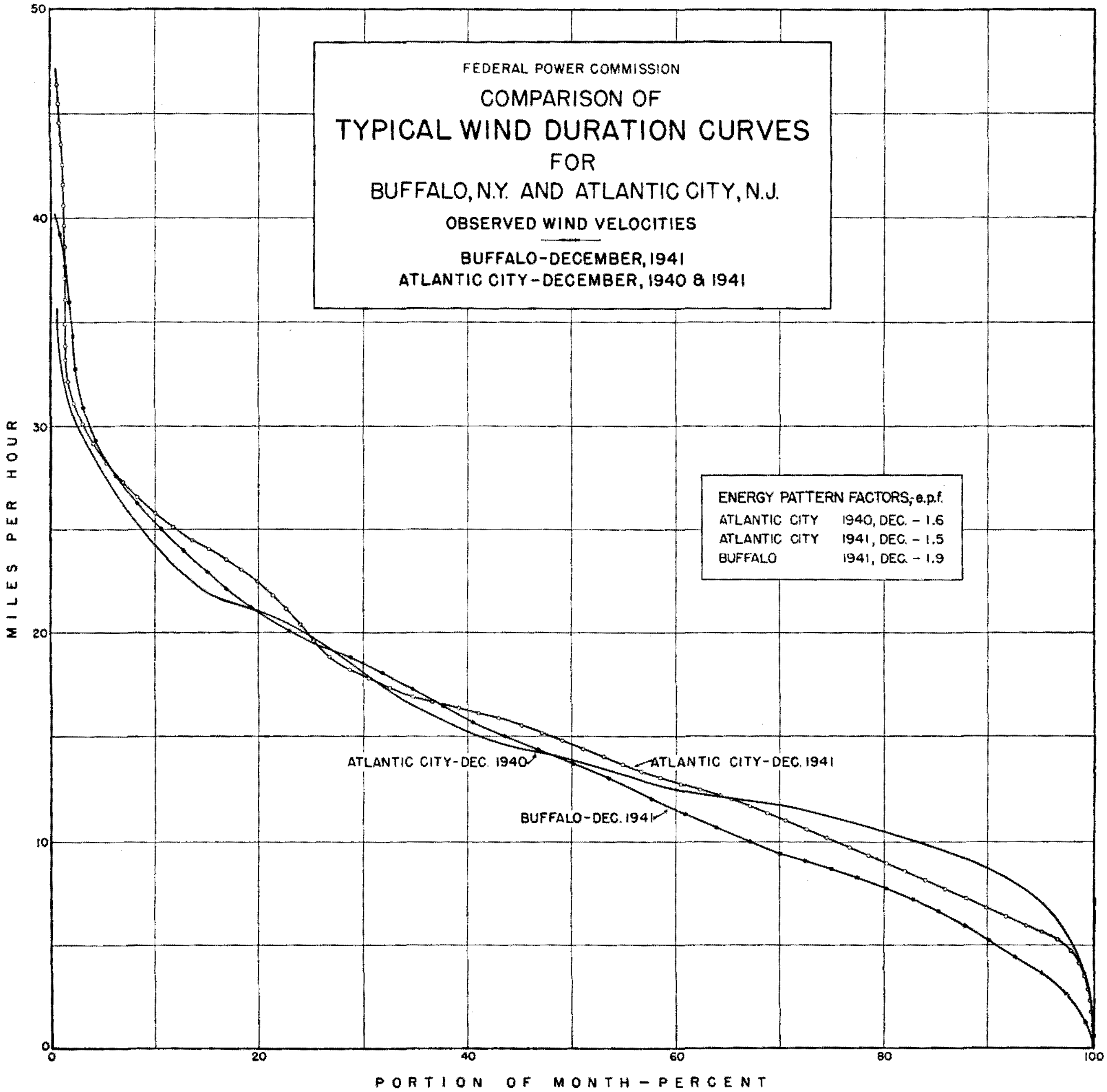


Figure 6

in the Press from time to time. The results of their investigation will be awaited with the keenest interest.

Considering wind energy from a broader point of view, it has a much wider significance than as an auxiliary to hydro. Only a few areas are fortunate enough to be so well supplied with habitable land, a suitable population and the necessary natural resources as to permit a dense industrial development, where electric power is at a very low cost and where a minimum cost is vital. Many other types of areas exist, well favoured in special ways, where electric power is not expected to be of low cost, but nevertheless should be essential. Each such situation must be examined on its own merits. Some examples may be suggested.

Where water has to be pumped to storage for irrigation or municipal supply in the absence of cheap power, wind energy on a "when available" basis may be quite satisfactory. Since the water is pumped to storage, intermittency offers no great difficulty. In some such cases it may well be that a modest general supply of electric power can be secured for the local area at the same time by making the wind-turbine an aerogenerator and thus getting a minimum continuous electric service for domestic use and for street lighting, firming through drawing down a certain amount of the stored water through hydroelectric units as necessary. This is an entirely practical scheme, the chief limitation being that the electric power would be somewhat more expensive than in the large-scale industrial networks. In such cases no doubt domestic users would be glad to pay much higher prices rather than to go without electricity.

It has occasionally been found economical to install what are called "pumped-storage" plants, which serve to supply large peak capacity from water lifted to high reservoirs by secondary power off peak. There are two large capacity plants of this type in Germany. Wind energy will often be a very helpful auxiliary in such cases and may render a project feasible, which, on account of the load curve or otherwise, would not be economical without the energy from the wind.

Certain specially favoured locations may be found where winds seem to be practically continuous, as sometimes happens in mountain country. In such cases wind-power is almost firm automatically.

In mining and other mass production undertakings, especially in mountain country, local transportation may be an important and expensive operation. With a reasonable average power in the wind, large tonnages might be handled, as by an aerial tramway, on a "when available" basis without disturbing either production or processing. Such cases depend upon local conditions.

In isolated locations where a limited amount of electric power is very desirable for comfort and health reasons, if winds are favourable, aerogenerators, with standby diesel engines, would be entirely suitable. The economic justification of the aerogenerator is the reduction in the cost of transportation and storage of fuel, and in the great simplicity of the installation and its operation. Military posts on distant islands might well fall in this class. It may develop that thermal storage in flash boilers, using steam or some more favourable fluid, will be feasible in certain cases.

In some heavily industrialized areas, using vast and growing quantities of power, the available hydro will eventually be exhausted. If cheap coal is scarce and if natural gas and petroleum are reserved for preferential uses, wind-power may ultimately enable such areas to continue to compete with other areas more favoured with steam and hydro-power. This is a condition not seriously on engineers' minds at the present time, but likely in some places to become something of a headache in the future.

It is always possible, where a community is determined to have electric power and where no fuel or hydro sites are to be had, to install aerogenerators and pump water to secure continuity of supply. For this purpose a suitable, high reservoir is necessary, but no great quantity of water, since it can be repumped and used again and again. There are few locations where some small storage at a suitable elevation cannot be found. A relatively very modest reservoir will stabilize wind energy for most small communities.

In this necessarily rather brief treatment of the subject, an effort has been made to give the power engineer, and others who have an interest in the vital matter of power supply, an insight into what to expect in utilizing the wind in wholesale quantities, also to indicate the ways and means by which its exploitation is likely to be brought about. No doubt others will devise different methods and types of structures, according to their own ideas, as is proper, but, by and large, the utilization of the wind is likely to develop generally along the lines here outlined on account of the unique limitations inherent in its characteristic behaviour.

In closing, the author again calls attention to the hitherto unrealized potentialities in the use of wind-power for those countries handicapped industrially in the vital matter of low-cost power. Realization in such cases, however, calls for energetic research, resourcefulness and sound engineering, as well as a high order of intelligent planning.

Bibliography

(1) Palmer Cosslett Putnam, *Power from the Wind*, Van Nostrand, New York, New York, U.S.A., 1948.

(2) S. Morgan Smith, Company, York, Pennsylvania, U.S.A., *Turbine Topics*, June 1943.

(3) Percy H. Thomas, *Electric Power from the Wind*, Federal Power Commission, Washington, D.C., U.S.A., 1945.

(4) Percy H. Thomas, *The Wind Power Aerogenerator*, Federal Power Commission, Washington, D.C., U.S.A., 1946.

(5) Percy H. Thomas, *The Aerodynamics of the Wind Turbine*, Federal Power Commission, Washington, D.C., U.S.A., 1949.

(6) W. R. Morgans, Aeronautical Research Committee (British), *Relation Between Ground Contours, Atmospheric Turbulence, Wind Speed and Direction*, R. and M. No. 1456, December 1931.

Note: Bibliographies are found in references 1, 5 and 6 above.

Report on the Utilization of Windpower in the Netherlands

DE HOLLANDSCHE MOLEN (SOCIETY FOR THE PRESERVATION OF WINDMILLS IN THE NETHERLANDS

ABSTRACT

Amongst the applications of raising energy from wind power the endeavours of *De Hollandsche Molen* deserve attention to put the existing windmill on a more economic and efficient basis.

Calculations, based on data concerning prevailing wind-frequencies, supplied by the Scientific Department of the K.L.M. (Royal Dutch Airlines) show that a fair size Dutch windmill of modernized construction on an average is capable of a yearly production of 235,000 h.p.hours at our coastline, the time of production of the maximum capacity being 3,800 hrs. per year.

Driving its own installation the windmill is not utilized to its full production capacity, whereas the inconstancy of the wind-velocity forms a considerable drawback.

In order to raise the power production of the mill and to overcome the last-mentioned disadvantage, a new system has been proposed by which the existing windmill takes part in the general electricity production by means of an electromotor which can be driven by the mill as generator.

During the windless hours this electromotor, connected to the electricity mains will, when necessary, drive the mill installation, whereas at increasing wind strength, the mill will take over this duty and, when wind power still further increases, will drive the electromotor as a generator as well, supplying electric energy to the mains.

This idea is now being tried out in a test installation.

The purpose of this report is to consider the feasibility of utilizing windpower in the Netherlands for the benefit of the community, an aim which, in the opinion of the society, could be achieved by using that power for generating electricity. The subject, however, must be considered in two sections:

(1) To create conditions under which the existing windmills could take an active part in such generation. Until now the windmills have furnished motive power and the preservation of these mills has so far been the only object of the said society.

(2) To study the possibility of generating electricity by means of aeromotors of new construction.

Actually the investigation mentioned under point 2 is most in line with the object of the UNSCCUR. This, however, lies beyond the aim of our society, although we realize that the utilization of windpower by new constructions, aeromotors and propeller-driven generators, would serve to render the public more wind-minded, should such investigations meet with success, and no doubt this would tend to serve our object.

However, the Dutch windmills could have only a modest share in supplying the total requirements of electricity in the Netherlands. Yet the employment of the existing windmills would utilize the available windpower more extensively and raise their future economic value as power producers. This is, of course, of real importance to the society which for more than a quarter of a century has been trying to preserve the windmills in the Netherlands for power production and for their characteristic beauty. The destruction of the windmills was called "an international calamity" by John Payne of the American Red Cross during the first years of the society's fight for their preservation.

Looking backward, one can see that the Netherlands has owed its great prosperity to a high degree to the utilization of windpower. It was windpower that drove Dutch sailing ships over the world seas and procured motive power for our industrial and agricultural development through the medium of the windmills.

For industrial purposes the windmill was an adequate source of supply of energy which brought various and, at that time, important industries into being. The industrial centre, situated along the banks of the River Zaan, may serve to illustrate how the industries of Holland owe their development to the windmills that were built by hundreds there in the seventeenth and eighteenth centuries, and have now grown into factories of international importance.

The windmills influence the agricultural welfare of the Netherlands by their use for driving water-pumping installations for drainage and the reclaiming of numerous lakes and vast stretches of submerged land. About three-eighths of the country lies below sea level and every drop of rain and ground water rising to the surface has to be pumped into the sea, a task which for the greater part is still being done by windmills. In rural districts the windmill is still being used for the grinding of grain as well as for other industrial purposes.

The importance of the windmill as an economic and a then adequate source of energy caused the erection of numerous mills all over the country, which for centuries have been a characteristic aspect of the rural beauty of the country, even to such a degree that windmills have become an inseparable feature of the Dutch landscape.

The development of the steam-engine and other caloric prime-movers of later years formed an ever increasing threat to the economic justification of the windmill, and the use of windpower was gradually replaced by the use of coal and oil. This process, moreover, has been stimulated by the extension of the electricity supply of the country, resulting in the demolition of many windmills. In recent years it has been feared that they would gradually vanish from the Dutch landscape, to the beauty of which they have so greatly contributed. The tendency to demolish has not yet been brought to an end and before this calamity is reached it is necessary and useful to consider whether the procedure is justified.

To begin with it is necessary to realize the enormous amount of energy wind can give. A few figures will illustrate this important fact.

Dry air of atmospheric pressure and at a temperature of 0 degrees C. weighs 1.29 kg. per cub. metre. This weight decreases as the temperature rises with the result that at 20 degrees C. it drops to 1.2 kg. The moisture in the air, when it appears in the form of vapour, decreases its specific weight whereas it has the opposite effect when the moisture is present in fine water-drops. The specific weight is therefore dependent in many ways on the atmospheric conditions and for the Netherlands the average weight of one cubic metre of air may be taken to be about 1.25 kg. at the usual height of a Dutch windmill.

At a wind velocity of 8 metres per second the motive power contained in 1 cub. metre of air is expressed by the formula:

$$\tfrac{1}{2}\, m.v^2$$

$$m \text{ being } \frac{1.25}{9.81} \text{ and } V^2 = 8 \times 8 = 64$$

This means that every cubic metre of air at a velocity of 8 metres per second carries an energy of 0.0637 × 64, equal to 4.08 kg./metres per second.

Through a surface of one square metre placed perpendicularly to the direction of the wind, 8 cub. metres of air will pass per second at a wind velocity of 8 metres per second, representing an energy value of 8 × 4.08 kg/metres, equal to 32.6 kg./metres per second or 0.436 h.p. This figure shows at a glance the tremendous amount of energy that windpower can furnish, even if account is taken of the fact that the theoretical maximum efficiency of air-driven machines such as windmills, aeromotors etc., is 59.26 per cent, thus bringing the figure of 0.436 h.p. per square metre of surface down to 0.2785 h.p. as the maximum wind-energy that can be utilized.

Windpower is proportional to the third power of the wind-velocity as the calculation above has shown, i.e., $\tfrac{1}{2}$ m.v.^{2} x.v. Wind-power, therefore, is highly dependent on the wind-velocity as well as on the length of time a certain wind-velocity prevails.

On the assumption that, for the existing Dutch windmills, it does not pay to take the costly measures necessary to utilize the excess of windpower over a velocity of 10 metres per second such as occurs during a relatively short time of the year, the calculation which expresses the number of hours during which a certain wind velocity prevails shows that per square metre of surface per year, theoretically 1,900 h.p./hours can be obtained from windpower at a capacity of 0.503 h.p.

These figures have been calculated at a height of 14 metres, the average height of the windshaft of a Dutch windmill, and at the maximum efficiency which theoretically can be obtained.

In this calculation it is assumed that the windmill does not produce power at wind velocities under 5 metres per second, although a modernized Dutch windmill starts rotating at a velocity of about 3 metres per second. The length of time that the maximum capacity of 0.503 h.p. can be produced is $\frac{1900}{0.503}$ equal to 3,800 hours per year.

The figures given above show that a mill of fair size carrying sails of 28 metres in total length and giving a working surface of 610 square metres can theoretically produce $610 \times 1{,}900$ or 1.16 million h.p./hours per year.

A modernized Dutch windmill has, on an average, 12 per cent efficiency of the total wind-energy striking the sails, i.e., 20.3 per cent of the wind-energy that can be utilized theoretically. Such a mill is capable of the production of 235,000 h.p./hours per year. This figure applies to the Dutch coastline. As the wind velocity decreases inland, the average figure for the whole country falls to 70 per cent.

Bearing in mind that this vast amount of energy is available free of charge, remains inexhaustible, is independent of social unrest or war, of labour or its specific production capacity, and the changing price level, one realizes that the utilization of this enormous source of energy remains of everlasting importance, even if the drawbacks, inherent in its characteristic nature, have to be taken into account.

Of these drawbacks the changeability of the wind is the most prominent, although the advantage must not be overlooked that in the period of heavy consumption of energy, namely in winter, windpower is stronger.

It is hardly to be expected that the prevailing shortage of fuel and lack of labour, especially in the coal-mines, will be overcome in the near future. This accentuates the importance of the use of windpower and consequently of studying means by which the Dutch windmill can be improved in order to compete more successfully with the caloric prime movers.

In view of the development of applied nuclear physics, which opens the possibility of gaining vast amounts of energy by nuclear fission to serve as a new source of energy for industrial purposes, the question arises whether it is still justifiable to invest new capital in an endeavour to raise the efficiency of the existing Dutch windmills, so long as 1 kg. of uranium is capable of producing as much energy as 2,000 tons of coal.

A few remarks will serve to place this generally overrated and much discussed prospect in correct perspective.

First of all, many are the difficulties which still have to be overcome before this source of energy can be applied to general use. In this respect we may refer to the statement of M. H. L. Price, published in *The Bulletin of the Atomic Scientists*, 1948, that within the coming thirty years it cannot be expected that nuclear energy will begin to take the place of coal.

Secondly, there are various divergent opinions regarding the estimated costs of production. According to the general view held in the United States, the cradle of applied nuclear fission, the capital charge for 1 kw. of installed nuclear production capacity surpasses by roughly 2.3 times that for coal-burning power-stations. On the other hand, a publication adapted to prevailing circumstances in the Netherlands, assumes these costs to be equal. But even on this assumption the total costs of producing power from coal as against nuclear energy work out as follows: for coal-burning power-stations, at 3 cents for 20,000 kw. and at 2 cents for 100,000 kw., installed capacity, and for nuclear energy stations at 2.9 cents and 1.8 cents, respectively. These figures show that in an economic sense no improvement worth mentioning can apparently be expected for the near future.

Thirdly, the source of energy production by nuclear fission may not be looked upon as a lasting solution for the future as the quantities of available high-grade uranium ores are limited. In the United States the source of energy from exploitable coal fields is 180 times greater than that of available and workable uranium deposits, whereas, according to Eugene Ayres, chief of the Chemical Department of the Gulf Research and Development Company at Pittsburg, the world resources of uranium are estimated at ten times those of the United States. Although low-grade ores of uranium and thorium are abundant, it is hard to predict whether these can be utilized economically for the purpose of energy production.

As far as the conditions in the Netherlands are concerned, it has to be borne in mind that no fissionable ores are available[1] and the coal reserves are relatively small, while wind-energy is plentiful and inexhaustible.

During the last twenty years much successful work has been done to improve the construction of the windmills, resulting in a considerable rise of efficiency. This consequence is of greater support to their maintenance for the future than drawing attention to their aesthetic value only. Moreover, it has been suggested that use should be made of the existing windmills for generating electricity by means of an electromotor connected to the mill.

During the windless hours this electro-motor, connected to the electricity mains, will when necessary drive the mill-installation; then as the wind increases the mill will take over this duty and, when the windpower still further increases, will drive the electromotor as generator at the same time.

In this way all the energy which the mill can produce in excess of the energy demand can be utilized for the community. This idea has met with such interest that it is deemed advisable to ascertain the advantage of this principle in practice by a test installation. It may be expected that in this way the economy of the existing windmills will be raised and a saving of coal for the general supply of electricity can be achieved. However, if the demolition of the Dutch windmills, which have already decreased since the beginning of this century from 8,000 to about 1,300, proceeds, the windpower these could produce will have to be replaced by increasing use of fuel. On the other hand, the electrified windmill will continue to produce energy by windpower for the sake of its own installation, and any excess produced will supply a certain quantity of electricity for general use.

In this way all the energy the windmill is capable of producing from windpower can be fully used in economizing on the supply of fuel. The windmills, after having been provided

[1] In the Netherlands Indies, however, thorium is found in moderate quantities.

with the electromotor mentioned above, will therefore have a new reason for existence which will enable them to continue to contribute to the beauty of the Dutch landscape.

Various factors will ultimately play a part in deciding whether the proposition in the preceding paragraph will be applicable and whether it will be justified economically, in view of the fact that the supply of energy by means of fuel is affected by social unrest, strikes, conditions of war etc., which can endanger the supply of fuel and its price. Counterbalancing factors are the uneven incidence of wind which decreases the value and influences the amount of the electricity produced by windpower, the rise in the costs of labour and maintenance, and the capital required for modernization and electrification of the mills.

It is hardly possible to calculate the value of the different items in advance, based on various assumptions; it is therefore highly desirable to give the principle involved a practical test by means of a trial installation.

Such a test installation is now being erected and subsidized by the Government, which voted a sum of 12,500 guilders for the necessary modernization and electrification of an existing windmill, the Benthuizermolen near Leyden, which has proved to be specially suited to the conditions required.

The execution of this work can be expected in the very near future after which the various tests, necessary to prove the soundness and general applicability of the principle, will be carried out.

Should the project be successful, we trust that the remaining windmills in the Netherlands will continue to be things of beauty and therefore joy forever!

Windpower: Its Advantages and Possibilities[1]

R. FARDIN

ABSTRACT

The active stage in the use of windpower is about to begin. Developments in modern aerodynamics augur very well for the use of the wind-wheel; the power derived therefrom can be used either directly or transformed into electricity and may become an appreciable economic factor in certain under-equipped countries. Wind is free and universal. The objective to aim at is to increase the comfort of isolated human communties, particularly in the polar regions where the winds are strong and fairly constant.

The cost of windpower per kwh. is governed only by the total cost of installation and maintenance expenses. It is decidedly less than the cost per kwh. of power produced by diesel-operated electric generating sets, which involve a considerable annual expenditure on fuel.

In view of the world's power requirements, it is to be hoped that the use of windpower installations will be extended; their development on an industrial scale might well become a valuable source of profit. As the problem is a world-wide one, it is desirable that an attempt should be made to organize international co-operation, with a view to setting up a research centre on winds and for the improvement of windpower equipment.

INTRODUCTION

It need not be demonstrated that the modern world suffers from an under-production of power; even in the best equipped countries there are a few areas which are either isolated, difficult to supply with combustibles or fuel, or which lack electricity because of the high cost of production.

In places where there is a power shortage and a favourable wind-system, windpower should be put to use.

The world is not lacking in areas with a good supply of wind. The attached map (Figure 1) shows the areas where the wind pattern is both regular and strong for a sufficient number of hours to make an economic use of the wind possible. These areas are mostly in the southern hemisphere. Generally speaking, islands have an excellent wind pattern but certain continental regions also have contours favourable to the rapid movement of air masses and are therefore rich in windpower (e.g., the Rhône valley in France).

The technical problems inherent in the use of windpower are by no means insurmountable, but the aerodynamic adaptation of the rotor requires careful study, varying with the nature of the problem presented by the wind pattern at a given site, the desired power, the purpose it is to serve, etc. In the present stage of aerodynamic science it should be possible to recover about 50 per cent of the power potential in the flow of air through the wind-wheel.

[1] Original text: French.

Later in the present study the writer will consider the economics of the use of windpower and will consider some of its possible uses. The conditions governing the use of windpower are, of course, numerous and it entails many problems. Wind-turbines may, however, be divided into two main types:

(*a*) Independent units (up to 500 hp.);

(*b*) Electric generators consisting of several units (above 500 hp.).

The first consists of wind turbines installed at a given site for the immediate use of power, as for instance at colonial outposts, farms or groups of isolated dwellings.

The second consists of wind-turbines installed at selected sites and coupled to an electrical distribution system. As this latter case is studied in detail in another paper, the writer will here consider mainly the economic value of single units.

I. THE TECHNICAL ASPECT

The technique of the use of wind-turbines is derived from the study of three main factors:

(*a*) Wind;

(*b*) Optimum aerodynamic adaptation of the rotor;

(*c*) Transformation and conservation of energy.

A short note on the problem of construction is also included in this paper.

(a) *Wind*

The greater the power to be obtained, the more thorough

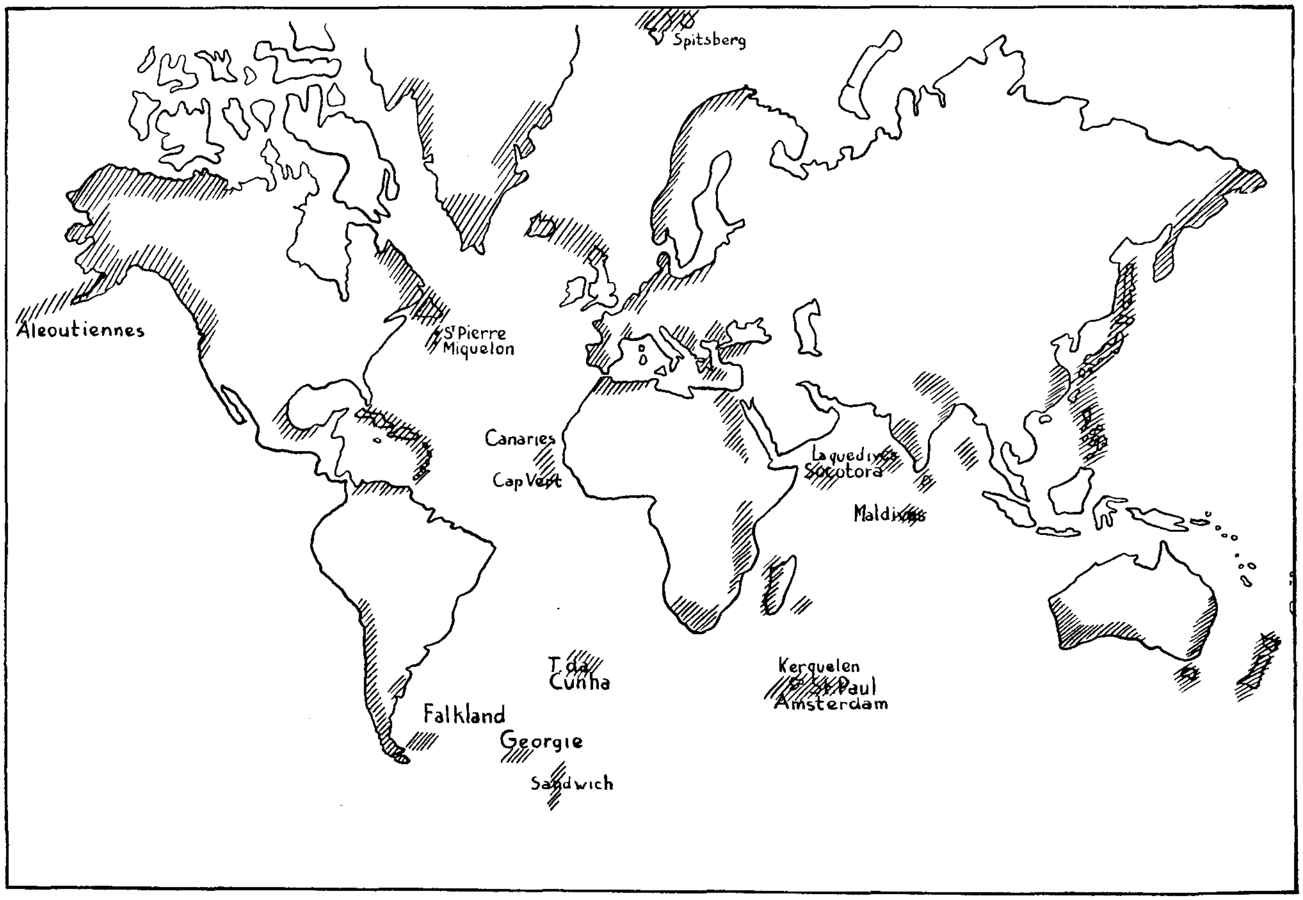


Figure. 1. Map showing main strong wind zones

must be the study of the wind as a source of energy at a given site. Existing meteorological data must be taken into account and contours studied, but without making the mistake of judging by wind-tunnel experiments; for the influence of the force of masses, so great in nature, is disregarded in the laboratory. If there are no weather statistics, as is the case in most of the newer countries, careful readings will have to be taken over a fairly long period in order to ascertain the optimum site and elevation. These surveys will naturally have to include a study of the most efficient average wind, the maximum gale intensity (in order to establish the required resistance of the structure), the maximum calm (in order to establish the required power of an auxiliary installation). For generators of only a few kilowatts, less extensive research will suffice. The influence of contours on the distribution of wind at ground level has been studied by many authors as indicated in the bibliography (2, 3, 4).[2]

(b) *Optimum aerodynamic adaptation of the rotor*

The energy potential of the wind varies with the density of the air at the chosen site and with the area of the circle swept by the rotor, and is proportional to the cube of wind-velocity. But it has been demonstrated (by the German research-worker Betz) that only 16/27 or approximately 60 per cent of this energy is recoverable. Hence a wind-wheel must be studied with this in mind and its blades adjusted accordingly. Modern research on aircraft propellers makes it possible to use a complete theory which takes account of the speeds induced by the slipstream. By these means one can appreciably improve the performance of the turbine and 50 to 55 per cent of the wind's energy potential may be expected to be recoverable.

There are, of course, numerous variable incidental factors affecting the question of the adaptation of the rotor, which is a complex problem, varying with each individual case. Still, for an average power supply (up to 30 kw.) it seems possible to construct a type of rotor sufficiently universal to justify production in assembly-line volume (5).

(c) *Transformation and conservation of power*

Generally speaking, the transformation of windpower is likely to take the form of conversion into electricity. It may, however, be considered as a direct source of power, for instance for water pumping or transformation into heat units (heat pump).

Transformation into electrical power remains its most common and most practical use. This can be done by driving a generator by means of a speed multiplier or an auxiliary turbine by means of air compression (Andreau system). In the first case the mechanism is housed in the hub of the wind-wheel, the whole being mounted on a swivelling platform. A distributing unit would be placed at the pylon base and if necessary could include an auxiliary electric generating set which would start up automatically when the output of the wind generator fell below a certain point.

Another important and complex problem is the storage of power. As the generator gives out current at a given speed of rotation, all power supplied by winds above the chosen

[2] Numbers within parentheses refer to items in the bibliography.

average velocity must apparently be wasted and it is even necessary to have an apparatus to regulate the power supply. Moreover, for periods of low windpower the deficit in current must be made up by a supply from a diesel-operated generator or a storage battery. It should be possible to solve this problem efficiently by storing up the power in such a way that wind energy would be recoverable at any speed and could be transmitted to the generator. The author is at present engaged in research on a device for this purpose and on a method of storing calories by heating a certain quantity of water.

NOTE ON THE CONSTRUCTION OF WIND-TURBINES

Owing to the world shortage of raw materials the manufacturer has to look very carefully into the problem of construction. A wind-turbine is made up of three main parts:

(*a*) Structural (blades, hub, pylon);
(*b*) mechanical (multiplier, swivel device);
(*c*) electrical.

Each part has its own characteristics which may vary with the site where they are intended to be used.

(a) *Structural part*

Except for very small units of not more than 1 or 2 kw. the blades are similar to those used for aircraft. A blade with a 6-metre span is in reality an aircraft propeller and should be constructed as such. The blades can be made of moulded impregnated wood, light alloy or high resistance steel according to their dimensions and the strains to which they will be subjected. The nature of the air by which they will be turned must be taken into account: whether hot and dry, salty, humid and tropical, or with frequent sandstorm winds or frost exposure. In the case of wooden structures the influence of biological agents must not be neglected.

It is worth noting that the manufacture of wind-wheel blades offers excellent reconversion possibilities for certain aircraft factories and would make it possible to hire or maintain in employment labour which is difficult to train and to recruit; in addition, nationally important factories could be kept in operation.

The hub or framework of the mechanical part on the top of the pylon is similar in structure to a turbine spindle. In other words, it is a light alloy frame, except in certain cases in which it may be made of plastic material.

The structure of the pylon varies with the size of the wheel and the maximum wind speeds. It may be of appropriate iron sections assembled by means of rivets or autogenous welding.

(b) *Mechanical part*

This part has no special characteristics; it is governed by the ordinary principles of engineering.

(c) *Electrical part*

This comprises a generator, a distribution system with the necessary cables and possibly a transformer. The shortage of thin sheet metal, electrolytic copper and high-quality insulating material makes the problem of supply difficult. In aerogenerators destined for hot climates great caution must be exercised concerning the use of certain insulating materials, as they have a tendency to be influenced by temperatures above 40 degrees and by humidity and biological agents.

Except for the construction of blades over a certain size (more than a 3-metre span) and for the electrical parts, which have to be built by specialists, the rest of the apparatus requires only ordinary work such as can be done in an easily erected workshop and with quite ordinary tools (drill, lathe, milling machine and autogenous welding apparatus).

Obviously, the construction of large units such as electric generating sets presents complicated problems for which a drawing office would be needed.

II. THE ECONOMIC ASPECT

Although the raw material, wind, is free, construction problems have to be considered in detail in order to establish a balance between the output in kilowatt hours and the cost of installation. Obviously, it would be foolish to build a tower 300 metres high to drive a wind-wheel 10 metres in diameter although excellent windpower might be obtainable at that altitude. Certain considerations which need not be entered into in a brief review of this kind lead to the adoption of a law for optimum pylon height and wheel dimension as a function of the desired power: the usual dimension for a wind-wheel is 15 metres.

The comparative features of a wind-powered and a diesel-powered electric generator, providing 30-kw. current for 2,000 hours per year over 20 years are given below:

Diesel powered	*Metropolitan French francs*	*Wind powered*	*Metropolitan French francs*
40 h.p. diesel engine	900,000	Wind-wheel with three 10-metre blades plus duralumin frame	400,000
220 v. 30 kw. generator	150,000	Transmission, regulation etc. ..	150,000
80 equipped accumulators ...	300,000		
Equipped control panel	100,000	220 v. 30 kw. generator	150,000
Sundry fixed installations	200,000	20 metre pylon ..	200,000
Research, amortization (20 years)		Sundry fixed installations	200,000
Profits	300,000	Research, amortization (20 years)	
		Profits	500,000
	1,950,000		1,600,000

Annual inspection and maintenance expenses for each installation are put at 100,000 francs; the diesel unit consumes 190 grammes per hp./hour or 18,500 litres, which, at 33 francs a litre, gives 610,000 francs, whereas the wind-turbine consumes nothing.

Let us take the case of a combined installation (diesel and wind-driven) in which the diesel unit operates for 500 hours per year and the wind-turbine for 1,500 hours. The total expenditure is:

Cost of wind-turbine installation ..	1,600,000
Cost of diesel installation	1,950,000
	3,550,000

The cost of fuel for 500 hours would be 152,000 francs. Thus the cost over a 20-year period would be:

$$\frac{3{,}550{,}000 + 20 \times (152{,}000 - 10{,}000)}{30 \times 2{,}000 \times 20} = 5 \text{ fr. } 60 \text{ per kwh.}$$

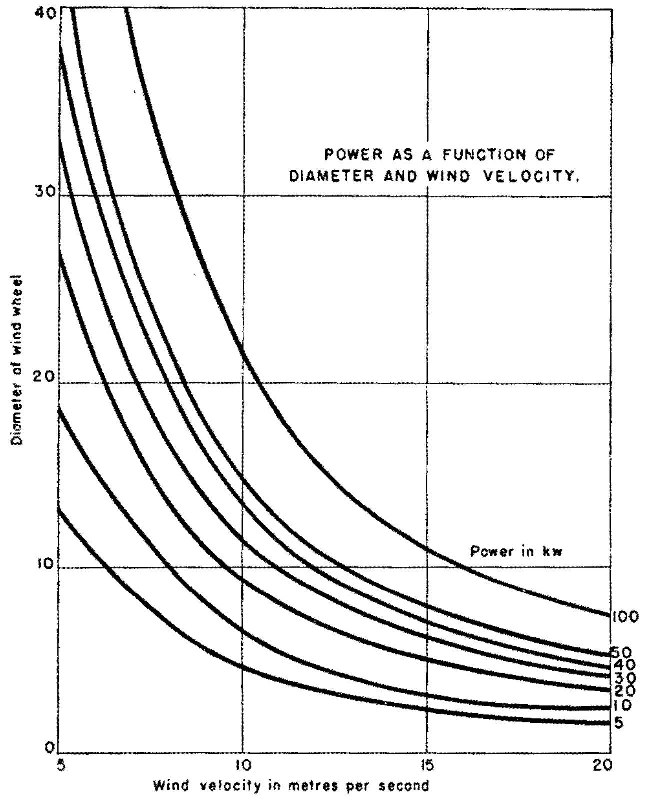


Figure 2

Hence the respective cost per kwh. for each installation in metropolitan French francs is as follows: wind turbine alone, 1.50; diesel alone, 12; wind turbine plus diesel, 5,60.

Even where a diesel-powered electric generator is already installed, the advantage of adding a wind-driven generator, if the site is favourable, is immediately evident.

Moreover as the fuel thus economized generally comes from the dollar or the sterling area, for countries short of foreign currency this represents so much money saved for the purchase of material useful in other economic sectors.

The same reasoning would apply in a comparison with thermal installations although the saving would be not so much on the poor-quality coal used for such generators as on the period of amortization of the boiler equipment which would consequently be prolonged, thus appreciably reducing the price per kwh.

A comparison of cost per kilowatt (installed) would be very useful but it is difficult to fix an average comparable cost for the different sources of energy. A multitude of secondary factors affecting the figure are involved, depending on the site, the abundance or scarcity of labour, and the transport of material or fuel to the site. It may be roughly estimated, however, that the cost per kilowatt of an installed wind generator would be at most equal to the lowest cost per kilowatt of a hydraulic power station driven by natural water power. In general, for power supplied by a group of wind turbines the price per kw. (installed) is reckoned as between 25,000 and 30,000 francs. With small wind turbines the price is less and even reaches a minimum at a power supply of about 20 kw. These figures are, however, only given as an indication, for they vary according to the conditions of use.

III. UTILIZATION

Obviously, the scope of utilization is vast although the power limit for economic installations is about three thousand (3,000) kw. It is technically possible to construct 10,000-kw. windmills, but it has yet to be proved whether it would even be an economically sound proposition. That is by no means sure. Installations of that kind are very costly: the size and hence the cost of certain parts of the structural, mechanical and electrical equipment, such as pylons and blades, increase in proportion to the square on the dimension. In the writer's opinion, the installation of very large wind turbines should only be undertaken with caution. So far, in view of the experience gained at Grandpa's Knob, a project as grandiose as that can hardly be entertained as a really sound undertaking. The writer does not doubt that the time for such things will come, but B-36 bombers were not built the day after Lindbergh's transatlantic flight. Progress must be achieved by stages and the installation of small or medium-power wind-turbines at a large number of places should serve as an excellent experiment. Numerous sites with plenty of available windpower are to be found both at sea and on the continents. In order to give an idea of the importance which aerogenerators may attain, a few suggestions for their use are given below:

(1) Fishing areas in the Polar and sub-polar regions. Power for lighting, heating, the canneries and repair workshops;

(2) Power for isolated lighthouses in all regions;

(3) Air bases, emergency bases, meteorological or W/T stations.

Power for lighting, heating or ventilation and for operating instruments.

Signalling.

These uses of windpower are of interest in all regions from the equator to the poles.

(4) Isolated farms in new territories: Africa, South America, Asia. Power for the provision of comforts (refrigerators, air conditioning) and for various types of work such as pumping water, irrigation, sawing wood, threshing, household and kitchen work. Possibility of radio communication (by transmitter-receiver) with the main centres. It should be possible to extend safety systems of this kind, such as already exist in Australia.

(5) Isolated mines, for lighting and work requiring low or medium power.

(6) A 5 kw. wind turbine mounted on mobile platform utilizable for all kinds of exploration work, geological research parties, medical missions etc.

The list could be extended indefinitely to take in numerous special possibilities.

At first sight it might appear that as many types of wind-turbine would have to be built as there are requests. But the reassuring fact is that there are many medium-size undertakings and few large undertakings. The standard demand may therefore be expected to be for about a 2-kw. model rising to 10 kw. and above in a few special cases. It would probably be worthwhile for a group of consumers to share a collective wind-turbine of a given power, which would cost less than several small models of comparable total power.

Statistical research in France and the French Union indicates that four universal types, of 1, 5, 15 and 30 kw., might be constructed, which means that production in standard sizes is conceivable.

Higher-powered units would require production in small series (10 or 20 turbines) or in single models.

CONCLUSION

The sole purpose of this brief review has been to attempt to prove the immediate usefulness of the wind as a source of energy and an economic factor. Numerous specialists have already turned their attention to this question in many countries including the USA, Great Britain, Denmark, USSR, Germany and France. Official bodies have been set up between which, so far as the writer knows, no co-ordination exists. In his opinion, the promotion of human well-being is an appreciable element in future peace and this fact should lead to the creation of a world windpower centre, to centralize the work, information and achievements of all scientists and technicians working together for the welfare of mankind.

Bibliography

(1) Palmer Cosslet Putnam, *Power from the Wind*, Van Nostrand, New York, New York, U.S.A., 1948.
(2) A. Baldit, *Météorologie du relief terrestre, vents et nuages*, Gauthier-Villars, Paris, France, 1929
(3) Link, "Air Currents in Hilly Country", *Zeitschrift für Meterologie*, vol. 14, no. 2 (1928), page 501, Germany.
(4) P. Queney, "Influence du relief sur les élements météorologiques, Berlin", *La Météorologie*, nos. 4 and 5, 1936, Paris, France.
(5) R. Siestrunck, *Le développement moderne de la théorie de l'hélice*, Gauthier-Villars, Paris, France, 1947.

General Reference Material

Palmer Cosslet Putnam, *Power from the wind*.
(6) H. Witte, "The use of Windpower; Progress and Prospects", *Die Technik*, November 1947, Berlin, Germany.
(7) E. M. Fateiv, "Wind Turbines", *Gossenergisdat*, Moscow 1946.

Summary of Discussion

The Chairman requested members of the section to present their papers as briefly as possible in view of the large number of documents to be examined.

Hitherto the section had been engaged in drawing up a balance sheet of available world energy resources and had paid particular attention to the depletion of petroleum resources as a result of increased consumption. The next step was to see how the development and utilization of fuels might be improved.

Viewing the problem as a whole, the Chairman stressed that the consumer might thoughtlessly waste resources which were not unlimited. What was needed was to teach the public how to make the best use of the energy available.

The Chairman recalled that much work had been done in Europe to improve efficiency in the consumption of fuel, particularly in respect of motor vehicles, and the conclusion had been reached that it was efficiency, and not speed, that should be improved. Owing to the scarcity of gasoline, European factories had succeeded in producing motor vehicles doing 50 miles to the gallon, whereas American cars could do only 15 to 22 miles to the gallon.

Dr. Macfarlane presented the paper of Messrs. Roxbee Cox and Williams on "Future Trends in Fuel Utilization".

He stated that the authors analysed, from the point of view of conservation, the utilization of the various sources of energy. As the time available for discussion was short, he proposed to concentrate on that part of the paper dealing with the supply of energy for traction.

In the field of civil and military aviation, there was every indication that the spark-ignition engine would be more and more replaced by the gas turbine. The gas turbine might be expected to find a place, too, in stationary installations for power generation. In the United Kingdom, for example, two 15,000 kw. open-cycle gas turbines and one closed-cycle plant of 12,500 kw., which would consume middle distillate fuels, were being constructed.

For rail transportation, the steam locomotive is being challenged both by the diesel engine and by electrification. The possibilities of the gas turbine must therefore be measured against these more efficient forms of traction. There would be great interest in the results achieved with oil-fired gas turbine locomotives, as well as in the research that was now being undertaken in the U.S. to run a gas turbine locomotive on pulverized coal.

Interesting experiments had recently been made to utilize residual oil fuel for marine diesels on British ships. If these proved as successful as they promised to be, considerable econ omies should be possible.

Mr. Uytenbogaart presented the paper on the "Future Outlook on Fuel Utilization" prepared by Mr. Broeze.

He emphasized the need of using fuels with maximum economy and outlined their various uses for domestic purposes in heating, cooking and lighting, and for technological purposes in producing heat and power.

While the problem of the production of energy by combustion seemed to have reached a more or less final stage, it must be remembered that the recent development of the internal combustion turbine might offer new possibilities. The direct utilization of electro-chemical phenomena at high temperatures, on the other hand, had hitherto not been successful, for want of proper equipment, but its application seemed to be practically unlimited.

Mr. Rose introduced the paper by Mr. Yellott on "Future Trends in Fuel Utilization and Conservation". The utilization of fuels was developing at a very rapid pace. In the ten years between 1935 and 1945, the consumption of energy in the United States had increased by 70 per cent while the population increase had been only 10 per cent. Since atomic energy could not yet be applied to industry, the only two available means of producing energy were the burning of hydrocarbons and the transformation by turbines of hydraulic energy. Fuels, — coal, oil products, natural gases — thus played a big part in modern life. An examination of the consumption of those fuels showed that in the United States 23 per cent of production was consumed by motor vehicles. That proportion could be reduced by improving the efficiency of motors, utilizing the exhaust heat of turbines, and using solid instead of liquid fuels.

Mr. Yellott's paper sketched the various types of energy-producing engines such as the condensing steam turbine, in which the losses were gradually being reduced to a minimum, and the non-condensing steam engine the use of which was apparently declining.

In the case of the internal combustion engine, the most widely used type was the piston engine. The diesel engine was employed in trucks and heavy vehicles because of its greater thermal efficiency. The gas turbine was mainly used in aviation and had the advantage of being able to consume several kinds of fuel; it did not require water, had a high order of efficiency and heat losses could be recaptured. Studies were being made in New York State on the use of coal as a fuel in an open-cycle gas turbine and the results thus far obtained were very encouraging.

Mr. Bushman gave a brief account of his paper on "Progress in Thermal Power Generation". He stressed particularly the use of hydrogen cooling and showed how the efficiency of the stations varied according to steam pressure.

The manufacturing costs of thermal stations could be reduced by using only one boiler for each turbine, using larger boilers, simplifying the steam and electrical layout, and employing less staff. Greater efficiency could be achieved with mercury steam installations than with ordinary turbines.

The Chairman presented to the meeting his paper on the "Future Outlook on Fuel Utilization". He emphasized the great variety of fuels available to industry and of devices used to transform the potential energy of fuels into kinetic energy. He pointed to the importance of the performance factor in the case of vehicles as well as of the complex nature of the factor of efficiency, which could be broken down into production efficiency, transport efficiency and transformation efficiency.

The interest of the consumer might not necessarily coincide with the goal of saving natural resources. Whether he was a manufacturer or a business man, the factor of costs would, from his point of view, overshadow all other considerations. The determination of costs was a complicated matter; operating costs included fuel costs, depreciation, operational labour costs and maintenance. Those factors would vary, of course, according to the economic conditions of each particular country.

The Chairman reviewed various types of engines including the spark ignition engine, turbo-jet engine, compression ignition engine and the gas turbine.

Finally, he emphasized that the employment of various engines and fuels was conditioned by performance, efficiency and facility of use. However, it had to be borne in mind that a particular country might often have to utilize equipment that was absolute but not amortized, that because of the financial situation it might have to encourage the consumption of national products which were sometimes less advantageous from the point of view of manufacturing costs, and finally, that it must keep in balance the consumption of the various products available in its home market.

Mr. Rettaliata commented upon the importance of the part which the gas turbine could play from the point of view of conservation. From a fuel conservation standpoint it would be almost a duty, he thought, to bring about the perfection of turbines which would operate at maximum efficiency. Such an undertaking would require the collaboration of the metallurgical industry, since it would be involved in the supply of alloys capable of resisting very high temperatures.

Mr. Rettaliata suggested the possibility of promoting the efficiency of thermal plants by the use of improved turbines and the reduction of the loss of energy by means of utilizing exhaust heat.

Mr. Hansen said that certain countries lacking foreign exchange could not obtain high-octane fuels; he would like to hear details concerning devices which would permit the utilization of lower-grade gasoline and wished to know whether such devices could be adapted to ordinary motors.

Mr. Uytebogaart said it was difficult to reply to that question off-hand. He could say, however, that a special device was being perfected which would connect the carburettor with a second gasoline tank containing an anti-knock fuel. Only during acceleration would this auxiliary fuel be injected into the carburettor.

The Chairman said that road tests had been made in Ohio and the conclusion had been reached that the period during which high-octane gasoline was consumed did not exceed ten per cent of the total elapsed time. For a European touring car the period was less than 20 per cent of the total time, and for a truck less than 25 per cent.

The Chairman wanted to know what the members of the section thought of the respective merits of turbines and motors. Personally, he was reserving his opinion on the question as long as the real manufacturing cost of a kilowatt produced by turbines in large industrial installations had not been determined.

Mr. Rose did not think that sufficient data were yet available on gas turbines to make it possible to judge their output satisfactorily. Nevertheless, he hoped that in the near future they would give results comparable to those obtained with the best turbines in current use.

The Chairman drew the attention of the meeting to Mr. Kennedy's paper on "Utilization of By-Products Gases Produced in an Iron and Steel Works" which had been circulated among the participants.

Mr. Fieldner commented on the paper by Messrs. Roxbee Cox and Mr. Williams.

There was a tendency in the United States to use good-quality liquid fuels in preference to coal, when the difference in cost was relatively small. There was in particular a tendency to manufacture synthetic liquid fuels from coal and other solid fuels in case the oil reserves should eventually become exhausted. From the point of view of the conservation of fuels, however, it should not be forgotten that in the manufacture of synthetic liquid fuel half of the calorific value of the coal or the natural gas was lost in the process of transformation. It would therefore be advisable to continue to use oil or natural gas wherever possible, and to convert into synthetic liquid fuel only deposits of poor-quality coal which was unsuitable for building up stocks and difficult to transport. When turned into a liquid fuel, it could easily be transported to the desired place by means of pipe-lines.

Mr. Aubert reviewed the paper by Mr. Giguet on "New Developments in Electric Energy Production".

The paper pointed out that sources of power, which were worked in accordance with the laws of thermodynamics, appeared chronologically in order of decreasing efficiency as regards cost and of increasing efficiency as regards quantities. The progress of technical processes had reduced the difference between the costs of successive *quanta* and contributed, simultaneously with the constant increase in demand for power, to bring new sources under exploitation. Only rarely did it reverse the order of succession of the *quanta*.

Despite the great diversity in potential sources of power, certain natural phenomena as they developed recapitulated, as it were, the general evolution of power economy.

That was the case in the harnessing of certain rivers, which, depending on the point where their course was considered, showed such different characteristics that the various sections into which they could be divided might justifiably be considered as essentially different sources of power.

In France, the Rhône fulfilled those conditions. Its course could reasonably be divided into three sections.

It had been possible to harness the upper section, from the Swiss frontier to Génissiat, by means of a single installation of 65 metres drop at Génissiat. There five Francis turbines of 70,000 kw. each supplied in an average year 1,700,000 kwh. at a price between 11 and 12 francs per kwh./year. The Génissiat plant had been put into operation in 1948.

The second section stretched from Valence to Mondragon. The fall there was only 0.77 metres per kilometre. The section would be divided into three works of about 25 metres drop, constructed on long by-passes. The total production of the section would be about 6,000 million kwh. The downstream installation was under construction at Bollène and would supply 2,000 million kwh. per year at a price of 35 francs per kwh./year. The installation of that section of the river had been made economically possible by the invention of the Kaplan wheel, or, at least, of the helical wheel.

The third section, with a fall of only 0.50 metres per kilometre, would comprise 17 works of variable drop (between 4.5 and 17.5 metres). It would be capable of producing 9,000 million kwh. per year, but at a price of more than 40 francs per kwh./year, which exceeded the present economic limit.

It would seem, however, that the working of that section would soon become economically feasible.

Mr. Raver introduced and commented on his paper on "Power for Industrial and Agricultural Development".

It had just been stated in connexion with a previous paper that the hydro-electric resources were very limited and that it was consequently essential to develop the generation of steam-electric power. It was also said that the scarcity of fuels and energy in contrast with the increase in population and requirements was becoming an ever more serious problem; thus the rational exploitation of hydro-electric power was particularly important. In the United States, the Pacific Northwest and the Columbia River Basin offered a striking example of a great hydro-electric power resource which is being developed.

Forty per cent, or 30 million kw., of the total undeveloped hydro-electric energy in the United States is to be found in the Columbia River Basin (55 million kw. represented the total electric generating capacity installed in the United States at the present time).

Among the large hydro-electric power stations in that region, the one at Bonneville had a capacity of 570,000 kw. and that at Grand Coulee a capacity of 2 million kw., of which 1,300,000 had already been exploited. The output of those two power stations had amounted to over 12,000 million kwh. in the year ending June 1949.

The Pacific Northwest offered a striking example of the advantage of electrical interconnexion and co-ordinated operation among the various power plants. The 11 major power systems in the region had pooled their resources, so that the energy produced could be utilized more completely. It had been estimated that an additional 600,000 kw. was available to the Pacific Nordthwest over what would be available without the pooling of resources. The transmission grid, which has been established in the Pacific Northwest, is a great step forward; it makes it possible to reduce the price of transmission, to facilitate the establishment of new decentralized industries and to provide a uniform rate for electricity throughout the various parts of the region.

Mr. Dahlgren summarized the paper by Mr. Saraoja on the production of power for industrial and agricultural development in Finland.

The paper stated that hydro-electric power was the chief source of energy in Finland. The pulp industry which owed its existence and development to the electrical power was the greatest consumer. As the available water-power underwent seasonal variations, the industry was also seasonal. Other industries, such as the manufacture of steel alloys, were also based on the utilization of hydro-electric power. Finally, electricity was the chief source of energy used for domestic heating, as there were hardly any gas-works in Finland.

The Chairman opened the discussion on the three papers which had just been submitted.

Mr. Velander recalled that he had been asked to prepare an introductory paper on the subject. As he had not been able to submit such a paper, he would take the opportunity to make some verbal comments. He wished in particular to draw the attention to certain points which differed from the generally accepted ideas.

In his country, Sweden, it was often said that industrial development had been based on the existence of cheap hydro-electric power. Nevertheless, especially in the specialized manufactures, the cost of the energy consumed amounted to a maximum of only 1 to 3 per cent of the manufacturing cost. There were doubtless certain industries such as the electro-chemical and electro-metallurgical ones, in which the cost price of the power was an important factor. Generally speaking, however, the low cost of electrical power was not enough in itself to explain industrial development. As to the use of electric power, other factors than cost, such as the universal availability, also played their part. Thus, in Sweden, many new industries had been established far away from the generating stations, thanks to the wide-spread transmission system. Wages were the chief factor in determining the manufacturing cost, and the efficient transmission of electricity made it possible to bring energy to the place where the most suitable labour was to be found.

Because of the distance which separated the places where energy and labour could be found, the industrial process had in some cases been divided, intermediate products requiring great amounts of energy, being produced near the power source and sent to industrial regions to be made into finished products.

Mr. Velander considered the cost of transmitting energy in electrical power lines in comparison with the cost of transporting energy in pipe-lines as oil or natural gas, which was common in the United States. He wondered whether it might not be more economic sometimes, instead of transporting electrical energy for heating purposes, to transport fuel in pipes – perhaps even gasified coal or peat. Another form of energy transportation had just been mentioned, namely the transportation of intermediate products.

Mr. RAVER did not agree, as far as the Northwest was concerned, with the suggestion that cheap hydro-electric power should be used for the production of semi-finished products which would then be sent to established industrial regions for finishing. In that region, cheap hydro-electric power is used for the production of basic aluminium most of which is sent across the country to plants in the East for fabrication into finished products, some of which are returned to the Pacific Nordthwest for sale. The need is for more fabrication plants in that region to supply the rapidly expanding western markets with finished products. Because of the uniform power rate throughout the Pacific Northwest, it is possible to locate such new plants in areas which will tend to counteract excessive concentration of population in large cities.

Mr. THOMAS summarized his paper on the use of windpower as a source of electric energy.

He wished to point out at the outset that the statement that wind energy was now available for electric utility service was intended to be taken literally, the only reservation being that provision would have to be made for a reasonable amount of time and for the necessary preliminary effort to design and produce the first actual full-sized structures.

Mr. Thomas then surveyed the principal steps which had led to the present stage in the designing of wind turbines. The studies had dealt with:

(1) The use of the principle of impact which was essential to the effective operation of the wind turbine;

(2) The intermittency and other vagaries of the wind;

(3) The aerodynamics of the airfoil and of the airplane propeller.

The somewhat startling dimensions of the large capacity turbine were rendered necessary by the small amounts of energy engendered by the wind.

The author had made a study-design for an aerogenerator with a capacity of 7,500 kw.

To tap as large a body of wind as possible, two wheels were provided, each 200 ft. in diameter, located on the two ends of a 235-ft. bridge, revolving on a turntable placed at the top of a 475-ft. tower. The wheels had three blades each, fixed in position in the hub, but without the feathering feature. To withstand the terrific aerodynamic thrust upon those blades, due to their very high speed, 550 ft. per second at the tip, a tension brace leading from the hub was provided for each blade to give it sufficient strength.

That very high power was desirable for two main reasons: first, the wheel of a high-speed, impact-type turbine like the above, drew upon a cylinder of the wind several times as great in diameter as the wheel itself, and so should be given a sufficient clearance from the ground for that air cylinder. Secondly, the velocity of the wind and its smooth streamline character were definitely more favourable several hundred feet above the surface. A sufficiently high average wind-velocity was very important for economy in the wind-turbine, and a more favourable velocity high above the ground assumed an almost dominating importance. That would be realized when it was remembered that, while over level ground, the wind velocity might increase some 40 per cent in the first 500-ft. rise in elevation, the energy content of the wind would then increase as the cube of that velocity, namely by 174.4 per cent. It was surprising to note that according to estimates, the cost of that 500-ft. tower was less than 25 per cent of the whole aerogenerator cost.

In a number of the larger countries, regular wind-velocity measurements had been made at many selected stations for long periods of time. Several millions of such readings had been recorded by the Weather Bureau of the United States of America and carefully analysed. An examination of data from some of the most important of the Weather Bureau stations showed the following characteristics, covering the observations for thirty consecutive years and for fifty stations scattered over the United States of America.

At least for the United States of America, the annual average of the hourly wind-velocity at any station was quite constant, with the minimum annual average of hourly readings never dropping more than 30 per cent below the long-time annual average.

In the same way, the monthly averages of the hourly velocities were found to be surprisingly constant, never dropping below half the annual average for that station. Even the weekly averages had a rather stable value.

The variations of the monthly averages within the year showed velocities in the months of July and September some 15 per cent lower, on the average, than the annual average.

In appraising those variations of velocity, it should be remembered that the energy in the wind varied much more widely than the velocity, since the energy was proportional to the cube of the velocity. There were, however, important compensating considerations.

The cost of such an aerogenerator would be somewhat below that of a low-cost steam plant. Maintenance costs would also be very low.

Mr. RINGERS summarized the report prepared by the Netherlands Society for the Preservation of windmills concerning the utilization of windpower in the Netherlands.

The society believed that windpower could be used for generating electricity. To achieve that aim, it was necessary first to create conditions under which existing windmills could be changed into electric power generators and secondly, to study the possibility of generating electricity by means of aeromotors of a new design.

The windmills in the Netherlands could, however, supply only a modest share of the total requirements of electricity in the Netherlands.

The modern windmill could now transform only 20.3 per cent of the theoretically usable wind energy and could produce 235,000 h.p./hours per year. Those figures applied only to windmills in the coastal region. As the wind-velocity decreased inland, the average figure for the whole country fell to 70 per cent of those figures.

Interesting experiments had been carried out during the preceding twenty years, leading to improvements in the construction of the windmills and to increased efficiency.

If the windmills were used as an electric-power generator, the electromotor could be used to drive the interior parts of the windmill during windless periods. Thus, the windmill would act sometimes as a dynamo and sometimes as a motor. Any surplus energy produced could be used for the needs of the community. Hence, the advantage of preserving windmills in the Netherlands.

During the past century the number of windmills in the country had decreased from 8,000 to 1,300, so that the electric power they could have supplied was now being produced from the usual fuels.

A test installation was being constructed with a subsidy of 12,500 guilders granted by the Government for the modernization and electrification of an existing windmill near Leyden. The tests to be carried out once that station had been completed would show whether there would be any advantage in transforming the still existing windmills in the Netherlands into electric power generators.

The CHAIRMAN asked Mr. Aubert to summarize the paper prepared by Mr. Fardin on "Wind-Power: Its Interest and Possibilities".

Mr. AUBERT outlined the paper prepared by Mr. Fardin. Mr. Fardin recalled, first of all, that there were isolated areas difficult to supply with fuel, and which lacked electricity because of the high cost of distribution. He then emphasized the part which could be played by windpower in those areas.

He divided turbines into two categories: first, units up to 500 h.p., which he thought were more interesting when they were used independently; and second, units of over 500 h.p., which might be usefully connected with an electrical distribution system. He recalled that while windpower could be converted into electricity, it could also be used either as a direct source of power or for transformation into heat energy (heat pump).

The CHAIRMAN asked Mr. Aubert to say a few words on the experiments carried out in France on the harnessing of tidal power.

Mr. AUBERT said at first that tidal power was similar to windpower in that it was not constantly available.

The harnessing of tidal water did not raise any difficult or even any novel technical problem. The experience gained from waterpower installations on rivers should make it possible to solve any such problem. The salinity of sea-water did not entail any serious difficulty, even as regards the corrosion of the metal parts of pipes and machines.

Plans had been made in France to build first in the estuary of a river a one way plant which would use tidal power only when the tide was going out. That plant would play the part of an auxiliary and would be connected with the national grid system, supplying only from two to three per cent of the French consumption. As the time of the tides could be forecast with the greatest accuracy, it would be easy to decrease or resume the output of other plants at the right moment.

The estuary to which it was referred was that of the Rance River where tides reached their greatest height in France, namely 11 metres. The plant which had been planned would produce 800 million kwh. per year, that is, half the capacity of the large Génissiat-dam plant.

Estimates with regards to the cost of the Rance plant would vary according to the methods envisaged for the construction of the engineering works; the choice between those methods had not been made yet.

It had also been planned to harness tide-power by a considerable installation that would be built in the vicinity of St. Malo. The estimated production would reach 20 thousand million kwh. per year and would thus meet a large part of France's requirements.

In practice, the only problem to be solved with regards to the harnessing of tidal power is the economical and technical problem of the cost of the installations.

Mr. KARPOV remarked that the available experience showed that it was possible to build medium-sized aeromotor plants. The only question to arise in the field of practical application was that of the production costs of those installations. Wind was a source of energy, but there were other cheaper sources of energy in existence. However, the production costs of other forms of energy might be high if used during peak periods only, so that as some authors had suggested, windpower might, although in some rare instances only, be utilized as an auxiliary. It should be remembered, however, that the only plant to be built on an industrial scale in the United States, in Vermont, had ceased working. Paradoxically, in the case of windpower, the source of power was absolutely free, but maintenance expenditure was so high as to make the final cost of energy prohibitive.

Mr. DE LUCCIA congratulated Mr. Thomas on his survey and research. He believed that wind was a valuable source of energy and of great potential value in regions where other sources were not easily available. As Mr. Thomas had said, windpower should be regarded as an auxiliary and not as a competitor with other sources of energy. It was an extremely valuable factor for the conservation of non-renewable resources. He had been very interested in Mr. Aubert's communication on the utilization of tidal power, and was glad to note that in the opinion of competent circles modern technology could now already harness tidal power.

Mr. THOMAS said, in reply to Mr. KARPOV, that according to the research carried out, the harnessing of windpower would be cheaper than the production of power from natural fuels, although it might be slightly more expensive than hydroelectric power.

Furthermore, he believed that, apart form the cost of the installation, aeromotors built according to his plans would last a long time and that maintenance costs would be very low.

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