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Progress in Stainless Steel Production by Top and Bottom Blown Converter

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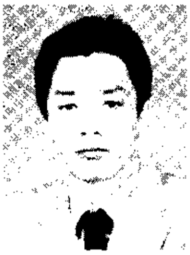
Taking the chance of stainless steelmaking integration at Chiba Works in April 1981, an 85 t new UHP melting furnace (MF) was erected and existing LD converters were converted into top and bottom blown converters as Chiba No.1 steelmaking shop for rationalization of the stainless steelmaking process. Saving energy by replacing electric power with coke and enlarging flexibility in material choices were considered to be the basic concept of cost reduction. To achieve this objective, hot metal dephosphorization, and inexpensive heat compensation system and high speed refining process using the top lance were developed. As a result, optimization of the stainless steel making process and hence cost reduction were achieved.

Progress in Stainless Steel Production by Top and Bottom Blown Converter*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1 Introduction

Steel production in Japan decreased under the impact of the oil crisis, and there is not now much hope that the future will see any great increases. On the other hand, stainless steel production has markedly increased in the past 20 years. With fields of application continuing to grow, demand will tend to increase.

Against this background, Kawasaki Steel planned the integration of all its stainless steel refining facilities at Chiba Works, and executed equipment renovation, centering around the revamping of the 85-t LD converter at the No. 1 steelmaking shop as a top and bottom blown converter (K-BOP).[1] As a result, stainless steel refining, using an electric furnace and K-BOP in an integrated production system from pig-iron to steel, has been realized along with cost reductions and productivity enhancement due to rationalization of the refining process. Basic concepts for realizing these objectives were low cost and flexible choice where raw materials are concerned, reduction of electric power use, and shortening of refining time; to execute these measures, development of various techniques was necessary.

As a result, an optimum refining process for stainless steel, capable of meeting various steel grade requirements, has been established, and rationalized, stabilized production is being carried out. The various techniques developed in this connection are now applied as well to the production of some specialty steels and high carbon steel,[2] and are greatly contributing to technical progress in the converter refining field. In this paper, K-BOP refining techniques for stainless steel are discussed.

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2 Features of Stainless Steel Refining Process and Equipment Specifications

2.1 Features of Stainless Steel Refining Process

Because raw material costs account for the greatest part of total manufacturing costs for stainless steel, the ability to select raw materials flexibly and at low-cost is very important from the viewpoint of cost reduction. Raw materials for making stainless steel generally include scrap and ferro-alloys, but Kawasaki Steel has worked to devise, in addition, techniques for using hot metal and ores to reduce the consumption of fello-alloys. Further, the company has established heat compensation techniques utilizing coke addition and post combustion, which are indispensable if hot metal and ores are to be used.

Kawasaki Steel has also established optimum blowing conditions for stainless steel production with K-BOP. These production conditions include control of the oxygen flow rate of the top lance in the K-BOP converter, by which both a shortening of decurburization time and promotion of sulfur vaporization are realized, and, in addition, CaO powder injection during the reduction period, which achieves the object of improving desulfurization capacity during reduction.

The fundamental conditions for optimum refining of stainless steel by K-BOP may be summarized in the following three points:

(1) Flexibility in selection of raw materials, including hot metal and ores
(2) Reduction of electric power consumption through low-cost heat compensation techniques
(3) Establishment of an optimum blowing pattern which combines appropriate top lance use and CaO powder injection during the reduction period.

The requisite techniques for realizing these fundamental concepts are shown in **Fig. 1**. Through application of

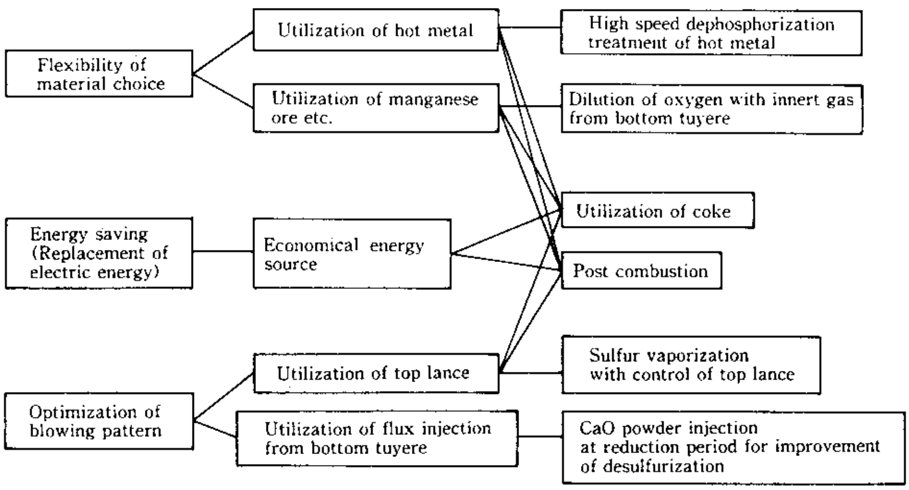

Fig. 1 Principle of cost reduction for stainless steelmaking

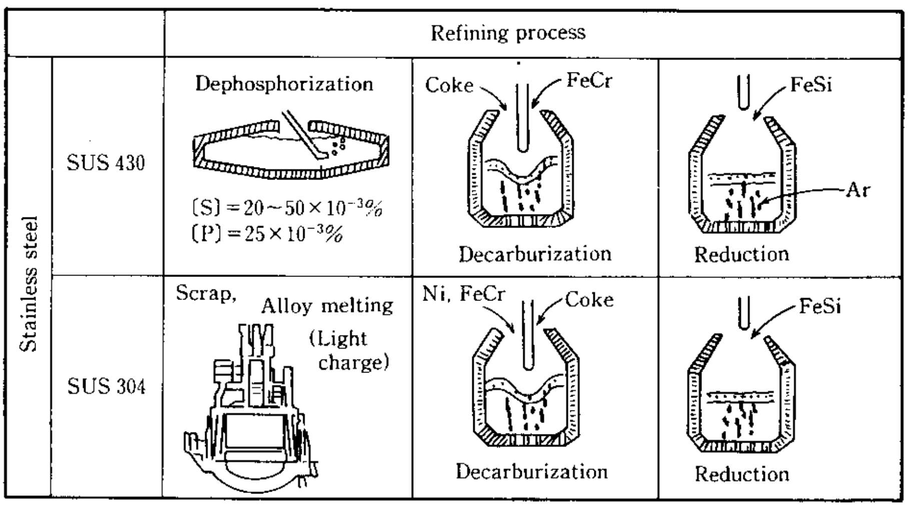

Fig. 2 Refining process of stainless steel at Chiba Works

these techniques, it has become possible, in the manufacture of stainless steel at Chiba Works, to select the optimum refining process to meet changes in circumstances and the requirements of various grades of steel.

The refining process for stainless steel is shown in **Fig. 2**. Ferritic stainless steel is manufactured from dephosphorized hot metal and high-carbon FeCr which are decarburized in K-BOP, using small-lump coke as a heat source. On the other hand, in the fundamental process for austenitic stainless steel, crude molten steel, made by melting low-cost stainless steel scrap in an electric furnace, is refined in K-BOP. However, it is possible, depending on conditions, to choose to decrease the quantity of scrap melted in the electric furnace and instead feed increased quantities of scrap and ferroalloys into K-BOP, or alternatively, to omit the electric furnace altogether and use hot metal. Both austenitic and ferritic steel production employ the single slag method, in which desulfurization and reduction and recovery of Cr oxides are performed simultaneously after decarburization in K-BOP.

2.2 Equipment for Stainless Steel Production

Specifications of main stainless steel production equipment at the No. 1 Steelmaking shop of Chiba Works are shown in **Table 1**. Electric furnace transformer capacity was increased to 65 MVA to cope with continuous casting. For hot metal pre-treatment in the torpedo car, blowing through a slanted lance is used, with a limebased dephosphorizer blown in at a rate of 450 kg/min.

Table 1 Specifications on the main equipment of stainless steel making facilities at Chiba Works

Items	Specifications
(1) EF	85 t UHP furnace
Capacity of transformer	65 MVA
Electrode	24 inches (3° slanted)
Dust collector	Bag filter, clean house
Noise reduction	Clean house
Wall and roof	Water cooling jacket, pipe
(2) Converter	85 t × 2 (combined blowing)
Combination of gases	Center: O_2, $O_2+Ar(N_2)$, $Ar(N_2)$ Annulus: Pr, $Pr+Ar(N_2)$, $Ar(N_2)$
Oxygen flow rate (max.)	Top lance: 175 Nm^3/min Bottom tuyere: 100 Nm^3/min
Flux injection (max.)	CaO or $CaCO_3$: 300 kg/min
Waste gas treatment	OG type
(3) Hot metal treatment	Torpedo injection
Flux	CaO based fluxes
Injection rate (max.)	500 kg/min (pneumatic control type)
Oxygen gas mixing (max.)	5 Nm^3/min ($O_2/N_2=5$)

With K-BOP, it is possible to decarburize by using diluted-gas, equivalent to AOD, by mixing an inert gas such as Ar or N_2 with O_2 at the tuyere. In addition, the following advantages make K-BOP a multifunctional refining furnace:

(1) Being equipped with a top lance, it has advantages in heat compensation such as coke-addition blowing and post-combustion, and productivity is high.
(2) Since propane and other cooling gases can be used, it has an advantage in tuyere protection.
(3) Since CaO powder injection is possible, it has an advantage in desulfurization in the reduction period.

K-BOP is also used in refining specialty steels other than stainless steel, and thus its equipment operation rate is very high. Further, adjustment to future increased production of stainless steel will be easy.

3 Stainless Steel Production Techniques with Top and Bottom Blown Converter

3.1 Hot Metal Pretreatment

Chiba Works, based on its capability of supplying hot metal from its large blast furnaces and the results of its past efforts in developing a hot metal dephosphorization technique using CaO-based fluxes,[3] uses dephosphorized hot metal in the manufacture of stainless steel. Particularly in making ferritic stainless steel, the use of hot metal permits bypassing of the electric furnace, thereby achieving major savings due to the reduction in electric power consumption.

To make stainless steel from hot metal, the following techniques are essential and/or effective.

(1) High-speed hot-metal dephosphorization
(2) Heat compensation using coke
(3) Heat compensation using post combustion
(4) Converter off-gas recovery
(5) Sulfur vaporization
(6) High-speed K-BOP refining

In the high-speed dephosphorization of hot metal, a constant supply of low-Si hot metal and a technique for high-speed injecting of the dephosphorizing agent are important. At the No. 6 BF of Chiba Works, the facts that [Si] content in the tapped hot metal is low and stable and desiliconization is performed at the casting bed are advantageous for dephosphorization treatment. An example of the temperature and composition behavior of hot metal during dephosphorization treatment is shown in **Table 2** and **Fig. 3**. Since at the time of ordinary steelmaking of stainless steel, sulfur vaporization at K-BOP and desulfurization in the reduction period are

Table 2 Changes in chemical compositions and temperature during hot metal treatment

	Chemical composition (%)					Temp. (°C)
	C	Si	Mn	P	S	
Tapping from BF	4.50	0.25	0.30	0.140	0.035	1 480
Before treatment	4.50	0.10	0.25	0.140	0.035	1 380
After treatment	4.25	Tr	0.22	0.020	0.020	1 280

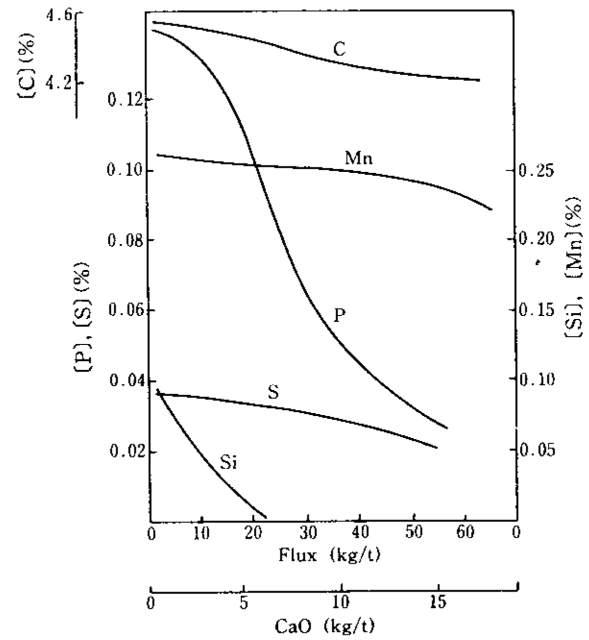

Fig. 3 Chemical changes in composition during hot metal treatment

presupposed, hot metal treatment is performed mainly for dephosphorization rather than for desulfurization.

Because it it necessary to synchronize dephosphorization with converter operation, the relatively high blowing speed of 450 kg/min has been adopted. However, because the solid/gas ratio is high at 130 kg/Nm^3 and slanted injection is used and, further, due to continued efforts to improve control of the quantity of hot metal introduced into the torpedo car, operational problems such as slopping and metal scattering have been effectively eliminated.

Changes in the hot metal pretreatment ratio are shown in **Fig. 4**. At present, more than 90% of ferritic stainless steel is made by the dephosphorized hot metal method, in which the electric furnace is not used. Hot metal temperature after pretreatment, also shown in Fig. 4, is related to heat compensation in the K-BOP and constitutes an important control item. High-speed blowing and thoroughgoing freeboard control have made it possible to maintain hot metal temperature after

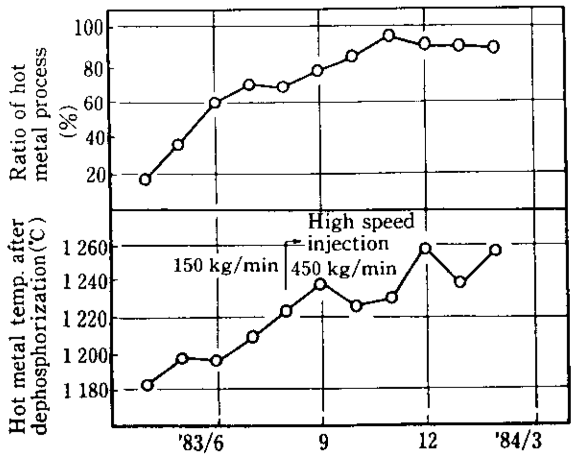

Fig. 4 Increase of ratio of hot metal process with improvement of hot metal dephosphorization operation

dephosphorizing treatment at higher than 1 250°C.

3.2 Heat Compensation System

Low-cost heat compensation is an indispensable technique for the use of pretreated hot metal in stainless steel production and the smelting reduction of ore. The heat balance during the use of pretreated hot metal is shown in **Fig. 5**. The hot metal mixing rate is low at 70 to 75%, and even if the oxidation reaction of carbon and silicon in high-carbon FeCr is taken into account, heat will be short for the blowing. As a result, development of low-cost, stable heat compensation techniques is necessary. To cope with this situation, Chiba Works uses addition of small-lump coke through the furnace top and a post-combustion technique utilizing the top lance.

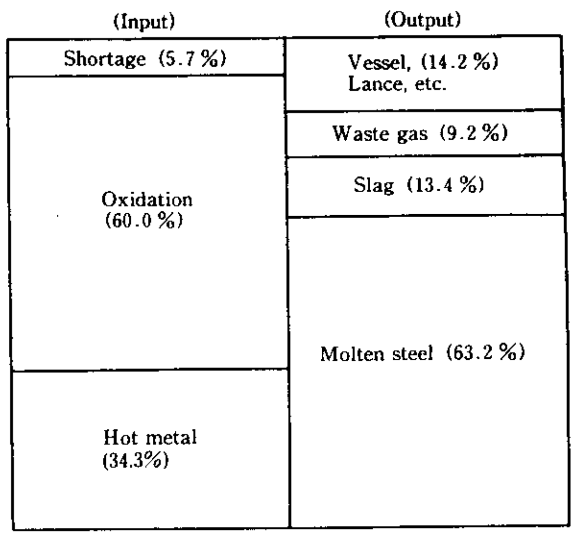

Fig. 5 Heat balance of hot metal process

3.2.1 Heat compensation system by top-addition of coke

The technique of using coke as a heat source has the following advantages over the FeSi method, which is widely used as a heat source:

(1) Small-lump coke, a surplus material in the steel mill, can be used.
(2) Even with large amounts of coke, the quantity of slag generated is small.
(3) CO gas generated can be used as an energy source.

In heat compensation by coke addition through the furnace top, the efficiency of the coke addition to the steel bath becomes important. Here the efficiency of coke addition is defined by Eq. (1).

$$\eta_1 = \frac{10 \cdot \Delta C + (V_1 - V_2) \times 12/11.2}{W_c \times 0.87} \times 10^2 \quad \cdots (1)$$

where η_1: Efficiency of coke addition (%)
ΔC: Decarburization amount (%)
V_1: Oxygen blowing amount (Nm^3/t)
V_2: Amount of oxygen consumed in oxidation of Si, Mn and propane (Nm^3/t)
W_c: Coke addition amount (kg/t)

Since K-BOP of Kawasaki Steel has a high bottom-gas flow rate and strong steel bath stirring power, high coke addition efficiency can be obtained, as shown in **Fig. 6**. Consequently, stabilized heat compensation is feasible by addition of coke through the furnace top, as shown in **Fig. 7**. Of the amount of heat theoretically generated from coke, as well as that supplied by post-combustion, the heat efficiency usable by the molten steel is extremely high at 85%, as shown in **Table 3**. When coke is used as a heat source, sulfur contamination from the coke is a cause for concern, but in K-BOP, as discussed below, it is possible to promote sulfur vaporization by top lance control, a major advantage of K-BOP.

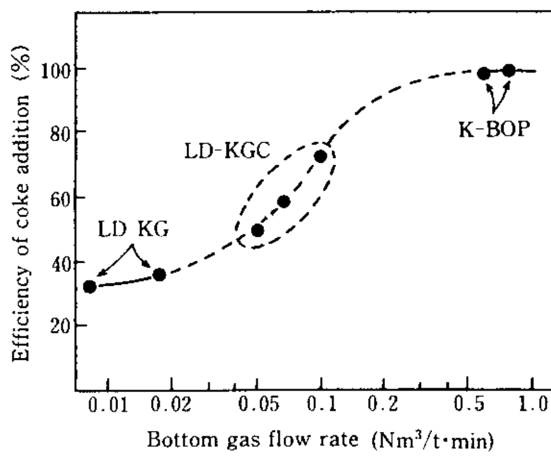

Fig. 6 Relation between bottom gas flow rate and efficiency of coke addition

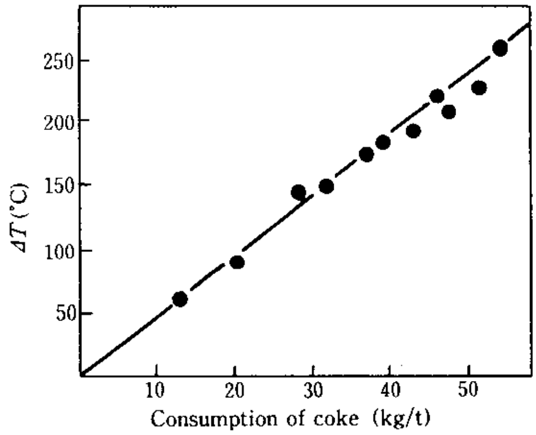

Fig. 7 Relationship between consumption of coke and increase of temperature of molten steel

Table 3 Heat efficiency of coke

Chemical reactions	Chemical content	
C ⟶ CO	83%	2 034 kcal/kg·coke
CO ⟶ CO_2	7.2%*	341 kcal/kg·coke
Sensible heat of CO	—	−785 kcal/kg·coke
Sensible heat of H_2	—	—
Sensible heat of N_2	—	−4 kcal/kg·coke
Moisture decomposition	6.0%	−331 kcal/kg·coke
Sensible heat of ash	10.8%	−45 kcal/kg·coke
Reaction heat of coke (cal.)		1 210 kcal/kg·coke
Reaction heat of coke (obs.)		1 029 kcal/kg·coke
Heat efficiency of coke		85.0%

* Without post combustion practice

3.2.2 Heat compensation by post-combustion

Although coke is a low-cost heat source, the long blowing time its use requires is a problem. Therefore, with the aim of reducing the unit consumption of coke, post-combustion of the CO gas generated in the furnace is positively used to supply heat to the steel bath. Through the use of a lance tip with a part of its Laval nozzle altered to a straight nozzle, promotion of post-combustion and improvement in heat efficiency are achieved. Ratios of post-combustion and heat efficiency are expressed by Eqs. (2) and (3).

$$\Delta O_2 = \Delta C\left(\frac{11.2}{12}(1 - \eta_2) + \frac{22.4}{12} \cdot \eta_2\right) \quad \cdots (2)$$

$$\frac{Q_{obs}}{\alpha} = (Q_{C \to CO} + \eta_2 \cdot \beta \cdot Q_{CO \to CO_2}) \quad \cdots\cdots (3)$$

where ΔO_2: Oxygen unit consumption (Nm^3/t-steel)

ΔC: Decarburization amount (kg/t)
η_2: Post combustion ratio (%)
Q_{obs}: Actual heat recovery amount (kcal/kg)
$Q_{C \to CO}$: Heat generation by carbon oxidation (kcal/kg)
$Q_{CO \to CO_2}$: Heat generation by CO gas oxidation (kcal/kg)
β: Heat efficiency
α: Constant

The relation between lance height and the ratio of post-combustion is shown in **Fig. 8**; the relation between the ratio of post combustion as defined in Eq. (2), and heat efficiency, in Eq. (3), is shown in **Fig. 9**. For equal oxygen flow rates, the straight-nozzle lance tip for post-combustion shows higher values both in the ratio of post combustion and heat efficiency. The improvement in heat efficiency is especially important from the viewpoint of economical heat compensation.

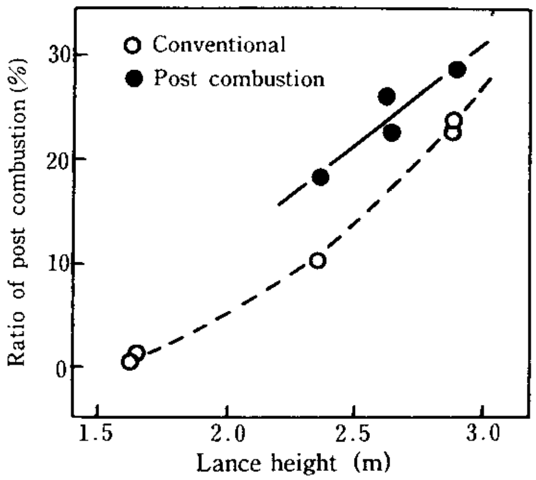

Fig. 8 Relation between lance height and ratio of post combustion

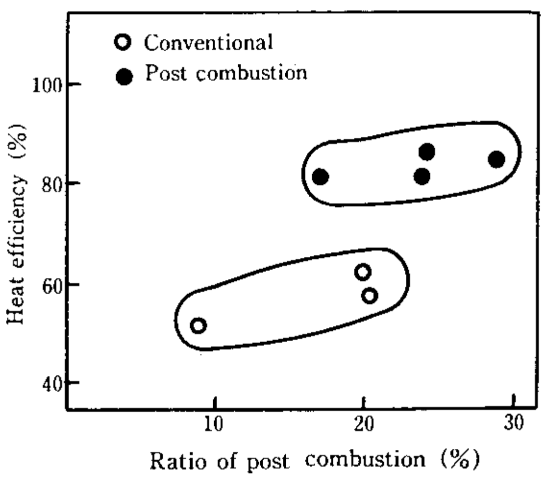

Fig. 9 Relation between ratio of post combustion and heat efficiency

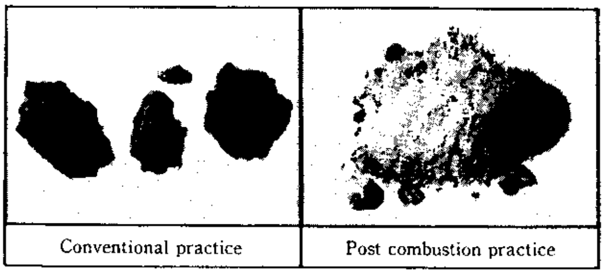

Photo 1 Macroscopic view of slag during decarburization period

The improvement in heat efficiency is reflected not only in the heat balance but also in the characteristics of slag. The external appearance of slag after decarburization of ferritic stainless steel is shown in **Photo 1**. The slag at the time of blowing with a process lance shows a ball shape in which lime is surrounded by metal. In contrast, when post-combustion is promoted, the slag shows little deposition of metal and disintegrates into powder several minutes after sampling. The reason for this is considered to be that when a post-combustion lance is used, post combustion occurs in the vicinity of the steel bath and the temperature at the slag surface rises, causing a decrease in the deposition of metal on lime.

The relation between thermal insufficiency in ferritic stainless steel production and required coke addition, with and without use of the post-combusion lance, is shown in **Fig. 10**. Through improvement in heat efficiency with use of the post-combustion lance, unit coke consumption has been reduced by about 15 kg/t. As a result, blowing time has been shortened by about 9 min, thereby contributing to the enhancement of produc-

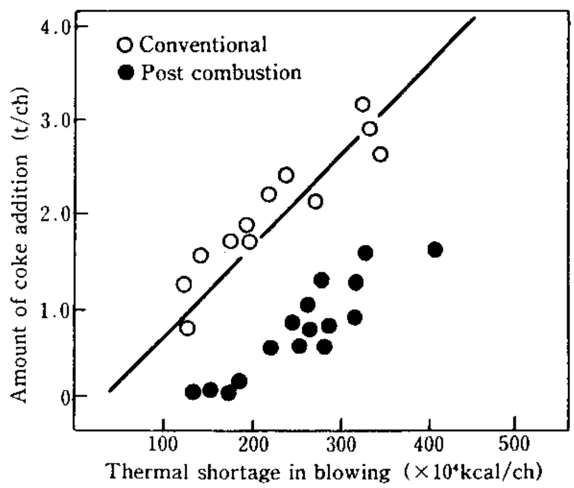

Fig. 10 Relation between thermal shortage in blowing and amount of coke addition

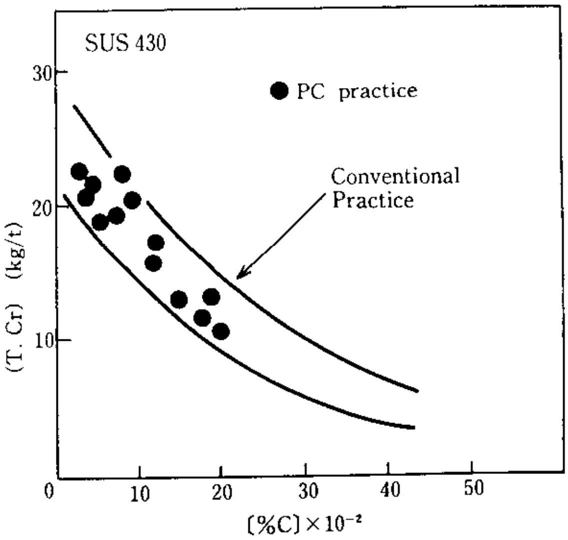

Fig. 11 Relation between [%C] and amount of (T. Cr) in slag

tivity.

The relation between [%C] in the steel bath and the amount of Cr oxidation in slag when the post combustion lance is used is shown in **Fig. 11**. No effect of the promotion of post combustion on Cr oxidation was noted. This is considered to be due to the strong steel bath stirring power of K-BOP, created by the high flow rate of the bottom-blown gas.

As an ancillary effect of the use of the post-combustion lance, deposition of metal on the mouth of furnace is eliminated, contributing greatly to the enhancement of crude steel yield.

3.3 High-speed Decarburization Technique and Sulfur Vaporization by Combined Use of Top-blowing Lance

3.3.1 High-speed decarburization technique

In shortening the operation time for stainless steel blowing with K-BOP, the top-blowing lance is markedly effective. The effect of combined use of the top lance is particularly evident when carbon concentration is high. The top lance is indispensable, moreover, for the manufacture of stainless steel from dephosphorized hot metal with greater decarburization than in the electric furnace process, in view of synchronization with continuous-continuous casting.

On the other hand, it was feared that when the top lance was used and the oxygen flow rate was increased, Cr oxidation loss would increase due to a rise in oxygen potential at the fire point. **Figure 12** shows the relation between [%C] and [%Cr] for various oxygen flow rates. If [%C] $\geqq$ 0.40% in the steel bath, even combined use of the top lance does not increase Cr oxidation loss, meaning that, if the oxygen top-blowing period is proper, high-speed decarburization becomes possible with K-BOP.

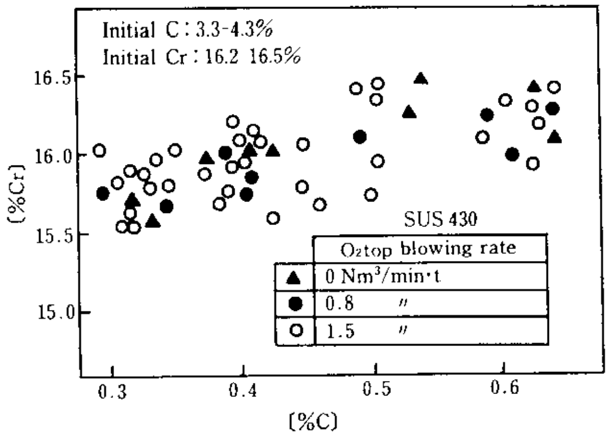

Fig. 12 Influence of oxygen top blowing rate on chromium oxidation during decarburizing period

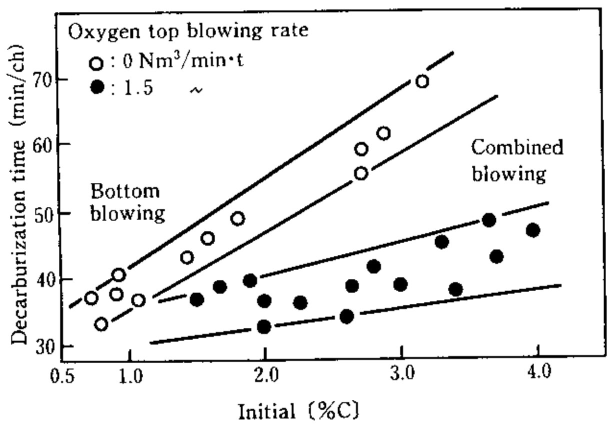

Fig. 13 Influence of oxygen top blowing on time required for decarburization

The effect of the top lance on decarburization time is shown in **Fig. 13**. Even if carbon concentration is high at the start of blowing, with K-BOP the degree of Cr oxidation loss is the same as that in the electric furnace process, while refining time is reduced, and it is possible to synchronize stainless steel production with continuous-continous casting.

3.3.2 Top lance and sulfur vaporization

With heat compensation using small-lump coke, contamination of the steel by sulfur from coke poses a problem. In this respect, the top lance is also effective, since it is possible to suppress sulfur contamination from coke by controlling the oxygen flow rate.

Examples of the S balance of the bottom blown converter Q-BOP and top and bottom blown converter K-BOP are shown in **Fig. 14**. In a comparison between

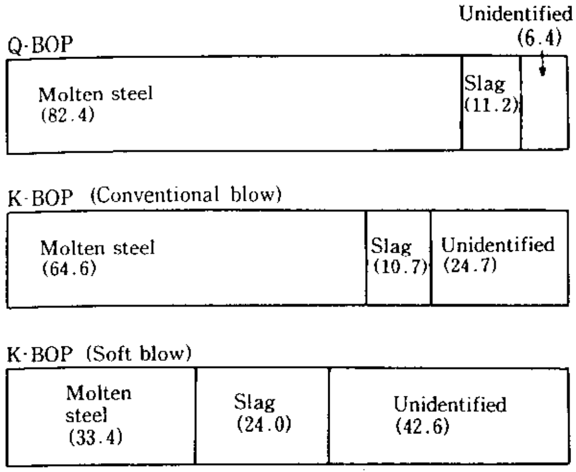

Fig. 14 Comparison of sulfur balance between Q-BOP and K-BOP

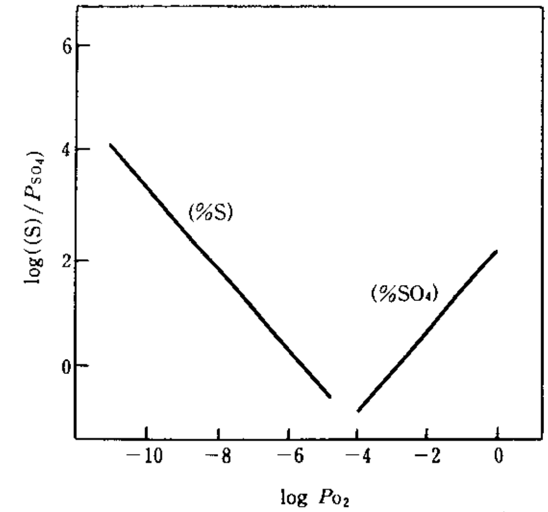

Fig. 15 Relation between P_{O_2} and $(S)/P_{SO_4}$

these two converters, the unidentified S amount in K-BOP is greater than that in Q-BOP, and the difference becomes increasingly conspicuous as the oxygen blowing from the top lance become softer. To investigate this unidentified S, dust-collector water was sampled. An example of the result is shown in **Table 4**. When coke was added and soft blowing performed, S concentration in the dust collector water was about five times higher than with blowing without coke. From this, it is considered that the unidentified S resulted from sulfur vaporization.

Table 4 Sulfur content in the waste gas and in the water of dust collector

	S	Phase of S
Waste gas (after dust collector)	40 ppm	COS, H_2S
Water of dust collector	50 ppm	SO_4^{2-}
Metal	0.023%	

In general, it is difficult to consider that sulfur vaporizes directly from molten steel, but sulfur vaporization from slag is quite plausible in terms of thermodynamics, as indicated by many reports on the matter.[4~6] **Figure 15** shows the relation between partial pressure of oxigen and the sulfur distribution ratio at the slag-gas boundary, as proposed by Turkdogan et al. As P_{O_2} increases, sulfur distribution at the slag-gas boundary decreases, until near $P_{O_2} = 10^{-5}$, S is most susceptible to vaporization. However, when P_{O_2} exceeds 10^{-5}, S becomes stabilized in slag in the form of (SO_4), and vaporization is difficult.

The increase in unidentified S with soft blowing in K-BOP is considered attributable to the fact that P_{O_2} at the slag-gas boundary increases and promotes sulfur vaporization. However, since no measured values of P_{O_2} at the slag-gas boundary were available, here the value of P_{O_2} in the slag phase was estimated from the slag analysis values[7,8], and the relation between P_{O_2} and the amount of unidentified S was investigated. **Figure 16** shows the relation between P_{O_2} and (%S) in slag. With soft blowing, a tendency was shown of a rise in P_{O_2} and a decrease in S concentration in slag. **Figure 17** shows the relation between P_{O_2} and the amount of unidentified S, and indicates that as P_{O_2} increases from 10^{-9} to 10^{-8}, the amount of unidentified S also increases. From the above, it is also hypothesized that unidentified sulfur results from promotion of sulfur vaporization.

Even if S from coke increases as shown in **Fig. 18** due to promotion of sulfur vaporization, S content in the steel bath at the blow end is low at 0.020%, and lower sulfur contents in stainless steel can easily be attained by subsequent reduction treatment.

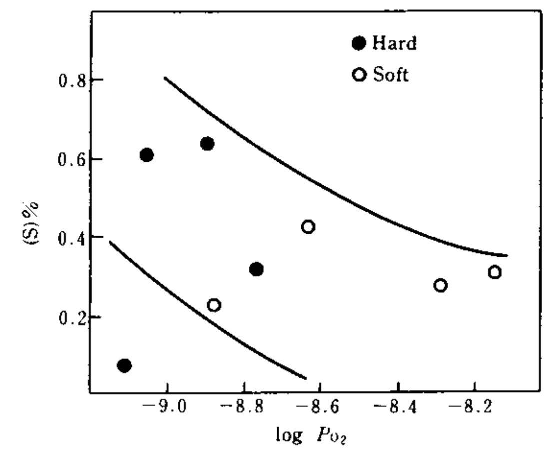

Fig. 16 Relation between P_{O_4} and (%S) in slag

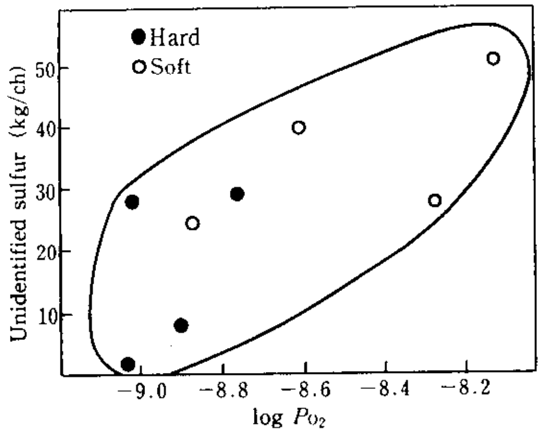

Fig. 17 Relation between amount of unidentified sulfur and P_{O_2}

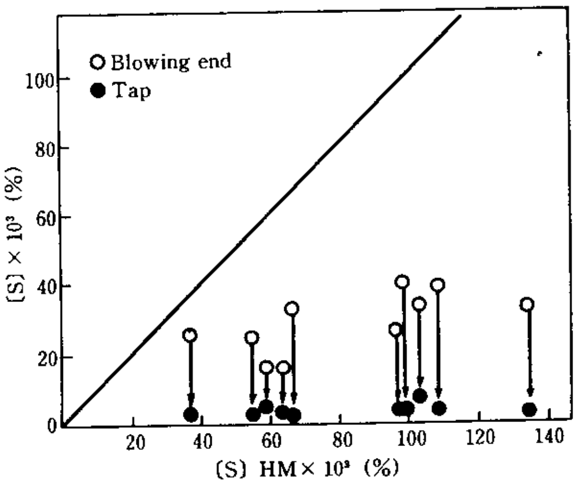

Fig. 18 Relation between hot metal sulfur and molten steel sulfur after reduction period

3.4 Ore Reduction Techniques

At the No. 1 steelmaking shop, the combination of K-BOP, with its function of dilution decarburization, and hot metal pre-treatment and the heat compensation techniques permits efficient reduction of ores such as manganese ore in the furnace. Consequently, manganese ore is used as an Mn source for stainless steel and high carbon steel. The so-called FeMn-free operation, in which it is not necessary to use FeMn alloy, has been incorporated in the production process. Mn yield is shown by Eq. (4).

$$Mn_Y = \frac{[\%Mn] \times 10^3}{W_{Mn} \times 0.342 + [\%Mn]_{HM} \times 10} \quad \cdots (4)$$

where Mn_Y: Mn yield
W_{Mn}: Unit consumption of manganese ore (kg/t)
$[\%Mn]_{HM}$: Mn in hot metal
$[\%Mn]$: Blow-end Mn

Figure 19 shows the relation between [%C] in the steel bath and Mn yield, as defined in Eq. (4). At [%C] ≧ 0.20% in the steel bath, Mn yield is stabilized at a high level of 90%. At [%C] ≤ 0.20% in the steel bath, Mn yield drops, but this drop can be suppressed by dilution decarburization. As a result, even in production of stainless steel which requires decarburization down to low C levels, in-furnace reduction of Mn ore can be easily accomplished.

However, depending on production processes and grades of steel, addition of Mn ore increases Cr oxidation loss. Thus it becomes necessary to establish a suitable pattern for introduction of Mn ore, corresponding to the production process and grade of steel. **Figure 20** shows the equilibrium diagram for Cr oxidation in austenitic stainless steel, based on Hilty's equation.[9] When Mn ore is added in the low-temperature, high-

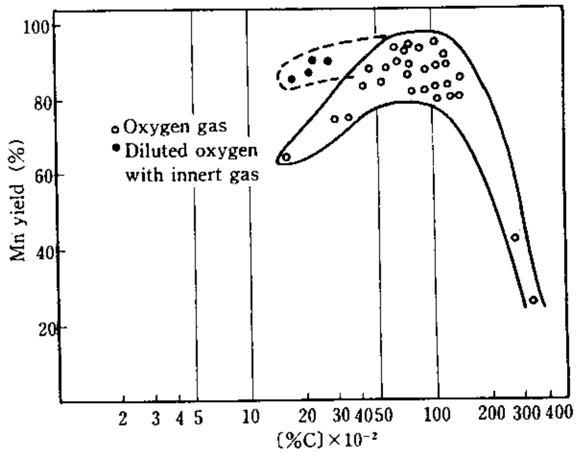

Fig. 19 Relation between [%C] and Mn yield

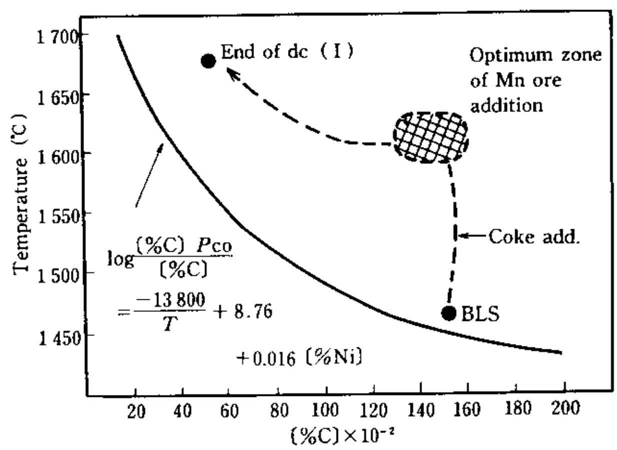

Fig. 20 Optimum zone of manganese ore addition

carbon zone immediately after the start of blowing, it is difficult to control [%C] in the steel bath; when Mn ore is added in the high-temperature, low-carbon zone near the end of blowing, it is difficult to control the steel bath temperature. For the optimum period for adding Mn ore, it is desirable to select timing when deviation from Hilty's Cr oxidation equilibrium is great.

Figure 21 shows the relation between the timing of Mn ore addition and the amount of Cr oxidation loss for austenitic stainless steel. The relation between the timing of Mn ore addition and Cr oxidation loss with K-BOP is greatly affected by the temperature at the start of blowing and [%C] in the steel bath. Under the electric furnace tapping conditions at Chiba Works, Mn ore addition prior to the 10 to 12 Nm^3/t of the end of decarburization period (I) has made it possible to control Cr oxidation loss at a level equal to that with the in-furnace FeMn alloy addition process.

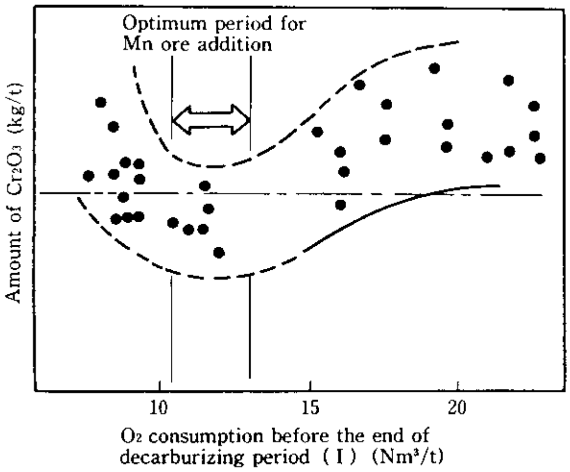

Fig. 21 Relation between manganese ore addition period and amount of Cr_2O_3

3.5 Improvement in Desulfurizing Reaction Efficiency by Lime Powder Injection in Reduction Period (Reduction Period F/I)

In K-BOP, the single slag method is employed, simultaneously accomplishing, in the reduction period, reduction and recovery of Cr oxides and desulfurization. Therefore, slag and metal were continuously sampled during reduction, and the reaction during the reduction period was investigated. As a result, it was concluded that the reduction reaction of chromium oxides is controlled by the migration rate of Cr oxides in slag shown in Eq. (5), and the desulfurization reaction is controlled by the migration rate of [S] in molten steel shown in Eq. (6).[10]

$$-\frac{d\{(W_S/\rho_S)(\%Cr_2O_3)\}}{dt} = k_P^S \cdot a_P\{(\%Cr_2O_3) - (\%Cr_2O_3)_{equiv.}\} \cdots\cdots (5)$$

$$-\frac{d[\%S]}{dt} = \frac{k_T^m \cdot a_T}{W_m/\rho_m}[\%S] + \frac{k_P^m \cdot a_P}{W_m/\rho_m}\left\{[\%S] - \frac{(\%S)}{L_S}\right\} \cdot (6)$$

where W_S: Slag volume (kg)
ρ_S: Slag density (kg/m^2)
k_P^m, k_P^S: Mass transfer coefficient (m/s)
a_P: Surface area between slag and particle (m^2)
W_m: Amount of molten steel (kg)
k_T^m: Mass transfer coefficient (m/s)
ρ_m: Density of molten steel (kg/m^3)
a_T: Surface area between molten steel and particle (m^2)
L_S: S distribution ratio between slag and metal

The above Eq. (6) indicates that in order to increase the desulfurization reaction, an increase in the reaction boundary surface area between slag and metal is important, and for this purpose, lime powder injection is effective.[11] Consequently, utilizing the function of powder injection through the bottom tuyeres of K-BOP, lime powder injection during the reduction period is performed as a start of operation.

The results of such operation are shown in **Fig. 22**. Injection of lime powder instead of lump lime results in low [S] content after reduction and in reduced variation

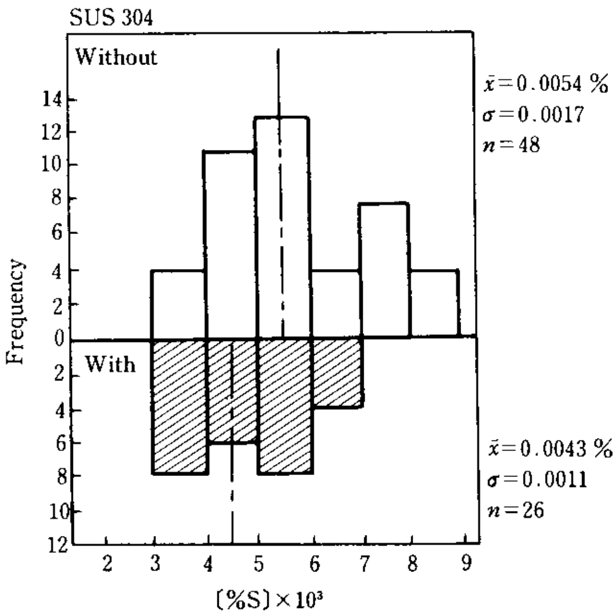

Fig. 22 Frequency of sulfur content after reduction period with and without CaO powder injection (10 kg/t)

in results. This is considered to be caused by the promotion of desulfurization and slag formation by the floating action of the lime powder. Further, by putting into practice the reduction period F/I, the amount of the CaO, not formed into slag, is decreased, and unit consumption of lime is reduced in with certain steel grades, thereby contributing greatly to cost reduction.

4 Concluding Remarks

Fundamentals of rationalization of the stainless steel refining process are reduction in the use of electric energy and the capability to select from a wide range of raw materials. To realize these condition, it was necessary to establish a hot metal dephosphorization technique, a low-cost heat compensation process, and a high-speed blowing technique which would fully utilize the top lance.

As a result of continuing efforts to develop these techniques, Kawasaki Steel has succeeded in developińg a highly efficient, economical stainless steel production process, achieving remarkable cost saving.

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