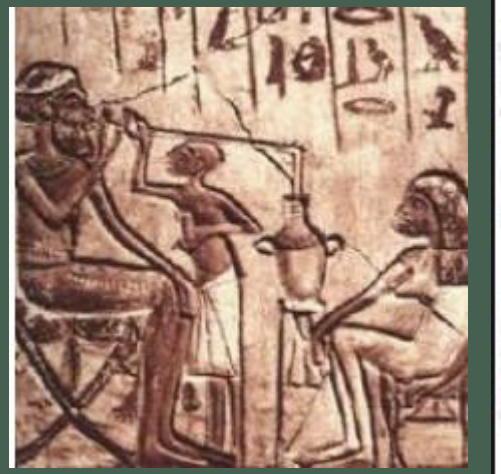
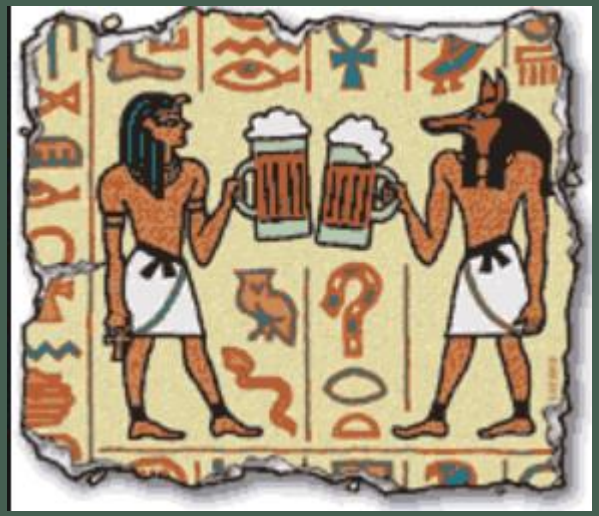
Production of Beer

12.1 BARLEY BEERS

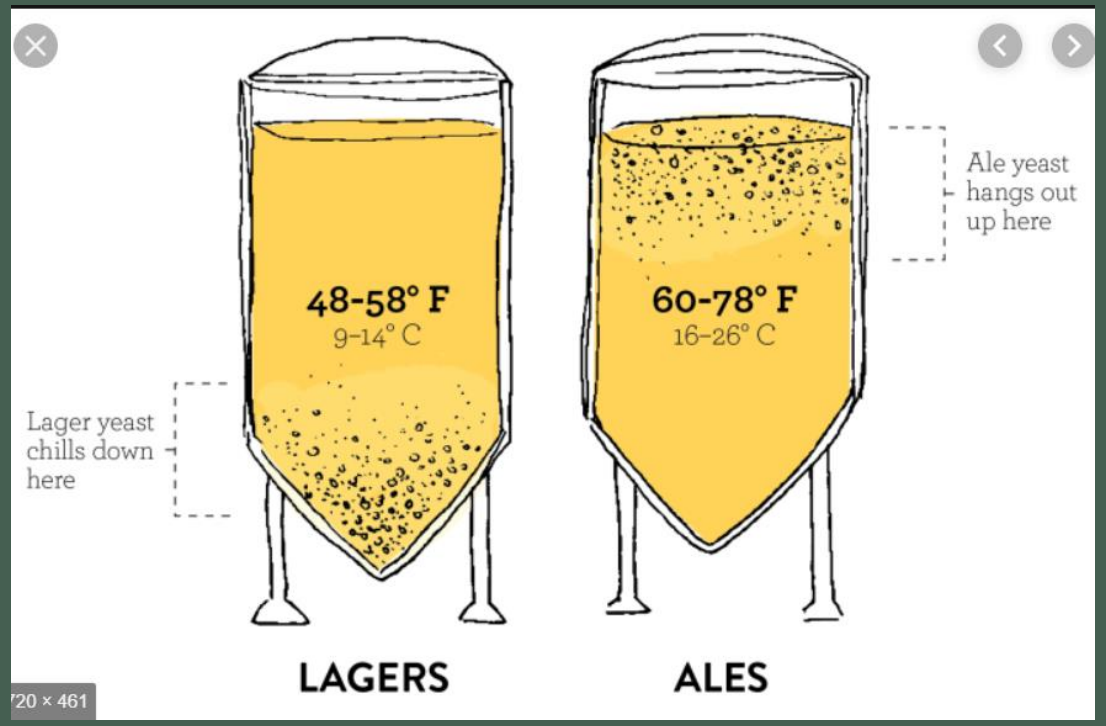
The word beer derives from the Latin word bibere meaning to drink. The process of producing beer is known as brewing. Beer brewing from barley was practiced by the ancient Egyptians as far back as 4,000 years ago, but investigations suggest Egyptians learnt the art from the peoples of the Tigris and Euphrates where man's civilization is said to have originated. The use of hops is however much more recent and can be traced back to a few hundred years ago.





12.1.1 Types of Barley Beers

Barley beers can be divided into two broad groups: top-fermented beers and bottomfermented beers. This distinction is based on whether the yeast remains at the top of brew (top-fermented beers) or sediments to the bottom (bottom-fermented beers) at the end of the fermentation.



12.1.1.1 Bottom-fermented beers

Bottom-fermented beers are also known as lager beers because they were stored or 'lagered' (from German lagern = to store) in cold cellars after fermentation for clarification and maturation. Yeasts used in bottom-fermented beers are strains of *Saccharomyces* uvarum (formerly *Saccharomyces carlsbergensis*). Several types of lager beers are known. They are Pilsener, Dortumund and Munich, and named after Pilsen (former Czechoslovakia) Dortmund and Munich (Germany), the cities where they originated. Most of the lager (70%-80%) beers drunk in the world is of the Pilsener type.

Bottom-fermentation was a closely guarded secret in the Bavarian region of Germany, of which Munich is the capital. Legend has it that 1842 a monk passed the technique and the yeasts to Pilsen. Three years later they found their way to Copenhagen, Denmark. Shortly after, German immigrants transported bottom brewing to the US.

(i) Pilsener beer: This is a pale beer with a medium hop taste. Its alcohol content is 3.03.8% by weight. Classically it is lagered for two to three months, but modern breweries have substantially reduced the lagering time, which has been cut down to about two weeks in many breweries around the world. The water for Pilsener brew is soft, containing comparatively little calcium and magnesium ions.

(ii) Dortmund beer: This is a pale beer, but it contains less hops (and therefore is less bitter) than Pilsener. However it has more body (i.e., it is thicker) and aroma. The alcohol content is also 3.0-3.8%, and is classically lagered for slightly longer: 3-4 months. The brewing water is hard, containing large amounts of carbonates, sulphates and chlorides.

(iii) Munich: This is a dark, aromatic and full-bodied beer with a slightly sweet taste, because it is only slightly hopped. The alcohol content could be quite high, varying from 2 to 5% alcohol. The brewing water is high in carbonates but low in other ions.

(iv) Weiss: Weiss beer of Germany made from wheat and steam beer of California, USA are both bottom fermented beers which are characterized by being highly effervescent.

12.1.1.2 Top-fermented beers

Top fermented beers are brewed with strains of Saccharomyces cerevisiae.

(i) Ale: Whereas lager beer can be said to be of German or continental European origin, ale (Pale ale) is England's own beer. Unless the term 'lager?' is specifically used, beer always used to refer to ale in England. Lager is now becoming known in the UK especially since the UK joined European Economic Community. English ale is a pale, highly hopped beer with an alcohol content of 4.0 to 5.0% (w/v) and sometimes as high as 8.0% Hops are added during and sometimes after fermentation. It is therefore very bitter and has a sharp acid taste and an aroma of wine because of its high ester content. Mild ale is sweeter because it is less strongly hopped than the standard Pale ale. In Burton-on-Trent where the best ales are made, the water is rich in gypsum (calcium sulfate). When ale is produced in places with less suitable water, such water may be 'burtonized'? by the addition of calcium sulfate.

(ii) Porter: This is a dark-brown, heavy bodied, strongly foaming beer produced from dark malts. It contains less hops than ale and consequently is sweeter. It has an alcohol content of about 5.0%.

(iii) Stout: Stout is a very dark heavily bodied and highly hopped beer with a strong malt aroma. It is produced from dark or caramelized malt; sometimes caramel may be added. It has a comparatively high alcohol content, 5.0-6.5% (w/v) and is classically stored for up to six months, fermentation sometimes proceeding in the bottle. Some stouts are sweet, being less hopped than usual.

12.1.2 Raw Materials for Brewing

The raw materials used in brewing are: barley, malt, adjuncts, yeasts, hops, and water.

12.1.2.1 Barley malt

As a brewing cereal, barley has the following advantages. Its husks are thick, difficult to crush and adhere to the kernel.

This makes malting as well as filtration after mashing, much easier than with other cereals, such as wheat.

The second advantage is that the thick husk is a protection against fungal attack during storage.

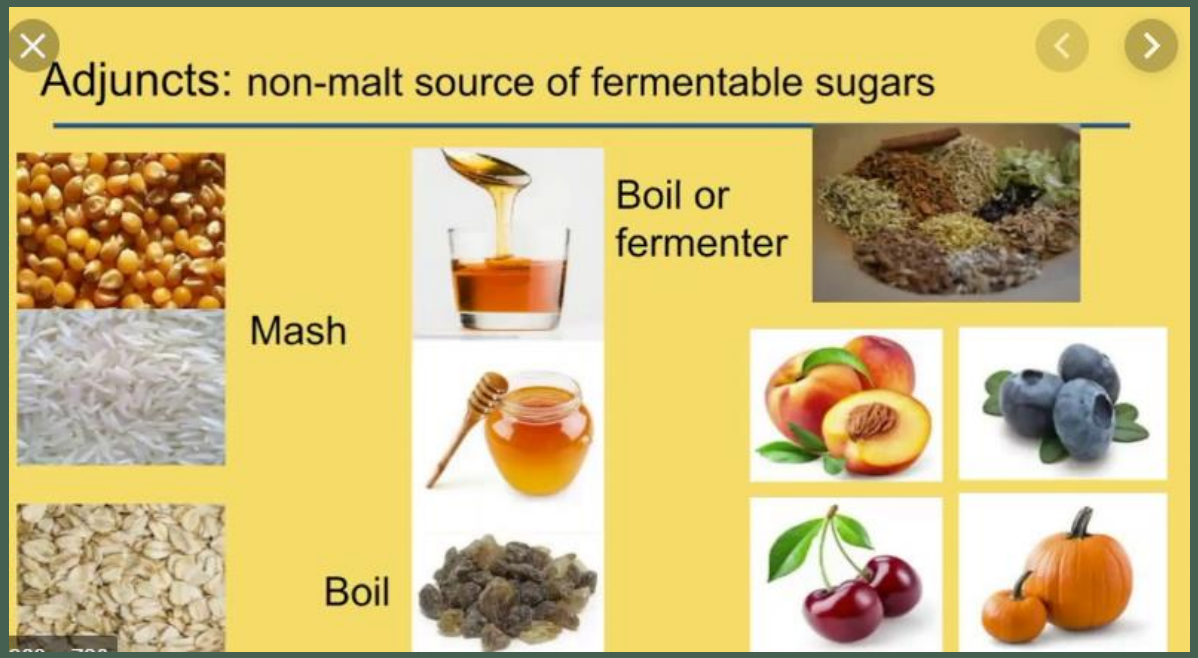
Thirdly, the gelatinization temperature (i.e., the temperature at which the starch is converted into a water soluble gel) is 52-59°C much lower than the optimum temperature of alpha-amylase (70°C) as well as of beta-amylase (65°C) of barley malt. The effect of this is that it is possible to bring the starch into solution and to hydrolyze it in one operation.

Finally, the barley grain even before malting contains very high amounts of beta-amylase unlike wheat, rice and sorghum. (Alpha-amylase is produced only in the germinated seed).

Two distinct barley types are known. One with six rows of fertile kernel (*Hordeum vulgare*) and the other with two rows of fertile kernels (*Hordeum distichon*). These differ in many other properties and as a result there are thousands of varieties. The six-row variety is used extensively in the United States, whereas the two-row variety is used in Europe as well as in parts of the US. The six-row varieties are richer in protein and enzyme content than the two-row varieties. This high enzymic content is one of the reasons why adjuncts are so widely used in breweries in the United States. **Adjuncts dilute out the proteins i.e. increase the carbohydrate/protein ratio. If an all-malt beer were brewed from malts as rich in protein as the six-row varieties, this protein would find its way into the beer and give rise to hazes. The process of malting, during which enzymes (amylases and proteases) are produced by the germinating seedling will be discussed later.**

12.1.1.2 Adjuncts

Adjuncts are starchy materials which were originally introduced because the six-row barley varieties grown in the United States produced a malt that had more diastatic power (i.e. amylases) than was required to hydrolyze the starch in the malt. The term has since come to include materials other than would be hydrolyzed by amylase. For example the term now includes sugars (e.g. sucrose) added to increase the alcoholic content of the beer. Starchy adjuncts, which usually contain little protein contribute, after their hydrolysis, to fermentable sugars which in turn increase the alcoholic content of the beverage.

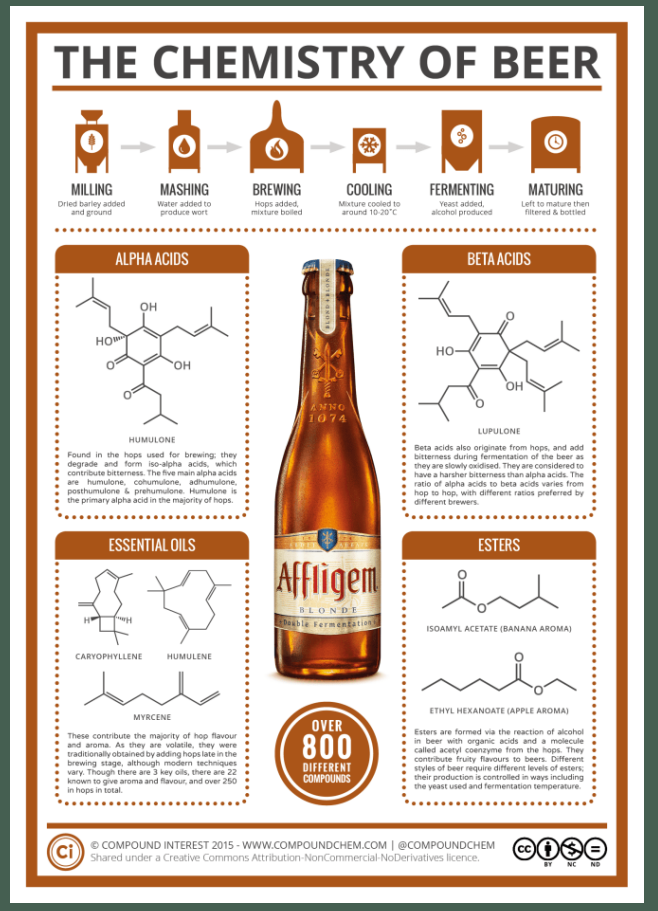


Adjuncts thus help bring down the cost of brewing because they are much cheaper than malt. They do not play much part in imparting aroma, color, or taste. Starch sources such as sorghum, maize, rice, unmalted barley, cassava, potatoes can or have been used, depending on the price. Corn grits (defatted and ground), corn syrup, and rice are most widely used in the United States.

When corn is used as an adjunct it is so milled as to remove as much as possible of the germ and the husk which contain most of the oil of maize, which could form 7% of the maize grain. The oil may become rancid in the beer aid thus adversely affecting the flavor of the beverage if it were not removed. The de-fatted ground maize is known as corn grits. Corn syrups produced by enzymic or acid hydrolysis, are also used in brewing. Since adjuncts contain little nitrogen, all the needs for the growth of the yeast must come from the malt. The malt/adjunct ratio hardly exceeds 60/40. Soy bean powder (preferably defatted) may be added to brews to help nourish the yeast. It is rich nitrogen and in B vitamins.

12.1.2.3 Hops

Hops are the dried cone-shaped female flower of hop-plant *Humulus lupulus* (synomyn: *H. americanus, H. heomexicams, H. cordifolius*). It is a temperate climate crop and grows wild in northern parts of Europe, Asia and North America. It is botanically related to the genus Cannabis, whose only representative is Cannabis sativa (Indian hemp, marijuana, or hashish). Nowadays hop extracts are becoming favored in place of the dried hops. The importance of hops in brewing lies in its resins which provide the precursors of the bitter principles in beer and the essential (volatile) oils which provide the hop aroma. Both the resin and the essential oils are lodged in lupulin glands borne on the flower.



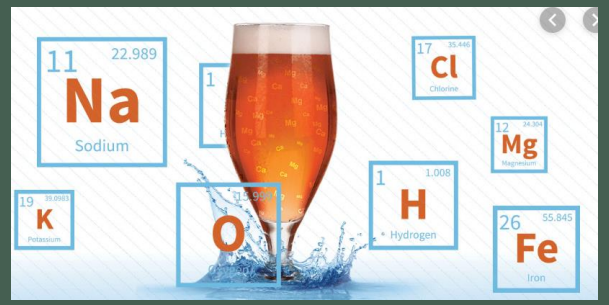
In the original Pilsener beer the amount of hops added is about 4 g/liter, but smaller amounts varying 0.4-4.0 g/liter are used elsewhere. The addition of hops has several effects:

(a) Originally it was to replace the flat taste of unhopped beer with the characteristic bitterness and pleasant aroma of hops.
(b) Hops have some anti-microbial effects especially against beer sarcina (*Pediococus damnosus*) and other beer spoiling bacteria.
(c) Due to the colloidal nature of the bitter substances they contribute to the body, colloidal stability and foam head retention of beer.
(d) The tannins in the hops help precipitate proteins during the boiling of the wort; these proteins if not removed cause a haze (chill haze) in the beer at low temperature. This is further discussed under beer defects later in this chapter.

12.1.2.4 Water

The mineral and ionic content and the pH of the water have profound effects on the type of beer produced. Some ions are undesirable in brewing water: nitrates slow down fermentation, while iron destroys the colloidal stability of the beer. **In general calcium ions lead to a better flavor than magnesium and sodium ions. The pH of the water and that of malt extract produced with it control the various enzyme systems in malt, the degree of extraction of soluble materials from the malt, the solution of tannins and other coloring components, isomerization rate of hop humulone and the stability of the beer itself and the foam on it. Calcium and bicarbonate ions are most important because of their effect on pH. Water is so important that the natural water available in great brewing centers of the world lent special character to beers peculiar to these centers.** Water with a large calcium and bicarbonate ions content as is the case with Munich, Copenhagen, Dublin, and Burton-on-Trent are suited to the production of the darker, sweeter beers. The reason for this is not clear but carbonates in particular tend to increase the pH, a condition which appears to enhance the extraction of dark colored components of the malt. Water low in minerals such as that of Pilsen (Table 12.1) is suitable for the production of a pale, light colored beer, such as Pilsen has made famous.

Water of a composition ideal for brewing may not always be naturally available. If the production is of a pale beer without too heavy a taste of hops, and the water is rich in carbonates then it is treated in one of the following ways:



(a) The water may be 'burtonized' by the addition of calcium sulfate (gypsum). Addition of gypsum neutralizes the alkalinity of the carbonates in an equation which probably runs thus:

$$2Ca(HCO_3)_2 + 2CaSO_4 \longrightarrow 2Ca^{++} + 2H_2SO_4 + 4CO_2$$

(b) An acid may be added: lactic acid, phosphoric, sulfuric or hydrochloric. CO_2 is released, but there is an undesirable chance that the resulting salt may remain. The CO_2 released is removed by gas stripping.
(c) The water may be decarbonated by boiling or by the addition of lime calcium hydroxide.
(d) The water may be improved by ion exchange, which may if it is so desired remove all the ions.
One or more of the above methods may be used simultaneously.

Table 12.1 Mineral content of water in some cities with breweries

	Mineral content in ppm						
Place	*Total Solids*	Ca^{2+}	Mg^{2+}	SO_4^{2-}	NO_3^-	Cl^-	HCO_3^-
Miwaukee	148	34	11	20	0.8	6.6	
New York	28	6	1	8	0.5	0.5	11
St. Louis	201	22	12	77	4	10	65
Pilsen	63	9	3	3		5	37
Munich	270	71	19	18		2	283
Dublin	3	100	4	45		16	266
Copenhangen	480	114	16	62		60	347
Burton-on-trent	1,206	268	62	638	31	36	287

(c) The water may be decarbonated by boiling or by the addition of lime calcium hydroxide.
(d) The water may be improved by ion exchange, which may if it is so desired remove all the ions.
One or more of the above methods may be used simultaneously.

12.1.2.5 Brewer's yeasts

Yeasts in general will produce alcohol from sugars under anaerobic conditions, but not all yeasts are necessarily suitable for brewing. Brewing yeasts are able, besides producing alcohol, to produce from wort sugars and proteins a balanced proportion of esters, acids, higher alcohols, and ketones which contribute to the peculiar flavor of beer. A number of characteristics distinguish the two types of brewers' yeasts (i.e. the top and the bottom-fermenting yeasts).

(a) Under the microscope Sacch. uvarum (Sacch. carlsbergensis) usually occurs singly or in pairs. Sacch. cerevisiae usually forms chains and occasionally cross-chains as well. These characteristics must however be taken together with other more diagnostic (particularly the biochemical) tests given below.

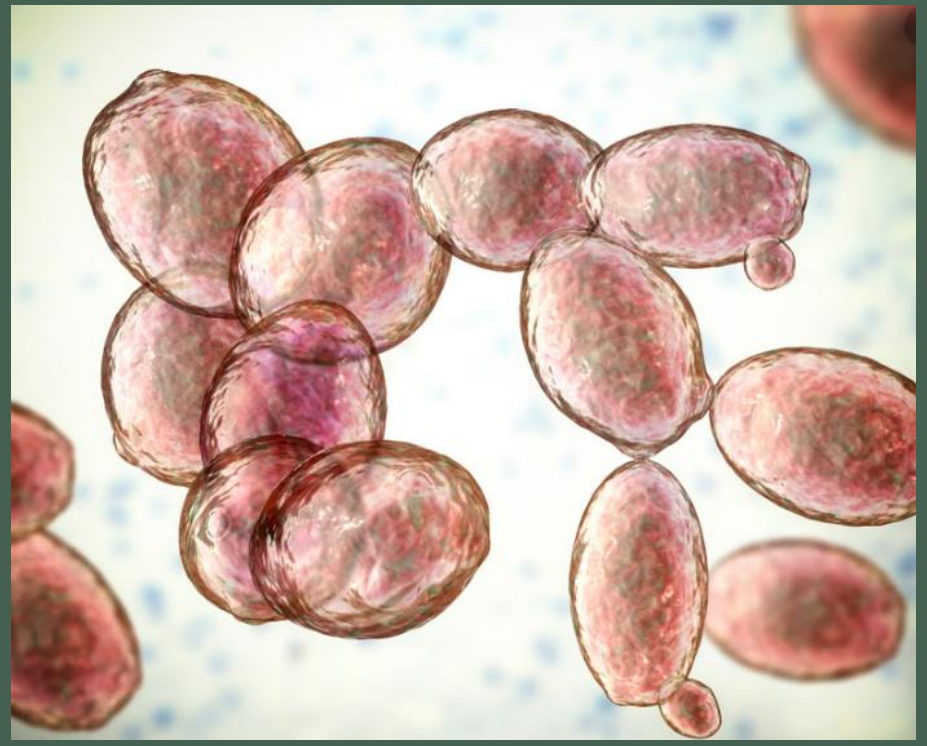
(b) Sacch. cerevisiae sporulates more readily than does Sacch. uvarum.

(c) Perhaps the most diagnostic distinction between them is that Sacch. uvarum is able to ferment the trisaccharide, raffinose, made up of galactose, glucose, and fructose. Sacch. cereisiae is capable of fermenting only the fructose moiety; in other words, it lacks the enzyme system needed to ferment melibiose which is formed from galactose and glucose.

(d) Sacch. cerevisiae strains have a stronger respiratory system than Sacch uvarum and this is reflected in the different cytochrome spectra of the two groups.

(e) Bottom-fermenters are able to flocculate and sink to the bottom of the brew, a characteristic lacking in most strains of Sacch. cerevisiae. Bottom ferments are classified into rapid settling or slow-settling (powdery); settling characteristics affect the rate of production, some secondary yeast metabolites, and hence beer quality.

Yeasts are reused after fermentation for a number of times which depend on the practice of the particular brewery. Mutation and contamination are two hazards in this practice, but they are inherent in all inocula.



Differences between Ale and Lager Yeast Strains

Ale Yeast	Lager Yeast
Saccharomyces cerevisiae (ale type)	*Saccharomyces carlsbergensis*
Saccharomyces cerevisiae (ale and distillers yeast)	*Saccharomyces uvarium* (*carlsbergensis*)
	Saccharomyces cerevisiae (lager type)
	Saccharomyces pastorianus (current taxonomic name)
Fermentation temperature (18-25°C)	Fermentation temperature (8-15°C)
Cells can grow at 37°C or higher	Cells cannot grow above 34°C
Cells cannot ferment the dissacharide melibiose	Ferments melibiose (glucose – galactose)
Strains with distinctive colonial morphology on wort-gelatin medium	Strains do not have a distinctive morphology on wort-gelatin medium
"Top" fermentation.	"Bottom" fermentation.

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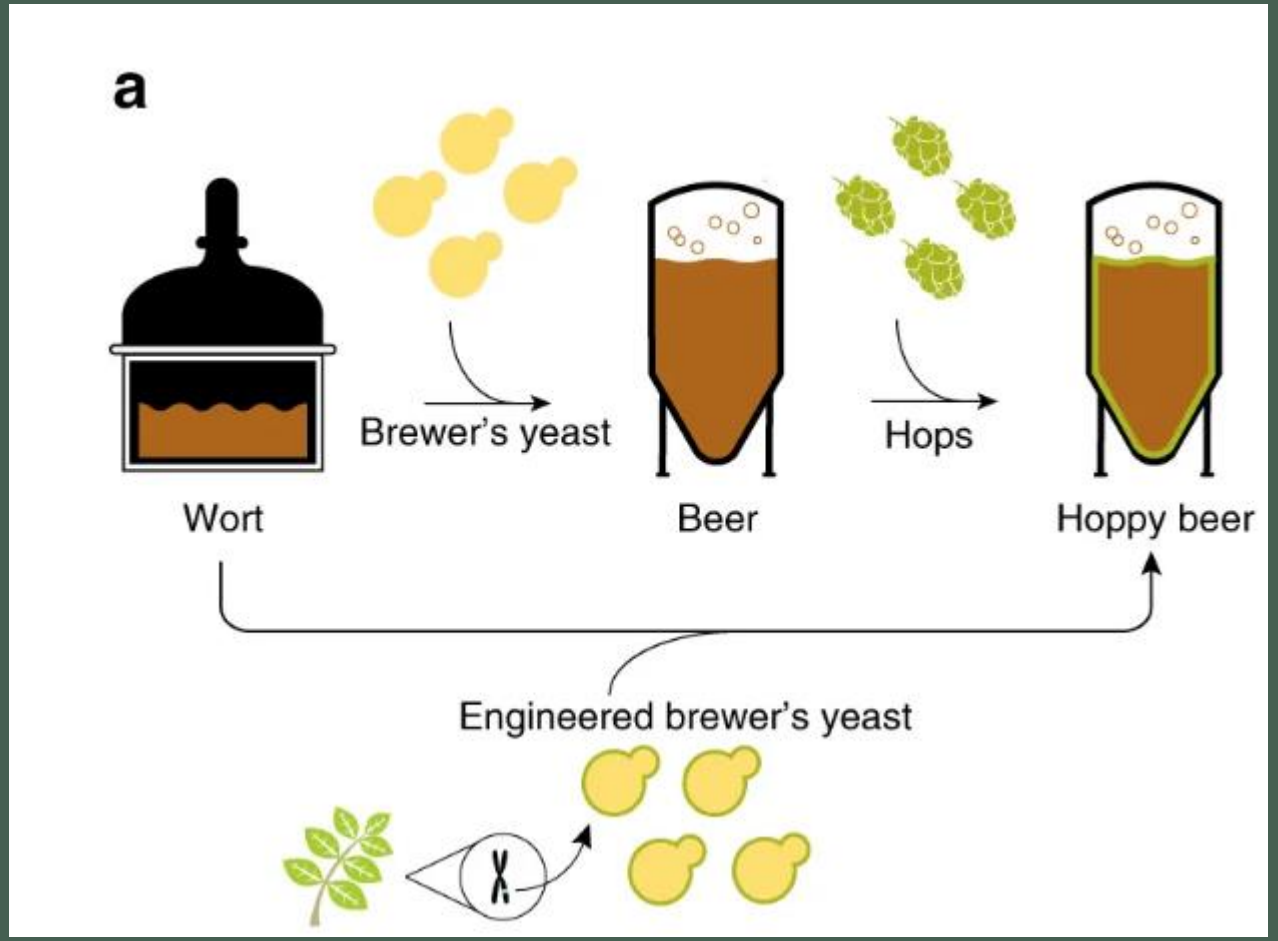
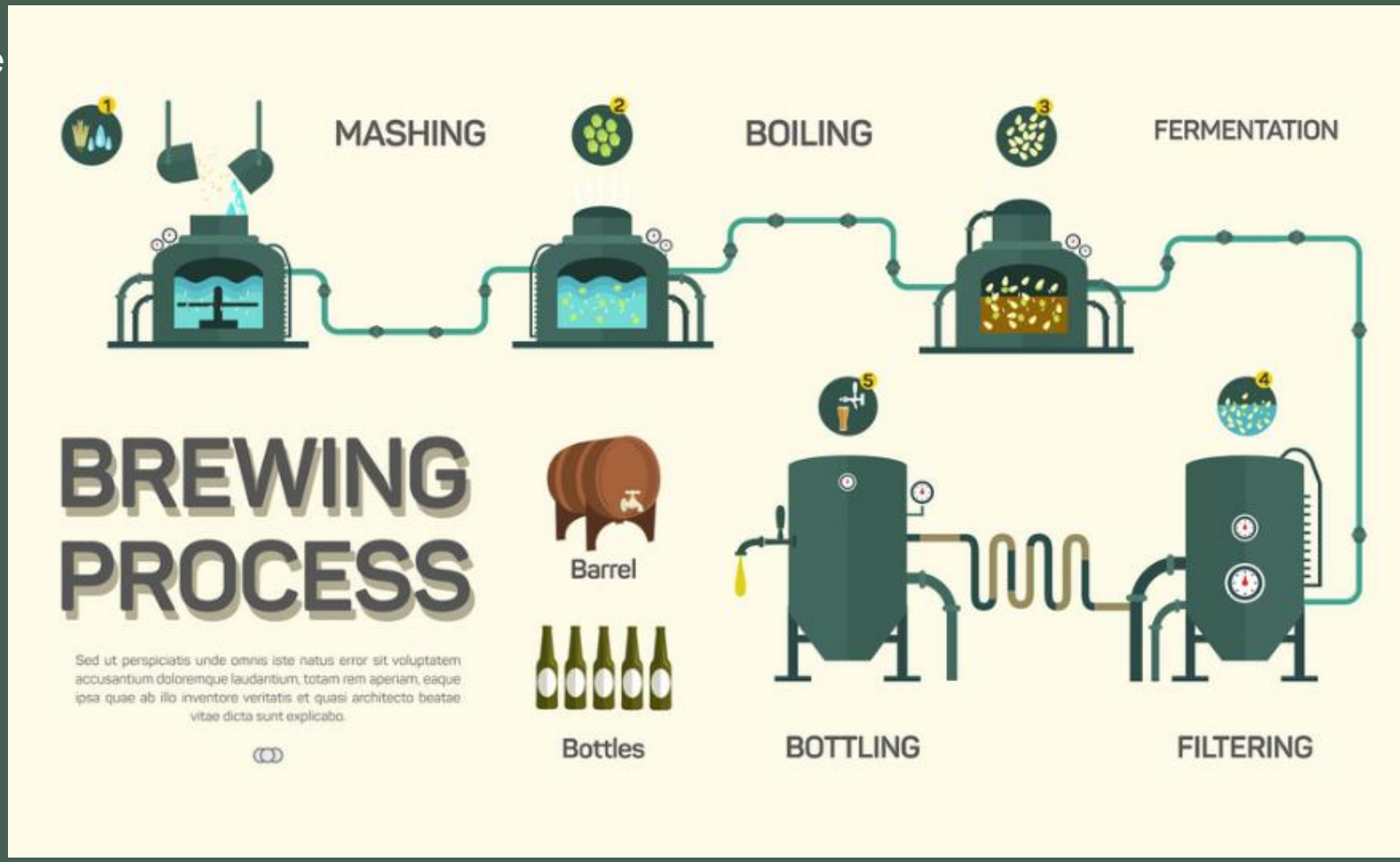


12.1.3 Brewery Processes

The processes involved in the conversion of barley malt to beer may be divided into the following:

1. Malting
2. Cleaning and milling of the malt
3. Mashing
4. Mash operation
5. Wort boiling treatment
6. Fermentation
7. Storage or lagering
8. Packaging

Of the above processes, malting is specialized and is not carried out in the brew house. Rather, breweries purchase their malt from specialized malsters (or malt producers). The description to be given will in general relate to lager beers and where the processes differ from those of ales this will be pointed out.



12.1.3.1 Malting

The purpose of malting is to develop amylases and proteases in the grain. These enzymes are produced by the germinated barley to enable it to break down the carbohydrates and proteins in the grain to nourish the germinated seedling before its photosynthetic systems are developed enough to support the plant. However, as soon as the enzymes are formed and before the young seedling has made any appreciable in-road into the nutrient reserve of the grain, the development of the seedling is halted by drying, but at temperatures which will not completely inactivate the enzymes in the grain. These enzymes are reactivated during mashing and used to hydrolyze starch and proteins and release nutrients for the nourishment of the yeasts.

Not all barley strains are suitable for brewing; some are better used for fodder. During malting, barley grains are cleaned; broken barley grains as well as foreign seeds, sand, bits of metal etc. are removed. The grains are then steeped in water at 10-15°C. The grain absorbs water and increases in volume ultimately by about 4%. Respiration of the embryo commences as soon as water is absorbed. Microorganisms grow in the steep and in order not to allow grain deterioration the steep water is changed approximately at 12-hourly intervals until the moisture content of the grain is about 45%. Steeping takes two to three days.

12.1.3.1 Malting

The grains are then drained of the moisture and may be transferred to a malting floor or a revolving drum to germinate. The heat generated by the sprouts further hastens germination. Sometimes moist warm air is blown through beds of germinating seedlings about 30 cm deep. Water may also be sprinkled on them. The plant hormone gibberellic acid is sometimes added to the grains to shorten germination time. The grain itself synthesizes gibberellic acid and it is this acid which triggers off the synthesis of various hydrolytic enzymes by the aleurone layer situated on the periphery of the grain. The enzymes so formed diffuse into the center of the grain where the endosperm is located.

In the endosperm, the starch granules are harbored within cells. These cell walls are made up of hemicellulose, which is broken down by hemicellulases before amylases can attack the starch. Alpha-amylase (see discussion on mashing below) is also synthesized by the grain. Beta-amylase is already present and is not synthesized but is bound to proteins and is released by proteolytic enzymes.

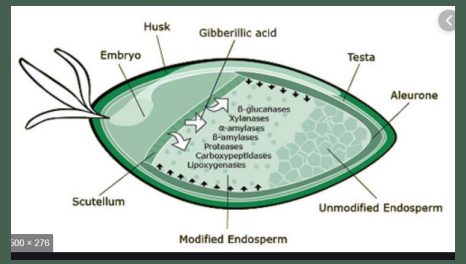
'Modification' or production of enzymes is complete in four to five days of the growth of the seedling; the extent being tested roughly by the sweet taste developed in the grain and by the length of the young plumule. The various enzymes formed break down some quantities of their respective substrates but the major breakdown takes place during mashing.

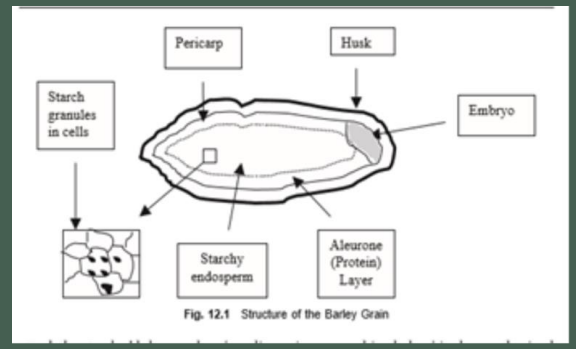
12.1.3.1 Malting

Further reactions in the grain are halted by kilning, which consists of heating the 'green' malt in an oven, first with a relatively mild temperature until the moisture content is reduced from about 40% to about 6%. Subsequently the temperature of heating depends on the type of beer to be produced. For beer of the Pilsener type the malt is pale and has no pronounced aroma and kilning takes 20-24 hours at 80–90°C. For the darker Munich beers with a strong aroma drying takes up to 48 hours at 100 – 110°C. For the caramelized malts used for stout and other very dark beers, kilning temperature can be as high as 120°C. Such malts contain little enzymic activity.

At the end of malting, some changes occur in the gross composition of the barley grain as seen in Table 12.2. The rootlets are removed and used as cattle feed.

Weight loss known as malting loss occurs at each stage of malting and the accumulated loss may be as high 15%. The barley malt with its rich enzyme content resembles swollen grains of unthreshed rice and can be stored for considerable periods before being used.





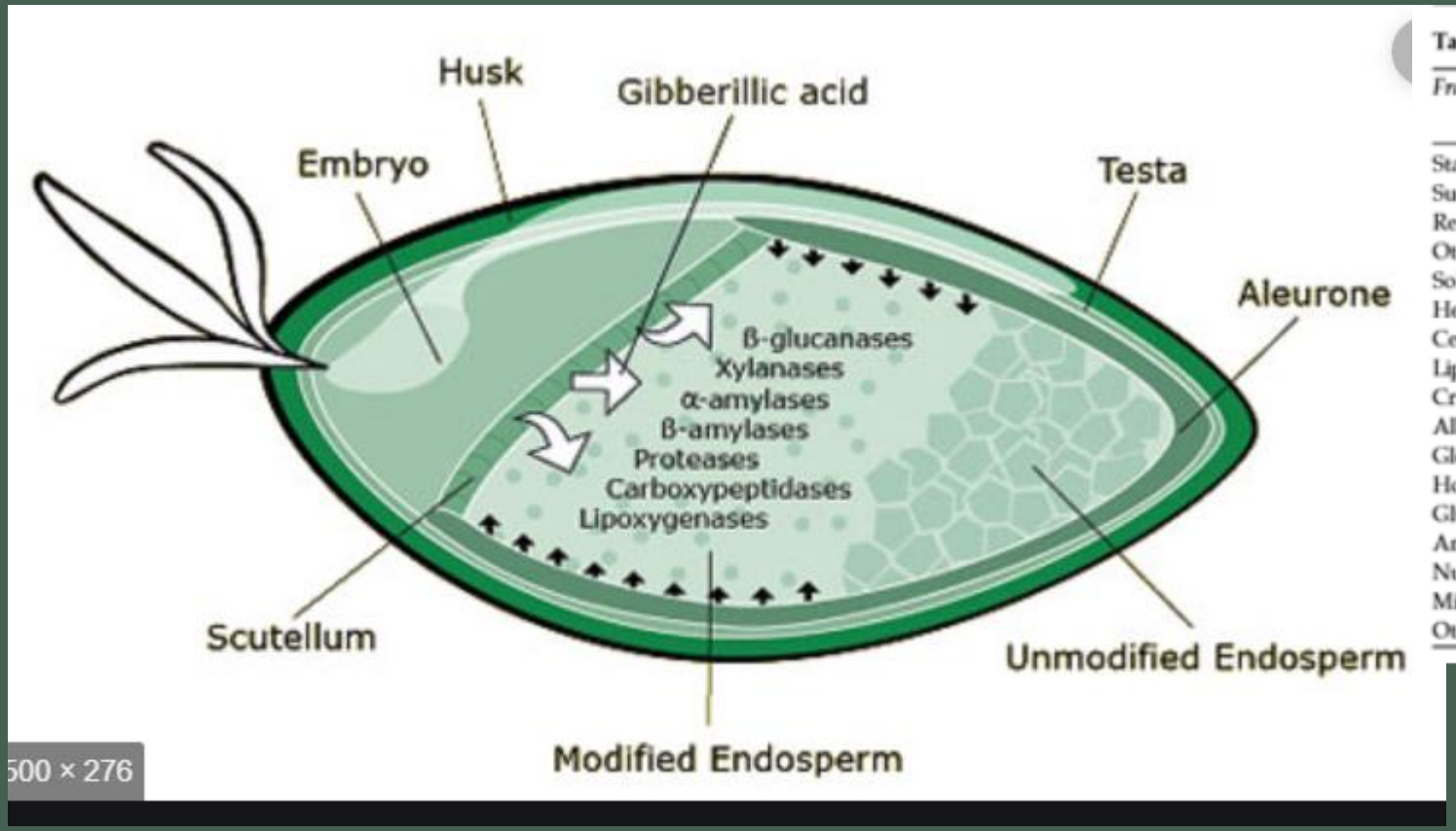


Table 12.2 Composition of barley grain before and after malting

Fraction	*Proportion (% dry weight)*	
	Barley	*Malt*
Starch	63-65	58-60
Sucrose	1-2	3-5
Reducing sugars	0.1-0.2	3-4
Other sugars	1	2
Soluble gums	1-1.5	2-4
Hemicelluloses	8-10	6-8
Cellulose	4-5	5
Lipids	2-3	2-3
Crude protein (N x 6.25)	8-11	8-11
Albumin	0.5	5
Globulin	3	-
Hordein-protein	3-4	2
Glutelin-protein	3-4	3-4
Amino acids and peptides	0.5	1-2
Nucleic acids	0.2-0.3	0.2-0.3
Minerals	2	3
Others	5-6	6-7

12.1.3.2 Cleaning and milling of malt

The barley is transported to the top of the brewing tower. Subsequent processes in the brewery process occur at progressively lower floors. Lagering and bottling are usually done on the ground level floor. In this way gravity is used to transport the materials and the expense of pumping is eliminated. At the top of the brewing tower, the barley malt is cleaned of dirt and passed over a magnet to remove pieces of metals, particularly iron. It is then milled.

The purpose of milling is to expose particles of the malt to the hydrolytic effects of malt enzymes during the mashing process. The finer the particles therefore the greater the extract from the malt. However, very fine particles hinder filtration and prolong it unduly. The brewer has therefore to find a compromise particle size which will give him maximum extraction, and yet permit reasonably rapid filtration rate. No matter what is chosen the crushing is so done as to preserve the husks which contribute to filtration, while reducing the endosperm to fine grits.

12.1.3.3 Mashing

Mashing is the central part of brewing. It determines the nature of the wort, hence the nature of the nutrients available to the yeasts and therefore the type of beer produced. The purpose of mashing is to extract as much as possible the soluble portion of the malt and to enzymatically hydrolyze insoluble portions of the malt and adjuncts. In the sense of the latter objective, mashing may be regarded as an extension of malting. In essence mashing consists of mixing the ground malt and adjuncts at temperatures optimal for amylases and proteases derived from the malt. The aqueous solution resulting from mashing is known as wort.

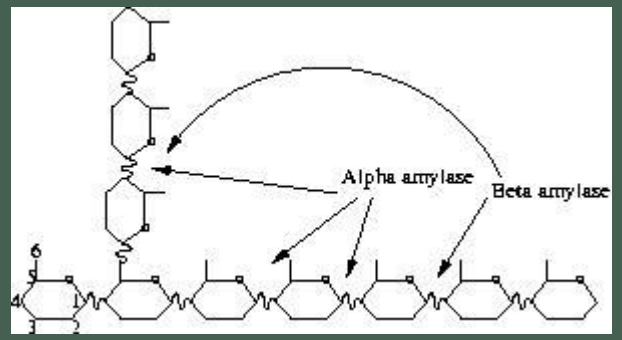
The two largest components in terms of dry weight of the grain are starch (55%) and protein (10-12%). The controlled breakdown of these two components has tremendous influence on beer character and will be considered below.

12.1.3.3.1 Starch breakdown during mashing

Starch forms about 55% of the dry weight of barley malt. Of the malt starch 20-25% is made up of amylose. The key enzymes in the break down of malt starch are the alpha and beta-amylases. The temperature of optimal activity and destruction of these enzymes as well as their optimum pH are given in Table 12.3 (Starch and its breakdown are also discussed in Chapter 4).

Table 12.3 Temperature optima of alpha- and beta-amylases

Enzyme	*Optimum temperature*	*Temperature of destruction*	*Optimal pH*
Alpha-amylase	70°C	80°C	5.8
Beta-amylase	60-65°C	75°C	5.4



12.1.3.3.2 Protein breakdown during mashing

The breakdown of the malt proteins, albumins, globulins, hordeins, and gluteins starts during malting and continues during mashing by proteases which breakdown proteins through peptones to polypeptides and polypeitidases which breakdown the polypetides to amino acids. Protein breakdown has no pronounced optimum temperature, but during mashing it occurs evenly up to 60°C, beyond which temperature proteases and polypeptidases are greatly retarded. Proteoloytic activity in wort is however dependent on pH and for this reason wort pH is maintained at 5.2-5.5 with lactic acid, mineral acids, or calcium sulphate.

12.1.3.3.3 General environmental conditions affecting mashing

The progress of mashing is affected by a combination of temperature, pH, time, and concentration of the wort. When the temperature is held at 60-65°C for long periods a wort rich in maltose occurs because beta amylase activity is at its optimum and this enzyme yields mainly maltose. On the other hand, when a higher temperature around 70°C is employed dextrins predominate. Dextrins contribute to the body of the beer but are not utilized by yeast. Mash exposed to too high a temperature will therefore be low in alcohol due to insufficient maltose production.

The pH optima for amylases and proteolytic enzymes have already been discussed. The optimum pH for beta-amylase activity is about the same as that of proteolysis and as can be seen in Table 12.3, a fortunate coincidence for the maximum production of maltose and the breakdown of protein.

The concentration of the mash is important. The thinner the mash the higher the extract (i.e., the materials dissolved from the malt) and the maltose content.

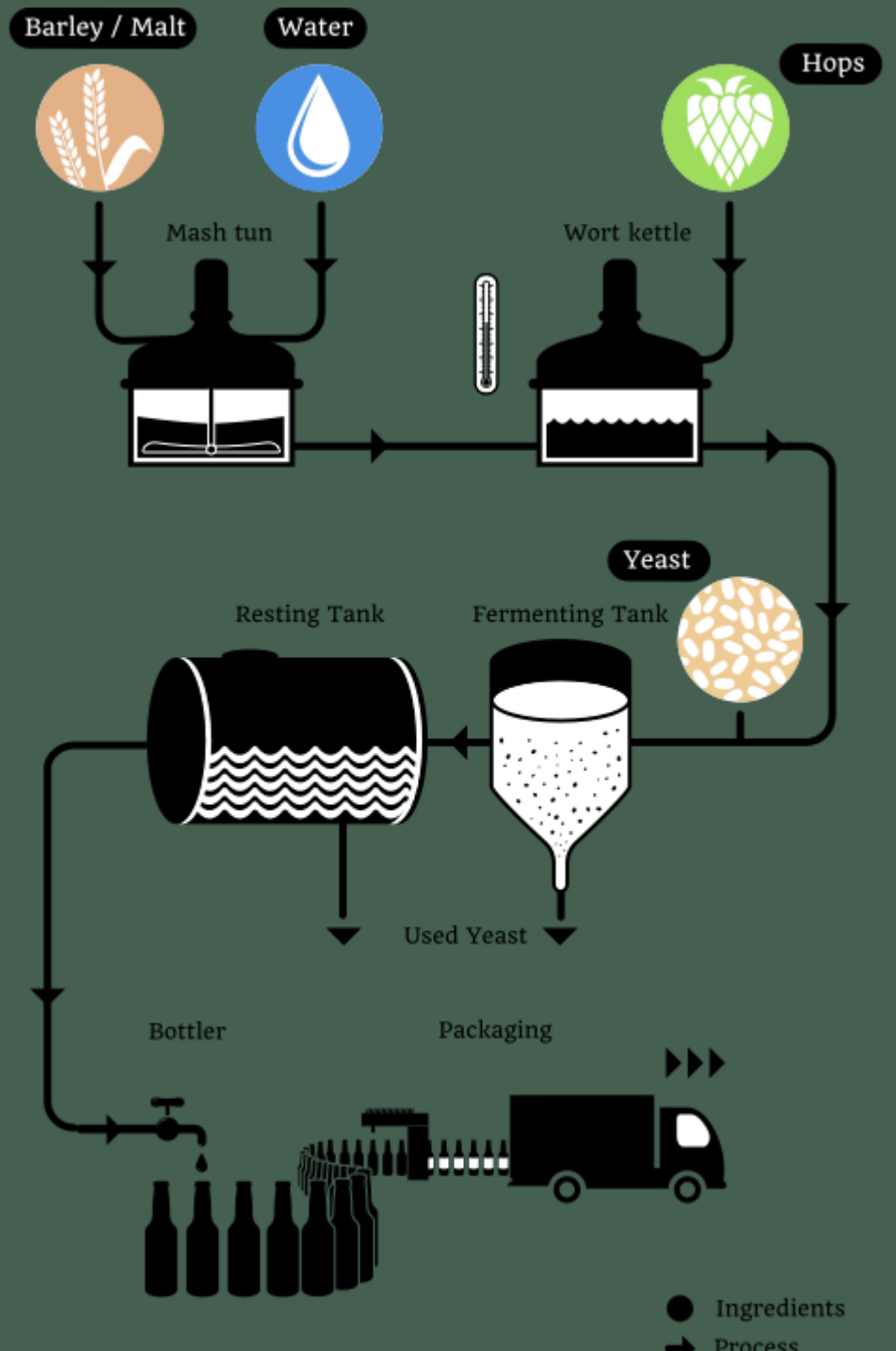
12.1.3.3.4 Mashing methods

There are three broad mashing methods:

(a) Decoction methods, where part of the mash is transferred from the mash tun to the mash kettle where it is boiled.

(b) Infusion methods, where the mash is never boiled, but the temperature is gradually raised.

(c) The double mash method in where the starchy adjuncts are boiled and added to the malt.



12.1.3.3.4 Mashing methods

(i) Decoction methods: In these methods the mash is mixed at an initial temperature of 35-37°C and the temperature is raised in steps to about 75°C. About one-third of the initial mash is withdrawn, transferred to the mash kettle, and heated slowly to boil, and returned to the mash tun, the temperature of the mash becoming raised in the process. The enzymes in the heated portion become destroyed but the starch grains are cooked, gelatinized and exposed. Another portion may be removed, boiled and returned. In this way the process may be a one, two or three-mash process. In a three-mash process (Fig. 12.2) the initial temperature of 35-40°C favors proteolysis; the mash is held for about half hour at 50°C for full proteolysis, for about one hour at 60-65°C for saccharification and production of maltose, and at 70-75°C for two or three hours for dextrin production. The three-mash method is the oldest and best known and it was originated in Bavaria, West Germany. Figure 12.2 shows the temperature relations in a three-mash decoction. The decoction is used in continental Europe.

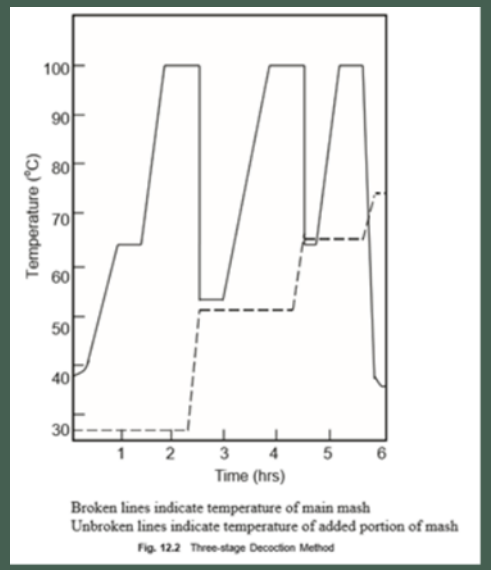
12.1.3.3.4 Mashing methods

(ii) Infusion method: The infusion method is the one used in Britain and is typically used to produce top-fermenting beers. It is carried out in a mash tun, which resembles a lauter tub of lager beer, but it is deeper. The method involves grinding malt and a smaller amount of unmalted cereal, which may sometimes be precooked. The ground material, or grist, is mixed thoroughly with hot water (2:1 by weight) to produce a thick porridge-like mash and the temperature is carefully raised to about 65°C. It is then held at this temperature for a period varying from 30 minutes to several hours. On the average the holding is for 1-2 hours. The enzyme acts principally on the starch and its degradation products in both the malted and unmalted cereal, and only a little protein breakdown occurs. Further hot water at 75-78°C is sprayed on the mash to obtain as much extract as possible and to halt the enzyme action. It is believed by some authors that this method is not as efficient as the double mash or decoction method in extracting materials from the malt. No part of the mash is boiled from mashing-in to mashing-off. It is, however, more easily automated, but a malt in which the proteins are already well degraded must be used since the high temperature of mashing rapidly destroys the proteolytic enzymes.

12.1.3.3.4 Mashing methods

(iii) The double-mash (also called the cooker method): This method was developed in the US because of its use of adjuncts. It has features in common with the infusion and the decoction method. Indeed some authors have described it as the downward infusion method whilst describing the infusion method mentioned above as an upward infusion method. In a typical US double mash method ground malt is mashed with water at a temperature of 35°C. It is then held for an hour during the 'protein rest' for proteolysis. Adjuncts are then cooked in an adjunct cooker for 60-90 minutes. Sometimes about 10% malt is added during the cooking. Hot cooked adjunct is then added to the mash of ground malt to raise the temperature to 65-68°C for starch hydrolysis and maintained at this level for about half hour. The temperature is then increased to 75°C-80°C after which the mashing is terminated. During starch hydrolysis completion of the process is tested with the iodine test.

12.1.3.3.4 Mashing methods



Various combinations of the above methods may be used, depending on the type of beer, the type of malt, and the nature of the adjunct.

12.1.3.3.5 Mash separation

At the end of mashing, husks and other insoluble materials are removed from the wort in two steps. First, the wort is separated from the solids. Second, the solids themselves are freed of any further extractable material by washing or sparging with hot water.

The conventional method of separating the husks and other solids from the mash is to strain the mash in a lauter (German for clarifying) tub which is a vessel with a perforated false-bottom about 10 mm above the real bottom on which the husks themselves form a bed through which the filtration takes place. In recent times in large breweries, especially in the United States, the Nooter strain master has come into use. Like the Lauter tub, filtration is through a bed formed by the husks, but instead of a false bottom, straining is through a series of triangular perforated pipes placed at different heights of the bed. The strain master itself is rectangular with a conical bottom whereas the Lauter tub is cylindrical. Its advantage among others is that it can handle larger quantities than the Lauter tub. Besides the Lauter tub and the strainmaster, cloth filters located in plate filters and screening centrifuges are also used.

The sparging (or washing with hot water) of the mash solids is done with water at about 80°C and is continued till the extraction is deemed complete. The material which is left after sparging is known as spent grain and is used as animal feed. Sometimes liquid is extracted from the spent grain by centrifuging, the extract being used to cook the adjuncts.

12.1.3.3.6 Wort boiling

The wort is boiled for 1-1½ hours in a brew kettle (or copper) which used to be made of copper (hence the name) but which, in many modern breweries, is now made of stainless steel. When corn syrup or sucrose is used as an adjunct it is added at the beginning of the boiling. Hops are also added, some before and some at the end of the boiling. The purpose of boiling is as follows.

(a) To concentrate the wort, which loses 5-8% of its volume by evaporation during the boiling;
(b) To sterilize the wort to reduce its microbial load before its introduction into the fermentor.
(c) To inactivate any enzymes so that no change occurs in the composition of the wort.
(d) To extract soluble materials from the hops, which not only aid in protein removal, but also in introducing the bitterness of hops.
(e) To precipitate protein, which forms large flocs because of heat denaturation and complexing with tannins extracted from the hops and malt husks. Unprecipitated proteins form hazes in the beer, but too little protein leads to poor foam head formation.
(f) To develop color in the beer; some of the color in beer comes from malting but the bulk develops during wort boiling. Color is formed by several chemical reactions including caramelization of sugars, oxidation of phenolic compounds, and reactions between amino acids and reducing sugars.
(g) Removal of volatile compounds: volatile compounds such as fatty acids which could lead to rancidity in the beer are removed.

During the boiling, agitation and circulation of the wort help increase the amount of precipitation and flock formation.

12.1.3.3.6 Wort boiling

Pre-fermentation treatment of wort: The hot wort is not sent directly to the fermentation tanks. If dried hops are used then they are usually removed in a hop strainer. During boiling proteins and tannins are precipitated while the liquid is still warm. Some more precipitation takes place when it has cooled to about 50°C. The warm precipitate is known as "trub" and consists of 50-60% protein, 16-20% hop resins, 20-30% polyphenols and about 3% ash. Trub is removed either with a centrifuge, or a whirlpool separator which is now more common. In this equipment the wort which is fed into a flat centrifuge, is thrown at the side of the equipment and finds its way out through an outlet on the periphery. The heavier particles (the trub) are thrown to the center and withdrawn through a centrally located outlet. The separated wort is cooled in a heat exchanger. When the temperature has fallen to about 50°C further sludge known as 'cold break' begins to settle, but it cannot be separated in a centrifuge because it is too fine. In many breweries the wort is filtered at this stage with kieselghur, a white distomaceous earth.

The cooled wort is now ready for fermentation. It contains no enzymes but it is a rich medium for fermentation. It has therefore to be protected from contamination. During the transfer to the fermentor the wort is oxygenated at about 8 mg/liter of wort in order to provide the yeasts with the necessary oxygen for initial growth.

12.1.3.4 Fermentation

The cooled wort is pumped or allowed to flow by gravity into fermentation tanks and yeast is inoculated or ‘pitched in’ at a rate of 7-15 x 106 yeast cells/ml, usually collected from a previous brew.

12.1.3.4.1 Top fermentation

This is used in the UK for the production of stout and ale, using strains of Saccharomyces cerevisiae. Traditionally an open fermentor is used. Wort is introduced by a fish tail spray so that it becomes aerated to the tune of 5-10 ml/liter of oxygen for the initial growth of the yeasts. Yeast is pitched in at the rate of 0.15 to 0.30 kg/hl at a temperature of 15-16°C. The temperature is allowed to rise gradually to 20°C over a period of about three days. At this point it is cooled to a constant temperature. The entire primary fermentation takes about six days. Yeasts float to the top during this period, they are scooped off and used for future pitching. In the last three days the yeasts turn to a hard leathery layer, which is also skimmed off. Sometimes the wort is transferred to another vessel in the so-called dropping system after the first 24-36 hours. The transfer helps aerate the system and also enables the discarding of the cold-break sediments. Sometimes the aeration is also achieved by circulation with paddles and by the means of pumps. Nowadays cyclindrical vertical closed tanks are replacing the traditional open tanks. A typical top fermentation cycle is shown in Fig. 12.3.

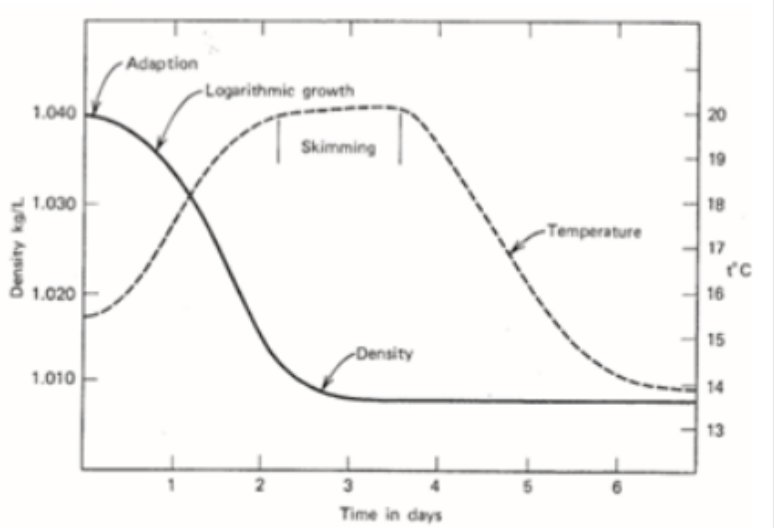


Fig. 12.3 Typical Fermentation with Top-fermenting Yeast

12.1.3.4.2 Bottom fermentation

Wort is inoculated to the tune of 7-15 x 106 yeast cells per ml of wort. The yeasts then increase four to five times in number over three to four days. Yeast is pitched in at 6-10°C and is allowed to rise to 10-12°C, which takes some three to four days; it is cooled to about 5°C at the end of the fermentation. CO2 is released and this creates a head called Krausen, which begins to collapse after four to five days as the yeasts begin to settle. The total fermentation period may last from 7-12 days (Fig. 12.4).

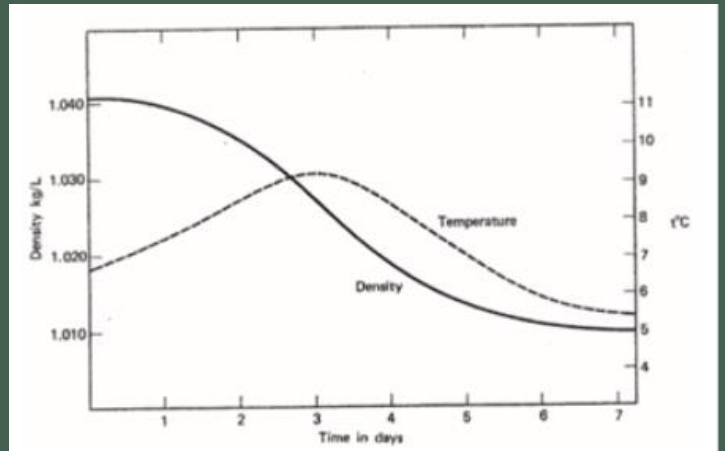


Fig. 12.4 Typical Fermentation with Bottom-fermenting Yeast

12.1.3.4.3 Formation of some beer components

During wort fermentation in both top and bottom fermentation anaerobic conditions predominate; the initial oxygen is only required for cell growth. Fermentable sugars are converted to alcohol, CO2 and heat which must be removed by cooling. Dextrins and maltoteraose are not fermented. Higher alcohols (sometimes known as fusel oils) including propanol and isobutanol are generated from amino acids. Organic acids such as acetic, lactic, pyruvic, citric, and malic are also derived from carbohydrates via the tricarboxylie acid cycle.

12.1.3.4.4 Monitoring following fermentation progress

The progress of fermentation is followed by wort specific gravity. During fermentation the gravity of the wort gradually decreases because yeasts are using up the extract. However alcohol is also being formed. As alcohol has a lower gravity than wort the reading of the special hydrometer (known as a saccharometer) is even lower. The saccharometer reading does not therefore reflect the real extract, but an apparent extract, which is always lower than the real extract because of the presence of alcohol. In the UK and some other countries the extract is measured as the direct specific gravity as 60°F (15.5°C) x 1000. Hence, with wort with sp. Gr. of 1.053 the extract would be 1053°. Outside the UK extract is measured in °Balling or °Plato. Both systems measure the percentage of sucrose required to give solutions of the same specific gravity. The original tables were designed by Von Balling. Improvements and greater accuracy were made on Von Balling's tables first by Brix and later by Plato but the figures were not changed drastically. For this reason °Balling, °Brix, °Plato are the same except for the fifth and sixth decimal places (Table 12.4). °Brix is used in the sugar industry, whereas Balling (United States) and °Plato (continental Europe) are used in the brewing industry.

12.1.3.4.4 Monitoring following fermentation progress

Table 12.4 Comparison between original gravity and percent extract

Original gravity	°B	°P
1.01968	4.925	5.00
1.02370	5.931	6.00
1.02774	6.920	7.00
1.03180	7.913	8.00
1.03591	8.917	9.00
1.04003	9.925	10.00
1.04419	10.921	11.00
1.04837	11.920	12.00
1.05260	12.928	13.00
1.05684	13.943	14.00

The apparent extract, real, extract, and alcohol content are related to each other as well as to the original extract, i.e., the solids in the original worts and may be read from tables. The degree of attenuation is the amount of extract fermented, measured as a percentage of the original or total extract, hence an apparent and a real degree of attenuation both exist.

12.1.3.5 Lagering (bottom-fermented beers) and treatment (top-fermented beers)

(a) Lagering: At the end of the primary fermentation above, the beer, known as 'green' beer, is harsh and bitter. It has a yeasty taste arising probably from higher alcohols and aldehydes.

The green beer is stored in closed vats at a low temperature (around O°C), for periods which used to be as long as six months in some cases to mature and make it ready for drinking.

During lagering secondary fermentation occurs. Yeasts are sometimes added to induce this secondary fermentation, utilizing some sugars in the green beer. The secondary fermentation saturates the beer with CO2, indeed the progress of secondary fermentation is followed by the rate of CO2 escape from a safety valve. Sometimes actively fermenting wort or Kraeusen may be added. At other times CO2 may be added artificially into the lagering beer. Materials which might undesirably affect flavor and which are present in green beer e.g. diacetyl, hydrogen sulfide, mercaptans and acetaldehyde are decreased by evaporation during secondary fermentation. An increase occurs in the desirable components of the beer such as esters. Any tannins, proteins, and hop resins still left are precipitated during the lagering period.

12.1.3.5 Lagering (bottom-fermented beers) and treatment (top-fermented beers)

Lagering used to take up to nine months in some cases. The time is now considerably shorter and in some countries the turnover time from brewing, lagering, and consumption could be as short as three weeks. This reduction has been achieved by artificial carbonation and by the manipulation of the beer due to greater understanding of the lagering processes. Thus, in one method used to reduce lagering time, beer is stored at high temperature (14°C) to drive off volatile compounds e.g. H2S, and acetaldehyde. The beer is then chilled at – 2°C to remove chill haze materials, and thereafter it is carbonated. In this way lagering could be reduced from 2 months to 10 days.

Lagering gives the beer its final desirable organoleptic qualities, but it is hazy due to protein-tannin complexes and yeast cells. The beer is filtered through kieselghur or through membrane filters to remove these. Some properties of lager beer are given in Table 12.5.

Table 12.5 Some properties of lager beer

Property	*Pilsener*	*United States lager beer*	*Danish Pilsener*	*English ale*	*English stout*	*Mounich Lowenbrau*	*Dortmund*
Original extract content °pc	12.1	11.5-12.0	10.6	15.0	21.1	13.3	13.6
Real extract content °pc	5.3	5.5	3.1	5.0	8.7	6.4	5.5
Alcoholic content, wt %	3.5	3.4-3.8	3.9	5.2	6.7	3.6	4.2
Protein content, wt %	0.28-0.35	0.3	0.6	0.6	0.5	0.8	
CO_2 content %		0.53	0.5	0.4	0.41		0.42
Color, EBC	10	2.7	5			40	8
Air in bottle, mL		1.5	2	8	10		6
pH		4.2-4.50	4				
Real degree of attenuation, %		60-75	69	66	59	48	60

12.1.3.5 Lagering (bottom-fermented beers) and treatment (top-fermented beers)

(b) Beer treatment (for top-fermented beers): Top-fermented beers do not undergo the extensive lagering of bottom-fermented beers. They are treated in casks or bottles in various ways. In some processes the beer is transferred to casks at the end of fermentation with a load of 0.2-4.00 million yeast cells/ml. It is 'primed' to improve its taste and appearance by the addition of a small amount of sugar mixed with caramel. The yeasts grow in the sugar and carbonate the beer. Hops are also sometimes added at this stage. It is stored for seven days or less at about 15°C. After 'priming', the beer is 'fined' by the addition of isinglass. Isinglass, a gelatinous material from the swim bladder of fish, precipitates yeast cells, tannins and protein-tannin complexes. The beer is thereafter pasteurized and distributed.

12.1.3.6 Packaging

The beer is transferred to pressure tanks from where it is distributed to cans, bottles and other containers. The beer is not allowed to come in contact with oxygen during this operation; it is also not allowed to lose CO_2, or to become contaminated with microorganisms. To achieve these objectives, the beer is added to the tanks under a CO_2, atmosphere, bottled under a counter pressure of CO_2, and all the equipment is cleaned and disinfected regularly.

Bottles are thoroughly washed with hot water and sodium hydroxide before being filled. The filled and crowned bottles are passed through a pasteurizer, set to heat the bottles at 60°C for half hour. The bottles take about half hour to attain the pasteurizing temperature, remain in the pasteurizer for half hour and take another half hour to cool down. This method of pasteurization sometimes causes hazes and some of the larger breweries now carry out bulk pasteurization and fill containers aseptically.

12.1.4 Beer Defects

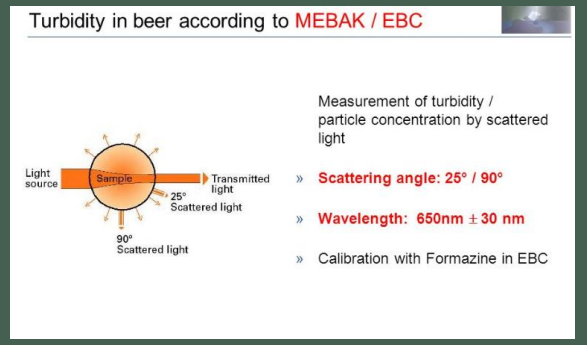
The most important beer defect is the presence of haze or turbidity, which can be of biological or physico-chemical origin.

12.1.4.1 Biological turbidities

Biological turbidities are caused by spoilage organisms and arise because of poor brewery hygiene (i.e. poorly washed pipes) and poor pasteurization. Spoilage organisms in beer must be able to survive the following stringent conditions found in beer: low pH, the antiseptic substances in hops, pasteurization of beer, and anaerobic conditions. Yeasts and certain bacteria are responsible for biological spoilage because they can withstand these. Wild or unwanted yeasts which have been identified in beer spoilage are spread into many genera including Kloeckera, Hansenula, and Brettanomyces, but Saccharomyces spp appear to be commonest, particularly in top-fermented beers. These include Sacch. cerevisiae var. turblidans, and Sacch. diastaticus. The latter is important because of its ability to grow on dextrins in beer, thereby causing hazes and off flavors.

Among the bacteria, Acetobacter, and the lactic acid bacteria, Lactobacillus and Streptococcus are the most important. The latter are tolerant of low pH and hop antiseptics and are micro-aerophilic hence they grow well in beer. Acetobacter is an acetic acid bacterium and produces acetic acid from alcohol thereby giving rise to sourness in beer.

Lactobacillus pastorianus is the typical beer spoiling lactobacilli, in top-fermented beers, where it produces sourness and a silky type of turbidity. Streptococcus damnosus (Pediococcus damnosus, Pediococcus cerevisiae) is known as ‘beer sarcina’ and gives rise to ‘sarcina sickness’ or beer which is characterized by a honey-like odor.



12.1.4.2 Physico-chemical turbidities

Non-biological hazes developing beer may be due to one or more of the following:

(i) Hazes induced by metals.
(ii) Protein-tannin hazes.
(iii) Polysaccharide sediments.
(iv) Oxalate hazes and sediments.

12.1.4.2 Physico-chemical turbidities

(i) Hazes induced by metals: Tin, iron, copper have all been identified as causing hazes in beer. An amount of only 0.1 ppm of tin will immediately produce haze in beer. It does not unlike other metals, acts as an oxidation catalyst, but precipitates haze precursors directly. It may occur in some canned beers. Copper and iron act as catalysts in the oxidation of the polyphenolic moiety of the protein-haze precursors of beer. They appear to be derived from both malt and hop (from copper insecticides) and also from the brewing plant. It has been suggested that EDTA (ethylenediaminetetraacetic acid) be used to form chelates with copper and iron and thereby prevent their deleterious action.

12.1.4.2 Physico-chemical turbidities

(ii) Protein-tannin hazes: The polyphenols of beer have often been solely and incorrectly referred to as tannins. Tannins proper are used to convert hides to leather but beer polyphenols cannot be so used. Polyphenols are widely distributed in plants. Beer tannings or polyphenols (Fig. 12.5) are derived from hops and barley husks. They react with proteins to form complex molecules which become insoluble in the form of haze. Hazes contain polypeptides, polyphenols, carbohydrates and a small amount of minerals.

Beer hazes are divided into two: Chill hazes (0.1–2 nm diameter particles) form at O°C and re-dissolve at 20°C. Permanent hazes (1.0–10 nm) remains above 20°C.

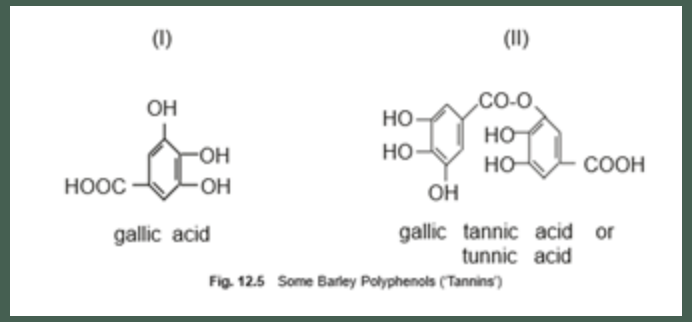


Fig. 12.5 Some Barley Polyphenols ('Tannins')

Protein-tannin hazes may be removed by:

(a) addition of papain which hydrolyzes the polypetides to low molecular weight components which cannot form hazes;
(b) adsorption of the polypeptides by silica gel and bentonite;
(c) precipitation of polypetides by tannic acid;
(d) adsorption of the polyphenols by polyamide resins e.g. Nylon 66.

12.1.4.2 Physico-chemical turbidities

(iii) Polysaccharide sediments: Freezing and thawing of beer may cause an unpredictable haze which can appear in the form of flakes. This haze differs from chill haze in being distinctly carbohydrate in nature. They were found in lager chilled to – 10°C and consisted mainly of Beta glucans derived from malt.
(iv) Oxalate sediments: Oxalate sediments may appear after several week's storage in beers rich in oxalate as a result of a low calcium content.
(v) Other beer defects: Wild or gushing beer is a defect observed as a violent overfoaming when a bottle of beer is opened. The taste is unaffected. Gushing is due to the formation of micro-bubbles; excess pressure may force the micro-bubbles back into solution. Gushing beers have been identified with malt made from old barley and trial brews have shown them to be associated with the presence of mycelia of Fusarium during the steeping.

The off-flavor developed when beer is exposed to sunlight is due to the formation of mercaptans by photochemical reaction in the blue-green region (420-520 nm) of visible light.

12.1.5 Some Developments in Beer Brewing

The description made above is of conventional beer brewing. Some developments have taken place both in the manner of the production of beer as well as in the type of beer produced: This section will look briefly at some of these.

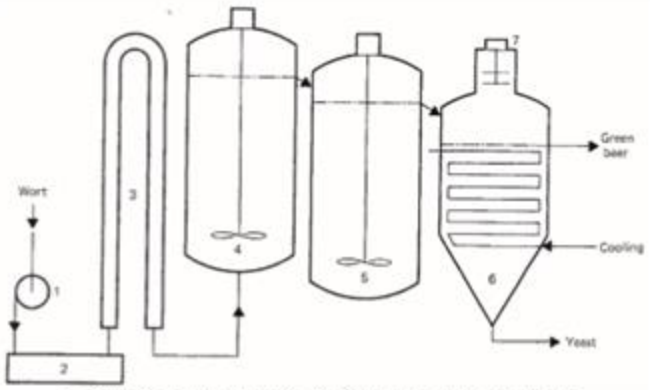
12.1.5.1 Continuous brewing

Although it is not yet widely used, continuous brewing is gaining gradual acceptance in many countries. In the current commercial continuous brewing systems, it is mainly fermentation that is continuous, secondary fermentation and lagering are usually batch.

Two systems of continuous fermentation are known: the open and the partially closed

12.1.5.1 Continuous brewing

(i) The open system of continuous fermentation: In the open system wort is fed continuously into the fermentor, while beer flows out at the same rate. The yeast is allowed to attain its natural concentration or steady state. In the system described here wort is collected batch wise from the brew house and may be stored for up to 14 days at 2°C before use. The wort is sterilized in a heat-exchanger prior to oxygenation. It is then passed through the bottom into the first tank, which is continuously stirred and where aerobic growth occurs. It is later passed into a second tank where conditions are anaerobic; alcohol and CO2, are formed in this tank. From there the beer with its suspended yeasts overflows into a third vessel for sedimentation. Finished beer is removed from the top and yeast cells from the bottom. The amount of yeast in the beer is just adequate for secondary fermentation. CO2 is collected from the top. The yeast employed is a special one which apart from imparting the right flavor, must be able to remain in active fermenting condition in suspension in the anaerobic vessel and yet be able to flocculate rapidly once in the cooled sedimentation tank. It is possible theoretically to use one tank, or more than two tanks for sedimentation. Indeed in another system three tanks are used, but two afford flexibility of design and use (Fig. 12.6).



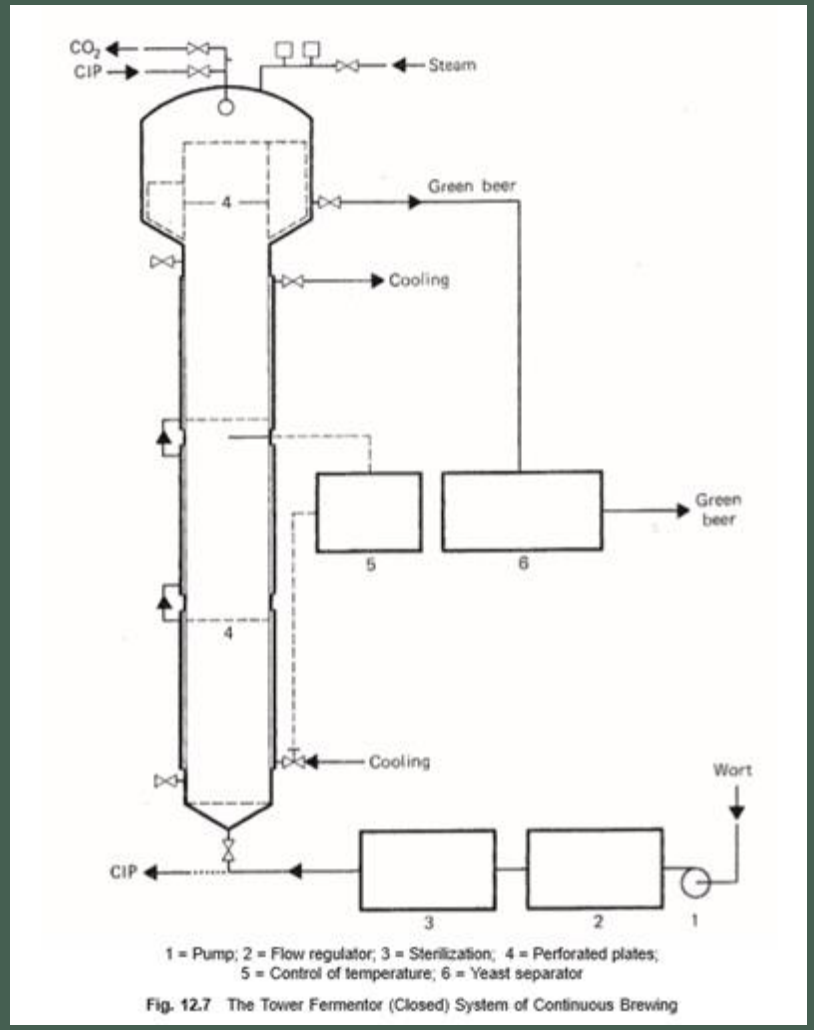
1 = Pump; 2 = Flow regulator; 3 = Sterilization; 4 = Perforated plates;
5 = Control of temperature; 6 = Yeast separator

Fig. 12.6 The Open System of Continuous Brewing

12.1.5.1 Continuous brewing

(ii) Partially closed system of continuous fermentation: In the closed system, yeast in held at a given concentration instead of allowing it to grow at its own steady state as in the open system. (The open system itself may indeed be modified to achieve a higher yeast concentration by recycling yeasts from the sedimentation tank into the first tank. The disadvantage of the modification is the possibility of contamination. Secondly, the returned yeasts are in a different physiological state of growth from those actively involved in fermentation, hence the wort and the beer quality may suffer). In the closed system, typified by the tower fermentor (Fig. 12.6), sterilized wort is pumped into the base of the cylindrical tower with aeration, if necessary, and the beer is drawn off at the top at the same rate. Yeasts attain a very high density, in excess of 350 gm/liter and wort becomes almost ready beer. The upper regions have a lower yeast concentration and serve partly as a final fermentation stage but especially as a means of separating the yeasts. Baffles enable the diversion of the rising CO2 and beer from the beer outlet. Its over-riding advantage is that beer can be produced in four hours if the lower regions have the optimum yeast concentration of 350-400 gm/liter. Special yeasts able to maintain the high mass at the lower level and yet able to pass out of the fermentor if adequate amount must be used. Although continuous brewing has not been generally adopted, its emergence forced brewers to make batch brewing more efficient and to find 'batch' answers to the advantages offered by continuous brewing.

12.1.5.1 Continuous brewing



1 = Pump; 2 = Flow regulator; 3 = Sterilization; 4 = Perforated plates;
5 = Control of temperature; 6 = Yeast separator

Fig. 12.7 The Tower Fermentor (Closed) System of Continuous Brewing

12.1.5.2 Use of enzymes

A number of firms now market enzymes isolated from bacteria and fungi which can carry out the functions of malt. The advantage of the use of these enzymes is to greatly reduce costs since malting can be eliminated entirely. Despite the great potentials offered by this method, brewers are yet unwilling to accept it. The consequences of eliminating or reducing the need for malt from the barley farmer and the malting industry, two longstanding establishments, would pose great difficulties in adopting this method. When enzymes to become generally used, care must be taken to ensure that not only the major enzymes, amylases, and proteases, are included but that others such as Beta-glucanases which hydrolyze the gums of barley are also present in the enzyme mixture. It must also be certain that toxic microbial products are eliminated from the enzyme preparations.

12.2 SORGHUM BEERS

12.2.1 Kaffir Beer and Other Traditional Sorghum Beers

Barley is a temperate crop. In many parts of tropical Africa beer has been brewed for generations with locally available cereals. The commonest cereal used is Sorghum bicolor (= Sorghum vulgare) known in the United States as milo, in South Africa as kaffir corn and in some parts of West Africa as Guinea corn. The cereal which is indigenous to Africa is highly resistant to drought. Sorghum is often mixed with maize (Zea mays) or millets, (Pennisetum spp). In some cases such as in Central Africa e.g. Zimbabwe, maize may form the major cereal. Outside Africa sorghum is not used normally for brewing except in the United States where it is occasionally used as an adjunct.

12.2.1 Kaffir Beer and Other Traditional Sorghum Beers

The method for producing these sorghum beers of the African continent as well as their natures are remarkably similar. They

(i) are all pinkish in color; sour in taste; and of fairly heavy consistency imposed partly by starch particles, and also because they are

(ii) consumed without the removal of the organisms;

(iii) are not aged, or clarified, and

(iv) include a lactic fermentation.

The tropical beers are known by different names in different parts of the world: 'burukutu', 'otika', and 'pito' in Nigeria, , 'maujek' among the Nandi's in Kenya, 'mowa' in Malawi, 'kaffir beer' in South Africa, 'merisa' in Sudan, 'bouza' in Ethiopia and 'pombe' in many parts of East Africa.

It is only in South Africa that production has been undertaken in large breweries; elsewhere although considerable quantities are produced, this is done by small holders to satisfy small local clientele. In South Africa, in fact, it is reported that three or four times more kaffir beer is produced and drunk than is the case with barley beers. The processes of producing the beer include malting, mashing and fermentation.

12.2.1.1 Malting

For malting, sorghum grains are steeped in water for periods varying from 16-46 hours. They are then drained and allowed to germinate for five to seven days, water being sprinkled on the spread-out grains. At the end of this period, the grains are usually dried, often in the sun or in the South African system at 50°-60°C in driers. Kilning is however not done. In some parts, the dried malt may be stored and used over several months.

Contrary to opinions previously held by many, sorghum malt is rich in amylases, particularly ∞-amylase, although the ungerminated grain does not contain β-amylase as is the case with barley. Sorghum has not received much attention as a brewing material, except occasionally as an adjunct in the United States. However in recent times interest has grown in West Africa in its use for malting and it may be that strains which perform in malting as well as barley does may be found.

It has been suggested that the saccharification of sorghum starch is brought about partly by the fungi which grow on the grains during their germination as well as by the germinated sprout. This, however, has been disputed vehemently by some workers. The fungi so implicated are Rhizopus oryzae, Botryodiplodia theobromae, Aspergillus flavus, Penicillium funiculosum, and P. citrinum.

12.2.1.2 Mashing

The malt is ground coarsely and mixed in a rough 6:1 (v/v) proportion with water and boiled for about 2 hours. During the boiling starchy adjunct in the form of dried powder of plantains, cassava ('gari') or unmalted cereal may be added so that an approximate 1:2:6 proportion of the adjunct malt and water is attained. It is filtered and is then ready for fermentation. In South African kaffir beer breweries the adjunct consisting of boiled sorghum or maize grits is added after the initial souring of the mash.

12.2.1.3 Fermentation

Two fermentations take place during sorghum beer production: a lactic acid fermentation, and an alcoholic fermentation. In traditional fermentation, the dregs of a previous fermentation are inoculated into the boiled, filtered, and cooled wort. This inoculum consists of a mixture of yeasts, lactic acid and acetic acid bacteria. The first phase of the fermentation is brought about by lactic bacteria mainly *Lactobacillus mesenteroides, and Lactobacillus plantarum.*

In the sorghum beer breweries in South Africa, the temperature of the mash is held initially at 48-50°C to encourage the growth of thermophilic lactic acid bacteria which occur naturally on the grain, for 16-24 hours. The pH then drops to about 3-4. The sour malt is added to the previously cooked adjunct of unmalted sorghum or maize, and sometimes some more malt may be added. It is then cooled to 38°C and pitched with the top fermenting yeasts.

In the traditional method yeasts and lactic acid bacteria are present in the dregs. The yeasts which have been identified in Nigerian sorghum beer fermentation are: *Candida* spp, *Saccharomyces cervisiae*, and *Sacch. chevalieri*.

12.2.1.3 Fermentation

Fermentation is for about 48 hours during which lactic acid bacteria proliferate. Thereafter it is ready for distribution and consumption. No secondary fermentation of the kind seen in lager beer, lagering, or clarification is done. The live yeasts, and the lactic acid bacteria are consumed in much the same ways as they are done in palm wine. In some localities the fermentation lasts a little longer and the flavor is influenced by a slight vinegary taste introduced by the release of acetic acid by acetic acid bacteria.

Sorghum beers usually contain large amounts of solids (Table 12.6) mainly starch apart from the microorganisms. For this reason some authors have regarded them as much as foods as they are alcholic beverages an alcoholic beverage.

Table 12.6 Properties of South African sorghum beer

Properties	*Small scale*	*Factory*
pH	3.5	3.4
Alcohol	0.1	3.0
Solids (%w/v)		
Total	4.9	5.4
Insoluble	2.3	3.7
Nitrogen (%w/v)		
Total	0.084	0.093
Soluble	-	0.014