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Reference
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Reference 1

7. P. G. Forrester, M. J. Neale, and A. D. Newman, *Inst. Mech. Engrs. London Proc. Automobile Div.* **175**, 537–546 (1961).
8. E. R. Booser, "Bearings Book," *Machine Design* **33**, 95–103 (March 1961).
9. J. E. LaBelle, *Handbook of Mechanical-Wear*, Univ. of Michigan Press, 1961, pp. 378–400.
10. W. O. Wright, *Design News* **12**, 148–151 (Nov. 1, 1957).
11. I. C. Sleight and L. W. Sink, *Sleeve Bearing Materials*, Am. Soc. Metals, Cleveland, Ohio, 1949, pp. 60–81.
12. J. W. Midgley, *Inst. Mech. Engrs. London Proc. Automobile Div.* **175**, 553 (1961).
13. G. Carlyon, *Machine Design* **32** (21), 168–171 (1960).
14. L. H. Gillespie and G. S. Hudson, *Iron Steel Engr.* **37** (4), 151–156 (1960).
15. H. S. White, *J. Res. Natl. Bur. Std.* **57**, 185–204 (1956).
16. P. G. Forrester, *Metallurgical Rev.* **5**, 507–549 (1960).
17. R. J. Thompson and K. B. Goldblum, *Mod. Plastics* **35**, 131–138 (April 1958).
18. F. F. Simpson, *Inst. Mech. Engrs. London Proc. Automobile Div.* **175**, 528–536 (1961).
19. R. E. Lee, Jr., "Bearing Materials and Lubricants for High Temperatures," *Mater. Design Eng.* **55** (3), 109–114 (March 1962).
20. M. B. Peterson, R. E. Lee, Jr., and J. J. Florek, "Sliding Characteristics of Metals at High Temperatures," *ASLE Am. Soc. Lubrication Engrs. Trans.* **3** (1), 101 (1960).
21. R. E. Lee, Jr., "Materials for High Temperature Bearing Application," *Metals Rev.* **31** (5), 18 (May, 1958).
22. G. W. K. Ford, D. M. Harris, and D. Pantall, "Gas Lubricated Bearings," *Engineering* **182**, 555–562 (1956).
23. M. W. Riley, "How to Select and Specify Glass," *Mater. Design Eng.* **44** (5), 139–154 (Nov. 1956).

General References

E. R. Booser, *Mater. Design Eng.* **48** (4), 119–130 (1958).
E. B. Etchells, *Machine Design* **26**, 232–234 (1954).
R. E. Lee, Jr., "Bearing Materials and Lubricants for High Temperatures," *Mater. Design Eng.* **55** (3), 109–114 (1962).

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BEER AND BREWING

made from or high in starch

Beer may be, and generally is, defined as an alcoholic beverage made by the fermentation of a farinaceous extract which is obtained from a starchy raw material, barley (used in the form of malt). Although it is possible to replace some part of the barley with other starchy material, eg, corn, rice, wheat, oats, or potatoes, barley is always the main constituent of brewing materials. Between the ripe barley grain and the cool, satisfying glass of beer there are many production steps, involving some of the most difficult disciplines of physical science. Despite all that science has accomplished for brewing in the last hundred years, there are, nevertheless, many fields in brewing which depend on knowledge acquired empirically through generations.

The making of alcoholic beverages is nearly as old as mankind itself. Wherever any form of culture was established, people discovered how to make some type of fermented drink, and in earlier stages always from some naturally found sugar-containing material, such as the agave juice of Mexico, the juice of the sugar maple, the juice of grapes, or honey from wild bees. The making of beer demanded a higher form of culture, however, because the people had to establish themselves as agriculturists and produce some sort of grain.

Barley was undoubtedly employed in the preparation of fermented liquors long before the dawn of recorded history, especially in places where it was the chief cereal used for food. Beer is known to have been widely used as a drink in ancient Egypt and has been traced back to the age of the pyramids, some four or five millennia BC, but recent investigations suggest that the Egyptians learned the art of making beer from the peoples of the valleys of the Tigris and Euphrates, where beer played a large part in the domestic economy 5000 to 7000 years BC. Barley was the predominant cereal of the ancient world, the basis of barter and exchange in Chaldea 3000 to 5000 years BC, and when displaced by spelt for bread making, it still retained its preeminence as the raw material of brewing and has continued to do so except in countries where the abundance of rice placed that cereal in an unassailable position as the source of the national fermented beverage. The use of barley for brewing is, however, not based on traditional usage alone. It has technical advantages which place it above all other cereals for that purpose. Barley differs from the other common cereals in that the husk adheres to the kernel after threshing, as it does in spelt, wheat being a much later laborsaving introduction. This renders the processes of malting and subsequent extraction of the fermentable products much easier than with wheat or other grains. Barley grows well in countries in which the vine, rice, or palm cannot be cultivated. Since it is a storehouse of starch, which can be converted readily and naturally to fermentable sugars, together with proteins, ash, and other valuable constituents, it is the logical source material for the national beverage of these countries. See also Alcoholic beverages, distilled.

Emmer wheat

Types of Beer

Lager Beers. These beers are so named because they are stored or lagered after fermentation in cold storehouses for clarification and flavor purposes. They are also known as *bottom-fermented* beers because the type of yeast used in their production falls to the bottom of the tank at the end of fermentation.

The various types of lager beer include Pilsener, Dortmund, and Munich, named after the German cities in which they gained prominence; malt tonics which are low in alcohol but which have high nutritional value with their large amounts of iron, phosphates, and vitamins; and steam beer which is a highly effervescent (due to its high carbon dioxide content) tart beer found mainly in California.

Pilsener or light beer. This is a pale beer which can be characterized as having a medium hoppy taste. It contains 3.0–3.8% alcohol by weight and is lagered for two to three months. The brewing waters for this type of beer are soft with only small amounts of salts. Some 70–80% of all beer consumed in the world is of this light-lager type. *Near beer,* a mild beverage containing 0.4% alcohol by weight, is made by reducing the alcoholic content of pilsener beer by a distillation process.

Since the American public expects beer to be sparkling clear, and to remain so even when ice-cold, and since the distribution of beer from coast to coast under varying climatic conditions demands an exceptional colloidial stability of the beer, a pilsener-type beer with superior stability has become the standard type of American beer.

Dortmund. This is also a pale beer but with less hops than pilsener but more body in taste. The alcohol content is 3.0–3.8% by weight; storage time is from three to four months. The brewing waters are hard with rather large amounts of carbonates, sulfates, and chlorides.

Munich beer. Munich is a dark-brown aromatic beer with a full-bodied, slightly sweet taste. It is only mildly hopped. The alcoholic content is from 2.5–5.0% by weight and the storage time is from three to five months. The brewing waters have many carbonates but only small amounts of other salts. Bock, Salvator, and Würzburger beers are Munich-type beers.

Bock beer, a seasonal beverage made with carmelized or highly roasted malts, is traditionally brewed in the winter to be brought out in the spring. It is regarded as too satiating for all year consumption.

Ale. Ale is an English-type malt beverage made with *top-fermenting* yeast. It is pale with a pronounced hops taste and aroma with 4.0–5.0% alcohol. In Burton-on-Trent, England, where the best ales are made, the brewing water is very rich in calcium sulfate; in other ale-making places it is usual to "burtonize" the water by adding calcium sulfate. In addition to the amount of hops used in the brewing, more dry hops are added during storage in order to give the pronounced hop aroma in the finished beverage. There are two kinds of ale—pale or bitter ale and mild ale; bitter ale is strongly hopped and has a dry taste whereas mild ale is sweeter tasting. The famous English "half and half" is half bitter and half mild ale. In England the word beer is used as a general term but most often the beverage referred to is ale.

Top-Fermenting Beers. Beers made from top-fermenting yeast include porter, stout, weiss-beer, which is a pale tart beer made from wheat malt, and lambic beer from Brussels.

Porter. Porter is a dark-brown, full-bodied beer with a heavy foam. It is less hoppy and slightly sweeter in taste than ale; it contains 5% alcohol by weight. Porter is made with some dark or black malt.

Stout. Stout is a very dark beer with a sweet, slightly burnt taste and a strong malt flavor. It is heavier than porter and is strongly hopped. It contains 5–6.5% alcohol by weight. Storage time is up to six months and fermentation usually goes on in the bottle. Dry and sweet stout are brewed, the difference being in the amounts of black malt, caramel malt, and hops used.

Lambic beer. Lambic beer, made in Brussels, is one of the few top-fermented beers still brewed in Belgium. It is made from 60% malt and 40% unmalted wheat. The beer is strongly hopped, and fermentation is spontaneous with wild yeasts, lactic acid bacteria, and brettanomyces. Fermentation and storage take place in the same vats and the beer is kept there from two to three or more years.

At one time there was a clear distinction between beer and ale. In 15th century England, ale was a beverage which was strong in alcoholic content but which did not contain hops or any other herbs. In later years ale and beer were so designated according to the type of yeast used, top-fermenting yeast for ale and bottom-fermenting yeast for beer. This distinction still holds true today although through modern scientific advances it is now possible to produce ale and beer in various ways and so bottom-fermenting yeasts are often used to make ale in the U.S. and stout and porter in Denmark.

Brewing Materials

Barley Malts (see also Malts and malting). Barley, the principal raw material of beer, may have either two or six rows of fertile kernels and also varies in many other qualities so that there are several thousands of forms throughout the world. European breweries use almost exclusively two-row barleys, whereas in America the six-row barleys are mainly used. The two-row barleys are richer in extract than the six-row, but the latter are richer in enzymes and play a role when large amounts of adjuncts are used. See Table 1 for an analysis of two-row and six-row barleys (1).

Table 1. General Analysis of Barleys

	Two-row	Six-row
starch, %	60	52
sugars, %	2.5	2.5
hemicelluloses, pectins, etc, %	8	11
cellulose, %	4	7
lignin, %	1.5	3
protein and other nitrogenous substances, %	9	9
fat (ether extract, traces of resins), %	2.5	2.5
ash, %	2.5	3
tannin, %	small quantity	small quantity
water, %	10	10

malting forms enzyme by germin. (barley → malt)
enzymes, proteins, starch in H_2O is wort
Amylases (starch in mashing)
Proteases (protein in germination)
hemicellulases (cell tissue)

During the malting process the raw, hard, flat-tasting barley is changed to a crisp, mellow, sweet-tasting malt. In earlier times a separate malthouse was always part of the brewery, but this has changed and today many breweries, especially in the U.S., buy all their malt from special malteries.

germination? - to cause to sprout

The germ is only a small part of each barley kernel, the rest being proteinaceous cell tissue, filled with starch which is reserve nourishment for the young plant (see also Cereals). However, the starch and proteins, which constitute the fermentable extract, are not directly soluble in water. The aim of malting is to form by means of germination substances, the so-called enzymes, which will later help to break down starch and proteins to less complex compounds which are soluble in water. When these substances are dissolved in water, the resulting liquid is known as *wort*.

wort is unfermented beer extract after mashing.

Brewers are especially interested in the starch-splitting amylases. They are formed in barley during germination, but their period of reaction comes during the mashing. The protein-splitting enzymes, the proteases, are formed and react during the germination so that some of the proteins of the barley are split into compounds more or less soluble in water. In addition to the proteases there is another group of enzymes, the hemicellulases, which split the cell tissue, thereby leaving the starch open to attack by amylases.

The character of the malt plays a large role in the beer that is to be produced. The two extremes in malt character are reflected in pilsener and Munich beers. For pilsener beer a pale malt with no pronounced aroma must be used; the drying of malt takes some 20 to 24 hr ending with temperatures of 80–90°C (175–195°F). Munich,

pilsener vs Munich

the darker type of beer, demands malts with a pronounced aroma; in this case the drying takes up to 48 hr ending with temperatures of 100–110°C. Although the water content of the final malt in all cases is 3–4%, the interplay of water content and temperature during the drying is of fundamental importance for the character of the malt. The pale malt must be dried down fast to the final temperature; the dark malt must have a suitable high water content when the temperature rises. Special malts such as caramel and black are used for the production of dark beers. They have pronounced color and aroma but little or no diastatic power. Table 2 gives an analysis of various kinds of malt used in different beers (2).

standing?

Table 2. Analysis of Malt

	Pilsener	Munich	Danish Pilsener	Danish Munich	English
moisture, %	6.1	4.2	3.8	2.1	3.5
extract, °P[a]	78.0	77.0	79.7	79.2	82.6
color[b]	2	11–14	3	10	2
diastatic activity, W – K	300	90	200	110	230
protein, % on dry	11.4	11.4	10.1	11.1	9.0
protein, % sol	4.2	3.8			
permanent sol protein, % of total	37.3	33.0	37.5	36.0	40.2

[a] See page 317.
[b] According to the European Brewery Convention.

Adjuncts. Adjuncts in the form of cereal products are often a part of the brewing materials used in the production of the very stable, nonsatiating, sparkling beers preferred by the American consumer. Since barley malt usually contains more enzymes than are necessary for the splitting of the available starch, the mixing of malt with larger or smaller amounts of unmalted, starchy material is widely used today. By using adjuncts, it is also possible to add sugar directly during various steps of the brewing, instead of procuring fermentable sugar through the splitting of starch during mashing. Since adjuncts are essentially starch with very little protein content, they are a source of additional alcohol, but otherwise contribute little to the color, taste, aroma, or protein content of the beer.

mashing splitting of starch? => Add'n alcohol

Corn (*Zea mays*), the greatest source of cereal adjuncts, is milled in two ways—wet or dry. Milling removes as much as possible of the germ and husk in which most of the fatty oil, present in amounts up to 7%, is located. Refined grits, obtained from the wet milling of corn, is the highest yielding and purest cereal adjunct. Corn grits, obtained by dry milling, is the most commonly used cereal adjunct. Rice has satisfactory brewing qualities and can be used together with or instead of corn grits, depending upon availability and price. Milo grits (sorghum) and cassava (manioc) have proved to be acceptable substitutes during grain shortages. Wheat, unmalted barley, and potato starch have been used only in limited amounts and with limited success. Brewing sugar and syrups are excellent brewing materials when properly prepared and free from iron. Soybeans are often added in small amounts. Soybeans appear to aid in the nourishment of the yeast and improve fermentation; they contain rather large amounts of various B vitamins.

Besides the qualitative aspect, the use of adjuncts also has an economic aspect in that the various unmalted cereals are usually cheaper than the barley malt.

Hops. By hops the brewer understands the blossoms of the female hop plant, which grows wild in North and Middle Europe, North Asia, and North America. The hop plant is perennial and produces a new vine each year. New hop gardens are grown from cuttings of underground runners, which are planted 7–8 ft apart with approximately 700 "hills" to an acre. Each hill consists of 4–6 cuttings, from which vines are trained to climb on strings to overhead wire trellises. The hop plant is vulnerable to insect and blight attack unless carefully sprayed and tended. The oldest and most famous centers of hop cultivation are Saaz in Bohemia, Hallertau in Bavaria, and Kent in England, but excellent hops are now grown in the states of California, Washington, and Oregon in the United States, as well as in Belgium, France, Yugoslavia, and Russia. Great care is taken to suppress the growth of male hop vines in the vicinity of hop gardens since seeding is undesirable. Seeds do not contribute anything valuable to beer and may increase the weight of hops by 25%. "Seedless" hops are defined as those having less than 3% seeds and are sold at premium prices. In August the crop is ripe and ready for picking. The hop cones are picked by hand or by machine and are dried in layers of about 60 cm at temperatures near 55°C in kilns with artificial drafts. It is often a common practice to burn sulfur under the kiln to preserve the green color of the hops. Table 3 presents the composition of hops (3).

Table 3. Composition of Hops

Component	Percent of total weight
water	12.5[a]
ash	7.5
raw cellulose	13.3
proteins	17.5
ethereal oil	0.4
ether extract (mainly resins)	18.3
tannin	3.0
proteinfree extract substances	27.5

[a] Would be closer to 8% in American practice.

lacking flavor or zest

The effects of the addition of hops are multiple. Originally the principal aim was to compensate the insipid sweet taste of the unhopped beer with the characteristic bitter taste and aroma of the hops. However, other considerations later became apparent; the biological stability of the beer is highly increased and the head retention and body of the beer are improved when hops are added.

100 liters

The amount of hops added varies from 40–400 g/hl (hectoliter). In the original pilsener beer the amount is about 400 g, but elsewhere much smaller amounts are used. The amount of hops/hl of finished beer is decreasing all over the world. In the U.S. it has gone down from 175 g/hl (0.46 lb/bbl) in 1946 to 130 g/hl (0.345 lb/bbl) in 1957, and in Denmark the picture is very much the same, the average amount being about 120 g/hl.

hops ⇒ bitter taste

By far the most important constituents of the hops are the bitter substances, humulone, lupulone, and their transition products, which give beer its characteristic taste; moreover, it is said that lupulone has a weak aroma which is carried over into the beer. The antiseptic effect of hops, especially marked against beer sarcina and ?

more benefits of hops

other bacteria, is due to the bitter substances, above all the humulone and its transition products. Because of the colloidal nature of the bitter substances, and their great surface activity, they contribute to the body and foam head retention of beer. Like other ethereal oils, those of hops are volatile and disappear almost completely during the brewing process unless they are added shortly before the end of the boiling step. The content of tannin in hops has some significance in that it combines with proteins of the wort to form nonsoluble substances, thereby contributing to the precipitation during boiling of the wort. Some of these substances do not precipitate until very low temperatures are reached and then they are very finely dispersed; they may be the cause of turbidities in beer. During the last ten years these bitter substances have been investigated thoroughly and their composition as determined at the present time is α-acids (cohumulone, humulone, adhumulone), β-acids (colupulone, lupulone, adlupulone), and soft and hard resins. α-Acids are responsible for 85–95% of the bitter effect of hops in that during the boiling they are transformed into iso-α-acids (isocohumulone, isohumulone, and isoadhumulone), which are the most important bitter substances of the beer. The rest of the bitterness of the beer is due to the soft and hard resins; the β-acids under normal conditions are not converted during boiling and do not contribute anything to the bitterness of the finished product. Table 4 shows the utilization of the α-acids.

thin tightness

Table 4. Example of the Utilization of α-Acids

Place of utilization	Amount of α-acids, mg/liter
in hops	72.1
in hopped wort	39.8
in green beer with flocculating yeast	33.9
in green beer with nonflocculating yeast	30.9
in unfiltered beer after storing	31.0
in bottled and pasteurized beer	30.5

foam lumps or fluffy masses

Formerly, it was normal to examine the hops by hand and rate them on appearance and odor, but today brewers measure α-acids chiefly, and on the basis of these measurements decide on the hop rate to use.

During the last forty years there have been more and more experiments done in Europe using concentrated hop extract instead of fresh hops, but use of hop concentrates or extracts plays little or no part in American practice.

Brewers Yeast. Yeast (qv) for brewing may be propagated from single cell cultures (pure cultures) but it usually is recovered after fermentation is completed and then used over again for many generations. Smaller breweries may buy process-yeast from other breweries. There are two types of yeast used in brewing—*top yeast* which forms spores, ferments vigorously at elevated temperatures, and tends to float on top of the beer and *bottom yeast* which does not usually form spores, is well adapted to slow fermentation at low temperature, and settles to the bottom of the tank at the end of fermentation.

Different races of yeast, whether they are pure cultures or constituents of an ordinary mixed pitching yeast, can be distinguished by the rate at which they ferment or the degree to which they will attenuate wort under normal conditions. The latter does not imply that the yeasts actually have different attenuating powers since they

weaken

will ferment wort to the same extent if kept in suspension by continuous shaking, as in the experimental method for determining limiting attenuation. This is a function of the composition of the wort and not of the yeasts themselves. The difference depends on the flocculating properties of the yeasts. Some tend to flocculate in the wort and the rapid stream of gas bubbles evolved in top fermentations brings the small clumps to the surface. Fermentation would consequently cease unless the heads so formed were roused (vigorously mixed) back again. Others remain suspended in a more discrete or finely divided state throughout the fermentation and fully attenuate the wort, with little or no rousing. There is thus a reciprocal relation between flocculation and attentuation. This is exemplified by two types of yeast in English breweries, which are often described as fast and slow yeasts. top

Similar differences characterize the two types of bottom-fermentation yeasts, named after the weakly attenuating Saaz and the strongly attenuating Frohberg yeasts. The former flocculate readily and are known as "break" yeasts, while the latter, "dusty" or "powder" yeasts, remain suspended in the worts. The latter are preferred for beers that must be fully attenuated and very stable in trade. bottom

Brewery yeasts have generally all been regarded as varieties or races of *Saccharomyces cerevisiae*, but Stelling-Dekker considered that the top- and bottom-fermentation yeasts were specifically different and classified them as *S. cerevisiae* and *S. carlsbergensis*, respectively. Mendlik suggested that they have arisen as the result of a process of selection in a yeast that originally contained both types. As a result of the low-fermentation temperatures used in lager breweries, certain types persisted while others which preferred higher temperatures were gradually eliminated until only the former were left to form the bottom yeasts now in use. Both species include many races, which have been separated as pure strains and, hence, are known as culture yeasts. The characteristics of the races of *S. carlsbergensis* are by far the better known as pure cultures are more generally employed in bottom-fermentation breweries. Various strains of both yeast types have individual flavor characteristics. Brewers yeast, therefore, is not selected solely on the basis of fermenting power but decidedly on the flavor it gives beer.

Water. It is a well-known fact that the brewing water has great influence on the character of the beer and, likewise, that the hardness of the water manifests itself as greater or lesser alkalinity towards the weak acids of the mash; accordingly, it is a question of pH.

The brewing water plays so large a role that some of the world's best-known beer types, such as Pilsener, Munich, Dortmunder, and Burton Pale Ale, owe their reknown to the special properties of the water used in their production. Today it is possible, thanks to the recognition of the influence that the mineral constituents of the water exercise on beer during its production and to the development of suitable methods of water treatment, to prepare a certain water for the production of a certain beer type. Table 5 lists the mineral content of water in various brewing centers in the U.S. and Europe (4).

Long before the concept of pH was known, the influence of the minerals of the water was empirically demonstrated in the various methods of production of both malt and beer. A water with a large carbonate content, such as in Munich and Copenhagen, demanded long-grown and highly dried malt together with slow mashing and protracted boilings of the mash because this neutralizes the carbonates. Such waters are best suited for dark types of beer, and the original beer types of Bavaria

* use this correlation w/ color types of beers.

Table 5. Mineral Content of Water Used in Brewing

	Mineral content, ppm						
City	Total solids	Ca^{++}	Mg^{++}	SO_4^{--}	NO_3^-	Cl^-	HCO_3^-
Milwaukee	148	34	11.0	20.4	0.8	6.6	
New York	28	6.0	1.2	7.7	0.5	1.0	11
St. Louis	201	22	12.0	77	4	10.0	65
Pilsen	63	8.7	3.0	3.2		5.4	37
Munich	270	71	18.5	18.4		2.0	283
Dublin	3.2	100	3.7	44.9		15.8	266
Copenhagen	480	114	15.6	62.4		60.0	347
Burton-on-Trent	1,206	268	62.0	638	31	36	287

and Denmark were dark and rather low in hops content. The water in Pilsen is poor in minerals; it is best suited for pale beer made from malt dried at low temperatures and with methods of mashing which do not favor a rise in acidity. The water from Dortmund contains both carbonates and sulfates, and these latter counteract the alkaline effect of the carbonates so that the beers of Dortmund also are pale. Still more characteristic is the water from Burton-on-Trent in England; the special beer there is made from very pale malt and mashing by infusion.

When the water which is available for brewing is not suitable for the desired beer type, the question of treating the water arises. If the production of a pale beer with a fine hop taste is desired and the water is rich in carbonates, which is usually the case, one of the following methods of treatment can be used:

1. Addition of gypsum (burtonizing)
2. Addition of acid
3. Decarbonation
4. Demineralizing by ion exchange

Addition of gypsum alters the composition of the water towards that of Dortmund. The calcium sulfate tends to neutralize the alkalinity of the carbonates. By addition of acid, carbon dioxide is set free and the carbonates are transformed into salts of the acid concerned. In practice, sulfuric acid, hydrochloric acid, phosphoric acid, and lactic acid are used. These methods are very easy to employ, but there is the drawback that all the salts stay in the water and this is not desired for all beer types. Decarbonation is a removal of the carbonates, either by boiling or by addition of lime. Until about 1940 it was not possible to improve the brewing water through ion exchange as with boiler water because this treatment exchanges the desired Ca^{++} and Mg^{++} with Na^+ but leaves behind the undesired carbonate buffer-system. Nowadays, it is possible to treat brewing water through double ion exchange, by which all salts are completely removed.

Production of Beer

The production of beer is carried out in four main steps: mashing, fermenting, storage or lagering, and bottling or racking. This method of brewing has been used in Germany, England, Holland, Belgium, and the Scandinavian countries for the past 400 to 500 years. Even today, there are not any basic differences in apparatus and arrangement; there are often differences in the final product, the beer itself, and the manner in which it is served to consumers, but even these differences are decreasing.

Mashing is the process whereby, by help of the enzymes, as much as possible of the valuable substances of the brewing materials are made soluble. The malt to be *used in the brewing is crushed in order to make the substances to be extracted accessi-*ble to the water. The brewing materials are "doughed-in" or infused with a suitable amount of water; this is known as *mashing-in.* The mixture of water and brewing materials is then called the *mash* and is treated according to one of the various mashing methods which will be described later. The malt extract contains maltose, dextrins, and other sugars, pentosans, proteins and breakdown products, minerals, tannin, and some coloring substances. The extract is dissolved in water, and the

malt crushing

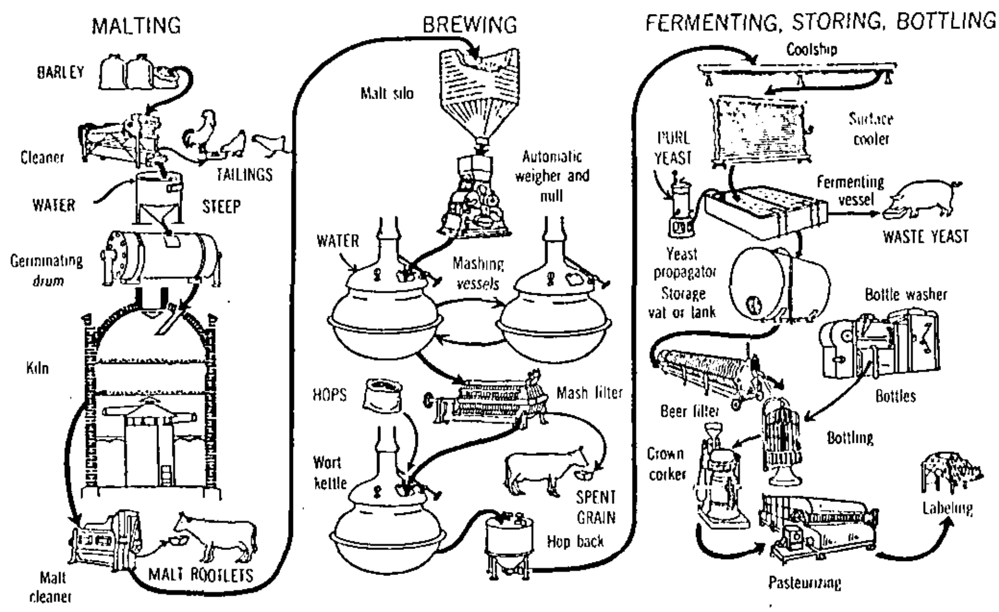


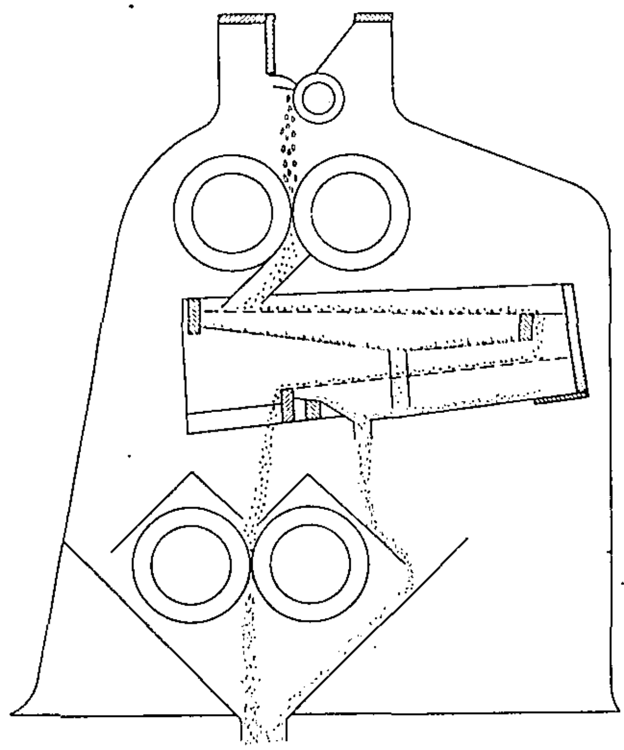
Fig. 1. Flowsheet for the production of beer (the coolships and surface coolers can be replaced by a centrifuge and a plate cooler) (5).

resulting liquid is then known as *wort.* When malt is extracted with cold water, only about 15% of the dry matter is obtained; in the brewing process about 80% of the dry matter of malt is extracted due to enzymic action during mashing. Wort is then pumped into a lauter tub or mash filter, where it is separated from the undissolved part, known as the *spent grains.* The wort runs into the wort kettle, where it is boiled with hops; when this is accomplished, the wort is separated from the spent hops in a hop back and then pumped out of the brewhouse for cooling and fermentation. Figure 1 is a schematic representation of beer production.

MALTING

Grinding of Malt. In the crushing of the malt it is essential to get the extract-yielding substances of the malt separated from the husks and finely ground. The husks, on the other hand, must stay as whole as possible because they are of great importance as filtering materials in the separation of the wort from the spent grains.

Malt mills are found in different forms: with two or four rollers with or without shaking screens, and with six rollers with shaking screens. There are also mills with



Malt mill

Fig. 2. Diagram of a malt mill with four rollers and shaking screens.

three or five rollers, the latter with shaking screens. The malt is partly crushed between the first pair of rollers, after which there is a screening operation; the fines from this by-pass the second pair of rollers, but the husks, with adhering material, pass to the second pair of rollers, where the husks are freed from the remaining parts of the kernels. A diagram of a four-roll malt mill is shown in Figure 2.

MASHING

Mashing is a continuation and extension of the modification and breakdown of the extract-yielding substances of the malt, which begins during malting. It consists of (a) dissolving those substances directly soluble in water, (b) enzymic breakdown followed by solution of a series of substances important for the type and character of the beer, and (c) separation of the dissolved substances. The breakdown during the mashing is regulated by time, temperature, pH, and concentration of the mash.

Enzyme Action. Quantitatively, the breakdown of starch to dextrin and maltose is by far the most important. It takes place according to the following equations:

$$\underset{(162\text{ g})}{(C_6H_{10}O_5)_n} \rightarrow \underset{(162\text{ g dextrin})}{n/x\,(C_6H_{10}O_5)_x} \qquad \underset{(162\text{ g})}{(C_6H_{10}O_5)_n} \rightarrow \underset{(171\text{ g maltose})}{n/2\,(C_{12}H_{22}O_{11})}$$

Table 6. Gradual Breakdown of Starch to Glucose

Product	Number of glucose units, n	Color with iodine
starch	2000	blue
high molecular dextrins	100	blue
low molecular dextrins	100	blue
	40	blue
	30	violet
erythrodextrins	20	red
achroodextrins	10	colorless
nonasaccharides	9	colorless
octasaccharides	8	colorless
heptasaccharides	7	colorless
hexasaccharides	6	colorless
pentasaccharides	5	colorless
tetrasaccharides	4	colorless
trisaccharides	3	colorless
maltose	2	colorless
glucose	1	colorless

Starch constitutes about 55% of the weight of the barley kernel. The starch particles are either rather large, 22–30 μ, or quite small, 1–3 μ; a middle size does not exist. Starch is a polymer-isomer mixture of two fractions, amylose and amylopectin. Amylose dominates in the interior of the starch particles, whereas amylopectin is found to a greater extent in the outer layers. Amylose is built of glucose units, bound together by α-1.4 bindings to straight chains, and in such a way that the chain is formed into a spiral. The length of the chain is normally over 200 units giving $M = 36{,}000$ or more. Amylopectin is also built of glucose units, but it is branched. In the straight parts between the branches the bindings are α-1.4 and the length is from 10–18 units. At the branching points there are also α-1.6 bindings. The molecule of amylopectin is big, with a molecular weight of from 50,000 to 200,000. In barley the proportion of amylose to amylopectin is about 25:75, which is normal for cereals.

According to the latest information regarding the breakdown of starch (see also Enzymes; Starch), the following four amylases are engaged: (a) α-Amylase breaks down α-1.4 bindings; (b) β-amylase, α-1.4 bindings (β-amylase only breaks down the amylose to the extent of 70%, and a complete breakdown demands assistance of the so-called Z-enzyme; for this reason amylose is believed to have a few β-1.3 bindings); (c) Z-enzyme, β-1.3 bindings; and (d) R-enzyme, α-1.6 bindings.

From the fact that both amylose and amylopectin are built exclusively of glucose units, it should be possible to have glucose alone as the end product. It is necessary, however, that on the way to this complete breakdown some intermediate products must appear, which like starch consist of chains of glucose units, only with less links than starch. These intermediate products will have less and less glucose units as the breakdown advances. Table 6 shows the gradual breakdown of starch to glucose (6).

The carbohydrate composition of wort can be determined by chromatography; a normal wort composition is detailed in Table 7 (7).

α-Amylase is resistant to comparatively high temperatures; in the mash its temperature optimum is at 70°C and it is destroyed at 80°C. It has pH optimum at 5.8. β-Amylase is already destroyed at 75°C, and in the mash its temperature

Table 7. Carbohydrate Composition of a Normal Wort

Carbohydrate	Content, g/100 ml
monosaccharides (glucose)	0.98
disaccharides (maltose)	5.77
trisaccharides	1.29
tetrasaccharides	0.26
pentasaccharides	0.10
hexasaccharides	0.16
heptasaccharides	0.15
octasaccharides	0.19
nonasaccharides	0.13
higher carbohydrates	1.08
extract,	
°P[a]	10.65
g/100 ml	11.11
total carbohydrates,	
g/100 ml	10.11
% of extract	91.0
fermentable carbohydrates,	
g/100 ml	7.74
% of extract	69.7

[a] See page 317.

optimum is from 60 to 65°C. It has pH optimum at 5.4. Consequently, the more dextrin formed, the higher the temperature of the mash is. A long pause at 60–65°C gives, on the other hand, a wort rich in maltose. In this way it is possible to regulate the fermentability of the wort as maltose is easily fermentable and dextrin is unfermentable.

The breakdown of the proteins of the barley albumins, globulins, hordeins, and glutelins starts in the malt house and continues during mashing by help of enzymes, proteases, and peptidases. Protein breakdown during mashing has no pronounced temperature optimum; it takes place rather evenly during the whole mashing up to 60°C, above which the activity of the proteases and peptidases is highly reduced. The protein breakdown is highly dependent on pH; at lower pH there is an increase in breakdown. Nowadays, it is usual to acidify pH from 5.0 to 5.4 whereas a pH of 5.4 to 5.8 was formerly used. This is believed to influence the shelf life of the beer in a favorable way.

In malt about 30% of the proteins are soluble in water. The breakdown during mashing brings 30–40% of the malt proteins over into the wort. Of the wort proteins about one third are precipitable by tannin and about two thirds are peptides and amino acids. The proteins which are precipitable by tannin contribute to the head retention of beer and are, therefore, desirable. In what degree they participate in the formation of turbidity, and especially which fractions are active, is not yet fully known, but these factors are being investigated.

The peptides, too, are little known and not even their amount can be stated with any certainty. They are believed to be of no great importance to wort or beer. The free amino acids, however, are well known; they serve mostly as nourishment for the yeast, and their amount falls to half during fermentation.

During the mashing, small amounts of tannin from the malt, and especially from the husks, go into solution, and during the later boiling with hops, more tannin goes into

Table 8. Extract Yield and Fermentation by Mashing at Different Temperatures

	Yield after being mashed for 2 hr at					
	40°C	50°C	55°C	60°C	65°C	70°C
extract yield, % of dry matter	25.4	36.8	57.1	76.9	79.8	79.6
fermentable sugar, % of dry matter	15.0	23.3	39.5	57.2	60.0	51.5
noncoagulable protein less amino acids, mg/100 g malt dry matter	268	312	354	350	334	322
amino acids, mg/100 g malt dry matter	170	196	189	183	172	152

Table 9. The Effect of pH on Yield of Maltose

pH at mashing in	pH in the wort	Maltose, % of extract
4.40	5.05	68.8
4.80	5.20	72.8
5.20	5.50	72.2
5.60	5.75	71.4
6.00	5.95	70.0
6.40	6.30	66.7

Table 10. Effect of Mash Concentration on Yield of Extract and Maltose

Concentration of mash (malt/water)	Extract yield, %	Fermentable extract, %
1:2	71.7	52.3
1:2.7	77.0	56.3
1:4.0	80.0	58.5
1:5.3	79.9	57.8

the wort. The Brewing Industry Research Foundation has shown that tannins from both barley and hops are of leucoanthocyanin nature and in some cases are derivatives of quercitrin, and that catechins are not found. Beer turbidities are rich in tannin of the leucoanthocyanin type, and everything suggests that tannins from malt and hops are responsible for the condensation products which, together with the wort proteins, form the turbidities in the finished beer.

A rise in temperature has such influence on the enzymatic processes that until a certain temperature is reached the effect increases and then falls abruptly at higher temperatures (see Table 8) (8).

The pH has great influence on the enzymatic processes during mashing although the variations caused by different brewing waters are rather small. Only through acidification is it possible to bring about such shifts that the transformations are decisively influenced. β-Amylase has pH optimum at 5.4, α-amylase at 5.8, and the normal mash has a pH of about 5.4 during saccharification. Table 9 shows the effect of pH on the production of maltose (9).

The concentration of the mash has such an influence that thin mash increases both yield of extract and the formation of maltose (see Table 10) (10).

Mashing Methods. Since mashing, the mixing of the crushed brewing materials with water, is the central process of brewing, it has been the object of numerous

mashing definition

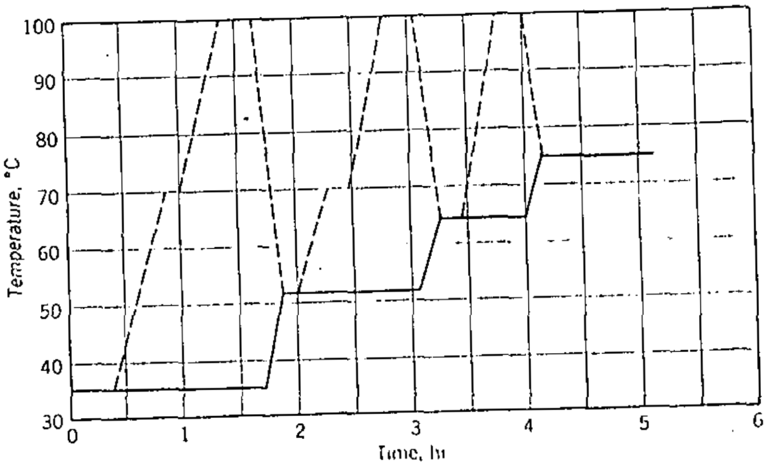


Fig. 3. Temperature-time diagram for a three-mash method.

experiments, and from these some methods have been established as the more *normal*. The choice of method has been based more often on the technical advantages or defects of the different methods than on knowledge of their chemical characteristics.

Mashing methods are divided into two groups—decoction methods, in which parts of the mash are boiled, and infusion methods, in which no boiling of mash takes place.

1 boil down

parts of the mash are boiled

Decoction Methods. There are three different kinds of decoction methods, including the three-mash method, the double-mash method, and the one-mash method. With the *three-mash method* the mashing-in is at about 35°C, and after that a part of the mash, the first mash, is taken into the kettle, where it is heated to boiling, quickly or slowly, and with or without rest for saccharification. After a long or short boiling time, the mash is brought back to the mash tub, where the temperature of the whole mash is raised to 50–55°C. Figure 3 shows a diagram of the three-mash method. With malt rich in enzymes it is possible to let the temperature in the mash rise quickly; with a malt poor in enzymes the temperature must rise slowly. Then a second mash (again a portion of the entire mash) and, lastly, a third mash is treated in the same manner; the temperature of the whole mash is then raised first to 62–66°C, the saccharification temperature, and then to about 75°C, the mashing-off temperature. The three-mash method originated empirically from the Bavarian brewers and spread from them to many beer brewing countries. Later times have theoretically proved the adequacy of the method and the scientific results regarding the enzymes have brought no objection against the general outline of the method. With a *double-mash method* the mashing-in is at 50–55°C, after which a first mash brings the whole mash to 62–66°C, and a second mash brings it to around 75°C. With a *one-mash method* it is normal to mash-in at the saccharification temperature, 62–66°C, and let the only mash bring the temperature to 75°C.

convert into sugar

2 *Infusion Methods.* With the infusion methods the whole mash is gradually heated from mashing-in to mashing-off. There is no boiling of mash, and the demand for a proper crushing of the malt is imperative because boiling of the mash helps to destroy the cells of starch in order to let the amylolytic enzymes work on the starch molecules. When no boiling occurs, the crushing of the malt must be as fine as pos-

no boiling of mash takes place.

sible, while taking into account the run-off of the wort. With the infusion method no enzymes are destroyed by boiling. It is the classic method for top-fermented beer, and it is employed exclusively for all English types of beer. It is the simplest and quickest method and the one which is most easily made automatic. American practice in mashing is to have a short-time infusion process. There are also combinations of these methods, eg, in Denmark today it is normal to mash-in at 35–40°C and boil one mash which brings the temperature of the whole to between 62–66°C, after this the whole mash is heated gradually to 70° and at last to 75°C. The mashing methods must never be completely fixed but must be flexible according to the type of beer desired, and moreover to the quality of the malt and adjuncts in different shipments and from different years.

Mash Filtration. When all soluble substances are brought into solution by means of the mashing, the next objective is the separation of the wort from the spent grains, the undissolved part. This is done in two phases—the first wort is drawn off by filtration and then the remaining extract is washed out by sparging. The mash is transferred from the mash tub to separate equipment for filtration. A filter bed is provided by the mash itself in the form of malt husks, which keep the grains porous during filtration. Rather than acting as a strainer, the filtration equipment merely supports the filter cake and husks. The simplest type of equipment is a *lauter tub*, which is a cylindrical tank with a false bottom of slotted plates upon which the mash settles. A set of vertical knives is affixed on a crossarm which slowly turns around the center axis, whereby the knives cut or plow through the grain layer and prevent it from being compressed during the run-off. After the first wort is drawn off, the grains still contain 80% liquid and the residual extract must be recovered by washing or sparging with hot water. Allowing for the dilution effect of the sparging water, it is necessary to regulate the concentration of the original wort to about one and a half times as high as the desired percentage of extract in the total wort. Another type of filtration equipment is a mash filter of the regular plate-and-frame type with filter cloth. It is particularly well suited for large-scale operation since the run-off is fast, and in addition a higher yield can be attained than with lauter because the mash layer in each frame is thinner and permits the brewing materials to be ground finer. Experimental methods of separating the mash by means of a centrifuge rather than by the filtration process have been examined during the past thirty years but thus far results have not been completely successful. Mash filter run-off is not necessarily faster than that of a lauter. Modern valley-bottom lauters of large diameters (26–30 ft) with shallow grain beds can run off in even shorter times than can a comparable mash filter. More labor is required with present-day mash filters, but efforts are currently being made to automate their operations so that the labor required will be the same. Mash filters still have a slight advantage as far as efficiency of extraction because less extract remains in the spent grains.

spray or sparkle for aeration.

During filtration the first wort runs into the wort kettle together with extract washed from the grains by sparging. After filtration the grains are sold either directly, or first dried, as cattle fodder, called brewers spent grain, an important by-product of brewing (see Feeds, animal).

BOILING, SEPARATION, AND COOLING OF THE WORT

The boiling of the wort has three purposes: (a) to evaporate a suitable amount of the sparging water; (b) to bring about the precipitation of the sludge; and (c) to dissolve the bitter substances of the hops in the wort. The boiling of the wort does not affect the composition of carbohydrates or the low molecular protein conversion products. The high molecular protein conversion products, the so-called wort proteins, are broken down so far that they do not coagulate during boiling. But it is well known that tannins in acid media (pH below 7) are able to precipitate wort proteins and that some of the sediment thus produced is of reversible character. As mentioned before both malt and hops contain tannins, and it is known that the sludge is of protein–tannin character. In practice there is a distinction between hot sludge, an irreversible coarse sediment formed during the wort boiling, and cold sludge, a reversible very fine sediment formed during the cooling of the wort.

It is normal to boil the wort vigorously with hops for 1.5–2 hr; some breweries outside the U.S. use pressure kettles, in which the wort is boiled under a certain excess pressure (low) and at a temperature of about 105°C. Large kettles are not used because they take too long to bleed back to atmospheric pressure and this produces adverse taste results.

The boiled wort should be separated from the hops and sludge as soon as possible. The separation from hops and some of the sludge takes place in a hop back (hop strainer in American terminology). This may be round or square, but it is fitted on the inside with perforated plates of steel or bronze, which keep back the hops and some sludge. After this, the wort must be cooled down to the *pitching temperature*, the temperature at which the yeast is added. The older method divided the cooling into two phases. In the first the wort was pumped to big shallow vessels, called coolships, of steel or copper, where it stood quietly in layers of about 15 cm until the temperature was down to between 50 and 35°C. Here the hot sludge and some cold sludge was sedimented, the cold sludge beginning to separate at temperatures 60°C and below. From the coolships the wort was taken over refrigerators, built up of horizontal copper tubes, on the outside of which the wort ran down, while the cooling medium, cold water or brine, circulated inside the tubes, and at last into the fermenting vessels.

Today, nearly all breweries work with a more modern, easier, and much safer apparatus. From the hop back the wort is pumped to a hot wort-holding or surge tank from which it passes through a closed cooler. Some breweries place a centrifuge between the holding tank and the cooler in order to remove the hot sludge. The plate cooler consists of a set of frames supported by a horizontal stand similar to a frame filter, but instead of filter cloth there are thin sheets of stainless steel inserted

Table 11. Analysis of Worts

	Pale wort	Dark wort
extract, °P[a]	11.6	11.6
reducing sugars, maltose, °P[a]	8.3	6.8
reducing sugars, % of extract	71.5	58.6
final degree of attenuation (apparent), %	79	68
total protein, % of extract	3.91	4.38
protein which is not precipitated by tannin, % of extract	3.62	4.02
amino acids	0.98	1.27
pH	5.62	5.47

[a] See page 317.

between the frames. Wort flows on one side of the plates and the cooling medium on the other. Some breweries cool the wort before the centrifuge, whereby it should be possible to remove the cold sludge, as well as the hot sludge, but most of the cold sludge is so finely dispersed that removal by centrifuging is not possible.

In order to ~~remove~~ completely all sludge, both hot and cold, which many breweries do, the wort must be cooled and then filtered through kieselguhr.

As soon as the wort is cooled down to 50°C or below, it is an excellent culture medium for all possible microorganisms. Therefore, the modern apparatus, in which the wort is cleared and cooled completely protected from the influence of microorganisms of the air, is much safer in contrast to the old open coolships and open coolers, from which it was not possible to keep all microorganisms away.

The dry matter of the sludge consists of the following:

hop resins	5-8%
protein	55-65%
other organic matter, including tannins	20-30%
ash	2-8%

sludge

The composition of pale and dark worts is shown in Table 11 (11).

The wort now contains no enzymes as they are destroyed during its boiling, but it is rich in different vitamins of the B group. Wort is an excellent nutriment because the mashing can be looked upon as an artificial digestion of the raw materials of the malt.

FERMENTATION

During fermentation sugar is converted into alcohol and carbon dioxide by the aid of yeast.

Chemistry. At the beginning of this century not much was known about the chemical nature of fermentation other than Lavoisier's equation,

$$\underset{\text{glucose}}{C_6H_{12}O_6} \rightarrow 2\,\underset{\text{ethyl alcohol}}{C_2H_5OH} + 2\,CO_2$$

Now numerous single steps, several of which are catalyzed by special enzymes, are known, and almost all of the corresponding coenzymes are also known. The wort does not contain much glucose, but mainly the disaccharides maltose and saccharose. Normally, the yeast hydrolyzes ~~these~~ to simple hexoses, which are then converted according to the above reaction. The process of fermentation, however, is more complicated than this simple equation shows as this is only the total result of many different reactions. Before the sugar molecule starts to take part in the conversion, it has to be changed into an active form. This active form, common to the three fermentable hexoses, glucose, fructose, and mannose, reacts very easily and is therefore unstable; it is believed to be formed directly by certain hydrolyses of polysaccharides, but in addition it is formed through the influence of a certain activator in the yeast, hexochinase. The activated hexose combines spontaneously with two molecules of phosphate, which is an indispensable helper in all fermentations (and probably in all conversions of carbohydrates). Simultaneously, or immediately after, the most important process of the breakdown occurs, the splitting of the six carbon atom chain into two parts with three carbon atoms in each. This splitting is caused by the enzyme zymohexase, which is found in yeast, combined with cozymase, a thermostable activator of rather small

ignore
split 6 carbon
ring

molecular size. At the splitting, two molecules of triosephosphate, possibly phosphoglyceraldehyde, are formed, and these are dehydrated by the aldehydrases of the yeast to phosphoglyceric acid. This again is converted into phosphopyruvic acid, which is split by carboxylase into carbon dioxide and acetaldehyde, and this last is converted into alcohol.

$$\text{hexose} \xrightarrow{\text{hexochinase}} \text{active hexose} \xrightarrow{(+\ 2\ \text{phosphate})} \text{hexosediphosphate} \xrightarrow{\text{zymohexase}}$$

$$2\ \text{triosephosphate} \xrightarrow{(-2\ \text{H})} 2\ \text{phosphoglyceric acid} \xrightarrow{(-\ 2\ \text{phosphate})} 2\ \text{pyruvic acid} \xrightarrow{\text{carboxylase}}$$

$$2\ \text{carbon dioxide} + 2\ \text{acetaldehyde} \xrightarrow{(+\ 2\ \text{H})} 2\ \text{alcohol.}$$

The yeast itself is a one-celled plant with a size between 5 and 10 μ. It consists of a cell wall surrounding the nucleus and protoplasm. It lives on the fermentable hexoses, and for propagation the amino acids are used. In addition, the yeast demands potassium, magnesium, iron, phosphate, and chlorine, and the organic growth factors biotin, mesoinositol, pantothenic acid, aneurin, nicotinic acid amide, and pyridoxin. Because the different yeast races have very different demands regarding these growth factors, yeast classification nowadays is done via biochemical experiments.

The aroma and bouquet of beer depends mostly on the protein assimilation of the yeast. The basis is the fermentation of amino acids, which, via imino acid and α-ketone carbon acid, are converted to aldehyde, and this again by disproportionation to alcohol and acid. Higher alcohols and esters of these give aroma and bouquet to the beer. The composition of the wort and specific properties in the yeast play a deciding role in this regard.

Concerning the fermentation and assimilation of carbohydrates, research in the last few years has determined a much discussed question in former years, namely that some kinds of yeast are able to ferment the polysaccharides maltotriose and maltotetraose.

differences

Fermentation Processes. Fermentation is carried out in breweries in two very distinct ways. These processes are known as top-fermentation and bottom-fermentation depending on whether most of the yeast rises to the surface of the beer or sinks to the bottom of the fermenting vessel when multiplication is completed. The guiding principles are the same in both processes; the chief differences are in the nature of the yeast, the temperatures used, and the manner in which the yeast crop is removed from the beer. The first stage of active fermentation and the second or cleansing stage, in which the yeast heads are removed, are managed in several ways in top-fermentation breweries. These are known as *fermentation systems*, two of which, the *Burton Union* system and the *Yorkshire Stone Square* system, are still characteristic of the districts in which they were developed. In bottom-fermentation breweries, the beer is run down from the fermenting vessels, leaving a firm sediment of yeast. The underlying consideration in the fermentation process, regardless of the method used, is always the fact that not only the alcohol content of the beer, but also, in large measure, its flavor and stability depend on successful fermentation. The aim of the process is always to mix a healthy pitching yeast with the wort, under conditions that will ensure a rapid commencement of yeast growth so that other microorganisms have little opportunity to establish themselves in the wort. Since the pitching yeast must be collected from one fermentation for use in another, it is equally necessary to protect it from infection and to save only yeast which is uncontaminated. For this reason yeast that separates

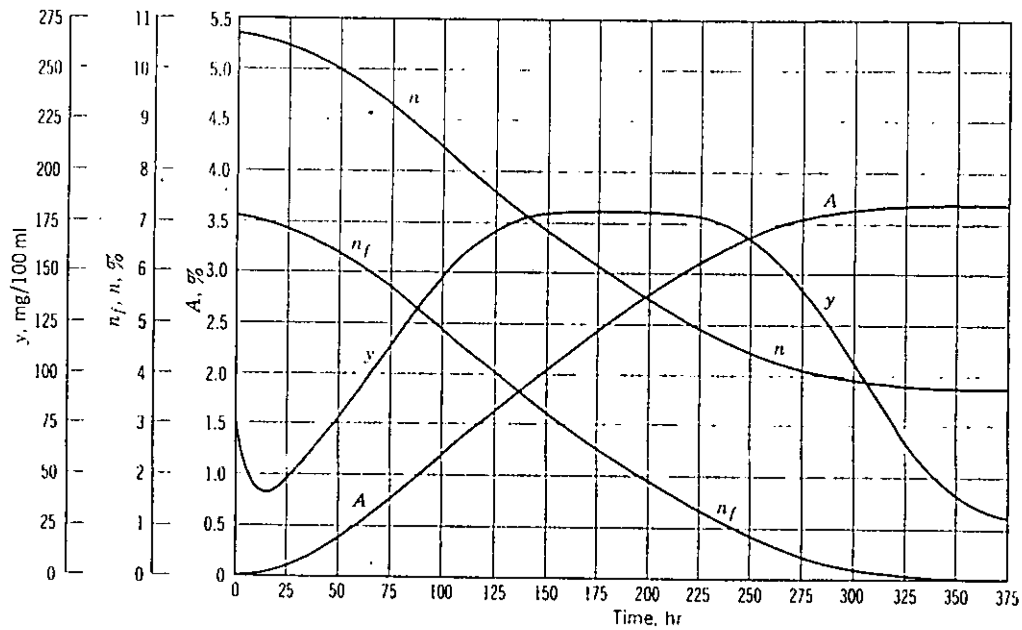


Fig. 4. Diagram of analytical curves of primary fermentation with bottom-fermentation yeast (12). The curves are identified as follows: A, alcohol; n, extract; n_f, fermentable extract; y, suspended yeast solids.

first and is contaminated with hop resins and protein matter and yeast that separates last and forms a protecting cover for the wort is rejected. Only the middle crop is used again; this can be the middle head of top fermentation or the middle layers of sedimenting bottom yeast.

Top-fermentation yeasts normally demand somewhat higher temperatures in order to develop. Bottom-fermentation yeasts are very active at temperatures as low as 6–8°C, whereas top-fermentation yeasts do not really start below 14–15°C.

With both types of yeast the fermentation is divided into *primary fermentation,* during which the yeast propagates and most of the carbohydrates are converted to alcohol and carbon dioxide; and *secondary fermentation* (known as *lagering*), during which the rest of extract is fermented, causing the beer to be saturated with carbon dioxide, also during which some sedimentation takes place and the beer is "ripened."

With bottom-fermentation yeast the primary fermentation (see Fig. 4) lasts about 8 days at temperatures between 8 and 12°C, after which the beer is transferred to closed tanks. The lagering takes place in these tanks at temperatures around 0°C and lasts from two weeks to three months. Bottom-fermentation yeasts are employed in the production of lager beer all over the world. In Denmark and in many other places top-fermentation yeasts are only used for dark beers rich in extract and poor in alcohol. In England and places where brewing has its origin from England, top-fermentation yeasts are used for all kinds of beer, even those rich in alcohol.

Gravity and Degree of Attenuation. During fermentation the gravity of the wort decreases because the extract is disappearing. If nothing more happened, the saccharometer would show the real, gradually decreasing extract of the fermenting worts. However, alcohol is being formed, and this has a lower gravity than water

Table 12. 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

and, therefore, lowers the gravity of the wort even further. In the fermenting wort or in beer the saccharometer does not show the real extract but an apparent extract, which is always lower than the real extract.

In Denmark and many other countries the strength or specific gravity of the wort is measured as °Balling (°B) or nowadays °Plato (°P) which refers to the percent of extract (sugar) in the wort. In England and some other countries it is usual to give the strength of the wort as original gravity. Table 12 shows the comparison between original gravity and percent extract.

The apparent extract, real extract, and alcohol have a certain relationship and there is also a relationship between these figures and the original extract (the solids content of the original unfermented wort). Balling investigated these relationships about a hundred years ago and communicated his findings in his teachings on attenuation.

The final beer (with original extract between 10 and 14°B) has 88–92% water, 2.5–4.0% alcohol, and 5–8% extract. In this the saccharometer does not show the real extract because the water–extract mixture is diluted by alcohol. What the saccharometer shows is the apparent extract, which Balling called m.

To get the real extract one has to boil the beer for some time in order to remove all alcohol and then replace the evaporated alcohol and some water with water alone. In this pure water–extract solution one will get the real extract, which Balling called n.

The amount of alcohol is found by taking the specific gravity of the water–alcohol mixture, which evaporated during the boiling of the beer (Balling called this A). Balling found that 2.0665 g extract gives 1.0000 g alcohol, 0.9565 g carbon dioxide, and 0.1100 g yeast. The carbon dioxide and yeast content add up to 1.0665 g.

Balling called the original extract of the beer p. By analysis, the original extract of the beer may be found as follows: in 100 g of beer the fermented extract is $A \times 2.0665$ g, and the whole original extract is $(A \times 2.0665 + n)$ g. Minor corrections are necessary because the carbon dioxide and yeast are removed from the beer so that 100 g beer corresponds with $100 + A \times 1.0665$ g wort. This amount of wort has the above mentioned amount of extract $(A \times 2.0665 + n)$ g, and

$$p = \left(\frac{(A \times 2.0665 + n)\ 100}{100 + A \times 1.0665}\right)(°\mathrm{B})$$

This formula usually gives values for p which are too high, up to 0.2°B, depending upon fermenting conditions.

The corrections in Table 12 from Balling figures to Plato figures for percent of extract were made because the sugar solutions Balling used were not as pure as it is possible to make them today.

Degree of attenuation means the amount of fermented extract measured as a percentage of the total extract, and in analogy with the above-mentioned there is an apparent and a real degree of attenuation, of which the former is the highest. With original extract $p = 10.64°B$; apparent extract $m = 2.94°B$; and real extract $n = 4.44°B$, the apparent degree of attenuation is

$$\left(\frac{p - m}{p}\right)(100) = \left(\frac{10.64 - 2.94}{10.64}\right)(100) = 72.4\%$$

and the real degree of attenuation is

$$\left(\frac{p - n}{p}\right)(100) = \left(\frac{10.64 - 4.44}{10.64}\right)(100) = 58.3\%$$

Contaminants of Beer. Besides the culture yeasts, which are necessary for the production of beer, there are in nature many wild yeasts, molds, and bacteria which may contaminate the beer. By constant cleaning, brewers try to keep to a minimum the number of microorganisms harmful to beer on the premises and in the brewery operations. If the number of harmful microorganisms is allowed to increase, disaster for the brewery is ahead. An analysis of the sources of infection and their importance is extremely worthwhile. With infections it should be understood that the infecting organisms are of the nonpathogenic type. Because of its low pH, beer does not support the growth of organisms pathogenic or harmful to man. The infecting organisms merely increase the acidity or otherwise affect the flavor and thus make the beer less palatable but not toxic.

It is interesting to note that foreign organisms capable of growing in beer are most often introduced through contamination of inoculating yeast. Contamination from the air is of less importance since most of the organisms in the air are fungi, which grow only on the surface of beer, and this small fraction is generally weakened by drying. Termo bacteria are possible contaminants which easily cause spoilage of wort prior to fermentation. They have little effect on the flavor if they are subdued, as they usually are, by a rapid starting fermentation. Much more dangerous are the foreign organisms in pitching yeast because by their very presence they have proved themselves fit to grow in beer and to compete with the yeast. Fortunately, the type of organisms that may spread the most before being detected is wild yeast, which does not present a great danger in modern brewing. Bacterial contamination which produces acid and off-flavor is really dangerous because bacteria may strike quickly. They multiply during all stages of the fermentation, whereas yeasts grows vigorously only during the initial phase; however, the bacteria, unlike wild yeast, are not in direct competition with brewers yeast.

Among the bacteria that attack beer are lactic acid bacteria, both as rods, such as different lactobacilli, and as cocci, such as different pediococci, formerly called beer sarcina, which give off diacetyl and impart to the beer a butterlike flavor. Diacetyl may also, under certain conditions, be formed by culture yeast so that the presence of it does not necessarily mean an infection by pediococci.

During the lagering period, temperatures are generally so low, close to freezing, that bacterial growth is insignificant. Bacteria carried through the filters have only a slight chance for development if the beer is pasteurized because this destroys all microorganisms. For unpasteurized beers they may be dangerous.

Microbiological research in this century on both yeasts and organisms harmful to beer has brought about a much improved biological control of brewing operations and hygiene. Great aids in this regard are the vast improvements in detergents and disinfectants and the discovery of new germicides, such as the quaternary ammonium compounds (qv), which because of their great surface activity give a penetrating disinfection.

Course of Fermentation. The temperature in the cooled wort is normally between 6 and 10°C, adapted so that the fermentation starts rapidly and is finished in 8 to 10 days. During fermentation the temperature must not go higher than 11 to 12°C because the beer may suffer in regard to both taste and head retention, and the higher temperatures also favor the development of bacteria. A very cold fermentation, on the other hand, may weaken the culture yeast and favor the growth of wild yeasts.

The amount of pitching yeast is between 0.30 and 0.75 kg per hl of wort, and normally 0.5 kg will be suitable.

During fermentation heat is developed, and the conversion of one molecule of glucose results in 27 kcal. The yeast utilizes 3 kcal for growth and 24 kcal is given off to the surrounding liquid. This development of heat must be counteracted by cooling the fermenting wort.

The first visible signs of fermentation are seen after 12 to 20 hr. Then the wort can no longer dissolve the formed carbon dioxide, which goes to the top and forms a white layer of foam. Rising with the carbon dioxide are certain amounts of sediments, which consist mostly of hop resins and proteins. By and by, the surface of the wort is covered by a dense, creamy foam. The cover increases as the fermentation becomes more vigorous and displays a series of highly regular formations from creamy "low curls" to foamlike "high curls." As the fermentation proceeds, the cover subsides and drops since fewer bubbles ascend to support the cover and the increased alcohol content affects it.

When the daily drop in extract is down to 0.1 to 0.2% extract, the beer is ready for transfer to the lagering tanks. The finished beer will contain from 0.40 to 0.60% by weight of carbon dioxide, but from the fermenting vessels it contains 0.15 to 0.25% by weight of carbon dioxide. The additional amount of carbon dioxide must be made during the slow afterfermentation and will need from 0.7 to 1.0% extract, or it may be added through carbonation of the beer during filtration.

Until the middle of last century all fermenting vessels were made of wood, normally oak, Pomeranian pine, Oregon pine, cypress, or California redwood. The vessels were coated on the inside with a layer of shellac, paraffin, or pitch, and they were always open. Nowadays, because it is almost impossible to keep wood biologically sterile, nearly all fermenting vessels are of metal, either aluminum, glass-enameled steel, or stainless steel, and many of them are closed in order to make it possible to collect the carbon dioxide formed during the fermentation.

In the fermenting room the temperature is held at about 50°C. This room and the lagering cellars were formerly always real cellars, which were cooled with natural ice, gathered from lakes during wintertime, stored in special ice-houses, and used during the rest of the year. Nowadays, with the knowledge there is of insulation and with modern refrigeration, fermenting and lagering cellars do not have to be underground anymore.

The surplus yeast is normally used as supplementary fodder for several domestic animals. It has great food value since about two thirds of the dry matter is protein. In addition the yeast has large amounts of vitamins of the B group, and it is the best natural source of all these. At last it should be mentioned that evaporated yeast juice, made by extraction of debittered yeast, is a good and cheap substitute for beef extract as it is very near to it in composition and food value.

LAGERING

With the end of the primary fermentation the product is beer, but it is greatly lacking in both taste and stability. The taste is unharmonious, harsh, and bitter, and it has a peculiar yeasty aroma which probably comes from higher alcohols and aldehydes. Both the biological and the physico-chemical stabilities are unsatisfactory.

Priming. In England, however, the beer is regarded as practically finished at this stage, only lacking a final polishing of taste and appearance. The taste is corrected through the so-called "priming," which is an addition of a small amount of a strong sugar solution mixed with caramel. The composition of the "priming sugars" are characteristic for each brewery and, therefore, secret. After priming, the beer is racked and "fined," which consists of adding a small amount of isinglass, "the finings." The cask is left undisturbed for a few days, during which time the finings settle, adsorbing all other floating particles. The sediment settles so hard on the inside of the cask that even transportation does not shake it loose, and the beer can be served clear for some time until a renewed fermenting begins.

Low-Temperature Lagering. In continental Europe and in the U.S. the method of improvement is lagering at low temperature in closed vats or tanks. In transferring the beer to these containers, the balance that exists in the beer by the end of the primary fermentation is disturbed, the liquid is stirred to such an extent that the remaining fermentable sugar becomes evenly distributed, and the beer is aired and at the same time cooled so that the toxic effect of the alcohol on the yeast diminishes. All these influences cause a renewal of fermentation, which at first is rather lively, and, later, when the temperature drops, very weak. The chemical and physical processes during lagering are important, but, especially regarding the former, not at all well

Table 13. Changes in Volatile Substances During Lagering

	Higher alcohols, mg/liter	Volatile acids, mg/liter	Esters, mg/liter
green beer			
Frohberg yeast	7.2	6.3	2.9
Carlsberg yeast	8.3	8.3	2.6
After 1 month's lagering			
Frohberg yeast	9.2	5.9	7.1
Carlsberg yeast	10.3	5.2	4.1
After 2 months's lagering			
Frohberg yeast	10.2	6.3	7.3
Carlsberg yeast	12.0	6.2	4.6

known. The carbon dioxide formed during the rather lively fermentation at the start removes with it some volatile substances (aldehydes and acids) and this tends to diminish the "young" bouquet of the "green" beer. The remaining higher alcohols and acids, probably aided by esterases of the yeast, are converted to esters, which also help in changing the taste and aroma of the beer. Table 13 shows the changes in volatile substances during lagering (13).

It is clearly seen from Table 13 that esters are formed and that changes also occur in the other groups. However, because the characteristic fine taste and aroma of beer depend on numerous different substances, the amounts of which are very small, an analytical investigation of these changes in taste and aroma is very difficult. In this regard the lagering offers no troubles or possibilities for changes; these changes all occur during former stages. There is one variation which is especially reflected during the lagering and that is the amount of adjunct used. Much adjunct gives, as mentioned, a high attenuation, which means much alcohol in the beer, and this again gives rise to the formation of more esters than would normally occur.

By means of pressure regulators, pressure is generated in the closed lagering vessels and is kept at the value corresponding to the final amount of carbon dioxide desired in the beer.

Continental practice allows the primary fermentation in the fermentor to proceed until it is 1.5 to 1°P above final fermentation or end-fermentation. At this point the beer is put into the lager cellar tanks and allowed to ferment out slowly in the cold under pressures of about 3 lb. A ripening and mild self-carbonation takes place.

In general, American practice merely allows beer to end-ferment in the fermentor, and then it is put into lager or ruh tanks for 1 or 2 weeks. Beer is then carbonated, filtered, finished, and packaged. After filtration, chill-proofing agents containing proteolytic enzymes, such as pepsin or papain, and sometimes amylolytic enzymes are added.

Kraeusening. Another process, which is not practiced much on the European continent and only by a few brewers in the U.S. is that of *kraeusening*. End-fermented beer from the fermentors is put into the lager tanks and then a certain percentage of young beer which is just beginning to ferment, called kraeusen, is added. Fermentation proceeds at a low temperature and under pressure. This requires more time and, hence, is a more expensive process.

Formerly all lagering vessels were made of wood like the fermenting vessels Today, only tanks of aluminum, stainless steel, or glass-enameled steel, and in some few instances tanks of concrete, which are provided on the inside with a wax or stainless steel lining, are used.

Control of Beer Turbidities. Much is demanded of beer today in regard to appearance and stability. From the beginning it must be completely bright and must stay so for many months under normal temperatures. Moreover, it must not be hazy or turbid when stored in a refrigerator. The turbidities formed in beer in the course of some time, or by cooling in a refrigerator, consist mostly of protein-tannin compounds. Chill haze is mostly reversible, which means that the beer gets clear again when heated, whereas the turbidities formed during a certain length of time—oxidation haze—are irreversible.

To counteract the tendencies of beer to form turbidities many different methods have been tried during the years. The principal measure is to keep the beer as cold as possible during the last part of the lagering and during filtration. In connection with this, many different methods of converting the proteins, which are part of the turbidities, have been tried. These proteins are rather high molecular breakdown products of the original proteins in the malt, but in addition to being part of the turbidities they also help in supporting the foam in the finished beer. Because of this it is difficult to have a beer with a good shelf life and at the same time a good head retention and vice versa. For a number of years breweries have employed the addition of certain enzymes, such as pepsin or papain, which help in breaking down the high molecular protein substances. From Germany, where all additions of foreign substances that go into solution are prohibited, comes the treating of beer with bentonite. Bentonite selectively adsorbs those protein substances that take part in the turbidities but none of the bentonite itself goes into solution. Many breweries have precipitated these protein substances during the lagering through addition of tannin. Activated carbon has likewise been used for adsorption. Even when they help the stability of the beer, all these methods will, to some extent, diminish the head retention. During the last few years, many experiments have been performed in another direction, namely a partial removal of the tannins taking part in the turbidities of beer. The tannins are adsorbed onto very finely ground nylon or perlon powder which is mixed with beer and after some time separated along with the adsorbed tannins. This treatment also improves the stability of the beer, but with no harmful effect on head retention.

Control of Oxygen in Beer. Since 1940, scientific investigations have shown how important oxygen is to the properties of beer. Aiding in this was the concept of redox potential. But beer has no reversible redox system, and since it is difficult to measure the pH of beer potentiometrically, a practical and now very wide-spread method, the Indicator Time Test (ITT) was developed. Many methods have also been developed for the measurement of air, especially oxygen, in beer on its way from the fermenting room to the bottle or can. These experiments have brought about the practice of moving beer from one vessel to another only under an atmosphere of carbon dioxide. Some breweries go so far as to fill the bottles with carbon dioxide before the beer goes into them. An easier method is to counteract the oxygen in the bottled beer through the addition of ascorbic acid or a glucose oxidase system. However, neither method is entirely satisfactory.

FILTRATION

At the end of lagering, the beer is in possession of the desired organoleptic properties, but it is still slightly hazy. To remove this, brewers formerly used isinglass or agar-agar; nowadays, however, filtration is the only means, and until about 1940 filtration through filter mass was used exclusively. The filter mass, which consists of cotton fibers, was normally mixed with about 1% of asbestos fibres and compressed wet into cakes, 5–6 cm thick. The cakes were then placed in frames in special filters. Filtration by filter mass was, and still is, usually arranged as double filtration so that the beer first passes through one half of the filter and later through the other half. Studies of this form of filtration have established that the filter mass partly exercises a purely mechanical filtering effect, depending on the size of the pores, and partly an adsorption effect. The latter decreases during the filtration, and this affects the quality of the beer because with a newly washed filter mass the beer is finely polished at the start of the filtration whereas at the end the beer is not so finely polished. A finely polished beer is one which is sparkling in appearance and has a good shelf life.

About 1940 two methods for prefiltration were developed to facilitate the work of the mass filter and thereby save labor, heat, and water. One method, developed in Europe, consisted of placing one or more centrifuges before the filter; the other, developed in the U.S. consisted of installing kieselguhr filters for the prefiltration. Both methods filter evenly over the whole filtration period but can only be used for prefiltration as they are unable to hold back the finest particles of the haze. In Europe the kieselguhr filter has been further developed so that many breweries today employ it as the only filter. From Europe also comes another form of filter, the sheet filter, in which the beer passes through prefabricated and hardpressed thin sheets of cotton fibers. The sheets may be of different hardness and thereby filter the beer more or less sharply; they can be so fine in the pores that even bacteria are kept back and the beer is filtered sterile. The sheets are used for short periods and then replaced, whereas in the mass filter the filter mass is used over and over again with washing and pressing of cakes in-between. Sheet filtering is probably the most expensive form of filtration (see Table 14) (14).

Table 14. Comparison of Costs with Different Methods of Filtration

Method	Cost, ¢/bbl
double mass filter	16.9
kieselguhr filter	9.8
centrifuge and sheet filter	17.6
centrifuge and kieselguhr filter	12.0
kieselguhr filter and sheet filter	18.5

PACKAGING OF BEER

After filtration the beer is put into pressure tanks or bottling tanks, from which it is taken to racking or bottling. During these last operations it is very important that there be (*1*) no loss of carbon dioxide, (*2*) no admission of air (oxygen), and (*3*) no infection, especially when beer is sold unpasteurized. To avoid loss of carbon dioxide it is necessary to keep the beer constantly under a pressure so high that it corresponds with or preferably is a bit over the partial pressure of the carbon dioxide dissolved in the beer. To avoid admission of air, it is normal to let the beer always meet a counter-pressure of carbon dioxide both in bottling tanks, pipes, and fillers. Infections are avoided here, as elsewhere in the brewery, through daily cleansing and disinfection of all parts which come into contact with the beer.

Bottling. In former times all beer left the brewery as "keg" or "draught" beer, but since the end of the nineteenth century it has been usual to bottle at least some of the beer. Today, bottling and canning have attained real importance; in some places all beer leaves the brewery in this way, while in other places the draught beer still is from one third to one half of the total output. The emphasis on canning and bottling of beer has produced extensive changes in bottling machines so that the newest, highly mechanized installations which the big breweries employ today are far removed from the first, very primitive apparatus used.

The machines of the bottling plant include a bottle-washing machine, bottling or canning machine, crowner, pasteurizer, and labeling machine.

In the bottle-washing machine the returned bottles or the new ones directly from the glass factory are thoroughly cleansed. After a preheating and eventually a prerinsing, the bottles are soaked in a soda solution of a certain strength, from 0.5 to 4–5%, with a temperature between 70 and 80°C. Some bottle soakers also contain nylon brushes for cleansing bottle interiors. After soaking, the bottles in some machines are also sprayed internally and externally with the soda solution before going to the after-rinsing, but in other machines all the spraying is done in the after rinser. Here the bottles are sprayed with hot water, lukewarm water, and finally cold water. Machines in the U.S. are usually fitted with three, four, or five compartments for soaking with varying strengths of caustic soda and varying temperatures. Caustic soda strengths are set by law not to be below certain minimums. In some instances caustic sprays for bottle interiors are used as well as brushes. The final rinse is performed using sprays of filtered water. Most European machines spray the bottles with the soda solution.

The clean bottles are transferred to the fillers with conveyor belts and are usually inspected on the way so that bottles which are not clean enough may be sorted out. The filling is always done under a certain counter pressure in accordance with the amount of carbon dioxide in the beer. From the bottling tanks the beer is transferred by carbon dioxide pressure or by way of a pump. The filler is fitted on top with a reservoir, from which the beer is distributed to the various filling valves. When a bottle comes into the machine, it is first provided with a counter pressure equal to the one over the beer in the reservoir. When this is established, the beer starts to run and fills the bottle. After the bottle is filled, the faucet or valve is closed and the bottle moves on to the crowner. Normally, on newer machines the counter pressure is relieved gradually, and not suddenly. In filling the bottles the beer displaces all the air therein, and it is very important that the last of the air in the head space be displaced through a slight overfoaming between filler and crowner. Some filling machines are so arranged that the bottles first are exposed to a certain vacuum, about 90%, and then filled with carbon dioxide before the beer enters. The method is expensive and not completely satisfactory. In the crowner the bottles are closed with crown corks and pass on to the pasteurizer.

Pasteurization. The word pasteurization was introduced in the years 1865–1867 to the wine and brewing industries as the term for a heat treatment of wine and beer to make these products more stable. This treatment uses the method patented by Pasteur in 1865. Pasteurization was originally limited to a heat treatment of beer and wine but it was quickly extended to the treatment of a large group of other foodstuffs, and today the definition of pasteurization is a partial sterilization, especially of fluid foodstuffs and stimulants, by a moderate heat treatment.

In the pasteurization of milk it is important that all pathogenic microorganisms be destroyed, while lactic acid bacteria are left more or less intact. Therefore, the pasteurized milk is not sterile, it is only freed from pathogenic bacteria and some putrefactive bacteria.

In the pasteurization of beer it is important that all microorganisms which are likely to develop in beer be destroyed, while certain spores of bacteria that cannot develop under the given circumstances are left more or less intact. By means of pasteurization the beer reaches an unlimited biological stability.

Since the advent of pasteurization this heat treatment has held its own as the only perfect method to make beer biologically stable, and the undesirable effects, with regard to taste and shelf life, which follow the heat treatment under uncontrolled conditions, have only been able to delay the spreading of pasteurization in countries with conservative brewing industries. Today, thanks to the results of scientific investigations, these drawbacks can be reduced to a minimum, and the practice of pasteurization is spreading.

In a modern, fully automatic pasteurizer, the bottles are heated during 20 min to about 60°C, kept at that temperature for another 20 min, and at last cooled to about 20°C in 20 min. Such apparatus is expensive to procure and expensive to operate in regard to consumption of water and heat even though the heating water is recirculated by means of pumps and heat exchange is arranged between the heating and the cooling zones. Moreover, the beer, as mentioned, is kept for 20 min at the pasteurizing temperature which, together with parts of the heating and cooling, causes the beer to be kept at rather high temperatures for 30–40 min; this is undesirable in regard to stability and taste. This method is known as "long-time" pasteurization. Many American and European breweries have been able to shorten the length of time required for long-time pasteurization.

About twenty-five years ago several research centers started experiments with "short-time" or "bulk" pasteurization, and since then many breweries have adopted this method of pasteurization. With this method the beer is treated between the bottling tank and the filler in a plate apparatus in which the beer is heated to a pasteurizing temperature of about 70°C, which is maintained for 30 sec, after which follows the cooling. The treatment lasts about 2 min, which results in less undesirable effects regarding taste and stability. Moreover, this apparatus is much cheaper to procure and operate. However, this method has one drawback which many brewers consider fundamental; the once sterilized beer from the plate apparatus may be reinfected, either in the pipes or the filler or from the bottles if they are not completely sterile. In order to use this method it is extremely imperative to have what is known as "sterile filling."

To guard against reinfection of the bulk pasteurized beer, a new filling method, called "hot filling," was developed in Germany in 1957. With this method the beer is pasteurized in a plate apparatus at about 70°C and then bottled at that temperature in special fillers which can operate at that temperature and under the corresponding pressure, which is between 8 and 12 atm. However, the use of hot filling of bottles is not practical when cartons of bottles of finished beer are stacked on pallets in a warehouse. Heat is then held and this is equivalent to an accelerated aging process. Some method of cooling must be developed and thus far the solution to this problem has not been easy to find.

After pasteurization the bottles are labeled. Nowadays, the bottling plants of bigger breweries are very highly mechanized with great savings in manpower as a result. There are mechanical unloaders of cases before the washing machines and mechanical loaders after the labeling machines so that the bottles are never touched by hands all the way through the bottling plant.

Canning. Distribution of beer in cans decidedly reduces the weight of the packaged beer and eliminates the problems of returning the empty glass containers and cleaning them for reuse. Another advantage of cans over bottles is the better heat transfer through the thin metal walls, which facilitates pasteurization at minimum temperatures as well as rapid cooling before serving the beer. Furthermore, the can provides complete protection against "light damage." Ultraviolet light causes photochemical reactions in beer whereby hydrogen sulfide and mercaptans are liberated causing an off-odor.

The filling of beer in cans follows the same principles as bottling, but great demands are made on the quality of the beer cans. They are usually made from 60-lb tin plate although experiments are now in progress with 55-lb. Almost all tin plate is 0.25-lb tin. Tin, however, reacts with beer proteins to form insoluble tin proteinates; therefore, the cans are given an inside lacquer coating. This coating must be chemically inert and must not impart any flavor or odor to the beer. The most satisfactory lacquers have been formulated from vinyl resins, which, however, adhere rather poorly to plain tin. The vinyl lacquer, therefore, is applied over a base-coat of normal food lacquer of the oleoresinous type. Lacquers formulated from tung oil and oil-soluble phenol-formaldehyde resins have proved to be particularly well suited; they are applied to the flat sheet and baked at 150–200°C for 10–20 min. Epoxy-base coatings have also been found to be excellent. Lithographic decorations are applied to the outside before forming the can. The cylindrical shell is assembled and the soldering line is sprayed with base lacquer before the final application of vinyl lacquer. The end pieces are similarly treated and furnished with a ring of composition rubber to provide a tight seal when they are crimped onto the can. The entire can must be perfectly covered because beer in contact with the smallest amount of tin will soon become hazy. The tin coating must be continuous and free of pinholes in order to prevent electrolysis and the introduction of iron into the beer from the steel-base metal. Top cans to be sealed with crown corks present a special problem because of the heavy impact during crowning, and, therefore, a final inside coating with crystalline wax has been adopted: this wax is derived from high-melting paraffins of petroleum base. Cone-top and wax-coated cans are rarely used in the U.S.

The canning of beer originated in the U.S. and about one third of the total U.S. output is canned. But many other countries have adopted this method of packaging the beer during the last few years. In Denmark three breweries have installations for canning, but the cans are used exclusively for export and no canned beer exists on the Danish market. In Sweden two of the biggest brewing concerns are canning beer

Table 15 Properties of Beer

Property	Pilsener Urquell	U.S. lager beer	Danish pilsener	English ale	English stout	Munich Löwenbrau	Dortmund
original extract content, °P	12.1	11.5–12.0	10.6	15.0	21.1	13.3	13.6
real extract content, °P	5.3	5.5	3.4	5.0	8.7	6.4	5.5
alcohol content, % by weight	3.5	3.4–3.8	3.9	5.2	6.7	3.6	4.2
protein content, % by weight		0.28–0.35	0.3	0.6	0.8	0.5	0.6
CO_2 content, % by weight		0.53	0.50	0.40	0.41		0.42
color[a]	10	2.7	5			40	8
air in bottle, ml/bottle		1.5	2	8	10		6
pH		4.25–4.5	4				
real degree of attenuation, %		60–75	69	66	59	48	60

[a] According to the European Brewery Convention.

for home consumption, and in England many breweries have adopted this method of packaging.

Racking. Racking of beer, that is putting it into kegs for draught sale, is done in the same way as the filling of bottles. The kegs, made of wood with special coatings or aluminum or stainless steel, are cleansed and sterilized and brought to the racking machine, which operates isobarometrically in the same way as the bottle fillers. Draught beer is sold mostly in a rather local market and, therefore, is sold unpasteurized. If the beer is shipped over longer distances, it may also be pasteurized, either in a plate apparatus before filling or in the keg after filling.

Properties of Beer

The properties of the finished beer naturally vary with the type and place of origin. The properties of beer from different countries are listed in Table 15.

However, the figures listed in Table 15 do not say much about the quality of the beer; this can only partly be expressed in figures based on objective measurements. The quality consists of the following attributes: aroma, taste, appearance, formation of foam, and stability of foam. Of these, the first two are still unaccessible to objective measurement. It is true that a quantitative expression of the aroma exists in the amount of volatile alcohols, acids, esters, and aldehydes, but the most important attribute, the quality, cannot be expressed in this way. Appearance, foam formation, and foam stability can be evaluated more easily. For judgment of taste and aroma, the "taste-testing panels" are the only way; these were developed early in this century and at the present time are the only way to measure differences in taste with any degree of confidence.

Nutritional Value of Beer

Only since about 1950 has the importance of beer as nourishment been basically examined. Beer is, of course, drunk primarily as a source of liquid and for its pleasant and refreshing taste. Nonetheless, its physiological properties are of great importance. The caloric content of beer is significant although in present-day light gravity beers it is not especially high. A 12-oz bottle of average beer yields approximately 156 calories. (The normal daily caloric intake of a man is about 2,500 calories.) The caloric value of beer is provided partly by the unfermented residues and partly by the alcohol. The metabolic role of the latter is not fully understood, but though it is not stored in the body, to some extent, it takes the place of carbohydrates, fats, and proteins so that with excess alcohol there may be a gain in body weight. Besides its

Table 16. B Vitamins in German Beers

Vitamin	Average value, micrograms/liter	Variations, micrograms/liter
thiamine (B_1)	40	25–60
riboflavin (B_2)	280	118–420
pyridoxin (B_6)	470	300–750
nicotinic acid	8,800	6,500–10,500
pantothenic acid	790	470–1,100
biotin	5.3	2.6–8.0

caloric value, beer also contributes to the mineral requirements of the body and supplies useful quantities of vitamins of the B complex.

Table 16 lists the amounts of B vitamins in fourteen German beers (15). These results correspond with similar investigations of English and American beers.

An additional special use of beer is in the control of sodium intake in treatment of diseases, such as congestive heart failure, high blood pressure, and certain kidney and liver ailments. Studies carried out at Yale University have recently confirmed the value of beer in reducing nervous tension, a fact already known to millions of beer drinkers.

Two Danish researchers have studied the role of beer in a diabetic diet. *Diabetes mellitus,* which is caused either by a low production of insulin in the body or by an excessive demand by the body for it, requires the patient to exercise very careful control over his carbohydrate intake. Studies have shown that a bottle of average beer contributes less than one tenth of the daily optimum carbohydrate intake and of the daily caloric requirements of the average diabetic and that up to two bottles of beer can safely be included in a diabetic diet.

Beer Defects

Among the beer defects the turbidities are of primary importance. They may be induced by oxalic acid (from the barley, 10–20 mg/liter), metals, chilling, and heating (pasteurization). The chill and oxidation hazes are the most frequent and they appear through reactions between polypeptides, from the globulin, hordeines, and glutelines of barley, and tannins. Some researchers believe that they may appear through reactions between polypeptides and pentoses but without tannins. The ways and means to counteract these tendencies have been mentioned previously (see p. 321). During the last ten years several methods have been developed, by which it is possible at an early date to predict the shelf life of the beer; these include titration with sulfate of ammonia or with ascorbic acid. "Light damage," which occurs through the influence of ultraviolet light, is due to organic sulfur compounds, eg, ethyl thioglycolate, which is formed photochemically from cystin and into which flavin and a dehydrase also enter. The best protection against light damage is to use brown bottles, through which the least amount of ultraviolet light passes and, of course, cans.

"Wild" beer is a very unpleasant and very dreaded defect in beer. It is a rather violent overfoaming of beer from the bottle immediately after opening; however, this does not affect the taste of the beer. Much research has been done to discover the cause of this defect, and it has been found that certain metals may contribute, but the primary cause is believed to be the barley from certain years in which various conditions during harvesting might be at fault.

Recent Developments in Beer Production

Continuous Operations. The malting and brewing from the beginning and until now have always been operating with "batch" processes. During the past fifty years many industrial processes have shifted from batch working to continuous methods, as in the production of ethanol and butanol, and certain microorganisms. During the last few years there has been an increased interest in the malting and brewing industries for making their processes continuous. One of the advantages offered by continuous working would be that the quality of the product can readily be maintained at a uniform level, thus avoiding the variations from one batch to another. Furthermore, continuous methods are more adaptable to automatic regulation and are therefore likely to reflect lower labor costs. Important, too, is the time which might be saved by drastic reductions in the frequency of cleaning equipment because continuous processes can often be operated for long periods before cleaning becomes necessary. Undoubtedly, the most important advantage accruing from a change to continuous methods would be that present production could be achieved by a much smaller plant. This increased efficiency over the traditional methods would stem substantially from the elimination of the slower phases of the process. Thus, once the maximum rate of fermentation is achieved, it can be maintained and there will be no slackening off, such as occurs in the conventional batch method, during the final stages of fermentation. The American practice of using batch processes at rates of up to 24 brews per day (each brew may be 600 bbl or more) is so close to a continuous stream as to be indistinguishable. In this method automation of brewhouses has reduced required personnel to 1–3 men per shift.

One of the disadvantages of the continuous brewhouse is that there is a loss of flexibility in material choices dictated by changing economics. Problems of cleaning are also great. Continuous processing at any point in the brewing process can take place only if a substantial reduction in cycle time can be made. The present state of knowledge indicates that it may be possible to ferment beer continuously if the size of the brewery is below 500,000 bbl/year. Also no examples have been given of successfully matching the flavor of an existing highly successful beer. At the present time there are no installations which embody the continuous operation of all the steps; only partial steps are in operation and many of these are on a pilot scale. Unless lagering can be accomplished in days or hours instead of weeks, the completely continuous large brewery, in excess of 1,000,000 bbl/year, is not presently possible nor will it be so in the next ten years.

In the malting industry there are some half-continuous systems in practical operations, such as the American "Frauenheim," the German "Wanderhaufen," and the French "Morel" systems. In Canada a step has been taken in this direction by the "Domalt" continuous Flow Malting System, which is the first really continuous malting system, developed by Dominion Maltings Ltd. and erected at Toronto.

The brewing processes are less adaptable to continuous operation, but nevertheless some different systems have evolved. In Moscow there is a continuous brewhouse, producing 40 hl of wort per hour. In England two systems have been tried, one by the Brewing Industry Research Foundation and the other by the firm Aluminum Plant and Vessel. A continuous APV plant has been erected in a Swedish brewery.

Continuous fermenting is already worked on a large scale by Dominion Breweries in New Zealand, who have taken out a patent on their method. Almost 80%, or about 1.7 million hl, of their production is made by continuous fermentation.

CONCENTRATED BEER

During the spring of 1961 Union Carbide Corporation together with one of the leading U.S. breweries and a leading manufacturer of citrus juice announced a beer concentration process (16). Basically, this is a crystallization process in which water, constituting about 90% of a normal beer, is removed from beer by forming and growing pure ice crystals at temperatures below the freezing point of water and then separating these ice crystals from the beer concentrate. In this manner beer can be

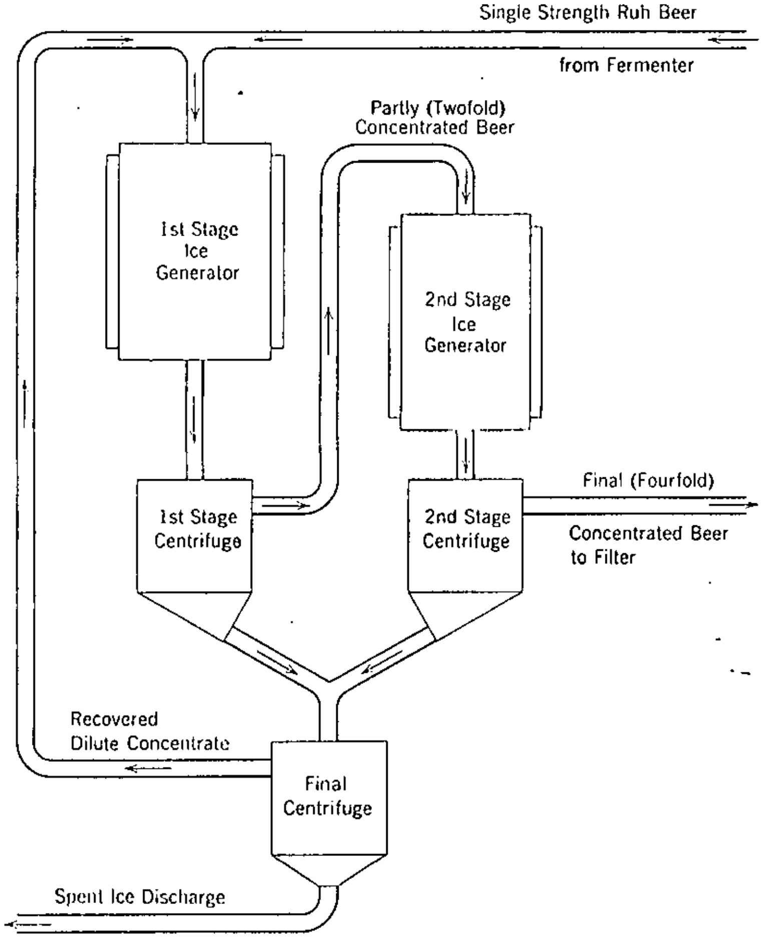


Fig. 5. Diagram of the beer concentration process.

reduced to as little as one quarter of its original volume. After filtering, the beer concentrate is ready for reconstitution by the addition of water and carbon dioxide. The entire process is a physical rather than a chemical one. Nothing is added to the beer at any point in this process for the purpose of facilitating the concentration or reconstitution of the beer. The Union Carbide freeze concentration process is now well established on a commercial basis in the orange juice field.

The process, still only in the pilot stage as applied to the brewing of beer, may be thought of as a sort of lagering process. Traditionally, ruh beer is held in large storage tanks for weeks after fermentation is completed in order to carry out proper lagering. During this period, certain constituents are precipitated from the beer. During the concentration and subsequent filtering step, some of the constituents that contribute to the instability of finished beer are removed. Since the concentration, filtering, and subsequent reconstitution can be accomplished in a matter of hours, if desired, the resulting beer can be ready for consumption shortly after fermentation is completed, rather than weeks later as is the case with present lagering techniques, or so it is claimed.

The beer concentration process is illustrated in Figure 5. At the end of fermentation unfiltered ruh beer is fed into an ice generator, where pure ice crystals are grown. The partly concentrated beer and ice crystals are separated in the first stage centrifuge and the partly concentrated beer passes to a second ice generator, where it is further cooled and additional ice crystals are grown. The crystals and the concentrated beer are separated in the second stage centrifuge. At this point the beer has reached its final concentration. The concentrate leaving the second stage centrifuge is filtered and is then ready for storage or reconstitution. Minor amounts of alcohol and soluble solids (beer extracts and flavoring components) are retained on the ice leaving the first and second stage centrifuges and are removed in a final centrifuge. The alcohol and soluble solids recovered in the final centrifuge are returned to the first stage to prevent losses.

The number and size of the ice generators and centrifuges are determined by the individual requirements of the brewery. Two-stage operation appears to offer the most economical and flexible operation. In view of the high refrigeration recovery from the ice, it is expected that present refrigeration capacity in many breweries will be adequate to supply the process after the addition of booster compressors to obtain the required low temperatures. The degree of concentration of the beer can be varied as desired. In general, a concentration of about 4:1 is preferred for economical operation, but lesser concentrations can readily be made and are within the control of the operator. The concentration system is operated continuously and automatically. The beer from the fermentor enters the first stage ice generator and the concentrate is discharged from the system in a continuous flow. The entire plant is completely instrumented to give full automatic control of the operation.

Reconstitution of the beer concentrate is accomplished by the addition of the desired amount of water and by carbonation in the normal manner. No special water is required for the reconstitution. In fact, the water used for reconstitution is not so critical to the taste of the final product as the effect of the water used for the brewing of the beer.

The concentration process results in three products, beer concentrate, beer reconstituted from the concentrate, and the recovered ice.

The beer concentrate is darker in color than beer produced by previous methods and slightly more viscous. A comparison of the compositions of beer concentrate and conventional beer is shown in Table 17 (17).

Table 17. Comparison of Compositions of Beer Concentrate and Conventional Beer

Constituent	Wt % of constituent in concentrate	Wt % of constituent in conventional beer
alcohol	15.00	3.75
extract	19.72	4.82
protein	1.40	0.39
reducing sugars	4.92	1.14
dextrins	10.56	2.30

The beer which is reconstituted from beer concentrate is identical in appearance with conventional beer. Table 18 shows a comparison of the compositions of beer reconstituted from beer concentrate and conventional beer (17).

Table 18. Composition of Beer Reconstituted from Concentrate and Conventional Beer

Constituent	Wt % of constituent in reconstituted beer	Wt % of constituent in conventional beer
alcohol	3.75	3.75
extract	4.67	4.82
protein	0.33	0.39
reducing sugars	1.14	1.11
dextrins	2.48	2.30

These analyses establish that beer produced by conventional methods and beer reconstituted from concentrate are alike from a chemical standpoint. Tasting is even better evidence of their similarity. A panel of expert tasters tried this new process beer and each panel member described it as high-quality beer.

The concentration process has many advantages, but the views upon it differ very much within the brewing industry. Much study still remains to see if the process can produce beer identical to that produced by the normal process.

Economic Aspects

Good beer is a drink which enjoys a unique popularity all over the world. During the years from the end of the last war and until 1954 the world beer consumption increased 30% and it is still rising. In 1954 the total production was 327 million hl or 34 million more than the top year of 1912. In 1960 the production was 387 million hl.

Table 19. Beer Production in 1960 in Various Countries

Country	Total amount of beer produced, in 1,000 hl	Per capita consumption, liter	Amount of beer exported, in 1,000 hl	Amount of beer imported, in 1,000 hl
Belgium	12,000	130	200	378
Luxembourg	393	126		
West Germany	54,000	104	915	150
Australia	10,525	102		
New Zealand	2,441	101		
United Kingdom	44,575	85	660	2,500
Denmark	3,288	72	800	
Austria	5,069	72	24	11
Switzerland	3,290	62	10	18
Canada	10,720	60		
United States	102,464	57	26	471
France	16,690	38	744	177
Sweden	2,330	31	14	20
Norway	880	24	20	
Netherlands	2,739	24	916	104
Cuba	1,332	21		
Argentina	2,338	12		
Italy	2,486	5	15	88
Other countries	109,926			
Total	387,486			

The per capita consumption differs very much from one country to another. Table 19 lists the total amount of beer produced, exported, and imported, and the per capita consumption in 1960 in various countries.

Denmark. In Denmark beer is a very popular beverage, by far the most important of the alcoholic beverages. For more than fifty years Danish breweries have concentrated all their efforts into making a good, pasteurized, bottled beer because the amount of draught beer required has been very small during these years. Thirty years ago draught beer was less than 2% and today less than 1% of the total beer consumption. Thus, in this field Denmark has a rather unique place among the European countries, having gained a great deal of experience in making bottled and pasteurized beer for so many years. During the years 1955 to 1960 Danish breweries started canning beer but only for the export market as no canned beer is sold on the Danish market. The production of beer has gone from 2.7 million hl in 1950 to 3.8 million hl in 1961. The export of beer in 1939 was about 100,000 hl but increased considerably after the war and in 1956 was 466,000 hl, and in 1961, 800,000 hl. Among the beer-exporting countries Denmark ranks in fourth place with the Netherlands, West Germany, and the United Kingdom exporting more. But for the moment Denmark has the world's second greatest exporting brewery with a Netherlands brewery exporting the greatest amount of beer. There is practically no import of beer into Denmark. Table 20 lists the various types of Danish beer and the taxes imposed on these beers.

Table 20. Types of Danish Beer

Category	Type	Limit on alcohol	Limit on original extract	Tax, kr/liter
	top-fermented, low in alcohol, high in extract	less than 2.25% by weight		free
II	bottom-fermented	less than 2.25% by weight		39.50
I	bottom-fermented, pilsener type		less than 10.75°P	158.30
A	bottom-fermented, export type		over 10.75°P but less than 13.00°P	198.55
B	bottom-fermented, strong beer		over 13.00 °P	237.55

More than 90% of the beer in Denmark is of category I; the beer for export is of category I and A. Denmark has thirty breweries making all categories of beer and about 100 very small breweries making only tax-free beer. The two biggest breweries make 80% of the total production.

Scandinavian Countries. In Norway the sale of beverages containing alcohol is bound by very strict regulations. Because the number of retail sale and licensed places is very limited, a considerable quantity of the beer produced is sold directly from the breweries to the private consumers. The import of beer is not great. The types of beer are nearly the same as in Denmark, and the most common is the pilsener.

In Sweden, as in Norway, the sale of beverages containing alcohol has for many years been under strict regulations although in Sweden they were somewhat relaxed in

Table 21. Swedish and Finnish Beers

Category	Alcohol content, % by weight	Original extract	Tax, marks/liter
Sweden			
I	not over 1.8		
II	not over 2.8		
III	not over 4.5		
Finland			
	not over 1.4	not over 5.0°P	free
I	not over 2.25		4
II	not over 3.20		16
III	not over 4.50		24

1955. Swedish beers are divided into three types (see Table 21). The canning of beer has been taken up by some of the bigger brewing concerns and canned beer is sold on the Swedish market.

In Finland, too, the restrictions on alcoholic beverages are strict. The making of stronger beers are governed by a state monopoly. Finland had total prohibition from 1919 until 1939, which proved fatal for the brewing industry. After repeal a new development started, but was interrupted by the war. There is no import and very little export. Table 21 lists the various kinds of Finnish beers.

In the three Scandinavian countries, Norway, Sweden, and Finland, nearly all the beer has been sold bottled for many years, as in Denmark, but in contrast to Denmark beer in these countries has been sold unpasteurized. Only during the last few years has pasteurization gained some foothold because of consumer wishes.

England. For many centuries England produced large amounts of beer and is still a leading country in this field. The beers of England differ very much from those of continental Europe since they are top-fermented and contain very little carbon dioxide. In England draught beer still plays a great role although the packaged beer is gaining every year. Packaged beer is at present between 35 and 40% of total beer consumed. Many English consumers have acquired a taste for the continental beers and England has for some years been the world's largest importer of lager beer. Now English brewers are entering this field, too, and several lager beer breweries have been erected during the last few years. The export of beer is mostly to other countries of the Commonwealth and the import is mostly from Ireland, Netherlands, Germany, and Denmark. The tax on beer in England varies directly with the specific gravity of the unfermented beer, the wort, which, of course, is directly related to its alcoholic strength after fermentation. In 1939 the tax on a pint of beer was 2d; in 1962 it was 8.5d.

Germany. In Germany the production of beer has risen sharply during the last ten years, from 18.2 million hl in 1950 to 54 million hl in 1960. Export, too, has increased considerably, from 120,000 hl in 1950 to 915,000 hl in 1960. As in England draught beer in Germany played the leading role for many years, but packaged beers are taking over more and more; in 1960 the latter was 60% of the total production, but still a very large part of this is sold unpasteurized. See Table 22 for the various types of German beers.

More than 98% of the total beer produced in Germany is of the category "Vollbier." Germany has a unique place among the beer brewing countries in that since about the year 1500 brewers have followed a decree called "Reinheitsgebot" which states what beer must be made from—"To make beer one must use barley malt, hops, yeast and water only and nothing else." This decree is still valid, and only beers made strictly for export are allowed to contain anything other than what is stated in the Reinheitsgebot. This, of course, considerably affects the use of adjuncts.

Table 22. German and French Beers

Category	Original extract, °P
Germany	
Einfachbier	2.0–5.5
Schankbier	7.0–8.0
Vollbier	11.0–14.0
Starkbier	16.0 and upwards
France	
petite bière	2.6–3.1
bière de table	5.0–5.6
bière bock	8.3–9.7
bière de luxe	11.8 and upwards

France. In France the production of beer (see Table 22) is mostly concentrated in the northern and eastern parts of the country with the southern and western parts preferring wine and cider. The production of beer has risen from 9.1 million hl in 1950 to 16.7 million hl in 1960, and packaged beer amounts to about 80% of the total production. Nearly all of France's export beer is sent to its own overseas regions.

Netherlands. In the Netherlands the consumption of beer is not very great, but this country is, and for many years has been, the world's greatest exporter of beer, although its standing is now threatened by West Germany. On the average the beer tax amounts to nearly 18 hfl per hl full beer (12.5°P). The various types of beer produced in the Netherlands are listed in Table 23.

Belgium. In Belgium, beer is the national beverage and the brewing industry is one of the most important industries of the country. As far back as such statistics were recorded, Belgium always has the highest per capita consumption of beer and still holds first place (see Table 23).

Table 23. Beers of the Netherlands and Belgium

Category	Original extract, °P
Netherlands	
donker lager	8.0–9.0
tussen bier	9.8–10.3
licht zwaar	11.0–12.0
donker zwaar	11.5–12.5
ekstra zwaar	16.0–and upwards
Belgium	
ménage B	2.4–3.9
	4.4–4.9
ménage A	6.2–6.7
II	8.8–9.3
I	11.0–11.5
supérieure	12.5–12.9
luxe	15.1 and upwards

Italy. The brewing industry of Italy does not represent an important part of the economy of the country. There are two important types of Italian beers—birra normale with an original extract of 11.2–11.9°P, and birra speciale with an original extract of 13.1°P and upwards.

European Associations. For the past few years in many of the European countries there has been a very great consolidation of breweries going on, especially in the United Kingdom, Belgium, France, and Sweden, while other countries have not been very affected by this trend. Table 24 lists the numbers of breweries in different countries for various years.

Table 24. Breweries in Different Countries

Country	Number of breweries in			
	1900	1921	1950	1960
United States	2,412	1,095	375	250
Germany	19,281	6,265	2,681	
United Kingdom	6,447	2,670	567	250
Belgium	3,223	1,502	650	425
France	2,540	1,227	638	250
Czechoslovakia	849	585	317	
Sweden	170			75
Denmark	379	214	170	120
Netherlands	503	257	60	

The brewing industries of the Common Market countries (West Germany, France, Netherlands, Belgium, Luxembourg, and Italy with Greece as an associated member) in 1959 formed a group called the Communauté de Travail des Brasseurs du Marché Commun which deals with the harmonizing of laws concerning production and sale of beer. In 1961 the brewing industries of the European Free Trade Area (EFTA) countries, United Kingdom, Denmark, Norway, Sweden, Austria, Switzerland and Portugal, formed a similar association called EFTA Brewers Information Center (EBIC). In addition to this the Council of Europe has been working for some years on the harmonizing of laws for the production and sale of wines, spirits, and beer.

On the technical and scientific side the brewers of the western European countries established rapport soon after the last war. In 1947 they met in Scheveningen in the Netherlands and formed the European Brewery Convention (EBC), which now holds a congress every other year. At these congresses brewers of all the European countries meet, together with guests from many other countries of the world, to discuss matters of technical and scientific interest. Between congresses the committees of the EBC hold meetings of their own. These committees include the Barley Committee, which sets up trials with old and new varieties of barley in all the member countries; the Analysis Committee, which works with the harmonizing of methods of analysis for barley, malt, wort, and beer; a subcommittee on "beer hazes," which has been working for some years; and a subcommittee to study hops, established a few years ago.

United States. The brewing industry of the U.S. is young in comparison with the European brewing industry even if there are breweries in the U.S. with a history of more than 100 years. But the U.S. has always, especially in the years after repeal of prohibition, made use of technical and scientific "know-how" and today stands in a very fine place among the brewing industries of the world.

1964

The beers of the U.S. are nearly all of continental European type although there are some ales of English type, but in contrast with the country of origin, they are made with bottom-fermentation yeasts. By far the greatest part of beer is of the pilsener type with an original extract between 11 and 12°P, and conforms to what could be called the "American Light Standard," light in taste, pale in color, rather bland with no pronounced hop aroma. On the average, American beer contains about 90% water, 5% carbohydrates, 3.5% alcohol, and some carbon dioxide, proteins, and minerals. In total production the U.S. brewing industry is the world's largest with more than 100 million hl per year, but in per capita consumption, 57 liters, the U.S. ranks below many other countries. The U.S. also has the world's largest breweries. In 1934, packaged beer was only about 25% of the total beer produced, but the years since then have brought great changes and today packaged beer is over 80% of the total. Very interesting in this connection is the great rise in canned beer production, which now is about one third of all beer produced in the U.S. Also the American invention, the one-way bottle, has gained much in the last ten to fifteen years so that now 20% of all bottled beer is packaged in this way. A one-way bottle is a lightweight glass bottle with a cone-top instead of a neck. In appearance it is much like the cone-top beer can, and the American glass factories call it a glass-can. The one-way bottle is furnished with the captions "No Deposit" and "No Return" cast into the glass. The weight of it is only about half the weight of a normal beer bottle. Most of the packaged beer produced in the U.S. is consumed in the home. Before prohibition draught beer accounted for 79% of all beer consumption.

*100 x10⁶ hL
yr

The highly mechanized status of American breweries is seen clearly when one looks at the output per worker. In Europe 900 to 1,000 hl per year per worker is considered good and the best breweries produce about 1,300 to 1,400 hl per year per worker. In the U.S. brewing industry the average lies at about 2,150 hl per year per worker.

As in all other countries the beer in the U.S. is taxed. The beer tax started in 1864 with $1.00 per barrel (1 barrel is 1.1734 hl) and is now $9.00 per barrel. This is the federal tax and added to it is the state tax which varies from one state to another, the highest being South Carolina with nearly $20.00 per barrel and the lowest, Maryland and Missouri with only $0.93 per barrel.

In the U.S. the technicians and the scientists of the breweries are organized in two associations, the Master Brewers Association of America (MBAA) and the American Society of Brewing Chemists (ASBC). Both have conventions each year, at which many brewers meet and exchange views on current problems. The ASBC has done much, similar to what the Analysis Committee of the EBC has done in Europe, to harmonize the methods of analysis in the brewing industry.

Canada. In Canada there are two main types of beer, lager, and ale. The lager, as in the U.S., is of continental type, made from bottom yeasts, pale and light in taste, and highly fermented. Ale is made from top yeasts, is heavier in taste, has more "body," is not so highly fermented, and has more hops. In addition, small amounts of porter, stout, and bock beers are made. Stout has more hops than porter and has a higher original gravity. Canadian beers must not contain more than 4% alcohol by weight, and most beers have this content.

The original French and English population in the eastern provinces prefer ale, and in the province of Quebec the beer consumption is 90% ale and 10% lager. In the western provinces the lager is the dominating beer and it is gaining ground all over Canada each year.

Bibliography

"Beer and Brewing" in *ECT*, 1st ed., Vol. 2, pp. 382–413, by Erik Krabbe and Henry Goob, Blatz Brewing Company.

1. H. L. Hind, *Brewing: Science and Practice*, Vols. 1 and 2, John Wiley & Sons, Inc., New York, and Chapman and Hall, London, 1938–1940, Vol. 1, p. 67.
2. *Ibid.*, p. 264.
3. J. De Clerck, *Lehrbuch der Brauerei*, Vol. 1, Versuchs- und Lehranstalt für Brauerei in Berlin, 1950, p. 59.
4. H. Jorgensen, *Brygmestern* **17** (11), 256 (1960).
5. V. Berglund, *Den Danske Levnedsmiddelindustri*, Nordisk Haandbogsforlag, Copenhagen, 1949, p. 254.
6. B. Trolle, *Beretning om Det 12 Skandinaviske Bryggeritekniske Mode*, Den Skandinaviske Bryggerhojskole, Copenhagen, 1959, p. 49.
7. B. Krause, *Laerebog i Maltningens og Brygningens Teori*, Tuborg-Fondet, Copenhagen, 1935, p. 148.
8. *Ibid.*, p. 151.
9. *Ibid.*, p. 156.
10. B. Trolle, *Beretning om Det 11 Skandinaviske Bryggeritekniske Mode*, Den Norske Bryggeriforening, Oslo, 1956, p. 165.
11. Ref. 7, p. 175–176.
12. B. Trolle, *Proceedings 3rd Congress, European Brewery Convention, Brighton, 1951*, Elsevier Publishing Co., Amsterdam, p. 132.
13. Ref. 7, p. 205.
14. H. Fischer and G. Fuchs, *Brauwelt Ausgabe B* **98**, 1860–1862 (1958).
15. F. Just and A. M. Herbst, *Brauerei*, *Wissenschaftliche Beilage*, Versuchs- und Lehranstalt für Brauerei in Berlin, 1954, pp. 123–126.
16. *Union Carbide Beer Concentration Process*, pamphlet, Union Carbide Development Co., Division of Union Carbide Corp., New York, 1961.
17. *Brewers Dig.* **36** (4) (1961); *Am. Brewer* **94**, 42 (1961).

General References

F. A. King, *Beer Has a History*, Hutchinson's Scientific and Technical Publications, London, pp. 11–15.

A. Mentz and C. H. Ostenfeld, *Planteverdenen i Menneskets Tjeneste*, Gyldenkalske Boghandel, Nordisk Forlag, Copenhagen, 1906, pp. 33, 39, 43, 48.

M. Weeks, Jr., *Beer and Brewing in America*, U.S. Brewers Foundation, New York, 1957.

Schweizer Bierbrauerverein: Europäische Integration und das Braugewerbe (in German, French, and English), Swiss Beer Brewing Association, Zurich, 1961.

Periodicals

American Brewer
Brewers Digest
Brewers' Guild Journal (London)
Brauwelt (Continuation of *Allgemeine Brauer- und Hopfen-Zeitung*) (Nuremberg)
Schweizer Brauerei- Rundschau (Zurich)
Svensk Bryggeritidskrift (Stockholm)

H. E. Høyrup
Bryggeriforeningen, Copenhagen