3.1 INTRODUCTION

This chapter provides an introduction to the brewing process; more detail on the individual processes involved can be found in subsequent chapters.

"Brewing" is defined in dictionaries as: "The making of beer by infusion, boiling, and fermentation." Brewing is not unique to beer production; it is also the essential first part of the process of whiskey production. In addition, saké production is a very different form of brewing. We are also
familiar with this term being applied to the making of tea, herbal infusions, and as a phrase in “brewing up trouble or mischief.”

Brewing is a craft that has evolved into a technology. The Oxford Dictionary defines craft as: “A skill, especially in a practical art” (https://en.oxforddictionaries.com/definition/craft). Brewers are skilled in the practical art of brewing, whether it is a million hectoliters of beer per annum of production in a big brewery or in a microbrewery. In the UK, from 1292 AD, guilds were established to represent the interests of those employed in the craft of brewing. In more recent times, from 1906, the UK brewers were represented by a body called the Incorporated Brewers’ Guild. In 2000, this guild was merged with the Institute of Brewing to form the Institute of Brewing and Distilling as we know it today. However, the original guild that dates from 1438 still exists today and is active as the Worshipful Company of Brewers (http://www.brewershall.co.uk/history-and-treasures).

In recent times, “craft” has been used as a marketing concept to help smaller brewers compete with multinational brewers; although it has to be said that some of these “craft” brewers are themselves major producers. In the United States, the Brewers Association has defined what they understand to be a “craft brewer” (www.brewersassociation.org/brewers-association/craft-brewer-definition): “An American craft brewer is small, independent, and traditional.”

Small: Annual production of beer less than 6 million barrels of beer.
Independent: Less than 25 percent of the craft brewery is owned or controlled (or equivalent economic interest) by an alcoholic beverage industry member who is not themselves a craft brewer.
Traditional: A brewer that has a majority of its total beverage alcohol volume in beers whose flavor derives from traditional or innovative brewing ingredients and their fermentation.

In this chapter, we will deal in general with the brewing of beer from barley malt because this is the main raw material employed worldwide. Chapter 2, in particular, describes other beer types and the use of a variety of raw materials. In Africa, for example, the use of sorghum has flourished—partly due to its availability but also due to restrictions on the import of barley malt in order to save foreign currencies that have necessitated finding alternative local raw materials. The brewing practices employed globally have become similar due largely to being originally from Europe, predominantly Belgium, Britain, the Netherlands, Scandinavia, and Germany.

There are some notable differences. For example, the traditional production method for cask-conditioned beer in the UK is essentially unique as is the use of a lactic acid fermentation to produce lambic beers in Belgium.

Government and social pressures have also had their influence on the types of beer being produced. The high taxation in some countries on the alcohol content or original gravity, notably in Britain, influenced the sale of lower-strength beers; but this trend was also affected by the industries in which the consumers were employed. Manual labor in steel manufacture, mining, and other heavy industries created a demand for low-strength, thirst-quenching beers. Concern about alcohol and its effect on the operators of machinery and on vehicle control has led to the introduction of low-alcohol and no-alcohol beers.

### 3.2 Outline of Brewing Steps

The following is a brief introductory description to the malting (Figure 3.1) and brewing (Figure 3.2) processes and their subprocesses. A more detailed description can be found in subsequent chapters.

1. **Malting**—converting barley into malt (further details in Chapter 5):
   a. Barley drying and dressing—remove debris, dry to store
   b. Barley storage—protect the barley to maintain its vitality
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c. Steeping—thoroughly soak the barley in water
d. Germination—spread the grain and let the barley germinate naturally
e. Kilning—stop germination by heat, develop color/flavor, and dry but still maintain enzyme activity
f. Malt storage—protect the malt until required

2. Milling—grind the malt (often with other cereals) to form grist.
3. Mashing—mix grist with water (liquor), enzymatic conversion of starch and protein into fermentable compounds (details in Chapter 11)

Figure 3.1 Typical barley malting process.

Figure 3.2 The typical brewing process.
4. **Wort Separation**—separate the liquid (sweet wort) from the solids (spent grains of draff) (further details in Chapter 11):
   a. Mash tun separation
   b. Lautering or
   c. Mash filtration

5. **Wort Boiling**—sterilization, coagulation, hop addition, and conversion and extraction, concentration (further details in Chapter 11).

6. **Trub Removal**—removing coagulated material and hop debris:
   a. Hop back, hop strainer
   b. Centrifuge
   c. Sedimentation
   d. Filtration
   e. Whirlpool.

7. **Wort Cooling/Aeration**—aerate (oxygenate) and cool the wort (further details in Chapters 5, 11, and 14).

8. **Yeast Handling** (further details in Chapters 8 and 14):
   a. **Yeast propagation**—preparation of pure culture.
   b. **Yeast storage**—maintain yeast in good condition (high viability/vitality, etc.) for use/reuse.
   c. **Acid washing**—treat the yeast culture with acid to reduce bacteria.
   d. **Surplus yeast**—sell excess to use in animal feeds, health foods, and to flavoring industries, and so on.

9. **Yeast pitching**—add the culture yeast to the wort.

10. **Fermentation**—yeast growth; flavor, alcohol, and carbon dioxide (CO₂) production (further details in Chapters 8 and 14).

11. **Yeast removal (flocculation)**—reduces yeast level in the immature beer.

12. **Aging**—matures and stabilizes the beer at low temperatures (further details in Chapter 15).

13. **Clarification**—removes particles to produce bright beer:
   a. **Fining**—uses a coagulant (isinglass) to remove yeast and so forth.
   b. **Centrifugation**—particle and yeast removal by centrifugal force.
   c. **Filtration**—particles trapped on a filter bed or on sheets (further details in Chapter 15).

14. **Packaging**—beer filled (racked) into its final container, bottle, can, or keg (further details in Chapter 16).

15. **Warehousing and Distribution**—storing and transporting the beer to the customer in perfect condition. (These aspects of the brewing process are not considered in the text.) However, novel developments in beer marketing are discussed in Chapter 23.

### 3.3 DISCUSSION OF INDIVIDUAL BREWING STEPS

#### 3.3.1 Malting

The malting process converts raw barley by controlled steeping, germination, and kilning into a product that is much more friable, with increased enzyme levels and modified chemical and physical properties. The first part of the malting process mimics what would occur in nature if the barley corn was left to germinate in the field. The grain is first steeped in cool water and drained occasionally to ensure that the corns are not asphyxiated. Two or three wet and dry periods are most common, and the moisture is raised from a storage moisture of approximately 12% to 45% to 46%.

Once thoroughly wet, the grains are laid out as a shallow bed, and they start to grow, producing roots and embryonic shoots. The grain bed is kept moist and cool by passing chilled wet air through the bed. The grain embryo produces and releases a plant hormone, gibberellin, which activates the aleurone layer of the grain to produce special proteins called enzymes. These enzymes, together with those already present in the grain, begin to break down (hydrolyze) the grain’s food reserves. If allowed to continue, a new barley plant would be formed, but the maltster stops germination as shoots (and roots) emerge from inside the grain. This is achieved by heating (kilning) the grain with
hot dry air. As well as drying the malt to preserve it, kilning also develops color and flavor. The roots are then removed mechanically and the malted corn stored ready for use.

Although the major malted cereal for brewing is barley, other cereals are malted for cost and specific purposes, mainly for the production of specialist beers: maize (corn), rice, rye, sorghum, oats, and wheat. Wheat malt is used in the production of weissbier (weizen bier or white beer). Rye malt is little used in brewing due to slow wort separation and haze instability in the resultant beer, but it is used in Canadian rye whiskey production. Also, some other distillers, using high proportions of unmalted grains, benefit from the high levels of enzymes in rye malt. Sorghum malt, mentioned earlier, is widely used in Africa and Central America both as a barley malt replacement in normal beers for economic reasons and also for trade reasons. Chapter 5 considers the topic of barley and malt in detail.

### 3.3.2 Milling and Adjunct Use

Barley malt can be supplemented with other cereals, either malted or raw, for specific purposes (provided local legislation permits their use). Malted cereals are discussed earlier (and in Chapter 5), but the raw unmalted cereals—barley, oats, maize (corn), rice, rye, sorghum, and wheat—are added as an adjunct for one, or a number, of the following reasons:

- To produce a more physically stable beer because they usually contain much less protein.
- To produce a beer with different flavor—maize (corn), for example, will give a fuller flavor compared to rice.
- To manipulate beer foam due to lower fat (lipid) levels and different protein spectra (all malt grists will also enhance beer foam stability; see further details in Chapters 9 and 20).
- To improve the ease and efficiency of processing in the brewhouse.
- To produce beer at lower cost—adjuncts generally cost less than barley malt.

When used as raw unmalted cereals in conjunction with barley malt, most cereals (and in particular maize [corn], rice, wheat, and sorghum) need to be precooked before being mashed with malt, due to the high gelatinization temperature of their starch content. Chapter 6 considers adjuncts in detail.

The malt itself needs to be milled first to produce a range of smaller particles called grist. This makes the malt easier to wet during the mashing stage and aids faster extraction of the soluble components from the malt during the enzymic conversion. Roller mills produce coarse grist for use with mash tuns or lauter tuns, but mash filters require a much finer grist, as produced by the more severe grain crushing of a hammer mill. The fineness of the grind is checked by analysis through a series of sieves (further details in Chapter 11).

### 3.3.3 Mashing

Mashing is the process of mixing the crushed malt, and cereal adjuncts if used, with hot water and allowing the mixture to stand while the enzymes degrade the proteins and starch to yield the soluble malt extract, which is called (sweet) wort, unhopped.

There are three principal mashing methods that have been developed to accommodate the equipment and materials available to the brewer.

- **Infusion mashing**—this is the classic British thick mash using a mash tun at a single temperature and without stirring. It requires high quality, well-germinated malt, and it is still used by smaller breweries. The separation of the liquid, sweet (unhopped) wort from the solids also takes place in the mash tun.
- **Decoction mashing**—this is the typical European mashing system that uses a series of different temperatures, more complicated brewing equipment, and often a less well-germinated malt. The
temperature increases can be achieved by automatically controlled heating panels or initiated by taking out (decocting) part of the mash, heating it to boiling point, and returning it to the mash vessel. This can be achieved one or more times: single, double, or triple decoction. In this way, optimal temperatures for proteolysis (about 40°C to 50°C) can be followed by optimal temperatures for starch hydrolysis (54°C to 65°C) and finally a high temperature for wort separation (about 70°C). Mash separation is usually carried out in separate equipment, such as a lauter tun or mash filter.

- **Double mashing**—known as the American double mash system, this process is used when cereal adjuncts (corn, rice, or wheat) require precooking (gelatinization) before addition to the main malt mash. Two separate vessels are employed—the cereal cooker and the mash mixer. In the cereal cooker, the adjunct is heated with water to about 85°C and held at this temperature for 10 min while the very viscous mash thins. Some malt, 5% to 15%, will usually be added to assist in this viscosity reduction; this is often called “sacrificial malt” because it is mainly its α-amylase that will be active at this temperature. Its effect is to reduce the viscosity by randomly hydrolyzing the starch molecules into smaller, less viscous dextrins. The cereal (adjunct) mash temperature can then be increased to the boiling point and transferred into the malt mash, which is already in the mash mixer at approximately 35°C (to achieve the temperature for starch hydrolysis). Mash separation is usually carried out in a separate vessel such as a lauter tun or with a mash filter.

### 3.3.4 Mash Separation

For the classic infusion mash, the processes of mashing and wort separation take place in the same vessel, the mash tun. With other mashing systems, the mash is transferred to either a second vessel, a lauter tun, or to a mash filter. Both systems accelerate the process; a lauter tun, due to its large diameter and shallow grain depth, gives rapid separation, and the mash filter uses pressure, a large filtration area, and a very thin grain bed depth to give very rapid separation and extraction. For both systems, the transfer enables a second mash to be started in the mash mixer while the first mash is being separated. Typically, a lauter tun takes 3 h, while a mash filter takes 2 h to complete the separation and to be ready for the next mash. The objective of this procedure is to produce bright wort and to collect the maximum amount of sugars (extract) from the solid (raw) materials. The used solids (spent grains) are sold as animal feed, draff/spent grains, for milk and beef cattle herds and poultry.

### 3.3.5 Wort Boiling

Wort boiling is a process unique to beer production because it is not required in the distilling or vinegar production processes. Wort boiling satisfies a number of important objectives:

- Sterilization of the wort to eliminate bacteria, yeasts, and molds that could compete with the brewing yeast and possibly cause off-flavors and beer instability.
- Extraction of the bittering compounds from hops added early to the boil and oils and aroma compounds from late hop addition (further details in Chapter 7).
- Coagulation of excess proteins and tannins to form a solid particle (trub), which can be later removed. This is important for beer stability and foam (further details in Chapter 20).
- Color and flavor formation.
- Removal of undesirable volatiles, such as dimethyl sulfide, by evaporation.
- Concentration of the sugars by water evaporation.

### 3.3.6 Trub Removal

Although there are differences of opinion whether wort should be cloudy, bright, or brilliant, it is important that most of the coagulated material formed during the boil is removed so that beer stability does not suffer. However, the degree of trub removal is much debated. Hot break is the name for the particles present in the hot boiled wort, and they are quite large (20–80 µm) in size.
A much finer particle (cold break, less than 2 µm) appears when wort is cooled below 60°C, and some brewers choose to remove it due to suspected effects on beer flavor and the coating of yeast cells, which could inhibit fermentation efficiency.

There are several methods for particle removal, depending on the available equipment and also whether whole hops or hop products have been employed:

- **Hop Back/Hop Strainer:** If whole hops are used, then a hop back or strainer is required to remove the hop debris by sieving. The hop back will also catch the trub, but a strainer does not and will require a further stage for trub removal.
- **Centrifuge:** Hot wort centrifugation is an effective method for removing hot break but is expensive in capital and running costs. Centrifuges are also prone to damage from small stones that are picked up with the barley during harvest and find their way into the process (details of the use of a centrifuge are discussed in Chapter 15).
- **Sedimentation/Flocculation:** The large particle size of the hot break means that it sediments quickly if the wort is run into a shallow vessel. This was the principle of the now almost obsolete coolship—a large, shallow, open vessel that held the wort while it cooled naturally and was clarified. The more modern sedimentation vessels achieve the same result but more efficiently and hygienically. Coolships are still employed in the production of lambic beers in Belgium since the pick-up of infecting organisms from the atmosphere is an essential step in the production of these beers. Alternatively, the particles can be made to float by attachment to air bubbles and then skimmed off the wort surface to be separated by the process of flocculation.
- **Filtration:** The trub particles can be removed by filtering through a bed of kieselguhr or perlite powder (details in Chapter 10); both can trap the solid particles.
- **Whirlpool:** The simplest and most elegant separation technique is the whirlpool (details in Chapters 1 and 11), which makes use of the centrifugal/centripetal force acting on the particles when the wort rotates after a tangential inlet into the cylindrical tank. The trub and hop debris are deposited as a mound in the center of the vessel, and the bright wort can be taken away from the periphery of the vessel, leaving the trub cone behind for later disposal.

### 3.3.7 Wort Cooling/Aeration/Yeast Pitching

The wort is cooled from almost boiling point to fermentation temperature through a heat exchanger, using cold water as the main cooling medium. The wort temperature for fermentation is typically 8°C to 15°C for lagers and 18°C to 22°C for ales.

Yeast is pitched (inoculated) into the wort, either directly to the cooled wort in the fermentation vessel or in-line en route from the heat exchanger to the fermenter.

Air or oxygen is also added to the wort as an essential nutrient for the production of yeast cell membranes and hence new cells. (The importance of oxygen is discussed in Chapters 8 and 14.) Injection is usually en route to the fermenter, but direct injection into the fermenter is also used, often if the vessels are of an open design. This has the added benefit of efficient mixing of the wort so that a representative sample can be obtained to determine the collection gravity.

Wort is a complex fermentation medium consisting of fermentable sugars (glucose, fructose, sucrose, maltose, and maltotriose), unfermentable dextrins, free amino nitrogen (FAN), ions, vitamins, and so on. The metabolism of wort by yeast is discussed in Chapters 8 and 14.

### 3.3.8 Yeast Handling

The handling of the yeast is key to the efficiency of brewery fermentations and to the quality of the final beer. Important steps in maintaining the vitality and viability of the culture are the appropriate pitching and cropping of the yeast, the propagation of the yeast from a laboratory culture to full-scale pitching, its storage for reuse, and the techniques employed for acid washing the yeast in order to
reduce infection. Surplus yeast is a valuable coproduct and is sold to the food flavorings industry (e.g., Marmite, Vegemite, and Cenovis), to distilleries, and to health supplement manufacturers.

### 3.3.9 Fermentation

There are two main types of fermentation—ale and lager; but, in addition, there is a wide variety of different fermentation systems and equipment that have been used for many years. It would be true to say that the definitions of ale and lager have become blurred over the years, and it is now difficult to define precisely what constitutes a lager and what constitutes an ale (details of these studies are in Chapter 8 and 14).

#### 3.3.9.1 Ale Fermentation

In brief, traditionally ale uses a *Saccharomyces cerevisiae* strain, a top-cropping yeast incubated at 18°C to 22°C. The fermentation is rapid and exothermic. Consequently, cooling is necessary to maintain a constant temperature. Fermentation does not always occur to its full extent but may be deliberately cooled early to flocculate the yeast and to leave some residual sugar for palate sweetness and secondary fermentation (as in cask-conditioned ale). The yeast can be cropped early from the vessel to prevent off-flavors from yeast autolysis and also to provide a healthy and vital yeast crop for subsequent fermentations.

The “green” (immature) beer is cooled slightly to encourage further yeast flocculation and then either filled directly into a cask or further cooled and filled into a cold tank for brewery conditioning. Isinglass finings are often added to the casks to aid clarification and, together with dry hops, are used to impart a strong hoppy character to the beer. (Further details of the use of isinglass finings and similar processing aids are discussed in Chapter 10.)

Early ale fermentation systems can still be found operating in some UK breweries. These include the Burton Union, Yorkshire Square, and Open Squares systems. These systems evolved as methods to obtain an efficient fast fermentation, to produce a yeast crop of the best quality for re-pitching, as a convenience for cropping the top-fermenting yeast, and for rapid removal of the yeast to halt fermentation and leave residual sugars (fermentability) in the beer. Ales are currently predominantly fermented in cylindro-conical vessels and, under these conditions, the top-cropping yeast adopts a bottom sedimenting characteristic. However, the subsequent processing stages remain similar (details in Chapters 8 and 14).

#### 3.3.9.2 Lager Fermentation

Lager yeast strains ferment at a lower temperature than ale strains, typically 8°C to 15°C. Bottom cropping *Saccharomyces pastorianus* yeast species, previously classified and termed as *Saccharomyces uvarum* or *carlsbergensis* (details in Chapter 8), are used. The traditional lagering process involved a primary fermentation using a flocculent yeast culture. This was followed by a secondary fermentation using a nonflocculent yeast at a lower incubation temperature—approximately 8°C (warm storage). This was succeeded by cold storage at 0°C, or less, in order to stabilize the beer. It is now more usual to “age” the beer at below 0°C after a single, complete primary fermentation (further details in Chapters 8 and 14).

### 3.3.10 Fermentation Process

For both ales and lagers, the basic fermentation process is similar. Yeast uses wort sugars and FAN to produce alcohol, carbon dioxide (CO₂), new yeast cells, and a plethora of flavor compounds. Typically, 5 to 20 million yeast cells are pitched per mL of wort. At the start of
fermentation, the yeast appears dormant with very little visible activity—this is the lag phase. However, a great deal is happening within each yeast cell. It is adapting to its new environment, and the cells begin to bud in order to produce new cells using free fatty acids and sterols produced from its intracellular carbon reserve of glycogen (a branched polysaccharide with a structure similar to amylopectin). Oxygen is also essential for this reaction. Under aerobic conditions, the yeast metabolizes glucose into two pyruvate molecules with a small energy gain, (the Embden-Meyerhof-Parnas [EMP] pathway, see Figure 3.3) and then via the Krebs cycle (also called the tricarboxylic acid [TCA] cycle, see Figure 3.4) and oxidative phosphorylation to carbon dioxide and water with a large energy gain.

As all the oxygen is soon used by the yeast culture and anaerobic conditions prevail, the Krebs cycle (or TCA cycle) and terminal oxidation is no longer possible, but the yeast can still produce pyruvate from glucose. However, pyruvate is acidic, and the yeast needs to remove it by metabolizing it to acetaldehyde and, subsequently, ethanol and CO₂ (Figure 3.3). There is no energy gain from this latter reaction, but a small amount of energy (as adenosine triphosphate, or ATP) does accrue from the metabolism of glucose to pyruvate. The waste products (ethanol, glycerol, CO₂, etc.) are transported out of the cell, and the excess CO₂ from the fermentation is vented from the fermentation either to the atmosphere or is collected for later use in the packaging process or sold to soft drink manufacturers, market gardeners, or other CO₂ users. A level of CO₂ remains in the beer to give it appropriate carbonation and effervescence.

Toward the end of fermentation, as the sugars are depleted, the yeast culture begins to flocculate. This can also be assisted by applying cooling to the fermentation. A good separation of the yeast by flocculation is important in order to obtain a clean, drinkable beer and for ease of processing through subsequent stages. Also, a good yeast crop is necessary for its reuse in a subsequent fermentation. (Details of yeast fermentation are in Chapter 8.)

![Diagram of the Embden-Meyerhof-Parnas pathway](image)

**Figure 3.3** The Embden-Meyerhof-Parnas pathway.
Fermentation also produces a range of flavor compounds, esters, alcohols, carbonyls, sulfur compounds, and so on, which give character to the beer. There are, however, some flavor compounds that are unpleasant and need to be reduced or removed during the later stages of fermentation or later in the lagering and cask conditioning stages. Such compounds include diacetyl (a vicinal diketone, VDK), which gives beer a rancid butter/butterscotch flavor and is produced by the yeast from pyruvate via α-acetolactate (a metabolite en route to the amino acid valine) (Figure 3.5); but given time, it will be metabolized toward the end of the fermentation (or maturation) by the yeast to acetoin and butanediol, both of which are not as flavor active as diacetyl (Figure 3.6).

Sulfur compounds such as hydrogen sulfide (H₂S), sulfur dioxide (SO₂), and dimethyl sulfide (DMS) are all volatile, and the CO₂'s purging action during fermentation can be sufficient to reduce them to acceptable levels if the vessel is allowed to vent freely. The formation of excessive H₂S and SO₂, although determined primarily by the yeast strain, is associated with conditions that restrict yeast growth. Also, the availability of oxygen at yeast pitching is a critical factor. It is important to crop the bulk of the excess yeast before maturation, generally by removing the beer from the sedimented yeast or with a centrifuge. Further details of maturation can be found in Chapter 15.
3.3.1 Aging

The maturation of the immature (green) beer to produce a stable, quality product suitable for filtration and packaging is called aging or, alternatively, cold conditioning or cold storage. Immature beer is sometimes called green beer because it often has the aroma character of green apples due to the presence of the carbonyl compound acetaldehyde.

The objectives of beer aging are:

- Chill haze formation
- Clarification
- Carbonation (to a limited extent)
In order to produce a beer of good colloidal stability in its final package, it is vital to promote, by storage at low temperatures (less than 0°C), the formation of chill haze, which comprises flocs of polypeptide/polyphenol complexes. These can be removed by slow sedimentation, filtration, or centrifugation to give a bright stable product (details of centrifugation in Chapter 15).

Long cold storage will bring about beer clarification by sedimentation of residual yeast, chill haze material, and other debris, but it is a slow process even in horizontal storage tanks. For superior tank utilization, it is preferable to have a short period of cold storage to allow the flocs to form (approximately two to four days), and then the beer is filtered (or centrifuged) to clarify it.

At the low temperatures of cold storage, there is minimal yeast activity, and the beer will not gain appreciably in CO2 content, even though the low temperature favors its solubility. Similarly, flavor change is minimal. Removal of polyphenol material as chill haze will eliminate harsh, bitter flavors from the beer, but a low yeast count and low temperature cannot be expected to rectify a diacetyl problem. Therefore, if aging is to be employed, it is important that primary fermentation is complete and produces beer with the correct final flavor profile. This is in contrast to the traditional “lagering” or warm storage process where higher yeast counts and a more favorable temperature, approximately 8°C, facilitates beer “maturation.”

The use of cold storage as a buffer stock in order to smooth sales fluctuations is commonplace. The low temperature minimizes any possible microbiological spoilage and any changes to the beer’s character. It is therefore a convenient point in the process to create a small holding stock, subject, of course, to the cost of providing the storage capacity.

3.3.11.1 Immobilized Yeast

Rapid maturation using immobilized yeast has been employed in several countries and by a number of brewing companies. The VTT Technical Research Centre in Finland, in association with Sinebrychoff AB, developed a process of immature beer heat treatment (65°C to 90°C for 7 to 20 min—during which it is very important that every effort be taken to exclude oxygen to prevent beer staling) followed by passage of this treated beer through a packed bed column of yeast immobilized on diethylaminoethyl (DEAE) cellulose particles. This will accelerate the breakdown of α-acetolactate to diacetyl and then to acetoin (Figures 3.4 and 3.5). A high quality beer can be the result. In addition, Alfa Laval of Belgium and the German company Schott Engineering have jointly developed a further generation of this rapid maturation process, again with the Finnish brewing company Sinebrychoff AB, using porous glass beads (Siran®) as the carrier. Both these processes reduce the maturation time from days or weeks to hours. A detailed review of immobilized yeast technology has been published5,6 and will also be discussed further in Chapters 14 and 15.

3.3.11.2 Chillproofing

Cold storage is a very effective means of chillproofing beer, but polypeptides and polyphenols are still present and, if a long shelf life is required, additional chill proofing treatments may be necessary. These treatments reduce, still further, the polypeptides and/or polyphenols in the beer so that colloidal haze formation will not occur and become visible during the beer’s shelf life.

In brief, proteins can be removed by absorption onto silica gel, which is then removed by filtration or by addition of a plant-derived proteolytic enzyme (e.g., papain from the papaya fruit), which prevents the polymerization of proteins by hydrolyzing them to smaller units. The use of proteolytic enzymes can have a negative effect on beer foam stability (details in Chapters 9 and 20). Polyphenols can be removed by absorption onto polyvinylpolypyrrolidone (PVPP) beads. PVPP is very effective as a remover of beer polyphenols but is expensive! However, PVPP can be regenerated, using a caustic treatment, and therefore used more than once (details in Chapter 10).
3.3.12 Clarification

Some clarification is required for most beers, although there are exceptions such as weiss beer and conditioned-in-package ales, which are served cloudy. Filtration will produce a bright sparkling beer that remains clear throughout its shelf life, provided the stabilization procedure has been correctly conducted. A coarse depth filtration using diatomaceous earth or perlites will remove most particles, and this can be followed by filtration through a cellulose filter sheet to give a polished, almost sterile, product. Health concerns, regarding dust from filter powders and the cost of their disposal as spent filter cake to landfill, has encouraged the use of alternative methods. Ultra-high-speed centrifugation, deep bed sand filtration, cross-flow filtration, and fining are some of the methods being employed, usually supported with a cellulose sheet filter, to give beer its final polish.

The filter is usually the last opportunity to make corrections to the beer prior to packaging. Typically, the adjustments that can be made are:

- The carbonation level, by adding/removing CO₂ (by membrane diffusion)
- Color adjustment with caramel or farbebier (colored beer)
- Hop products (extracts, etc.) added to correct bitterness, enhance foam, or to prevent light-struck compounds from forming (details in Chapter 7)
- De-aerated water blended into the beer in order to dilute (cut) it to its appropriate final alcohol strength (details in Chapters 9, 10, and 15)

3.3.13 Packaging

3.3.13.1 Packaging Containers

Packaging of beer can be conveniently divided into two categories:

- Large pack, which includes kegs, casks, and de-mountable bulk tanks
- Small pack, which includes cans and bottles (details in Chapter 16)

There are large differences among countries in the relative volumes of beer packaged into these two categories for a plethora of reasons: historical, political, and geographical. In the United Kingdom, for example, predominant ownership of the retail outlets by the breweries and the short delivery distances favored large pack containers. Also, the packages themselves did not have to sell or promote the product. In recent years, however, the increase in home beer consumption has seen a shift toward small pack, although large pack still dominates the market.

For casks and kegs, stainless steel is the most widely used material for its cost, durability, and hygiene, although some aluminum and wood casks are still in use. Bulk tanks of 8 hL capacity have been used in the United Kingdom and Scandinavia for direct delivery to the retail outlet as a unit or with a transfer of the beer from a road tanker to 4 or 8 hL bulk tanks in the outlet cellar. Although popular with larger UK retail outlets in the 1970s and 1980s, it has now almost disappeared from UK use but is still used in Scandinavia.

Glass still predominates the bottle market, although polyethylene terephthalate (PET) and polyethylene naphthalate (PEN) are increasingly being used for their weight and safety benefits, especially now that the major obstacles of pasteurization and barrier properties to oxygen pick-up and CO₂ loss appear to have been resolved. The reuse and recycling of glass is well-established. Returnable glass is still common in Germany, other parts of Central Europe, and in Canada. However, there has been a major switch from returnable to nonreturnable bottles (NRBs) in many countries. This has been driven by initiatives in the light-weighting of NRBs, the inconvenience of returnable cases, the costs and environmental considerations of bottle
washing, and the better payload of NRBs. Reuse of PET is not widely practiced but has been successful in Scandinavia.

Cans are manufactured from aluminum and tin-plate. In the United States, aluminum is the main material, but tin-plate is a strong contender in Europe and Mexico. Both materials are extensively recycled. The recent development of a can with a bottle-shaped neck is an attempt to capture the visual appeal and decorative opportunities that a bottle offers but with the very low weight of a can. Also, this container is fully recyclable.

### 3.3.13.2 Packaging Equipment

Two types of packaging equipment are in use for keg filling (racking): a linear machine comprising multiple lanes (up to 24) and a rotary machine with up to 24 stations, looking very much like a large version of a can or bottle filler.

Operation speed, diversity of keg size, and shape are a few of the factors that might determine which type of machine to employ. Speed of operation (diversity of keg size and shape are a few of the factors that will influence which type of machine to use) from just a few kegs per hour to more than 1000 kegs/hour are possible. Both types of washer/racker take kegs returned from the trade, wash and sterilize the inside surfaces, counter pressure and cool slightly with an inert gas—usually CO₂, and then fill with sterile beer under carefully controlled and monitored conditions. Air pickup is strenuously avoided, and a microbiologically sound product can be produced. The beer for filling is either pasteurized or sterile-filtered. By comparison, the filling speeds of bottles and cans are very fast, with throughputs of up to 2500 containers per minute possible. Further details of beer packaging systems are in Chapter 16.

### 3.3.14 Warehousing and Distribution

Finally, it is important that the beer is distributed rapidly to the consumer in superior condition. Currently, this is an increasingly complex operation, and the supply chain is a key element of successful distribution. It must be Remembered that an excellent product in the brewery does not guarantee that it will be excellent when it reaches the consumer! A consideration of distribution complexities is beyond the scope of this book, but brewers need to be conscious of the problems that might ensue during the movement of their beer from brewery to customer and take steps to mitigate all adverse effects. (A comprehensive discussion of beer quality can be found in Chapter 21.)

### REFERENCES