Third Edition

The Brewer's Handbook

The Complete Book to Brewing Beer

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Feedback/Acknowledgement

In preparing such a book we anticipate there will be errors, and we encourage the reader to send us comments. From simple typographical errors, to missing topics, errors in data or interpretation, and even suggestions for new approaches in explaining the art and science of brewing beer. All suggestions are encouraged. Please send your ideas to: apexbookpub@gmail.com. In closing, we acknowledge the work of the many researchers in the international beer brewing community that we have drawn upon in formulating this book, and also appreciate the feedback from those brewers who also helped in providing practical advice in how to brew beer.

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Introduction

In the past two decades we have witnessed unprecedented changes in the U.S. beer industry. The emergence of craft brewers and consumers' newfound appreciation for quality beer have resulted in what is often called the "Craft Beer Renaissance." Beer has taken on a new excitement and relevancy to the average person. It is no longer thought of only in the context of large commercial brewers with their mass-marketed beers. The marked increase in the number of brew pubs and microbreweries and the burgeoning growth in the number of home brewers indicate how deeply brewing beer has captured the popular imagination.

The Brewer's Handbook is intended to provide an introduction to brewing beer, and to give a balanced, reasonably detailed account of every major aspect of the brewing process. This book not only discusses brewing beer on a large-scale commercial basis, it has made every effort to address brewing practices typically used by craft brewers. Thus, its applicability extends to home brewers and to individuals working in the brewing industry and related fields.

The information in this easy-to-use reference guide is distilled from a variety of sources, including scientific literature, extension publications, and brewer experience and has the added value of numerous citations to more in-depth discussion on many topics. The book is thoughtfully organized presenting a seamless flow of topics within chapters making it easy to find specific information that interests the reader. *The Brewer's Handbook* has removed some of the intuition and guesswork in brewing beer. The result is a more consistent product of higher average quality level. It is written in a language that can be easily understood by anyone not having a background in brewing beer. Clarity is the touchstone that has been employed throughout this book.

1 Brewing Process

Beer is part of the history of civilization. There is evidence that people have been drinking beer since 3500 B.C. Beer is one of the most widespread and largely consumed alcoholic drinks in the world. It is a complex alcoholic beverage, containing numerous flavor-active compounds over a wide range of concentrations. Brewing is the process of producing of beer. The object of the entire process is to convert grain starches to sugar, extract the sugar with water, and then ferment it with yeast to produce the alcoholic, lightly carbonated beverage. Beer is more than just water, hops, malt, yeast, and possibly adjuncts. In the process in making beer, it involves malting, milling, mashing, extract separation, hop addition and boiling, removal of hops and precipitates, cooling and aeration, fermentation, conditioning, carbonation, and packaging.

Malting

The first step in the production of beer is malting. Malt contains a range of carbohydrates, composed of insoluble cellulose and soluble hemicellulose, dextrin, starch, and sugars. Starch, which accounts for about 50 to 60 percent of the weight of malt. To harvest that starch and convert it into sugars, the barley undergoes a process known as malting. The barley is soaked in water and the "germ" part of the seed begins to grow into the acrospire, i.e., germinate. This process activates, and develops diastatic enzymes inside the seed and also starts the process of unlocking starches from the endosperm, i.e., converting its stored starch into sugars. Plain, pale malt accounts for up to 100 percent of a brewer's grain bill depending on beer style. The purpose of the pale malt in the recipe is to provide diastatic enzymes and at least some of the fermentable sugars. Diastatic power, a measure of the malt's ability to convert starches into sugars. Specialty malts are made by heating the pale malt in a kiln until it browns. The browning or toasting of the malts occurs via the Maillard reactions, accentuating the malty-toasty flavor of the malt. Other specialty malts are made by soaking the pale malt in warm water. This activates the malts to begin sugar production, but since the pale malt roots and shoots have been damaged, the seed cannot grow. Instead, the sugars collect in and on the seeds. When these seeds are then dried and kilned, they result in a great source of caramel, toffee, and roasty malt flavors. The kilning process, however, also reduces the diastatic power to essentially zero. Although the main malted cereal for brewing is barley, other cereals are malted for specific purposes, mainly for the production of specialty beers: oats, corn, rice, rye, sorghum, and wheat. Wheat malt is used in the production of *Weiss* beer.

Milling

The second step in the brewing process is milling. In order to use the malt in the brewing process, the brewer has to break open the husks and expose the starch in the grain. Doing so also allows the enzymes that were formed during germination to be released once the crushed malt is added to water. The husks should be crushed as little as possible in order to prevent the undesirable tannins, bitter only one or two types of malts, or as many as seven or eight different types of specialty malts.

Acidulated Malt

This malt style actually came about as an innovative way for German brewers to have control over their mash pH while also adhering to the purity laws of *Reinheitsgebot*, which states that beer must only be made with malt, water, hops and yeast—so no additives like phosphoric or lactic acid in the mash. Proper mash pH (5.4 to 5.6) helps assure the enzymatic performance on which the brewer relies to break down gums, proteins, and starches. It also leads to proper wort pH, which affects yeast performance during fermentation and the final flavor profile of the resulting beer. Acidulated malts are commonly made by two different processes. Both start with the same malt processing typical for a base malt but finish with steps to enhance or add to the natural lactic acid found on the malt surface. The first method utilizes a fermentation step post-kilning to encourage growth of lactic acid bacteria already present on the malt, whereas the second method employs additions of a weak, food-grade lactic acid solution as a spray or steep during the germination stage of malting. The first method is considered to yield complex flavors—albeit more subtle acidity—than the second method. Fermented malts are generally thought to have capacity for adjusting mash pH by 0.1 to 0.2 points for each 1 percent inclusion, while the lactic acid-treated malts can adjust in the range of 0.3 to 0.4 points. At low usage rates, it is virtually unnoticeable but brings a bright acidity that can enhance an otherwise drab malt component.

Dextrin Malt

Dextrin malt is a type of malted barley used in brewing to increase dextrins in wort and finished beer (Figure 2.6). Dextrins are long-chain sugars that are unfermentable by brewer's yeast. Dextrin malt is the lightest in color, are high in unfermentables, and contribute to the beer's body without affecting color. Dextrin malts are similar to caramel malts but have been dried at a lower temperature to prevent the formation of color and flavor compounds. Caramelization of the sugars and darkening of the husk are avoided, thus the malts possess very little caramel flavor (residual sweetness). Dextrin malt does not impart the characteristic flavor and reddish hue of caramel malts, but adds smoothness, fullness of body, and initial head retention without affecting the color of pale or light lagers. Dextrin malt tends to impart a light flavor described as "sweet biscuit" and "full," but with little caramelized-flavor.

Beers have been formulated with up to 30 percent dextrin malt with no residual sweetness, though some brewers believe that using high proportions (>10%) of malt can impart a starchy flavor note (cloying sweetness) to the beer. Kunze reports that 8 to 12 percent is sufficient to improve foam and palate fullness (Kunze, 1996). Dextrin malt is most useful in lager beers because lager yeast uses more of the triple sugars in wort. The results are a lower terminal gravity and a lighter body compared to ale yeast in wort of similar starting gravity.

Figure 2.6 Dextrin malt

Melanoidin Malt

Melanoidin is a kilned specialty malt with an intense malt aroma and unique brewing characteristics. It has a high degree of modification of both proteins and starches, excellent friability, low beta-glucan values, and high acidity. These attributes help promote flavor stability, add body, and produce a smooth mouthfeel. Although some variants have sufficient enzymes to convert up to 100 percent of the starch, it is more commonly used at lower concentrations as the flavor can become too pronounced when it is the primary malt. Melanoidin malt is best used in dark or red-colored beers such as amber ales, Scottish ales, Irish red ales, bocks, and *Kellerbier*.

Smoked Malt

Smoked malt is made by drying the malt wholly or partially using the direct combustion gases of a wood fire, which imparts an intense smoky flavor. Traditional versions (associated with the city of Bamberg, located in Franconia, Germany) use beechwood as the fuel source. Other special woods (such as cherry and alder) are used in other areas of the world. Lightly smoked versions of this malt can be utilized for up to 100 percent of the grist charge. It is a unique, enzyme-active specialty malt that contributes an intense smoke, smooth, sweet, smoky flavor. It is vital that smoked malt be used at appropriate levels; excessive use completely overwhelms underlying flavors and results in undrinkable, monochromatic beers. In general, U.S.

Lupulin powder produces flavors in beer indistinguishable from those of leaf hops. Lupulin powder provides bitterness and aroma to the beer. The flavor depends on the variety, quantity and time of the addition. Lupulin powder is added to the wort kettle during the boiling process. Late kettle additions of lupulin powder (typically 5–20 min prior to the end of the boil) reduce alpha acid utilization but increase hop aroma and flavor. Hop utilization is normally within a range of 30 to 35 percent with early kettle additions (up to 15 min after the boil begins). When lupulin powder is added late in the boil, utilization can decline to 20 percent or less, depending on individual process conditions. Both additions can vary depending on the desired intensity and the beer style. The quantity of lupulin powder in an addition can be calculated using the alpha acid content of the powder and an estimated or known utilization. Lupulin powder is suitable for dry hopping or secondary fermentation of the brewing process. It imparts a pronounced hop aroma to beer.

Figure 3.6 Hop powder

Hop Extracts

Hop extract is a concentrated hop resin that contains alpha acids, beta acids, and essential oils. It's used throughout the brewing process in place of traditional whole-leaf or pellet hops. One major advantage in using hop extract is improved hop utilization. In the traditional brewing process, where dried hops are added directly to the kettle during boiling, only about 25 to 35 percent of the alpha-acids contained in the hops are utilized as iso-alpha-acids. In the modern brewing process on an industrial scale, the application of hop extracts and their isomers has become more popular. The use of hop extracts allows one to increase the utilization of the alpha-acids to 45 percent, whereas with isomerized extract to 45 to 60 percent utilization occurs. Other advantages include are reduced bulkiness, improved stability in storage, standardization, consistency, and reduced wort losses. Many brewers believe the only real way to ensure the "clean" addition of hop essences is with hop extracts, as they are not only free of contaminating bacteria, but also nitrate and pesticide residues. The major disadvantage of extracts is the slightly higher cost per bitterness unit compared to whole hops or pellets but considering the higher utilization rate this is not an issue. The cost for organic solvent extracts is generally lower than that for carbon dioxide forms. The extracts are packed in cans.

Carbon Dioxide Hop Extracts

Carbon dioxide extract is created by the extraction of hop pellets with food-grade carbon dioxide in to a liquid form. The results are a viscous extract that contains high concentrations of alpha acids, beta acids, and essential oils. Carbon dioxide extracts are commonly referred to as either Liquid or Supercritical extracts referring to their process conditions differing only in the temperatures and pressures of the carbon dioxide used. Under the more extreme, supercritical conditions, the carbon dioxide behaves as a supercritical fluid extracting some of the polar degradation products and hard resins. Almost no flavor characteristics are lost and many impurities are largely removed by the carbon dioxide extraction process.

Carbon dioxide extracts are not isomerized, so they need to be boiled just like regular hops to get bitterness. Due to the high concentration of alpha acids, carbon dioxide extracts can be used to partially or entirely replace leaf hops or hop pellets in the brewing process. As with whole hops and hop pellets, carbon dioxide hop extracts must be boiled to isomerize the alpha acids into soluble bitter compounds. A utilization between 32 to 38 percent can be achieved if boiled for at least 50 minutes. For the best utilization carbon dioxide extracts should be added early in wort boiling. However, owing to likely losses caused by protein precipitation, the product is best added 10 minutes after the start of boiling. Actual utilization will vary from brewery to brewery depending on process conditions. The flavor characteristics of the original hops are maintained. Early addition of carbon dioxide extract during wort boiling provides bitterness while late addition imparts some hop character due to the retention of some hop oils in the wort.

Isomerized Hop Extracts

The starting material for the production of iso-extract is carbon dioxide extract. Isomerized hop extracts require no boiling and adds bitterness no matter where it is added in the brewing process. The extract may be added to beer in the fermenter after the bulk of the yeast has been removed, or during transfer from the fermenter to the maturation vessel. Isomerized hop extracts can be used for partial or total replacement of bittering and for final adjustment of bitterness. If added to the wort, they will be subject to the same fermentation losses as iso-alpha acids from the hops.

Figure 7.1
Brewery bulk bag unloader. Bulk bag unloaders are available for manual operation as well as fully automated units incorporating electric hoists, bag massagers, flow control valves, load cells, and various methods of conveying the malt out of bulk bags.

is considerably cheaper or welded steel, which reportedly offers a higher level of protection from moisture.

There are multiple options for unloading bulk malt to a silo—pneumatically or mechanically by screw auger (available with a solid screw or a flex auger), horizontal conveyors, or bucket elevators.

As for the truck or railcar delivery and off-loading, the most common method is a pressure differential (PD) truck that pneumatically blows the malt into the top of the silo. With PD truck unloading a flexible hose is connected from a pressure blower to the PD truck and another from the PD truck to the conveying line. When the system is started, the blower pressurizes the PD truck and conveys material via positive pressure from the truck through the conveying line and directly into the silo. An inline magnet is usually installed in the conveying line to remove any metal particles which may be present in the conveyed material. It has the advantage of being able to lift the malt for several stories and to make several directional changes through gentle piping curves. Its disadvantages include high energy requirements and a tendency to damage malt if the system has not been properly designed.

Other options in moving malt and grain include solid screw conveyors and flex augers. Flex augers, as the name implies, have the ability to make several directional changes and are well-suited to installation after major components are in place. Flex augers perform best and damage malt least when operated at full capacity. Some breweries may also use horizontal (i.e., chain and flight) conveyors and bucket elevators because they offer more efficient movement of grain, lower power consumption, and minimal breakage, especially to very dry and friable malt. Bucket elevators are used to move malt to the top of the silo by means of buckets fitted to a rubber belt.

Storage

There are several ways to store malt; the appropriate method depends on the scale of the brewery. For a small craft brewery, malt storage may be in bags whereas in lager breweries malt is often stored in super sacks or a silo for bulk malt storage.

Bags

Keeping the brewing malt DRY is the absolute priority. Malt is hydroscopic, so it will naturally absorb moisture from its surroundings. Keep the brewing malt sacks away from walls or directly on the floor. Install pallet racking if you have the space and are planning to hold large quantities of stock. It is important to keep the air flowing around the sacks. Blocking the airflow can potentially lead to moisture and temperature build-up which, again, is the perfect environment for insects. Do NOT store

Figure 12.9
The Burton Union system, at Marston's called the Cathedral, is a unique yeast recovery system. It's a wood barrel fermentation system that was used predominately by the brewers in and around Burton-upon-Trent in the mid- to late 19th century. This is an idiosyncratic process and it's easy to see why other breweries have shied away from it over the years. It would be time consuming. It would be difficult to maintain such a large amount of equipment. Photo courtesy of Marston's.

dioxide gas produced during the fermentation carries over the yeast froth up through the swan neck into the trough, where cooling induces the yeast to settle. The beer that collects in the trough runs to the lower end and returns to the casks. After fermentation, the beer is discharged to other vessels, the "racking backs." The yeast is recovered from the trough for re-pitching. Adjusting the level of an outlet cock in each cask controls the final yeast count in the beer at transfer.

Unitanks

The vessel characteristics that make cylindroconicals so suitable for fermenting vessels also make them ideal for conditioning tanks. This has led to the installation of dual-purpose vessels, i.e., unitanks (short for "universal tanks") where primary fermentation and conditioning are carried out in the same vessel. Unitanks have cooling jackets located high in the vessel for fermentation and low in the vessel for conditioning. Unlike cylindroconical fermenters, the cooling capacity of unitanks must be sufficient to achieve and hold at sub-zero conditioning temperatures. These dual-purpose vessels are built to withstand higher pressures (>15 pounds per square inch, psi) since conditioning tanks are normally required to be top-pressured to maintain carbonation levels, which is not required in fermenters.

There are advantages to a single-tank operation, the most important of which is the reduction in total process time, compared to the two-tank approach. It is not necessary to decide on the ratio of fermenting to conditioning vessels needed for the brewery. Instead, calculations may be based simply on total capacity requirements and individual batch size. Unitanks avoid the intermediate tank-to-tank transfer and therefore avoids the possibility of oxygen pick-up. Also, the beer may also be exposed to other contaminants like microorganisms. While these organisms are not typically lethal, they may cause off-flavors. Losses (i.e., labor and detergents) associated with the number of cleaning and sanitation treatments are reduced. The ability to ferment under pressure allows higher fermentation temperatures to be used without the usual production of off-flavors/esters. Higher pressure also allows carbonating directly in the fermenter before packaging bright tank for clarifying. In smaller breweries, or where there is a need to produce short runs of several different beer qualities, unitanks probably offers more flexibility.

However, some of the disadvantages of dual-purpose systems (e.g., unitanks) include the production of beer with a different flavor profile from that of two-vessel systems. Dual-purpose vessels are maybe over-engineered since they must cater for all duties. Thus, conditioning vessels are essentially very simple since they need do little more than hold the green beer at a low temperature. The presence of facilities for yeast cropping, carbon dioxide collection, monitoring and control associated with primary fermentation are unnecessary and potential hygiene hazards the level of dissolved oxygen (DO). Today, the most common and easily achievable target for DO is less than 0.05 parts per million (ppm), although many brewers attain levels much lower than this target level (Gunn, 2014). The flash pasteurizer can cause the beer to degas as it moves into the holding region. This can be a serious issue (loss of carbonation). So, the brewer must pay particular attention to the pressure of the system and increase it significantly as it goes through the flash pasteurizer to ensure that the beer doesn't degas.

Tunnel Pasteurization

An alternative to flash pasteurization and sterile filtration is tunnel pasteurization. Tunnel pasteurization is performed on bottled or canned beer only. Tunnel pasteurization isn't typically used with kegs because of their compact size. The bottles are loaded at one end of the tunnel pasteurizer and passed under sprays of water as they move along the conveyor (Figure 17.2). The sprays are so arranged that the bottles and cans are subjected to increasingly hot water until the pasteurization temperature is reached and held there for the desired rest time. In the first preheat zone, the beer is heated with a water spray at around 35 degrees C (95°F) (Farber *et al.*, 2019). In the second preheat zone, the spray is about 50 degrees C (122°F). The heating zone uses water several degrees higher than the pasteurization temperature to bring the internal temperature of the bottle to the pasteurization temperature, typically about 60 degrees C (140°F). The bottles are then gradually cooled with water until they are discharged from the end of the pasteurizer. Temperature changes have to be made in stages to prevent the bottles from breaking. Bottle breakage is usually no more than 0.1 to 0.2 percent in the tunnel pasteurizer (Kunze, 1996). If greater, it is usually due either to poorly made bottles or the lack of head space.

Operation

As mentioned, the bottles and cans pass through several zones and are sprayed with water heated to increasing and then decreasing temperatures. In the case of bottles, zone temperatures are carefully graduated to avoid thermal shock and subsequent bottle breakage. During heating, gradients in excess of 22 degrees C (40°F) are common on both bottles and cans. However, because bottles are more sensitive during cooling, brewers should adhere to an upper limit of 22 degrees C (40°F) of the gradient between cooling zones (Alarcon *et al.*, 2014). Process times for cans are shorter because they are pasteurized using greater temperature gradients during heating and cooling. Typically, cans require 30 minutes for pasteurization compared with 45 minutes for bottles. For tunnel pasteurization, a package headspace of approximately 4 to 7 percent has to be provided to permit the beer to expand without breaking, rupturing, buckling, or otherwise damaging the package. However, excessive headspace should be avoided because it yields higher package-air values and greater material costs for the containers. The performance of the tunnel pasteurizer is usually monitored with the use of a traveling recorder, a device sent through the pasteurizer to check the time-temperature curve. The device consists of a temperature probe inserted in a bottle or can, a probe to record ambient temperature, and a

Figure 17.2

Tunnel pasteurization. It includes the usual preheat, heating, holding, and precool zones. All of the preheat and precool zones are paired together as regenerative pairs of zones.

media can be any solid material that the microorganisms are able to attach to, either natural or synthetic. The natural material used in wastewater treatment will be stone or rock, while the synthetic material is usually plastic or textile fibers.

Trickling Filter Process

In the trickling filter process, the wastewater is sprayed over the surface of a bed of rough solids (such as gravel, rock, or plastic) and is allowed to "trickle down" through the microorganism-covered media. The inert medium develops a biological slime that absorbs and biodegrades organic pollutants. Air flows through the filter by convection, thereby providing the oxygen needed to maintain aerobic conditions. At intervals surplus sludge sloughs away, and is collected in a settling tank. For BOD-rich wastewater, several filters may be operated in sequence. These systems occupy a large space and have a limited capacity for treating wastewater, thus are liable to "pond" if overloaded (Briggs *et al*., 2004).

Biofiltration Towers

A variation of a trickling filtration process is the biofiltration tower or otherwise known as the biotower. The biotower is packed with plastic or redwood media containing the attached microbial growth. Biological degradation occurs as the wastewater is sprayed into the top of the tower and as it trickles down it passes over the media. Treated wastewater collects in the bottom of the tower. If needed, additional oxygen is provided via air blowers counter-current to the wastewater flow. Biotowers have capacities about ten times those of trickling filters covering the same area (Briggs *et al*., 2004).

Rotating Biological Contactor Process

The rotating biological contactor process consists of a series of plastic discs attached to a common shaft. The discs are partially submerged in a trough of continuously flowing wastewater. As the discs rotate, a film of microorganisms growing on the discs consume oxygen from the air and substrate from the wastewater. In this way, organic materials (substrate) are removed from the wastewater.

Septic Tanks

For small breweries with low production and wastewater flows, installation of a relatively simple wastewater treatment system consisting of a settling tank (a septic tank) and with a subsurface drainage discharge area (a leach field) may meet their needs (Figure 25.1). In these systems, solids are allowed to settle in the septic tank, and the effluent is discharged to an adjacent leach field. The septic tank provides an anaerobic environment where some nitrogen transformations occur and microbes assimilate and decompose organic material. When the effluent is discharged to the soil, aerobic processes consume remaining BOD and convert much of the wastewater nitrogen to nitrate-N.

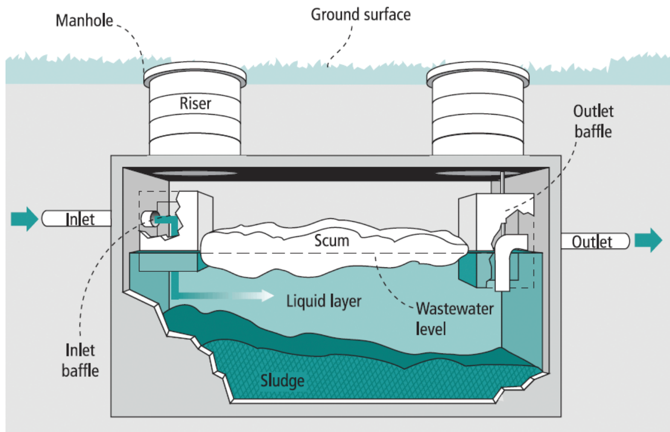

Figure 25.1 Septic tank

Septic tanks are often preceded by some device for gross solids entrapment so that the septic tanks do not get clogged with large solids. Typical devices of this sort include rotary drum screens, inclined screens, or self-cleaning strainers. Of these, inclined screens are perhaps the simplest, as they do not have moving parts. However, they do require a minimum static head for effective use (a driving force for the solids to roll off the screen while the liquid filters down through the mesh). This may require an extra pump to provide the head unless the production facility is sited on a hill that allows for gravity to provide the necessary head. Rotary drum screens are also an excellent option as they consist of a simple cylindrical rotating screen (similar in some ways to a destemmer basket) to separate gross solids from liquid. Actually, removable basket strainers in brewery floor drains may be the best and simplest alternative as long as they are frequently emptied into solid waste disposal on a regular basis.

In the simplest case, wastewater in a septic system flows by gravity into one or more septic tanks. Septic systems with two or more subsurface tanks are designed so that most of the BOD breakdown and settling will occur in the first septic tank with the second tank mostly used to protect against surges and as a backup. This way, regular maintenance and emptying can be focused on the first septic tank. If the tanks are located up-hill or at a significant distance from the brewery, install a small pump station to move the wastewater to the tank(s). The septic tanks must be cleaned out periodically to maintain the treatment system and to prevent carry-over of solids in the supernatant.