Packaging

<div align="right">**11**</div>

11.1 Introduction

At this stage in the process of producing beer, the product is ready for serving to customers. It has gone through the steps from grain to glass, almost. The beer sits in the conditioning tank and just needs a forum to enjoy. In some cases, the brewer wants to serve the beer directly to the customer. This is possible if the conditioning tank is connected to the tap AND if the customer can come to the brewery. But not all customers can.

In this chapter, we will explore the ways in which the brewer can distribute their craft to the customer. In addition to the taproom or bar at the brewery, the brewer can package their product in what is known as *small pack* or *large pack*. Small pack includes the single-serving-sized cans or bottles. Large pack refers to multi-serve containers such as kegs. Let us start our exploration with a look back into carbonation.

11.2 Carbonation and Other Gases

In Chap. 10, we uncovered the use of carbon dioxide to carbonate beer in the conditioning tank. We discovered the process by which brewers calculate the amount of carbon dioxide dissolved in their beer. We even found out the way to determine the number of grams of CO_2 that are dissolved in a given volume of beer.

11.2.1 Pressure Loss in Transferring Liquids

The volumes of CO_2 that are dissolved in beer in the conditioning tank must be retained as the beer moves into the package. Loss of the carbonation along the way must be protected against. This means that the beer must be protected from any reduction in the pressure of the beer due to transferring it from the conditioning tank to the packaging line.

Initially, it may seem that all the brewer needs to do is to maintain the pressure of the conditioning tank during the transfer. In other words, as the liquid flows along a horizontal pipe, the pressure of the liquid should remain constant. But this is not the case. As beer, or any liquid for that matter, is pumped from one location to another, it experiences friction. That friction can slow the flow of the liquid. And, as the liquid slows, the pressure of the liquid reduces. If that pressure is reduced to levels that will not support the level of carbonation that exists, the beer will degas.

Friction exists in the piping in many different ways. Henri Darcy studied this effect on the pressure of a liquid as it moves along a pipe. He found that the change in pressure (ΔP) could be calculated by an equation; we now call the Darcy Equation (Eq. 11.1). This equation relates the loss of pressure due to the length of a pipe, its flow rate, and the speed of the fluid flow. Note that this is not the same as Darcy's Law:

$$\Delta P_{\text{pipe}} = 4\phi \frac{L}{d} \rho u^2 \qquad (11.1)$$

where:
  ΔP is the pressure change due to friction in Pa,
  ϕ (phi) is the friction factor (unitless),
  L is the length of the pipe in m,
  d is the diameter of the pipe in m,
  ρ is the density of the liquid in kg/m^3, and,
  u is the mean velocity of the liquid in m/s.

The friction factor (ϕ) in this equation is not a constant, but instead, it is related to a value known as the Reynolds' number (Re). The Reynolds' number is a value that relates the forces that move the liquid to the forces related to the viscosity of the liquid. In other words, the Reynolds' number can help determine if the liquid is experiencing laminar flow or turbulent flow. Laminar flow occurs when the liquid flows without mixing laterally. Turbulent flow is just the opposite. Turbulence, or mixing, occurs laterally in a turbulent system. As we would expect, liquids that flow

laminarly do not experience much impact from the roughness of the inside of the pipe. Turbulently flowing liquids are greatly impacted from the pipe roughness. In fact, the friction factor for liquids flowing in a pipe can be determined through the use of a Pipe Friction Chart that plots the Reynold's number versus the pipe roughness.

Bends in the pipe, obstructions to the flow, and valves also impact the pressure of the fluid as it flows. The pressure drop can be quite large, even if the length of the pipe is not very long. Adding each of the friction losses for the individual obstructions allows us to calculate the pressure drop due to these obstructions. This is done using Eq. 11.2.

$$\Delta P_{\text{fittings}} = \sum \left(\frac{k \rho u^2}{2} \right) \tag{11.2}$$

where ΔP is the pressure drop in Pa,
    k is the constant of the particular obstruction (see Table 11.1),
    ρ is the density of the liquid in kg/m^3, and
    u is the mean velocity of the liquid in m/s.

Table 11.1 lists some approximate constants that indicate the measure of the friction of the particular obstruction. Values less than 1 suggest that the bend, valve, or obstruction has little impact on the pressure change in the flowing liquid. Values greater than 1 suggest a device that has a very large impact on the pressure of the system.

Table 11.1 Pipework frictional constants

Pipework or obstruction	k (unitless)	Pipework or obstruction	k (unitless)
Valves		Fittings	
Ball valve—open	0.05	90° square	1.3
Ball valve—2/3 open	5.5	90° rounded	0.75
Ball valve—1/3 open	200	45°	0.35
Butterfly valve—open	0.2	T—straight run	0.4
Butterfly valve—½ open	15	T—used as elbow	1
Globe valve—open	10	Coupling	0.04
Gate valve—open	0.15		
Gate valve—½ open	2.1		

These values are approximate and may be different for a particular system. In most cases, a range of values is possible based on a number of different factors

The total pressure loss of the system is then the sum of the pressure loss for the pipe run plus the pressure loss due to the fittings or obstructions:

$$\Delta P_{\text{total}} = \Delta P_{\text{pipe}} + \Delta P_{\text{fittings}} \tag{11.3}$$

Let us consider an example to determine the pressure differential along a pipe run. Assume beer with a density of 1010 kg/m^3 is moving along a 50 m pipe ($\phi = 0.0038$) at a velocity of 2.0 m/s, and that the pipe is 5 cm in diameter. This is shown in more detail in Fig. 11.1.

Inserting the values that we are given in the problem, and then solving the equation, provides the frictional losses due to the length of the pipe alone:

$$\Delta P_{\text{pipe}} = 4\phi \frac{L}{d} \rho u^2$$

$$\Delta P = 4(0.0038) \frac{50\,\text{m}}{0.050\,\text{m}} \left(1010 \frac{\text{kg}}{\text{m}^3}\right) \left(2.0 \frac{\text{m}}{\text{s}}\right)^2$$
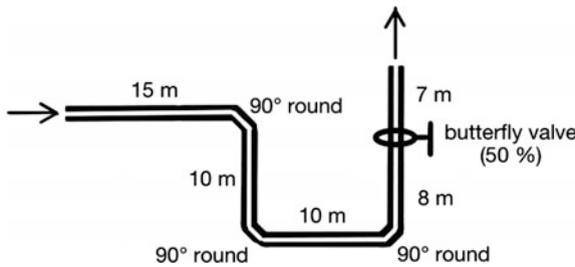
$$\Delta P_{\text{pipe}} = 61{,}408\,\text{Pa} = 61.408\,\text{kPa}$$

The frictional losses due to the fittings along the run are determined by adding each of the losses due to the fittings and the valve. Note that we have three 90° rounded bends and one butterfly valve. Solving the equation:

$$\Delta P_{\text{fittings}} = \sum \left(\frac{k\rho u^2}{2}\right)$$

$$\Delta P = 3\left(\frac{0.75 \times 1010 \frac{\text{kg}}{\text{m}^3} \times \left(2.0 \frac{\text{m}}{\text{s}}\right)^2}{2}\right) + 1\left(\frac{15 \times 1010 \frac{\text{kg}}{\text{m}^3} \times \left(2.0 \frac{\text{m}}{\text{s}}\right)^2}{2}\right)$$

$$\Delta P = 3(1515\,\text{Pa}) + 1(30{,}300\,\text{Pa})$$

Fig. 11.1 Example pipe run. There are three 90° rounded bends and one butterfly valve that is half-way open

$$\Delta P_{\text{fittings}} = 4545 + 30{,}300 = 34{,}845\,\text{Pa} = 34.845\,\text{kPa}$$

The total pressure loss along the pipe run is then the sum of these two frictional losses:

$$\Delta P_{\text{total}} = 61.4\,\text{kPa} + 34.8\,\text{kPa} = 96.2\,\text{kPa}$$

This is a significant loss of pressure in the liquid over the 50 m run. Keep in mind that this is a very long run in a microbrewery, but a fairly short run of pipe in a macrobrewery.

11.2.2 Other Gases Used in "Carbonation"

In addition to carbon dioxide, the brewer may decide to serve the beer using a different gas. In order for this to work, the gas must have a measurable solubility in the beer. For example, an April Fool's Day joke has been passed around suggesting that helium gas could be used to "carbonate" a beer. The joke is that you could drink the beer and when you talked afterward, your voice would become high-pitched from the helium. While it may be possible to force helium to dissolve in the beer, once the pressure was removed from the beer (i.e., the bottle was opened), the beer would completely, instantly, and violently degas. This would occur because helium has essentially no solubility in the beer. If someone were actually able to do this, the real joke would be the tremendous fountain of beer that would gush from the bottle as the cap was removed. Moreover, when you drink a beer, you tend to only breathe in a very small amount of the gas in the beer (most of the CO_2 in the beer is lost as bubbles to the atmosphere; the majority of the rest of the CO_2 ends up in your tummy.) So, the amount of helium a helium beer drinker would breathe would likely not be enough to change the pitch of their voice.

Which gases are soluble in water? The solubility is based on the ability of the gas to interact with water as governed by Henry's solubility constant (Table 11.2). This constant indicates the ratio of gas that dissolves in a liquid versus the partial pressure of the gas. As the constant gets larger, the gas becomes more and more soluble in water or beer. At the molecular level, the more polar the gas is, the more it interacts with water. The more interaction, the more the gas tends to dissolve in water. Too much interaction and the gas will be primarily dissolved in water and not form bubbles when the pressure is lowered. A nonpolar gas interacts very little

Table 11.2 H's solubility constants for selected gases. calculated using data from Sander, R., *Atmos. Chem. Phys.*, **2015**, *15*, 4399–4981

Gas	H (unitless)	Gas	H (unitless)
H_2	0.019	N_2	0.016
O_2	0.032	CO_2	0.83
NH_3	1400	N_2O	0.61
H_2S	2.4	SO_2	29
He	0.0090	CH_4	0.033

with the water and does not dissolve. Too little interaction and it will degas too quickly to be useful to the brewer.

Nitrogen gas (N_2) is much less soluble in water than carbon dioxide (CO_2) as can be shown by examining the values of the Henry solubility constant from Table 11.2; N_2 (0.016) versus CO_2 (0.83). Nitrogen's limited solubility means that it will degas quite well as the pressure of the beer is reduced and the beer is served. This leaves the beer much less "bubbly" after all of the nitrogen has left the beer because very little nitrogen will remain in the beer. In addition, if nitrogen alone is used to "carbonate" the beer, the formation of carbonic acid that provides a tart, crisp note to the beer will be lacking. The result would be a flat beer with a very nice head.

Nitrogen gas, as it forms bubbles in the beer, produces very tiny bubbles. This is likely due to the limited interaction between nitrogen molecules. These tiny bubbles tend not to combine into larger bubbles when they form a head on the beer. The result is creamier foam.

In practice, brewers tend to use a mixture of nitrogen gas and carbon dioxide gas. The ratio is about 25 % nitrogen to 75 % carbon dioxide. Both gases dissolve in the beer to some extent. The result allows carbon dioxide the opportunity to interact with the water in the beer and form carbonic acid. This still provides the tart flavor to the beer. The nitrogen gas rapidly forms the tiny bubbles and degases much of the beer when it is poured, but with enough CO_2 still in the beer, it does not go flat.

One fascinating thing about gases in beer is the mechanism of the formation of bubbles. Research is still being conducted to try to uncover the details of the mechanism, but recent results suggest that bubbles do not form spontaneously on their own. They can, but not at the pressures used to carbonate beer. Something has to initiate the formation of the bubble. This can be microscopic imperfections in the glass, dust, sediment, or a whole host of other things. The particles or imperfections act as nucleation sites where the gas can form a microscopic bubble. The bubble then clings to the site as it grows. If the gas is CO_2, the interaction is relatively strong and the bubble has to grow large enough in order to release from the nucleation site and drift up through the beer. If the bubble is N_2, the interaction of the bubble of gas with the nucleation site is fairly weak. This means that the bubble releases when it is much smaller than if it were CO_2.

In addition, the smaller bubbles of nitrogen gas tend not to interact with neighboring bubbles as much as carbon dioxide. Thus, the bubbles tend not to grow into larger bubbles. When only CO_2 is the gas in the beer, adjacent bubbles can interact with each other. The chance exists that these bubbles will merge into larger ones. And, the amount of surface area of the tiny bubbles means that a tremendous amount of beer is entrapped and suspended in the foam. The foam is very thick.

In actuality, when two bubbles do merge they do so by a process known as *disproportionation*. In this process, one of the bubbles gets larger while the other gets smaller. The reason for this mechanism of merger can be explored as shown in Fig. 11.2. Imagine that we have blown up each balloon and attached it to either end of the hose. In our example, we have placed a hose clamp to isolate each balloon from each other. Let us assume one of the balloons is slightly larger than the other.
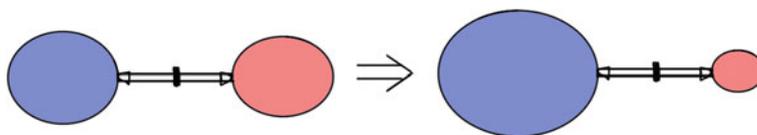
Fig. 11.2 Disporportionation analogy using balloons. On the *left* is the setup before the hose clamp is removed and the result is on the *right* after it is removed

When the hose clamp is removed, the smaller balloon gets smaller and the larger balloon gets larger. For the balloons this occurs because the small balloon has more tension in the plastic of the balloon. The more "stretched out" larger balloon is easier to stretch even more and gets larger. The latex walls of the smaller balloon are more taut and much harder to stretch.

The analogy of the balloons is directly related to what happens to the bubbles in the beer. The *Laplace pressure* drives the process. The Laplace pressure is the difference in pressure outside of the bubble and the inside of the bubble. It is very dependent upon the surface tension of the bubble. It turns out that the Laplace pressure is inversely related to the radius of the bubble. In other words, larger bubbles have a smaller Laplace pressure and tend to grow in size when they merge with other bubbles.

One property of nitrogenated (i.e., 25 % N_2 and 75 % CO_2) beers is that the perceived bitterness of the beer is greatly reduced. Research still needs to be completed to understand the mechanism of this effect. One theory involves the degassing that occurs when the bubbles rapidly form. This greatly reduces the carbonation level of the beer, its tartness, and its acidity. The reduction in these three factors will have an impact on the perceived bitterness of the beer. Evidence for this can be found by comparing the flavor of a normally carbonated IPA that has been degassed by stirring for 10 min versus one that is freshly poured from the bottle.

CHECKPOINT 11.1

What is the pressure drop in a wort ($\rho = 1055$ kg/m^3) that is pumped through a 10 m length of 4-cm-diameter pipe ($\phi = 0.0042$) with two 90° square bends and two 45° bends and ends in a wide-open ball valve? Assume the velocity of the beer is 1.0 m/s.

Would you expect a beer that it is pressurized with laughing gas (N_2O) to have a head similar to a nitrogenated or to a carbonated beer?

11.3   Packaging

Once the finished beer is ready to be shipped outside of the brewery, it is piped to the packaging line. The packaging line is a system that prepares the package (or "pack" for short), fills it, and seals it. In a brewery, this is the noisy machinery that customers love to watch. It is fascinating to see all of the intricate movements that the bottles or cans make as they move along the line.

In this section, we will explore the two options for packaging beer—small pack and large pack. Small pack refers to the single-serve packages such as bottles and cans. Large pack refers to kegs. The general principles of the packaging line are the same for both types of packages, irrespective of their size. In essence, the package must:

- Protect the beer from the environment
- Protect the beer so it does not harm the customer
- Contain a legally measured volume
- Dispense the product easily

Packaging also serves the function of advertising to the customer. This includes a number of key features such as looking good on the shelf, providing useful information to the customer (such as the style of beer and the amount within the container.), and draw in customers through advertising. While we often overlook this part of the package, it is very important to the brewer. More often than not, this can be the only time the brewer has the opportunity to entice the customer to try the beer and become a regular consumer. So the package is very well thought out and very well planned.

Not only is the label important (the look of the label, the artwork, the dimensions of the name of the beer), but also the shape of the package, the color of the package, and even the name of the beer become extremely important. With the shear number of different beers in the cooler at your local liquor or grocery store, standing out from the crowd is becoming more and more important. This is especially true in those stores with limited shelf space. The package must catch the eye of the consumer in order for the beer to sell. Then, once the beer is sold, the contents must appeal to the customer for them to consider a repurchase later.

11.3.1   Small Pack

In the USA, small pack is likely the main mode by which the customer consumes a particular beer. While the influx of new microbreweries continues to grow, there is still considerably more beer consumed outside of the taproom, bar, or tavern. Choices for the brewer to package their beer are everywhere.

11.3.1.1 Bottles

The most common of the small pack, especially for the craft beer industry in the USA are bottles. Bottles are glass containers that come in nearly any shape, size, or color. The standard bottle is shown in Fig. 11.3. The main areas of the bottle include the finish, the neck, the shoulder, the body, and the base. Labels that can be added to the bottle include a neck label, a body label, a back label, and a footer label (placed just above the base).

Bottles are manufactured in a very energy intensive process in a furnace at approximately 1500 °C. Silica (SiO_2) is first mixed with sodium carbonate (Na_2CO_3, also known as soda ash), calcium carbonate ($CaCO_3$, limestone), and colorizing agents. Cullet (broken glass) is often added to the mix in as much as

Fig. 11.3 Parts of a bottle
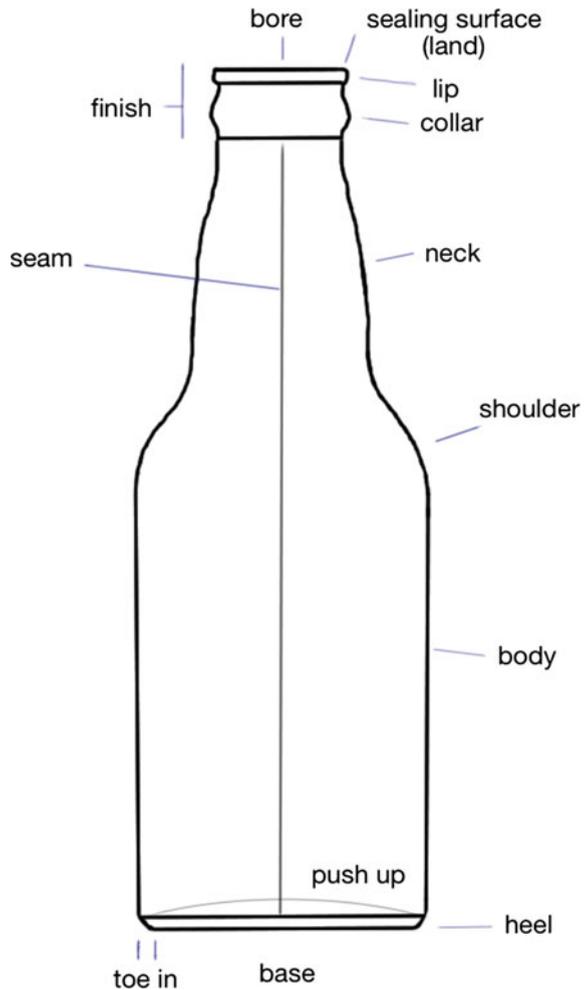
Table 11.3 Components that make up glass

Component	Percent (%)
Silica (SiO_2)	70
Sodium carbonate (Na_2CO_3)	15
Calcium carbonate ($CaCO_3$)	10
Colorant	5

90 % of the total. This addition can significantly reduce the temperature where the glass melts, making the preparation of new glass more efficient.

The color of the glass is determined by the trace amounts of metals that are added to the mixture. For example, if nothing is added, the glass is clear. If iron is added, the glass turns green, and if chromium is added, the glass turns brown. Addition of cobalt causes the glass to turn blue. The typical recipe for a batch of glass is shown in Table 11.3.

The powdered ingredients are blended and then fed into a furnace that is heated to around 1500 °C (Fig. 11.4). This mix floats on top of the existing molten glass in the furnace. As it melts and combines with the existing glass, it moves along the furnace until it reaches the *bridge*. There it must pass under the bridge through the *throat* and into the *working end* of the furnace. This pass under the bridge ensures that only the molten, mixed glass reaches the working end of the furnace. The molten glass then enters the *conditioning channel*, a shallow portion of the furnace where the glass begins to cool. The liquid glass flows into an *orifice* at the end of the channel and a *plunger* pushes a given amount of glass through the orifice. Shears cut the *gob* of glass as it passes through.

The gob then drops into a mold where the bottle begins to take shape. First the mold is sealed and pressurized on top of the gob. This forces the molten glass to the bottom of the mold. A wand at the bottom of the mold then blows air up into the center of the gob. This forms the top of the bottle as the molten glass has filled the bottom of the mold. The push of the air into the gob inflates the molten glass, cooling it enough that it begins to hold its shape. The glass at this point is a half-formed bottle known as a *parison*. Before the parison collapses back into a ball, the mold then inverts and the pressure reapplied to the top of the mold. This pushes the glass outward to fill the mold. This blast of air causes the glass to cool even more. The temperature is finally at the point where the glass does not flow quickly at all anymore. The mold is then opened and the bottle moves on to the finishing stages. The overall process is known as *blow molding* (or blow-blow molding).

The greatest disadvantage to blow molding is that the air initially blown into the gob does not always form symmetrically. In other words, the walls of the glass bottle may not end up with the same thickness. This causes some problems with packaging later especially if the bottle is weakened on one side due to the thinner walls.

The alternative to the blow mold is the *press and blow mold* (Fig. 11.5). The process was developed in Germany and refined by Owens-Illinois, one of the world's leading glass manufacturers. In this process, the gob is dropped into a mold
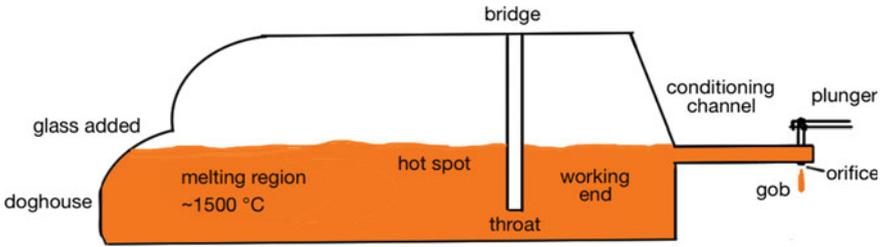
Fig. 11.4 Glass furnace

(Fig. 11.5a), and the mold is sealed (Fig. 11.5b). Then, an air injector is raised into the gob and air pressure is applied forcing the gob to take the shape of the mold (Fig. 11.5c). The parison is then removed (Fig. 11.5d), inverted, and placed into another mold. A seal is placed on top of the mold that also helps form the finish (Fig. 11.5e). Air is then pushed into this second mold forming the bottle (Fig. 11.5f). Immediately after forming (Fig. 11.5g), the bottle is put into an oven known as a lehr (pronounced "leer"). Inside the lehr, the bottles are reheated and then cooled slowly under controlled conditions in a process known as *annealing*, so that the glass does not crack as it cools.
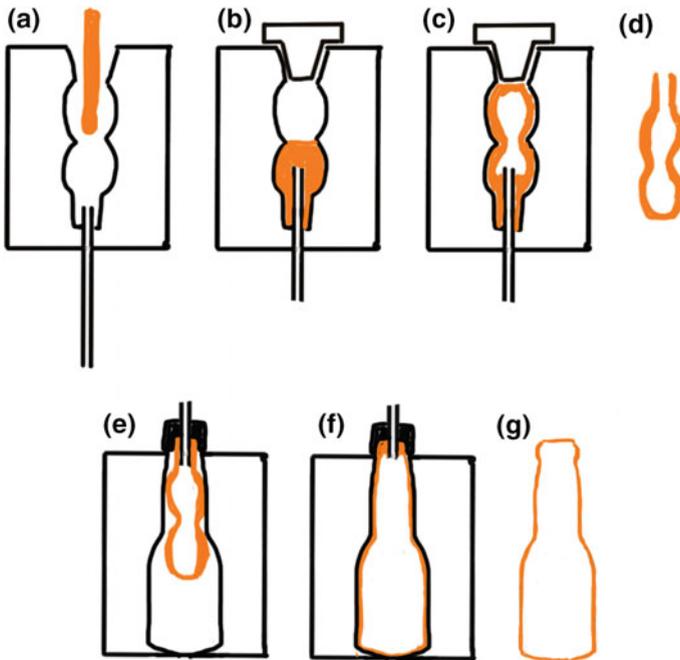
Fig. 11.5 Press and blow molding process

The final step in the process for manufacturing a glass bottle is to spray the bottles with a lubricant to ensure that the bottles do not get scuffed as they are manipulated during the packaging process. In addition, the bottles are sent to a measuring machine to ensure that each part of the bottle is within specifications, free of bubbles, and ready to be used. Any rejects are simply ground up and added back into the glass furnace.

Once at the brewery, the bottles join up with the finished beer at the packaging line. Most breweries that bottle have an automated process that involves machinery and robots that unpack the bottles from the shipping packaging. The bottles are then inverted and washed to remove any dust or lubricant that may have inadvertently gotten inside the bottle. The brewer can also spray the bottles with a sanitizer to ensure that all microbes are killed before the beer is added. However, if the bottles are sprayed with hot water ($\sim$80–85 °C), the heat of the water is often enough to sanitize the bottles. The action of the spray inside the bottles is also important as it can help to dislodge any dirt.

The bottles are then lined up and placed one after the other into the filler. Here the bottles are attached to the filler arm that comes down and seats on the sealing surface of the bottle. A vacuum is applied to the bottle and then the bottle is filled with CO_2. This is repeated a second time such that the gas in the bottle is about 99 % CO_2. Alternatively, the bottle can be nitrogen dosed by squirting a small amount of liquid nitrogen into the bottle. The liquid nitrogen instantly warms up and evaporates into gas that swells and pushes all of the air out of the bottle. This method results in filling the bottle with about 99.9 % N_2.

Beer then enters the bottle through a tube and fills up the bottle. The tube can be short or long. The long tube filler does a better job at filling the bottle from the bottom up. This means that only the top surface of the liquid is exposed to the atmosphere inside the bottle. And, results in a lower uptake of any residual oxygen gas that happens to be in the bottle. For many other reasons, however, the short tube filler tends to be found more often in the industry. With very little oxygen in the bottle due to evacuation and filling with CO_2 or dosing with liquid N_2, the short tube filler makes the case.

The filler continues to add the beer into the bottle by counter-pressure filling. This occurs by simply pressurizing the bottle to the same pressure as the finished beer and then opening a valve to allow the beer to flow into the bottle. A relief valve opens to allow the excess pressure of filling to continue to fill the bottle. It stops adding beer when the beer begins to exit the filler, or when a sensor is touched by the liquid. Then, the filler arm is removed as a puff of air is applied. This causes the top of the beer to foam. Alternatively, a spray arm can add a very small squirt of sterile water to the top of the beer in the bottle. The injection of water causes the beer to foam up, filling the top of the bottle entirely with foam.

Before the foam settles, a cap is placed on the bottle. A sleeve then pushes the cap into the bottle, sealing it. At this point, the bottle is filled and sealed. It moves to an inspection area where the level of liquid in the bottle is measured.

11.3.1.2   Cans

Aluminum cans are becoming more prevalent in the USA as a beer package. They offer some useful advantages over bottles:

- Completely impervious to light,
- More impervious to oxygen than a bottle,
- Lighter and easier to transport, and
- Less expensive.

Cans are manufactured from a sheet of aluminum in a roll. As the roll is fed into the machinery, it is sprayed with oils to aid in lubricating the machines and protecting the aluminum from uneven stretching and cracking. The first machine the sheet aluminum enters is the cupping press. Here, a press stamps out circles about 14 cm in diameter and then bends the aluminum into the shape of a cup. These cups are thicker than the finished package and much shorter. However, additional machines will stretch them out into the shape of the finished aluminum can (Fig. 11.6).

The cups (Fig. 11.6a) are then fed into the body machine. The cup is fitted onto a plunger that presses the cup through a ring. The cup stretches as it passes through the ring, elongating and thinning the cup. This occurs a number of additional times, each time the ring is slightly smaller. The finished product is a straight can that is open at one end ((Fig. 11.6b–d). The bottom of the can takes the shape of the plunger and looks just like the bottom of the finished can. The final thickness of the can ends up at about 115–120 μm.

Early aluminum cans were much thicker than the modern ones. Trial and error led to the development of "lightweighting" the cans by making them thinner. Today computer-aided design has allowed manufacturers to shrink the thickness of the can to the point where the can is significantly lighter (about 13 gm compared to the original 80 gm). This saves money on transportation and cost for the can.

The elongated can is then trimmed to the correct length (Fig. 11.6e) and sent to the washer. The cans move along a conveyor upside down and are sprayed with hot (60 °C) hydrofluoric acid (HF). This acid cleans the interior of the can and the exterior of the can, eliminating all contaminants, oils, greases, and other soils. The cans are rinsed, still upside down, with hot (60 °C) distilled water and then dried.
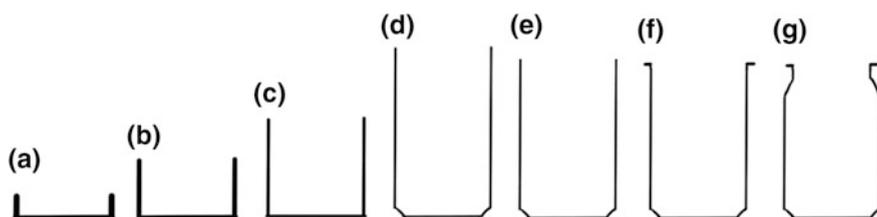
Fig. 11.6 Stages of development of the aluminum can

The cans then move under a roller that applies a coat of varnish to the bottom of the can. This is applied to aid in movement of the cans along a conveyor when they are turned right side up. A label is painted onto the can at this point. Typically, this is done in a rotatory machine where multiple rollers apply different patterns of ink to the surface of the can. Typical paint application can occur at the rate of over 1000 cans per minute. After all of the different colors have been applied, a coat of varnish is applied to the exterior of the can. This coat is placed over the paint to protect it. Heating the can in an oven dries the paint and varnish and hardens the exterior markings on the can.

Alternatives to painting a can are possible. While stickers or other glue-affixed labels are possible, they are typically not applied to the can. The cans are too flexible to ensure that the label does not peel off or fall off at some point later on. Instead, sleeves of plastic that have been printed with the label can be placed onto the can and then heated. The shrink-wrap goes on easily and can even be applied after the can is filled (which is the preferred time).

Next, a water-based varnish is sprayed on the inside of the can. This varnish is put in place to act as a barrier between the aluminum and the contents of the can. Because beer is somewhat acidic, it will react with aluminum slowly. If left in contact with the aluminum, the beer would eat its way through the can, causing it to rupture from the pressure.

In the final two steps, the can enters the *necker*—a machine that slowly rolls the can and forms the contraction at the top of the can known as the neck (Fig. 11.6f). The process of forming the neck occurs in increments (as many as a dozen or so) so that the aluminum is not torn or damaged in the formation of the neck. The *flanger* is the final stop for the can (Fig. 11.6g). Here it spins around rollers that crimp the top of the can and bend it at a 90° angle. This angle and the amount of the flange at the top are very important in the crimping step after the can is filled.

At the brewery, the cans undergo a very similar treatment to that experienced by the bottles. They are inverted and washed, then righted and enter the filler. The filler arm and can seal along the flange at the top of the can and the beer is placed in the can. The major difference here is that while the bottle can be evacuated repeatedly in order to replace the atmosphere inside the bottle with CO_2, pulling a vacuum on a can would instantly crush it. If the brewer wishes to replace the atmosphere inside the can prior to filling it, they can add a nitrogen doser to the packaging line just before the cans are filler.

Once full of beer, the cans move along the conveyor belt and a cap is placed on top as a jet of CO_2 disturbs the top of the beer. This causes the beer to foam slightly so that the end cap of the can floats on the foam, indicating that no oxygen is present inside the can once it is seamed. Then, the cap and can are joined in the seamer. The seamer spins the can while a device called a *chuck* rolls the end of the cap under the flange of the can. A second chuck then presses the seam together making a tight seal (Fig. 11.7).

Disadvantages to canning instead of bottling exist. Beer in a can is a little less carbonated than beer in a bottle due to the way that the bottles are filled. In other words, the bottles can be counter-pressure filled so that the pressure of the finished

Fig. 11.7 Can seal
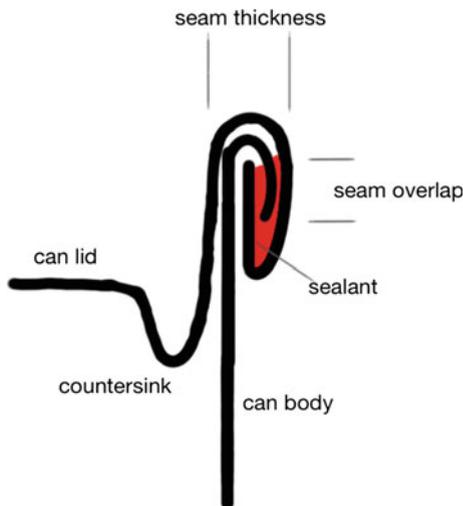
beer is not different from the conditioning tank. Because cans are not filled this way (i.e., beer is simply poured into the can), the carbonation decreases slightly after sealing until the pressure in the can rises to meet the pressure of the carbon dioxide that is dissolved in the beer. This can be adjusted by slightly over carbonating the beer at the filler or conditioning tank prior to canning. The other issue with cans is related to the way they are filled. It is very difficult to eliminate all of the oxygen from the can during the filling and sealing process. Thus, higher levels of oxygen can be entrapped inside the can as it is sealed. The levels are still quite low and often have only a minimal impact on the beer. However, some brewers strongly abhor the idea of oxygen, at any level, in their finished product.

11.3.1.3 Plastic

Plastic beer bottles are starting to have some impact on the industry. Plastic does have some advantages over the other small pack, but it also has some disadvantages as well. The main advantages are:

- Lightweight—about 25 g per bottle, but still heavier than aluminum,
- Recyclable—but so are glass and aluminum,
- Inexpensive—actually more expensive when you consider the requirement to use multilayer bottles (see below),
- Noise reduction—significant noise reduction compared to aluminum and glass during the fill process,
- Insulated—the plastic does offer a little insulation for temperature.

The disadvantages probably outweigh the advantages. Especially if we consider the arguments for each of the advantages:

- Slower filling speed—reduction in production levels,
- Permeable—gases can permeate through plastic,
- Not thermally stable—requires modifications to pasteurization process because the plastic may deform under heat.

While some manufacturers and brewers are moving to the plastic bottle because of its versatility in design, the plastic bottle has yet to hit the market with force. Addressing the issues of permeability and pasteurization are the hot topics of the day, and their solutions could see this form of small pack everywhere in the marketplace.

CHECKPOINT 11.2
Outline the steps required to bottle a beer, starting with silica and ending with the finished product.
Name two advantages and two disadvantages to the use of the glass bottle.

11.3.2 Large Pack

Large pack refers to the multi-serve vessels that are used to distribute beer outside of the brewery. Go to any bar or tavern in the USA and you will find a series of beers on tap. In other words, the bar has a number of kegs of beer from which to serve a beer. For the consumer, the best price for a pint of ale is had out of the keg. For the brewer, the lowest profit margin is on the keg. But only so many people can visit the taproom at the brewery, so this is the way to distribute the product to the masses.

Kegs originally were manufactured from aluminum. However, due to the malleability and ductility of aluminum, those kegs tend to be difficult to find anymore. It did not help the situation that the aluminum keg was easily taken to the recycling center—a fate of many kegs that were stolen. Modern kegs are made from 304 stainless steel. The keg itself is made in two parts by cutting circles of stainless steel and then forming a top half and bottom half using a technique similar to making an aluminum can. The final thickness of the stainless steel ends up at about 1.5 mm. The two halves are then TIG (tungsten inert gas) welded around the middle of the keg to make the final container. The neck and chimes are then welded onto the container to give the overall shape of the keg (Fig. 11.8).

Like aluminum kegs, stainless steel kegs can expand. Over time, the keg does grow slightly in size due to heating while under pressure or freezing of the product inside. Heating a keg can be very disastrous. As the keg gets warm the contents

Fig. 11.8 Cutaway view of a keg
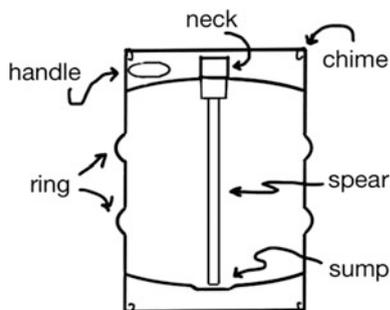
inside also heat up. The beer expands in volume as it gets warmer, and if there is not enough headspace in the keg to handle the increased volume of warm beer, the keg can actually rupture (at least 0.8 L of headspace is required to prevent this if the keg is heated to 70 °C). The main issue is that kegs get warm accidentally. If a keg gets left in a car out in the sun, the keg is placed directly in the sun, or the keg might even be left under a plastic tarp prior to an event, the temperature of the keg can increase. If the keg is placed in the freezer, one also needs to be careful. The cold temperatures might be cold enough to cause the beer to freeze inside the keg. Water, the major constituent in beer, expands as it approaches the freezing point. Thus, the frozen beer occupies much more space than cold beer. The keg could rupture or at the very least deform from the pressure.

Kegs tend to be pressure tested before they are finished in the manufacturing process. The standard pressure test is to ensure that the keg will not rupture below 90 psi. Since the standard operating pressures of the keg rarely get as high as 30 psi, this provides a large safety range for the keg.

In addition to the body of the keg, a *spear* is added. The spear attaches to the neck of the keg and provides a way to admit carbon dioxide and withdraw beer from the bottom of the keg. Because kegs are used worldwide, and because each region uses a variety of keg sizes and styles, the spear is also just as variable. However, every spear has four basic parts: body, stem, seal, and spring. The *body* is the point of attachment of the spear to the keg. Due to thefts, the attachments often involve locking rings or threaded ends that require special tools to dismantle. The body is also where a coupler is attached to connect the keg to a tap, filler, or cleaner. The *stem* is a long tube that reaches almost to the bottom of the keg. Often, the keg has an indentation at the bottom called a *sump* where the stem reaches. This is placed so that the majority of the product in the keg can be removed via the stem. A *seal* seats against the body that keeps the keg closed until the coupler is attached. And a *spring* holds the seal in place. When the coupler is attached, it pushes down on the spring and moves the seal out of the way. This allows gas to enter the keg outside of the spear, and liquid to be forced up the spear and through the coupler to the tap.

As we noted, there are many different spear arrangements based on where you are in the world. Here in the USA, the most common spear is known as a

"D-system" valve. This spear has an indentation in the body where the coupler seats and locks into place before the spring are pushed down. Other common arrangements include the "A-system" valves that are flat. These require that the coupler attaches to the outside of the spear body.

Kegs in the brewery take longer to fill than small pack, but follow a very similar process. First the kegs are placed onto a conveyor belt by either a robot or manually. The kegs are then inverted and passed into an external washer. The external washer sprays caustic and rinse water successively on the kegs and ensures that the outside of the keg is as clean as possible. Then, the kegs move on to the cleaner/filler. In some cases, a special machine is located before the cleaner/filler that checks to make sure that the spear is properly attached to the keg.

In the cleaner filler, the inverted keg is coupled to the machine and the spear engaged. In cycles, a blast of water is injected into the keg to rinse out any remaining beer or other material from the interior of the keg. This is then pushed out using air. Spraying caustic or another cleaner through the stem washes the keg. Because the keg is upside down, the caustic rushes to the end of the stem and sprays against the bottom of the keg. The caustic then collects at the top of the keg and exits through the gas port. The keg is then rinsed with water, and then sanitized by either spraying sanitizer through the keg or by rinsing the keg with water that is at least 80–85 °C. This hot water rinse can ensure that all microbes are killed inside the keg.

Finally, the keg is turned back over and carbon dioxide is blown through the stem. The CO_2 exits through the top of the spear until all of the air and oxygen have been removed. Restricting the flow of the gas exiting the keg increases the pressure of the CO_2. When the pressure is approximately the same as the pressure of the beer in the conditioning tank, beer is allowed to flow into the keg down the stem. In this way, the beer fills the keg from the bottom up, pushing out the excess gases in the way. A scale or flow meter is used to ensure that the exact amount of beer is added into the keg.

The keg is then detached from the machine and conveyed to the next station that cleans the body of the spear and applies a label around the neck of the keg. The station also attaches a cap to the neck to signal that the keg is full. They are then placed into the refrigerator and await their transportation to the bar or tavern.

Some keg fillers operate completely in the inverted position. The keg is washed inverted as before, but left inverted as it is filled through the gas port. This means that the beer still fills from the bottom up as the gas exits through the stem of the spear. The keg is still filled until the volume of beer in the keg matches the correct fill level. Again, this can be measured by many different methods.

11.4 Pasteurization

What is pasteurization? This is a process that was first discovered by French chemist Louis Pasteur in 1864 while he was exploring why wine tended to sour with age. By this time, he had already determined that yeast were the reason why the sugars were converted into alcohol and carbon dioxide, and that oxygen was not needed for yeast to survive. It was in the 1870s that he began working on fermentation problems in the brewing industry. His hope was to provide information that would help the French brewing industry surpass the German industry (who at the time had a very well developed brewing industry and produced some of the best beers in the world.)

What Pasteur found was that most of the yeast used to make beer in France was actually not pure yeast, but instead a mixture of bacteria, mold, yeast, and other fungi. He strongly advocated for heating the beer after it was made to eliminate these organisms and allow the beer flavor to be stable. He also suggested that tartaric acid be used to purify the yeast prior to its use. Unfortunately, this did not work very well.

It was Emil Hansen, a Danish chemist, who carried Pasteur's work further. Hansen worked at the Carlsberg Laboratory (a research company spun off from the Carlsberg Brewery in by its founder Jacob C. Jacobsen) on the problem of impure yeast. He determined that it was possible to separate a specific colony of yeast into a pure strain that would cleanly ferment wort into beer. This first strain of yeast he named *Saccharomyces carlsbergensis* after the laboratory where he worked. It was not until the mid 1980s that it was determined that this is the same species of yeast as *Saccharomyces pastorianus*, the lager yeast named after Louis Pasteur that was identified almost 15 years earlier than Hansen's work.

It was clear even then that Pasteur's contributions to the brewing industry were incredibly valuable. By far one of Pasteur's most important discoveries was pasteurization. This is the process that eliminates almost all microbes. It has been applied to milk, wine, juices, and beer. The goal of this process is to accomplish the task of eliminating microbes without changing the flavor of the product.

There are many different levels of elimination of microbes that must be considered. This is the same argument as between the words clean, disinfect, sanitize, and sterile. It typically results in the definition of the degree of elimination of microbes. For example, if something is made sanitary, it results in a 99.999 % of all microbes. This is typically the level of cleanliness needed in the brewery. To make something sterile, it needs to result in 99.99999999 % reduction in the microbes. This can be difficult to obtain.

How is the degree of pasteurization measured in the industry? The amount of "pasteurization" depends on the temperature and length of time. A pasteurization unit (PU) is one way to measure how much "power" is applied to the elimination of microbes in beer. Specifically, 1 PU is defined as the amount of "power" applied in a product heated to 60 °C for one minute. First defined by Del Vecchio in 1951, the PU is calculated from

$$PU = t_{(minutes)} \times 1.389^{(T-60\,°C)} \tag{11.4}$$

where t is the hold time in minutes, and T is the temperature of the beer reported in °C.

This equation works to calculate the number of PU that is applied to a beer when it is heated at any temperature. Note from the equation that this implies a tenfold increase in effect for every 7 °C increase in temperature. In addition, temperatures less than 60 °C generate very small PU values. In other words, holding a beer at a temperature less than 60 °C will require a significant amount of time to obtain any measure of PU value.

Let us assume the brewer wishes to achieve 30 PU. To obtain this many pasteurization units, the beer would need to spend 30 min at 60 °C. However, because of the equation, the degree of pasteurization is not linear with temperature. So, elevated temperatures are more effective at killing microorganisms. And, at those higher temperatures, the time to achieve the same PU will be reduced. As an example, let us rearrange Eq. 11.4 to solve for the time to achieve 30 PU at various elevated temperatures:

$$\frac{30\,PU}{1.389^{(T-60\,°C)}} = t_{(minutes)} \tag{11.5}$$

Table 11.4 does just this. It shows the hold times for a beer at various temperatures in order to get the same 30 pasteurization units. Note that increasing the temperature rapidly decreases the time required for the same effect. While it seems the best option would be to choose the greatest temperature, this is not the case. Increased temperatures have the potential to change the flavor of the beer. (What chemical reactions would you predict to occur and how would they change the flavor of a beer?).

Other values based on Eq. 11.4 are commonly used in the discussion of the pasteurization of beer. One predominant value is the decimal reduction time (D). This is the amount of time required, at a given temperature, to kill 90 % of the specific organism being studied. This value is very specific, so can only be com-

Table 11.4 Hold times at different temperatures to achieve 30 PU

T (°C)	T (°F)	t (min)	t (s)
60	140	30.00	1800.0
65	149	5.80	348.1
70	158	1.12	67.3
75	167	0.22	13.0
80	176	0.04	2.5

pared between organisms under very similar conditions. For example, in one study by Tsang and Ingeldew, *S. carlsbergensis* was found to have a $D = 0.004$ min, *Pediococcus acidilactici* had a $D = 0.867$, and *Lactobaccilus delbrukii* had a $D = 0.091$. Thus, *Pediococcus* is more thermally stable than other microbes.

The amount of PU needed to effectively eliminate microbes in beer will depend on the type of microorganisms we are trying to kill (as indicated as well by the decimal reduction time. For example, wild yeasts in are more resistant to heat than the standard Brewer's yeasts (*S. cerevisiae, S. pastorianus*). Therefore, the beer contaminated by wild yeasts will require more PU to make the product stable. Table 11.5 lists some common spoilage organisms in beer and how many PUs are required to have the same killing power as 1 PU on brewer's yeast. Note that Table 11.5 does not list enzymes. Flavor-damaging enzymes can also survive into the finished beer. To make sure that the beer is truly flavor stable as long as possible, it is imperative that any enzymes are destroyed in pasteurization. They tend to be quite thermally stable.

How effective is pasteurization? Applying 20 PU to a beer during pasteurization indicates that only 1 in 10 billion microbes has a chance of surviving. At 30 PU, this drops to only 1 in 10^{15}. The survivor, if one did survive, would be hard to find if you looked through an entire bottle of beer. Luckily, brewer's yeast produce invertase and the activity of this enzyme can be used to determine the effectiveness of the pasteurization. Typically, this is done by adding invertase to a beer and measuring its activity prior to the pasteurization and after the pasteurization. Then, the reduction in the activity is a measure of how effective the treatment is on the product.

CHECKPOINT 11.3

Some brewers only provide 15 PU to their product before shipping. How long would it take to obtain this amount of pasteurization if the hold temperature was 65 °C?

**Table 11.5** Pasteurization unit relationship to provide similar reductions in cell counts

Organism	PU
Saccharomyces cerevisiae	1
Pediococcus	1
Lactobacillus	5
Wild yeasts	10

11.4.1 Tunnel Pasteurization

There are two common ways in which beer is pasteurized. The first method is called tunnel pasteurization. In this approach, the beer is first packaged in bottles or cans and sealed. Then, the sealed packages are sent through a "tunnel" where they are sprayed with recirculating heated water. The product's temperature is slowly raised from bottling temperature to the desired pasteurization temperature and held there for the desired rest time. Then, the temperature is lowered back to bottling temperature by spraying the packages with cooler water.

An example tunnel pasteurization configuration is shown in Fig. 11.9. In this simple design, there are five regions where the product is either heated or cooled, and one region where the temperature remains constant. As the bottles or cans enter region 1 on a conveyor, they are slowly heated by water that was used to cool the packages leaving region 5. By coupling the entrance and exit water recirculation in this manner, the amount of energy required from outside of the system is minimized. Heat energy is added or removed as necessary through heat exchangers in order to keep the temperature of region 1 and 5 constant. Regions 2 and 4 are likewise coupled; again raising the temperature of the packages as they travel through region 2 and cooling through region 4. Region 3 in Fig. 11.9 is the main pasteurization region. It is here where the packaged beer is at our final, elevated pasteurization temperature and will spend most of its time through the tunnel.

Tunnel pasteurization does not work well with larger packages, such as kegs. With the increased volume of beer in the sealed container and the materials of the package itself, it would take an unreasonable amount of time and energy to ensure that the packaged beer is thoroughly heated. If pasteurization is needed for large pack, another method needs to be utilized by the brewer to effectively remove bacterial contamination from the finished beer.
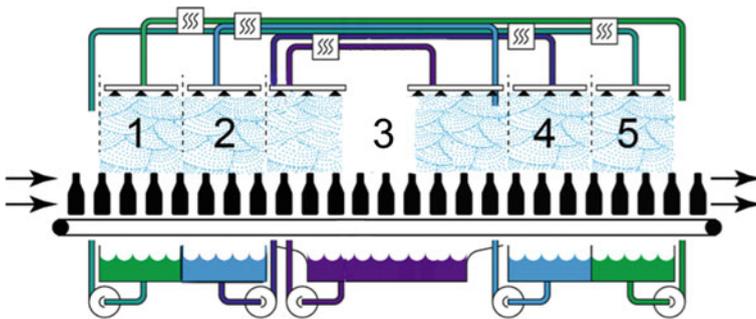
Fig. 11.9 Tunnel pasteurization system. Note that *region 3* is at the final pasteurization temperature, and that the speed of the conveyor determines the length of time that the product spends at this final temperature
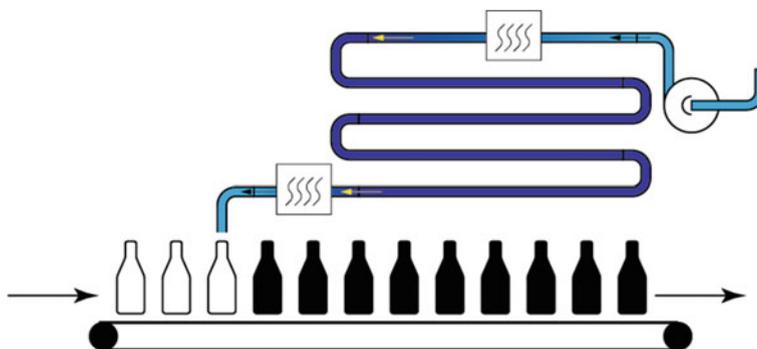
11.4.2 Flash Pasteurization

A second method is called "flash" pasteurization. In this approach, the beer is heated to pasteurization temperatures, held at that temperature for the desired amount of time, and then cooled *before* being placed in a package. This approach can be applied to virtually any packaging vessel; bottles, cans, or kegs. The approach requires the packaging vessel to be aseptically clean prior to filling. In addition, it also requires that the piping, tubing, and packaging apparatus itself be sterile. It would do no good at all to have a contaminated feed line from the pasteurizer to the bottle.

A generalized flash pasteurization method is shown in Fig. 11.10. The apparatus essentially consists of a plate chiller that is converted to allow one region to heat the beer, a second region to hold the hot beer, and a third region to cool the beer back to bottling temperature. The first step involves pumping the finished beer into a heat exchanger that warms the beer to the pasteurization temperature. The warm beer travels through a heated array of pipe ensuring that the beer spends an appropriate amount of time at pasteurization temperatures. Then the beer is cooled right before being sealed in an aseptically clean vessel.

Since the degree of pasteurization depends on the time the beer is held at an elevated temperature, we modify Eq. 11.4

$$PU = \left(\frac{V}{Q}\right) \times 1.389^{(T-60\,°C)} \tag{11.6}$$

where V is the volume of holding tube at the elevated temperature (in m^3), and Q is the volumetric flow rate (in m^3/min). The units of V/Q are then $m^3/(m^3/min)$ which reduces to min. This must be in minutes to calculate PU using this equation.

Fig. 11.10 Example configuration for flash pasteurization

As an example, let us assume that our pasteurization temperature is 65 °C. Table 11.4 indicates that we must leave the beer at this temperature for 5.5 min, or 348 s to achieve 30 PU. What we would like to calculate is the length of piping needed so that the beer stays at this temperature for the required time. First, let us assume that our bottle filler is capable of filling 6 standard 12 oz bottles every second. This implies we need a volumetric flow rate of

$$Q = 6 \times \frac{12 \text{ oz}}{\text{s}} \times \frac{29.6 \text{ cm}^3}{1 \text{ oz}} = \frac{2131 \text{ cm}^3}{\text{s}} \qquad (11.7)$$

Note that are units are not in m^3/min, but we will address this discrepancy as we move forward. Since, the demand for 30 pasteurization units requires a time of:

$$\left[\frac{V}{Q}\right] = 348 \text{ s}, \qquad (11.8)$$

All we need to do is find the volume of the piping. Plugging the answer to Eq. 11.7 into Eq. 11.8, we get:

$$\begin{aligned}\left[\frac{V}{2131 \text{ cm}^3/\text{s}}\right] &= 348 \text{ s} \\ V &= 741{,}588 \text{ cm}^3\end{aligned}, \qquad (11.9)$$

Assuming the pipe is a cylinder, Eq. 11.9 implies that

$$V = \pi r^2 l = 741{,}588 \text{ cm}^3 \qquad (11.10)$$

where

r is the radius of the pipe, and
π is a constant equal to 3.14159,
l is the length of the pipe.

If we assume that the pipe is 5-cm-(2 in.) diameter pipe, this implies that the length must be 9442 cm long (94.42 m). If we raise the pasteurization temperature to 70 °C, the time that the beer needs to spend in the pipe drops to 67.3 s, so the length is now about 18.26 m. Again, there is a trade-off; the higher temperature will reduce our equipment needs, but one runs the risk of changing the flavor of the beer. If we wanted only 10 PU applied to the beer for pasteurization, the length of tubing (at the same volumetric flow rate) gets even shorter.

One significant issue is important to consider with the use of a flash pasteurizer. Because the beer will be heated well above the finished beer temperature, we must consider that effect on the carbonation of the product. The same effect is seen in the tunnel pasteurizer, but because the bottles or cans are sealed, no carbonation is lost. The flash pasteurizer, on the other hand, 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 does not degas.

The heat exchangers themselves are very similar to the plate chillers that we explored in an earlier chapter. These devices use hot water to warm the beer to the appropriate temperature. They can be counter flow or concurrent flow and the volumetric flow rate becomes the determining factor in how much heat is applied to the beer. The typical design is as a counter-flow exchanger. Often, the water (or water-glycol mixture) is recycled from the chiller portion of the heat exchanger into the heater portion. Additional heat can be applied to ensure that the heater reaches the desired temperature. And then the water or water-glycol mixture is cooled down to allow the chiller to reach the appropriate temperature. This recycling saves tremendous amounts of energy for the brewery.

11.4.3 Other Methods of Pasteurization

Other types of devices exist to effectively result in pasteurizing beer. One such device involves the use of a filter.

A plate and frame filter is a device where a filter, typically a sheet of porous plastic with very small holes, is placed in a frame and then sealed. The beer is pumped into the frame and forced through the filter. Depending upon the size of the holes in the filter, the beer can be significantly cleaned of bacteria, yeast, and other particles.

Often the beer is passed through multiple filters that step down in size gradually until the holes are small enough so that no bacteria or yeast can pass through. After the beer is transferred, cleaning water is passed backwards through the filter to remove the particles that were captured. Alternatively, the frames can be opened and the filters discarded.

This is a very effective way to remove any particles from the beer. The biggest advantage is that microbes can be removed almost completely from the beer without the use of flavor-damaging heat. However, like the flash pasteurizer, contamination can be a significant concern post-filter. In addition, forcing the beer through small holes results in a decrease in pressure in the beer that can be significant enough to degas the beer. So the pressure must be increased as the beer flows through the plate and frame filter.

Chapter Summary

Section 11.2

Friction from pipes can reduce the pressure of a moving liquid. This can be determined using Darcy's Equation.
Nitrogen can be used to provide the bubbles in beer.
Bubbles in beer become larger through the process of disproportionation.

Section 11.3

Small pack refers to single-serving containers. This includes the bottle and the can.
Large pack refers to multiple serving containers such as kegs.

Section 11.4

Beer can have a longer shelf life if it is pasteurized.
Tunnel pasteurization and flash pasteurization can be used to eliminate microbes from the finished product.

Questions to Consider

1. How many pasteurization units would you expect from holding a beer sample at 25 °C for 6 h? Explain your answer.
2. What is the pressure drop in a 60 m pipe ($\phi = 0.0038$) that is 5 cm (2.5 in.) in diameter, if the flow rate is 0 m/s? Assume the density of the liquid is 1200 kg/m^3. What if the flow rate was 1.0 m/s? … 0.2.0 m/s?
3. A liquid with a density of 1100 kg/m^3 is pumped at 1.25 m/s along a 15 m pipe ($\phi = 0.0042$) that has a diameter of 10 cm (5 in.). What is the pressure drop in pascals?
4. A carbonated beer at 110 kPa is pumped from the conditioning tank to the packaging line along a 30 m straight pipe (5 cm; $\phi = 0.0029$). If the density of the beer is 1010 kg/m^3, what is the maximum velcocity allowed such that the beer does not decarbonate? Assume the beer will degas if the pressure falls below 100 kPa. What happens to the pressure if a 90° rounded bend is placed in the line?
5. A pipe run of 10 m (5 cm diameter, $\phi = 0.0032$) contains two 45° bends and two butterfly valves that are half-way open. If the liquid has a density of 1045 kg/m^3, what is the pressure drop across the pipe run?
6. Use the Internet to find a video that shows how aluminum cans are made. Outline the steps at each of the stages and compare that to the information in this chapter.
7. Use the Internet to find a video showing how bottles are made. How are designs and patterns on the glass put there?
8. Bottles tend to have a seam running down their length. From where does that seam arise?
9. Provide a list of pros and cons (two each) for each of the small packages that we discussed in this chapter.
10. A customer purchased a keg but did not use all of the beer in it. How is that beer removed when the keg is returned to the brewery?

11. Diagram the setup that would allow a brewery to use two wort chillers to flash pasteurize their beer. Show how the cooling or heating water could be recycled in this system.

12. Why is ammonia not a good gas to use to pressurize beer?

13. Which would likely produce bigger bubbles if it were used to pressurize a beer, O_2 or CH_4? Why?

14. Neither of the gases in question 13 is suitable for pressurizing beer. Explain why?

15. Would there be an issue if the brewer decided that they only wanted to produce 3 PU when pasteurizing their beer?

16. Cans are typically cleaned with HF in the manufacturing process. Use the Internet to look up HF and its safety information. Is this acid safe for consumption?

17. From the information in the text about aluminum cans, extrapolate some pros and cons that you might expect for an aluminum keg.

18. Which is more restrictive to the flow of a liquid, a ball valve or a gate valve? Explain your answer.

19. Two identical pipe runs are compared. One is 5-cm pipe, the other is 3 cm pipe. Which would have the greater pressure drop?

20. Outline the pros and cons (list two of each) for a plate and frame filter as compared to a flash pasteurizer.

21. A brewer has a flash pasteurizer that has a 3 m length of pipe ($d = 1.5$ in.) to use at the hold temperature. How fast in m/s could the beer ($\rho = 1.005$ g/mL) flow through the pasteurizer if she wanted 68 °C as the hold temperature and 1.5 min of time?

22. What would be the pressure drop in question 21 across that pipe length assuming that there were six 90° square turns? Assume, as well, that the pipe is relatively smooth ($\phi = 0.0028$).

23. A brewer needs to fill 24 16 oz bottles every 10 s in the filling line. If the pipe coming to the packaging room is 5 cm in diameter, what is the velocity of the beer in that line?

24. Provide a list of at least three ways in which a brewer would know that a keg was filled to the appropriate level.

25. Prepare a drawing that explains the steps in a blow mold. Consider Fig. 11.5 as an example of the resulting drawing.

Laboratory Exercises

Thermal Expansion of Water

This experiment is designed to illustrate the relationship between the volume of water and its temperature. From this, inferences about headspace in packaging can be made.

Equipment Needed

Graduated cylinder (100 mL)
5 beakers (250 mL)
Water
Hot water bath—adjustable
balance

Experiment

CAUTION: Hot glassware looks very similar to cold glassware. Wear heat resistant gloves when performing this experiment.

Use the hot water bath to warm approximately 1 L of water. As the water heats, use one of the beakers as a ladle and pour 100 mL samples into the graduated cylinder. Complete the task quickly so that the water maintains its temperature. Then pour the water from the graduated cylinder into a tared beaker. Obtain water samples at room temperature, 40, 60, and 80 °C.

Allow the four samples of water to cool to room temperature by leaving them on the bench, and then placing the beaker in a cool water bath. Once all four are at the same temperature, obtain the mass of each beaker. Do not forget to dry off the beakers after you have taken them out of the bath.

Plot the density of the water (all were 100 mL) versus the temperature of the water. Is there a relationship? Is it linear?

Use this information to determine how much headspace would be required (in mL) in a 12 oz bottle that passes through a tunnel pasteurizer. Assume the Pasteurizer holds the beer at 75 °C for 2 min. What would happen if the calculated amount of headspace did not exist?