Conditioning 10

10.1 Why Condition?

After fermentation, the beer produced is known as *green beer*. This product, while drinkable, is not finished, often is flat, and has a relatively unstable flavor profile. A conditioning or maturation process is required to convert the flavors into those desired by the brewer and to allow the beer to mature and settle into a more stable flavor profile. This process is akin to the preparation of most food in the kitchen.

You may have heard the phrase, it tastes better the second day. This is true for the author's chili which mellows and melds its flavors when it rests overnight in the fridge after being cooked. It is also definitely true for the author's pulled pork that requires a little time to allow the spices and smoky flavor to really bring out the flavor of the meat. Let us consider the process to make spaghetti. First, we grab a few ripe tomatoes and cut them open. Then, we scoop the seeds out and throw them into the compost. The meat of the tomatoes is chopped up (or squished between the fingers) until the entire mass has the consistency of a puree. The tomatoes are then added to a pot containing sautéed onions and garlic and the entire mixture brought to a simmer. Some liquid, chicken stock, wine, or water, is added and spices such as oregano and thyme are added. Once hot and mixed together, the spaghetti sauce is done. Just like green beer, it is edible and can adorn a pile of your favorite linguine. However, until it is simmered for a period of time (the author requires at least 2 h) or stored overnight in the fridge, the flavors have not developed into the recognizable spaghetti sauce that makes your mouth water when you taste it.

It is possible that the chef adds some sugar or baking soda to the sauce once it has started simmering. Just as in the maturation or conditioning of green beer, the brewer may do similar steps to adjust the acidity or flavor of the beer. In other words, conditioning is the time and place where the brewer "adds salt to taste."

Before we continue, it might be worthwhile to provide a few words about "stable" flavor in beer. While the beer that has undergone conditioning is ready to be consumed with a stable flavor profile, the flavors in a beer are never really 100 % stable. The brewer knows this, too. Beer does have a fairly limited shelf life. That

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shelf life can be extended by keeping the product cold and free of oxygen. But even under these conditions, the flavor of the beer is not entirely stable. The flavor will change. The brewer knows this and might even indicate a best by date on the packaging. That date may be weeks, months, or even years from the date it was brewed, but nonetheless, there is a time when the beer will no longer taste as good as the day it was brewed and conditioned.

Why is conditioning performed? There are many reasons why the brewer conducts this step, each of those reasons is outlined below. Conditioning can:

- Induce secondary fermentation to carbonate the beer;
- Mature the flavors and odors of the beer;
- Reduce or eliminate the potential of the beer to form haze;
- Adjust the flavor, color, or aroma in the beer;
- Adjust the amount of compounds to improve or reduce foam;
- Eliminate or reduce bacterial growth;
- Clarify the beer prior to filtration.

10.1.1 Secondary Fermentation

Secondary fermentation is often a highly desirable feature of the brewing process and is considered to be a conditioning step in the brewery. In this process, the *green beer* is transferred to storage tanks fitted with cooling jackets and pressure regulators or into a fresh CCV. Yeast concentrations out of the primary fermenter are often about a million yeast cells per milliliter of beer, and these active yeast cells can continue to consume the remaining sugars in the beer.

If the beer is then cooled, the process is known as *lagering*. In lagering, the tanks are cooled to 10 °C. Then, over a period of days or weeks, the temperature is lowered to about 1 °C or even lower. This causes the fermentation process, which starts out fairly slowly at 10 °C, to slow even more and more as the tanks get cooler. In addition, as the tanks get cooler, solid materials that are insoluble at these lower temperatures fall out of solution. The precipitation of these materials helps to clarify the beer. And once the temperature hits the lowest end of the range, even the yeast cells fall out of solution. Thus, the lagering process, once complete, results in a very clear beer.

In some cases, the beer at the end of the primary fermentation process requires a boost of yeast in order to continue the fermentation process. In these cases, two options are available for the brewer. In one option, a separate strain of yeast can be pumped into the green beer and allowed to ferment again. This may be the option chosen if the primary yeast strain used is unable to continue the fermentation of all of the remaining sugars. For example, if the brewer were interested in making a very high alcohol beer and the first fermentation was accomplished with a standard yeast, the addition of a more robust yeast might be needed to finish off the rest of the fermentable sugars. If the beer will be lagered with the additional yeast, the secondary yeast strain is often one that can handle the lower temperatures during the maturation process.

Alternatively, a portion of the wort from an actively fermenting batch of wort may be used to inoculate the beer in the secondary fermenter. This process is called *kräusening*. Most commonly used in the lagering process, the addition of kräusen (the yeast laden foam on an actively fermenting wort) can help mature the flavor of the cold green beer quickly because a very large bolus of fresh yeast is added to the beer.

10.1.2 Warm Conditioning

At the end of primary fermentation, the brewer may decide to speed up the action of the yeast on the beer. In these cases, the brewer warms the beer from the standard fermentation temperature by about 5 °C (9 °F) and holds it at that temperature for a period of time. As the temperature increases, the reactions inside the yeast proceed faster. Thus, the yeast cells work harder to uptake the remaining fermentable sugars. And when those sugars are depleted, the yeast uptakes other compounds that can provide energy. One of the more important classes of compounds that are consumed by the yeast when the fermentable sugars have been consumed is the VDKs (vicinal diketones). The main VDKs in question are diacetyl and 2,3-pentanedione compounds that have a flavor threshold that is quite low. For this reason, warm conditioning is also known as the "diacetyl rest."

The speed of the process is the main reason why a brewer often chooses this method to clean the flavors in the finished beer. The same result can be obtained at lower temperatures (i.e., the reduction of the levels of diacetyl, 2,3-pentanedione, and other off-flavor compounds), but the process occurs much slower. Typically, if a beer is cold conditioned, it may require multiple days, weeks, or even months in order to accomplish the same thing that happens in 12–24 h at the elevated temperature.

Diacetyl and 2,3-pentanedione concentrations begin to rise at the end of the rapid growth phase of the yeast during fermentation (see Fig. 10.1). Diacetyl arises from the production of α-acetolactate during the biosynthesis of amino acids by the yeast.

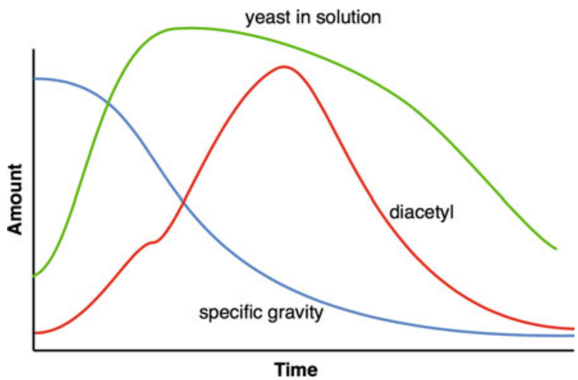


Fig. 10.1 Diacetyl concentrations during fermentation at normal fermentation temperature

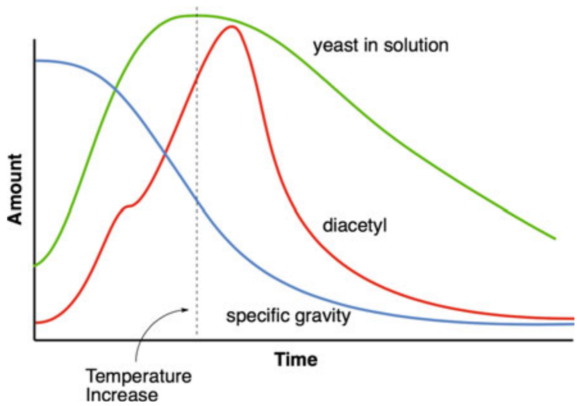


Fig. 10.2 Diacetyl concentrations during a warm conditioning phase

Levels of α-acetolactate can be as high as 200 ppm. As would be expected, the amount of α-acetolactate produced in the fermentation is highly dependent upon the composition of the wort and the temperature of the system. For example, if the wort has a high-FAN content, the production of α-acetolactate is limited. If the levels of valine and isoleucine in the wort are large, their presence suppresses the formation of the precursors to make them (i.e., α-acetolactate). Higher fermentation temperatures also have a positive impact on diacetyl production.

Warm conditioning takes place when the temperature of the fermenter is adjusted after the rapid growth phase of the yeast (Fig. 10.2). Note that the increase in the temperature causes a rapid change in the concentration of diacetyl in solution (and in the precipitous drop in the gravity of the wort.

Diacetyl during clean fermentation is only produced from extracellular α-acetolactate as shown in Fig. 10.3. The α-acetolactate undergoes a non-enzymatic oxidative decarboxylation to provide diacetyl. The rate of this process is highly

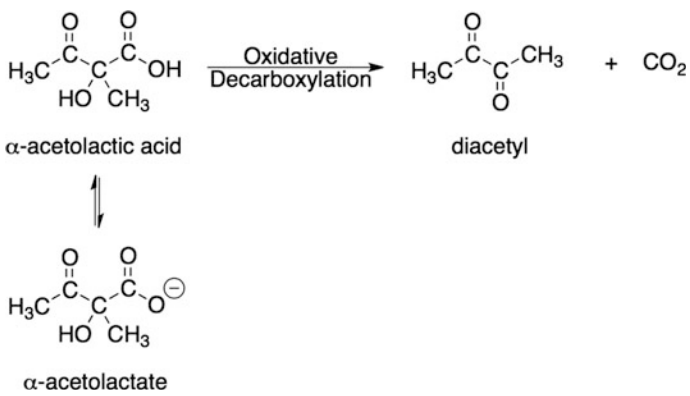


Fig. 10.3 Diacetyl production is an extracellular process. The rate of this reaction is dependent upon the temperature, pH, and presence of metal cations

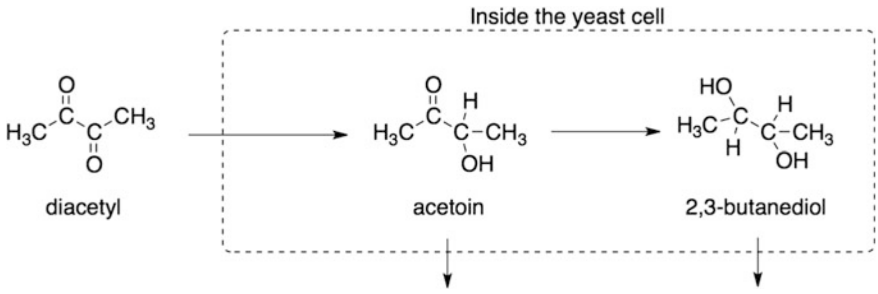


Fig. 10.4 Uptake of diacetyl and production of acetoin and 2,3-butanediol. The products can be further used by the yeast cell or excreted back into solution. However, the flavor thresholds for these compounds are much higher than that of diacetyl

temperature and pH dependent. The oxidative step in the process requires the presence of an oxidizer. Dissolved oxygen may serve as that oxidizer; however, the presence of metal cations in the solution may also act as sources of the oxidizer. In particular, Cu^{2+} and Fe^{3+} have been suggested as possible oxidizers.

As fermentable sugars in the wort decline in concentration, yeasts begin to uptake extracellular materials to use as energy sources. VDKs are one such source. If the yeast are still in suspension and have not flocculated too quickly, they will uptake these compounds quickly. If the yeast have already flocculated, had poor health due to stressed growth, or have already entered a cold conditioning stage, the rate of diacetyl and 2,3-pentanedione uptake is slow.

Diacetyl can reenter the yeast cell where it is reduced to acetoin and then to 2,3-butanediol (Fig. 10.4). Both acetoin and 2,3-butanediol can be excreted from the cell, but have limited flavor impact. This is extremely important because diacetyl imparts a perceptible butter flavor to the finished beer even at levels as low as 0.02 ppm. It is true that not every person can perceive the flavor of diacetyl even at elevated concentrations; however, some people are very sensitive to this compound. And, while it seems like a buttery flavor in your beer might be a good thing, after a few sips its easy to tell that it really does not belong in every style.

Alternatively, the brewer can add enzymes directly to the wort. In particular, -acetolactate decarboxylase can be added to the fermenter. This enzyme converts α-acetolactate directly to acetoin. It bypasses the yeast machinery and removes the diacetyl flavor from the beer. This is sometimes quite useful because of the particular conditions or strain of yeast used (e.g., an overly flocculant yeast strain would only slowly remove diacetyl).

CHECKPOINT 10.1
What type of reaction is happening when diacetyl is converted into acetoin? In your own words, explain why diacetyl is formed and then reabsorbed.

10.1.3 Other Adjustments

While removal of diacetyl and other VDKs is one of the most important goals of conditioning the beer, many other things can be done to stabilize the beer and adjust the beer to match the style parameters. Let us look at each of the different things that can be done and see how to accomplish these tasks.

Haze reduction Polyphenols (tannins) that are present in the beer after the initial stages of fermentation can combine with proteins (typically in the 10,000–60,000 molecular weight range). These larger complexes are held together with hydrogen bonds where the polar groups on both the polyphenols and the proteins interact (Fig. 10.5). Other hazes are also possible. These include the large β-glucan molecules and calcium oxalate crystals. Calcium oxalate crystals tend not to be an issue as they only form when there are significantly high levels of calcium in the beer after the fermentation is complete.

Reducing the haze can be done in the conditioning tanks through the addition of compounds that can remove the polyphenols and/or the proteins in the beer. An enzyme can be added to the beer that can break the proteins apart. These proteases include papain—a protease isolated from papaya. Papain is particularly good at cleaving protein bonds and breaking down these larger molecules into smaller ones.

Alternatively, the proteins can be removed by the addition of silica gel to the beer. The highly polar silica gel associates very strongly with the proteins in the beer. The resulting mass precipitates and falls to the bottom of the vessel where it can be removed from the clarified beer (also known as *bright beer*). Advantages to the use of silica include the significant reduction in proteins and β-glucans. Unfortunately, the disadvantages can outweigh the advantages. Removal of too much of the proteins reduces the amount and stability of the head on the finished beer. In addition, many of the flavor compounds have polar groups in them and if too much silica gel was used, the result could be a reduction in the flavor of the finished beer.

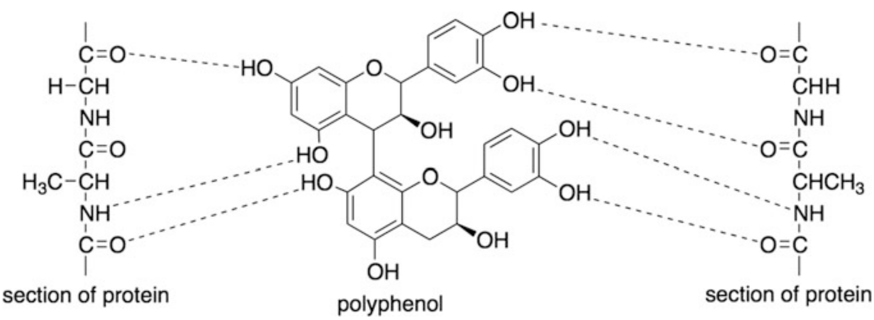


Fig. 10.5 Haze production from polyphenols and proteins. The polyphenols interact by sharing hydrogen atoms with multiple proteins. The result is a large protein that becomes insoluble in the beer. As more interactions occur, the haze becomes more and more stable

PVPP (polyvinyl polypyrrolidone) is another additive that is somewhat similar in structure to a protein. Thus, it binds to the polyphenols (tannins) in the beer and removes them by forming a precipitate. Of the fining agents, PVPP removes the astringent polyphenols while leaving much of the proteins behind to maintain a stable head on the finished product.

Other types of finings work to form a gel that entraps yeast, protein-polyphenol coagulates, and other larger compounds that would normally precipitate. These finings, however, rapidly speed up the process. Typically, they can clarify the beer completely within 4–5 days. Unflavored gelatin and isinglass are the two most commonly used. Gelatin is exactly what we know it as. When made up and solidified with fruit flavors, it jiggles and makes a great dessert for young and old alike. Isinglass is a form of collagen prepared from the swim bladders of fish (originally from sturgeon and now from cod). The bladders are removed from the fish and then treated and dried. Isinglass or gelatin can be dissolved in water and then added to the conditioning tank. When they set up, they precipitate and then coagulate the large proteins. The downside to use of these finings is that they remove essentially everything equally. It is best to not use these finings unless the yeast have accomplished everything for which they are needed, because once the gelatin or isinglass is added, the yeast will be nearly completely removed.

Carbonation While in the conditioning tank, carbon dioxide (CO_2) can be added to adjust the amount of carbonation in the beer. Typically, CO_2 is added until the beer contains 1.5–2.8 volumes of CO_2. This is accomplished by bubbling CO_2 through the beer while the tank is sealed. A tank of purified CO_2 is attached to the conditioning tank and the tank slowly pressurized. The best way to add the CO_2 is through a *carbonation stone*.

A volume of CO_2 is the typical measurement of the amount of carbon dioxide dissolved in the beer. One volume of CO_2 can be thought of as 1.0 L of CO_2 dissolved in 1.0 L of beer. Assuming that CO_2 behaves ideally (an assumption that is relatively acceptable at the pressures and temperatures that we will work with), we can use the ideal gas law to determine how many grams of CO_2 are in a given volume of CO_2. The ideal gas law is:

$$PV = nRT$$

where, P = pressure in atmospheres, V = volume in liters, n = number of moles, R = universal gas constant (0.082 Latm/mol K), and, T = temperature in kelvin.

Since the number of moles of any substance is equal to its mass in grams (m) divided by its molecular weight in grams/mole (mw), we can substitute this into the ideal gas equation:

$$PV = \frac{m}{mw} RT$$

Rearranging, gives us a way to calculate the mass if we know the volume of the gas:

$$\frac{PVmw}{RT} = m$$

Assuming that we measure the 1.0 volume of carbon dioxide at 1 atmosphere pressure and room temperature (25 °C, 298 K), the mass of CO_2 dissolved in the beer is (note that carbon dioxide has a molecular mass of 44 g/mol):

$$\frac{(1 \text{ atm})\ (1.0\boldsymbol{L})\ (44 \frac{\text{g}}{\text{mol}})}{\left(0.08206 \frac{\text{Latm}}{\text{molK}}\right)(298 \text{ K})} = 1.799 \text{ g } CO_2$$

In 1.0 L of beer, this would equate to 1799 mg/L or 1799 ppm CO_2 in the beer. Similarly, 2.0 volumes of CO_2 would equate to 3.599 g or 3599 ppm CO_2.

Carbon dioxide can also be bubbled through the beer as a way to scrub other compounds from the liquid. Volatile compounds, such as DMS, H_2S, and O_2, can be removed from the beer by bubbling CO_2 through the beer. This is best accomplished by leaving the vessel opens to the atmosphere to allow these volatile compounds to escape.

If the beer was carbonated in the primary or secondary fermenter, the pressure of CO_2 could be too great for the particular style. So the brewer could also adjust the volumes of CO_2 by decreasing the pressure on the tank. Care must be taken in this case to make sure that the pressure is slowly reduced in order to reduce the amount of foam that is generated during the process.

Flavorings The taste of the beer in the conditioning tank is one of the last places where the beer can be adjusted to give the flavor that is required by the brewer. For example, if the beer is lacking a particular concentration of ester (such as isoamyl acetate), that compound can be added. Adjustment of the beer flavor can also occur through the addition of fruit, spice, or other flavors. For example, a brewer may wish to add cherry flavoring to the beer. Adding artificial or natural cherry flavors while the beer is in the conditioning tank could do this.

Coloring Agents If the SRM of the beer is incorrect for the brewer's requirements, it can be adjusted in the conditioning tank. Typically, this is done by adding caramel color. Dosing this into the beer provides the appropriate color of the beer without adding additional flavor.

Hop Additions While hop additions typically take place in the secondary in what is called dry hopping, hop oils and reduced hop oils can be added in the conditioning tank. The addition of hop oils can adjust the flavor components to provide a hoppier flavor to the beer.

Isomerized hop oils can be added to increase the bitterness of the beer to match the brewer's style requirements. Dosing with these hop products will provide the bitterness without requiring the product to be boiled. Alternatively, the use of reduced hop oils can be advantageous. These compounds, which we discovered earlier in this text, can provide additional bitterness while at the same time increasing head retention and/or providing light stability.

Sugars The sweetness of the beer can also be adjusted at this point. This can be done through the addition of non-fermentable sugars such as lactose, or through the use of fermentable sugars. Though, if fermentable sugars are used, it is imperative that the yeast be removed from the beer or it will ferment again. This can be useful if the beer is to be "naturally" carbonated. But, it would be particularly disadvantageous if the beer were to be packaged with significant quantities of added maltose and still containing yeast.

This problem can be overcome if the beer is to be pasteurized or sterile filtered. Because these methods significantly reduce or eliminate yeast from the finished beer, additional sweetness can be added. Alternative methods to remove the yeast from the beer include adding bacteriostatic compounds to the beer. Typically, this involves the use of SO_2. Doing so, however, requires that the concentration of this compound be clearly noted on the label because some people are unable to consume this compound without significant health problems. In most countries, the limit of SO_2 is 10 ppm.

Yeast Yes, yeast can be added in the conditioning stage. This would typically be done to add a strain of yeast that is very good at cleaning up or adjusting some other parameter in the beer. For example, it may be added to clean up any remaining VDKs or to provide a yeast that can naturally carbonate the beer with the remaining fermentable sugars. The added yeast can later be removed through the use of finings or by sterile filtration, centrifugation, or pasteurization methods.

CHECKPOINT 10.2

If a beer has 2.2 volume of CO_2, what is the concentration of CO_2 in ppm? If the beer has 2800 ppm CO_2, how many volumes of CO_2 is this equivalent to? Assume the measurements are done at 25 °C and 1 atm.

A brewer adds nitrogen gas to the beer in the conditioning tank to reduce the level of CO_2. Why would the brewer use nitrogen gas instead of another gas?

10.2 Equipment Used in Conditioning

Beer in the conditioning tank requires that it be cold and pressurized. The beer should be able to be adjusted through additions of other materials and should be able to be removed when finished with conditioning. Finished beer from this step will move on to the packaging line. And it is with the requirements at this step that the equipment and vessels are designed.

10.2.1 The Conditioning Tank

The conditioning tank, see Fig. 10.6, is typically a vessel that is jacketed in order to adjust the temperature. It has ports that allow not only the addition of the beer via the bottom, but also along the side to allow the withdrawal of the finished beer. One of the ports usually allows the brewer to add carbon dioxide via a carbonation stone. Gauges and monitoring devices can also be found on the vessel. The body of the vessel is also jacketed so that the contents can be warmed or cooled with glycol or some other coolant.

One important thing to note about the vessel is that it typically has a much flatter bottom than the fermentation vessel. It is still concave to allow the beer to be removed entirely from the vessel, but because there is typically not that much material that precipitates compared to the CCV, the bottom can be flatter. A side port near the bottom is typically the location to remove the *bright beer* after

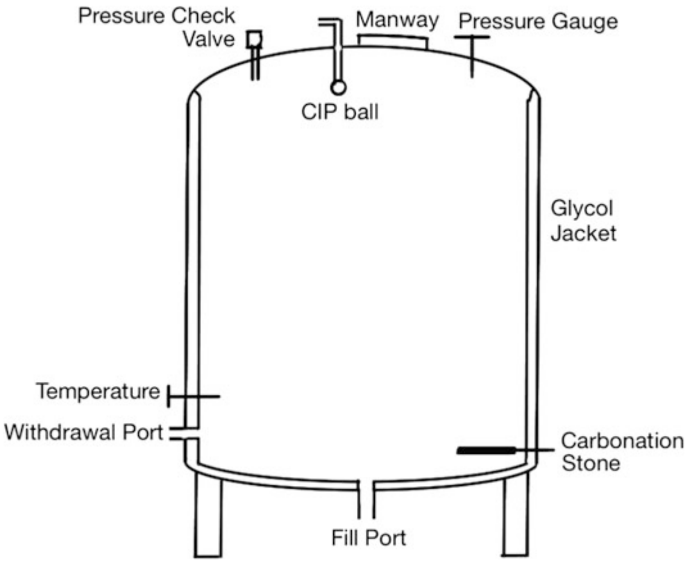


Fig. 10.6 The conditioning tank

conditioning. This is because any precipitates that form due to additives (such as PVPP used to reduce haze) will collect on the bottom near the central port.

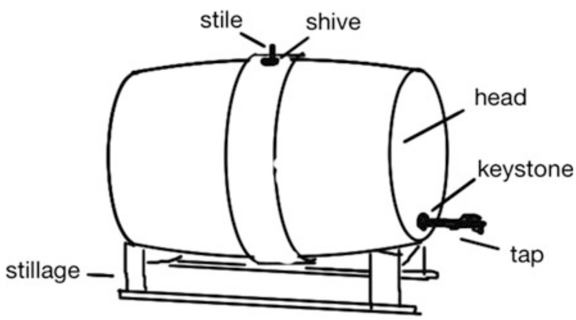
Alternative forms of the conditioning tank do exist. In fact, the CCV can be used as a conditioning flask as long as it can be pressurized safely into the 10–15 psi range. In addition, the CCV would work best if it was also jacketed and temperature controlled. This is not the best vessel to choose as the brewer would likely need to add a carbonation stone to the vessel after fermentation were complete—which could result in the loss of a significant amount of beer during the exchange. If the carbonation stone were in place prior to the start of fermentation, it would be possible that flocculating yeast and residual trub could clog the pores of the stone and render it less effective in carbonation. For this reason, should a CCV be employed as a conditioning tank, the brewer would likely naturally carbonate the beer by setting a pressure regulator on the blow-off arm to be equal to the final volumes of CO_2 desired in the beer.

10.2.2 Cask Conditioning

Another alternative to the stainless steel conditioning tank is the cask. Cask-conditioned ales are quite popular in some parts of the world (notably in Europe). While many patrons in the USA consider cask ales as a novelty, their popularity is beginning to catch on. With over 180,000 members, the Campaign for Real Ale (CAMRA) in the UK has worked since 1971 to advocate for cask ales, pubs, and consumer rights. This organization provides a listing of over 4500 pubs in the UK that support and offer cask ales. They also run an annual festival that highlights more than 900 cask-conditioned beers and ciders.

Cask ales are often fermented in a different vessel and then moved to the cask for conditioning. The cask itself has a very useful shape that results from how the cask is used as shown in Fig. 10.7. The specific parts of a cask have very specific names as well. Additions to the cask take place through a *bunghole* that lies on the central band of the cask. The bunghole is simply a hole in the keg that can be sealed by placing a bung (a stopper) into the hole. Once the additions are complete, a *shive* (a bung with a small hole in the center) is pounded into the bunghole. A *stile*, a peg

Fig. 10.7 The modern cask and its key features



that can be inserted into the shive, is used to control the conditioning process. That control could be to allow an active fermentation to expel barm from the cask, or it could be to pound the stile into the shive to allow the beer to carbonate. Another bunghole exists in the head of the cask near the edge. This hole is sealed with a bung known as a *keystone*. When the beer is to be served, a *tap* is hammered through the keystone. This pushes the keystone into the keg and replaces it with the firmly seated tap. Casks are stored on *stillage* while they mature. These racks can be designed to hold multiple casks and even stacked one on top of another to conserve space in the cellar. When the beer is to be served, it is moved to an angled stillage that tilts the cask forward to allow all of the beer to exit through the tap.

As you might imagine, tapping a cask involves a steady hand to hold the tap against the keystone and strike it firmly with a rubber or wooden mallet. The process pushes the keystone into the cask. And, because the cask is under pressure from natural carbonation, the process typically results in a spray of beer and foam. Poorly struck taps can spray a large amount of beer all over the person holding the tap in place.

As we noted much earlier in this text, early casks were wooden (Fig. 10.8). Some brewers continue to use the wooden cask because of the advantages of conditioning in contact with wood. The parts to the wooden cask are each named. The cask itself was made up of a series of *staves* that locked into the *head* boards (the edge pieces were known as cants). The bunghole located near the center was entirely placed in the middle of one of the staves. Another was placed entirely within one of the head boards. This ensured that the holes did not fall on a joint.

Either wooden or metal bands were tightened around the staves to hold them into place. Typically, there were three *hoops* on each half of the cask, the *bilge* hoop, the *quarter* hoop, and the *head* hoop. Construction of the cask was, and still is, an art. Until the casks were soaked in water, they tended to leak between the joints of adjacent staves and the head boards. However, once the wood soaks up enough water, the staves and head swell making a very tight fit.

Modern casks can be made of stainless steel. They have the same basic shape, but because the cask is a single piece of metal, no need for hoops exists. And

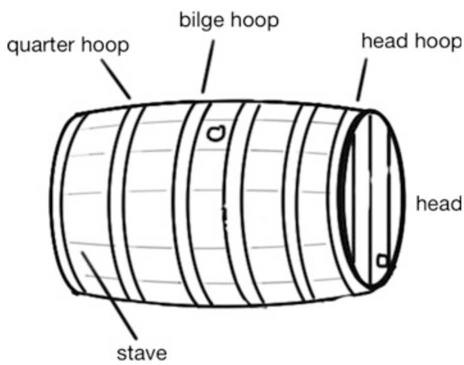


Fig. 10.8 The parts of the wooden cask

because there are no joints in the stainless steel casks, they do not leak. They still have the bunghole on the end and at the middle.

Typically, *racking* to a cask takes place while sufficient fermentable sugars remain in the beer. Thus, carbonation of the beer takes place in the cask. If sufficient sugars do not remain, the brewer can add *priming sugar* to the fermenter immediately before racking to the casks. This priming sugar tends to be corn sugar, dextrose, or even cane sugar depending upon the specific recipe. In some cases, caramelized sugars can be used to add additional flavor while also carbonating the beer.

If the yeast count is relatively low when the beer is to be racked to a cask for conditioning, additional yeast can be added. Approximately 1 million cells/mL is needed to ensure adequate carbonation and conditioning in the cask. This additional yeast is often added to the fermenter immediately prior to casking. This helps to ensure that the yeast are adequately distributed throughout the beer before it is racked. Conditioning in a cask does not limit the addition of other components to reduce haze, adjust flavor, etc., except that these additions tend to be performed in the fermenter immediately before racking to the cask.

Chapter Summary

Section 10.1

Conditioning is performed on beer to ensure flavor stability, reduce haze, and carbonate the beer.
Lagering is a fermentation process where the temperature is kept low, causing yeast metabolism to slow but dramatically reducing haze.
Warm conditioning, known as the diacetyl rest, is performed in order to speed the uptake of diacetyl during fermentation.

Section 10.2

The conditioning tank is a specialized vessel used to finish the beer before sending it to the packaging line.
Cask conditioning naturally carbonates the beer and allows flavor stabilization in a more traditional method.

Questions to Consider

1. Use Fig. 10.1 and add a line that indicates the concentration of ethanol as the fermentation progresses.
2. Use Fig. 10.1 and add a line that indicates the concentration of α-acetolactate.
3. Consider Fig. 10.3. Does this figure explain why the reaction is faster when the pH is lower? Why or why not?

4. Use the Internet and look up the freezing point (i.e., melting point) of ethanol–water solutions. At what concentration of ethanol would a beer need to be in order to be lagered at −3 °C?
5. Why is the carbonation stone placed at the bottom of the conditioning tank?
6. A brewer at 5000 ft altitude is carbonating beer. Is the concentration of CO_2 in a bottle of beer less than a beer that is made at sea level?
7. If a beer has 2.2 volumes of CO_2, what is the concentration in ppm? Assume that the measurement is done at 0.80 atm and 25 °C. How does this compare to a measurement performed at 1.0 atm and 25 °C?
8. A beer is found to contain 1200 ppm CO_2. How many volumes of beer is this?
9. In our calculations of the relationship between volumes of CO_2 and its concentration in ppm, we assume that the gas behaves ideally. CO_2 is not an ideal gas. For one reason, CO_2 interacts with itself (an ideal gas does not). If we were to perform the volumes to ppm calculation assuming CO_2 was a real gas, how would this change the result?
10. Calculate the ppm CO_2 in beer if it contains 2.6 volumes of CO_2. Assume the measurement is performed at 25 °C and 1.0 atm. Would this be different if the gas was N_2?
11. A brewer adds silica gel to the beer in the conditioning tank. Why would this be done and what disadvantages are there to doing so?
12. A brewer adds caramel sugar instead of caramel color to the beer in a conditioning tank. What would the effect of this be?
13. If a beer is found to only contain 250,000 yeast cells per milliliter, does the brewer have to add yeast when the beer is transferred to the conditioning tank? Why or why not?
14. A beer is transferred from the primary fermenter to the conditioning tank. It is found to contain ten million cells per pint. Is this enough yeast to perform a natural carbonation?
15. Why is oxygen not added when additional yeast is added to the conditioning tank?
16. Given the answer to question 15, what step in the process of transferring beer into a conditioning tank must be followed?
17. What happens to any precipitate (flocculated yeast, sediment, etc.) in a cask?
18. A brewer wishes to prepare a strawberry-flavored ale. This can be done using fresh strawberry puree, strawberry preserves, or artificial strawberry flavoring. Describe the pros and cons of each method.
19. Look up the structure of PVPP on the Internet. Then, indicate how this compound could mimic the structure of a protein.
20. Which do you think would be more volatile and provide an aroma to the beer: diacetyl, acetoin, or 2,3-butanediol? Why did you choose your answer?
21. In the introduction to this chapter, we noted that conditioning can reduce or eliminate bacteria in the beer. Describe how this might occur?
22. Calcium oxalate, also known as beer stone, can be an issue in beer. If the brewer thinks it may be an issue, how would it be removed in the conditioning tank?

23. A brewer forgets to perform a warm conditioning step. Can this step be added later in the primary fermentation? What effect would doing so have on the beer?
24. Why does lagering tend to clarify beer?
25. Why is the cask larger in the center than on the ends?
26. A beer is pumped into a 10-m-tall conditioning tank. The pump is 0.5 m below the filling port of the conditioning tank. What is the delivery head required to begin the transfer? What is the delivery head of the pump when the tank is full?
27. Would the delivery head for a pump be less if the beer from question 26 is transferred into the conditioning tank through the CIP ball?
28. What would happen to a carbonated beer in the conditioning tank, if the glycol cooling system breaks and the temperature rises from 40 °F to room temperature (72 °F)?
29. Using the information we have uncovered in this text, what would you do if the bitterness (by IBU measurement) did not conform to the brewer's expectations? Be sure to indicate what to do if it is too low or too high.

Laboratory Exercises

Diacetyl Determination in Beer

The measurement of diacetyl concentrations in fermenting wort are required to determine the ending point of the fermentation. In this experiment, diacetyl will be measured in commercial beer, and if possible, in an fermenting sample of wort.

Equipment Needed

2 or 3 12-oz samples of beer
distillation setup (250-mL distilling flask, heating mantle, still head, condenser);
graduated cylinder, 50 mL;
graduated cylinder, 5 mL;
volumetric flask, 10 mL;
pipettes, dropping with a bulb;
diacetyl (aka, 2,3-butanedione) 0.500 gm dissolved in 1.0 L water. Store in the dark in a cool location;
water, distilled
α-naphthol solution (4 g α-naphthol in 100 mL isopropanol). Add decolorizing carbon, shake or stir for an hour, then filter into an amber bottle);
creatine solution (0.3 g creatine in 80 mL 40 % aqueous KOH, store cold);
Optional:
Fermenting wort (prepare a 1.040 wort from dry malt extract and begin fermentation at room temperature 24–36 h prior to laboratory).

Experiment

Obtain 100 mL of beer (or fermenting wort). Place this into the distillation setup (see Fig. 10.9) and distill at least 15 mL into a 50-mL graduated cylinder containing about 5 mL water. Once the sample has been collected, turn off the distillation apparatus and dilute the distillate to 25 mL with water. Then, clean out the distillation apparatus and proceed to the next beer sample. WARNING: the samples may foam excessively during the distillation. Monitor the application of heat so that the distillation does not boil over.

Prepare solutions of diacetyl as follows. From the stock solution (500 ppm diacetyl), take 1 mL of the stock solution and add 99 mL water. This solution is 5 ppm diacetyl.

Prepare 5 standards from 0.5, 1.0, 2.0, 3.0, and 4.0 mL of the 5 ppm diacetyl solution by adding the indicated amount of the diacetyl solution to a 10-mL volumetric flask. Then, add 1.0 mL of α-naphthol solution and swirl. Then, add 0.5 mL of creatine solution and swirl again. Finally, add water to dilute the sample to the mark. Invert a few times to mix and then pour the solution into a test tube until ready to measure. Repeat the formation of the other standards by repeating the procedure with the indicated amounts of the 5 ppm diacetyl solution.

Exactly 5 min after pouring into the test tube, read the absorbance of the solution at 530 nm. Once all solutions have been measured, make a plot of the concentration of diacetyl versus the absorbance of the solutions. This is the standard curve (known as the Beer–Lambert plot, or Beer's law plot) for the measurement.

Then, each distilled sample is treated and measured. To do this, take 5 mL of the sample and add it to a 10-mL volumetric flask. Then, add 1.0 mL α-naphthol solution and swirl. Add 0.5 mL creatine solution and swirl again. Finally, dilute to the mark and invert the volumetric flask multiple times to mix. Pour the solution into a test tube. Exactly 5 min after pouring into the test tube, the sample should be placed into the spectrometer and its absorbance measured at 530 nm.

Determine the concentration of each of the distilled samples from the standard curve by referencing the absorbance of the distilled sample and determining the concentration of diacetyl in ppm.

OPTIONAL EXPERIMENT

A fermenting sample of wort can be sampled periodically (i.e., every 3 h) over a multiple-day period. If this is done, each 100 mL sample collected is placed into a plastic bottle and cooled to 2 °C until measured in the laboratory. If this is done, a plot of the concentration of diacetyl can be made for the particular fermentation.

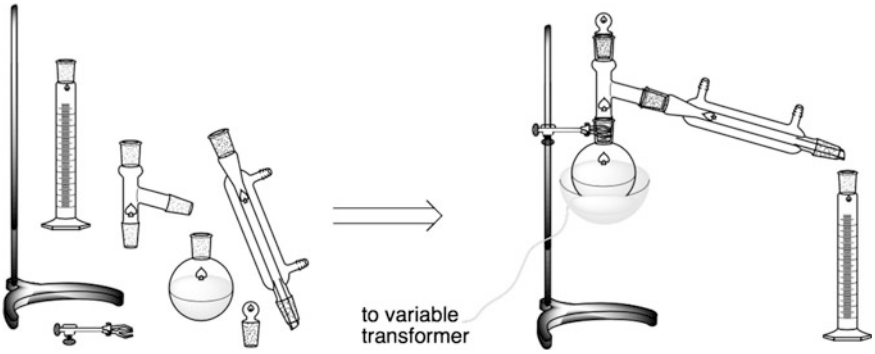


Fig. 10.9 Distillation setup. The parts *on the left* are assembled into the apparatus. Note the addition of the variable transformer to control the heating mantle. The condenser is cooled by attaching a hose to the condenser from the sink and running a hose to the drain

Adjusting the Color

This experiment is designed to illustrate how the SRM color of a beer sample can be adjusted in the conditioning tank.

Equipment Needed

Beer sample, 12 oz (best for this experiment if it is a very clear light-colored beer);
Caramel color solution (or a degassed sample of a dark and clear beer);
Spectrometer capable of measuring at 430 and 700 nm.

Experiment

Obtain a sample of beer and degas it by shaking it repeatedly for at least 10 min. Allow it to settle and the foam to collapse. Then, place the sample in the spectrometer and measure the absorbance at 430 and 700 nm. If the absorbance at 700 nm is smaller than 0.039 times the absorbance at 430 nm, the sample is considered free of turbidity. The SRM color is then 12.7 times the absorbance at 430 nm. If the absorbance at 700 nm is greater than 0.039 times the absorbance at 430 nm, the sample cannot be used (it is considered turbid). After measuring the color of the beer sample, use the caramel color to adjust the color of the beer sample. Take 10 mL of the beer and add a small amount of the caramel color (record exactly how much was added). Then, determine the SRM color of the sample. Repeat this at least 3 additional times.
Create a plot of the SRM color of the beer versus the amount of caramel color added. Is the plot linear? Why or why not?
Verify the plot by creating a beer sample with an SRM color of 18 and confirming the color using the spectrometer.