# BICEP #8

This session covers Proteolytic and Diastatic Enzymes, Mashing and Sparging, Astringent and Sweet off flavors and Category 17 - Sour Ales. Thanks to Scott Ofslager for providing photos and writing the original draft for some of the malting and sparging sections.

### Key to Abbreviations and Text

**Bolded Text (except for headers) is important information which you should know for the exam.**

*Italic Text is "just for fun" and won't be covered on any of the exams.*

***** This material might appear on the Online Qualifier Exam.

† This material might appear on the Tasting Exam.

‡ This material will be (or might be) tested on the Written Proficiency Exam.

## Part 1: Proteolytic and Diastatic Enzymes*‡

Before we can discuss mashing, we must discuss the crucial enzymes which make mashing (and beer) possible. While there are many different enzymes found in malt, for simplicity they can be broken into two categories: Proteolytic Enzymes and Diastatic Enzymes.

## A) Proteolytic Enzymes

**Works on: Proteins.**

**Optimum Temperature *Range*: 113-122 °F (active 103-122 °F).**

***Description:* Proteolytic enzymes naturally occur in malt. In the mash, they degrade larger proteins in the malt into smaller proteins and amino acids (the building blocks of proteins).**

**Proteolytic enzyme action is encouraged during mashing by using a "protein rest" at about 120 °F for 15-20 minutes.** During this time:

1) Proteinase breaks down proteins into smaller fractions such as polypeptides, which are necessary for good head retention.

2) Peptidase breaks down polypeptides into peptides & amino acids, essential for proper yeast growth & development.

**The highest protease enzyme levels are found in pale, fully-modified malts.**

**There is no enzyme activity (either proteolytic or diastatic) in crystal/caramel or roasted malts.**

**Effects on *Mashing Process*:** Proteolytic enzyme action has the following effects on the brewing process

1) Improved lauterability of mash when using high-protein malts (e.g., wheat, rye) meaning faster runoff and less risk of stuck mash. In turn, this helps minimize exposure to oxygen and fewer potential problems associated with a difficult lautering process.

*2) Aids yeast health by breaking (some) proteins into amino acids which the yeast can use to grow. This reduces the need for yeast nutrients and the risk of improper fermentation.*

***Effects on the Finished Beer:*** Proteolytic enzyme action has the following direct effects on the finished beer:

**1) Reduced cloudiness** due to smaller protein particles.

**2) Aids head retention** due to production of medium- and short-chain polypeptides.

3) An excessively long protein rest (1+ hour) can reduce head & body.

4) Insufficient peptides and amino acid levels can lead to poor yeast health, indirectly causing yeast-derived off-flavors (e.g., diacetyl, acetaldehyde, higher alcohols) and reduced wort attenuation.

## B) Diastatic Enzymes

***Works on:*** Starches.

***Description:* Diastatic enzymes naturally occur in malt. In the mash, they degrade larger starches in the malt into smaller starches (e.g., dextrins) and fermentable simple sugars (e.g., mono & disaccharides).**

**They begin working as soon as starches in the malt are gelatinized** by being soaked and heated in the mash (gelatinization temperature varies by type, usually 80-160 °F).

**The highest diastatic enzyme levels are found in pale, fully-modified malts.** These are so-called "hot" malts with very high rating in degrees Lintner or Windisch-Kolbach. Some malts contain just enough diastatic enzymes to convert their own starches. Other malts have enough diastatic enzymes to convert their own starches and some extra starches.

**There is no enzyme activity (either proteolytic or diastatic) in crystal/caramel or roasted malts.**

**The two most important diastatic enzymes are Beta Amylase and Alpha Amylase.**

### 1) Beta Amylase

***Optimum Temperature Range:* 130-150 °F. Denatured above 154 °F**

**Beta Amylase produces monosaccharides (e.g., maltose, glucose)** by breaking off maltose units from reducing ends of starches by cleaving 1-6 bonds. **It is unable to quickly reduce large starch chains and is unable to reduce branched starch chains** (e.g., amylopectins).

***Effects on Beer:* Mashing at temperature ranges which favor Beta Amylase action produces more fermentable wort, but thinner-bodied beer with lower head fullness and retention.**

### 2) Alpha Amylase

***Optimum Temperature Range:* 149-158 °F. Denatured above 167 °F)**

**Alpha Amylase breaks links from starches at random** by cleaving 1-4 bonds. **This produces short-chain starches**

## Helpful Mnemonics

**M.A.L.T.** = More Alcohol, Lower Temperature. Because mashing at temperatures preferred by Beta Amylase results in a fermentable wort.

**Beta Amylase:** It's "beta" because it's a "wimp" compared to alpha amylase. It can't stand higher temperatures and it nibbles on molecule ends while alpha randomly tears apart big starch molecules. It's also the "first act;" alpha amylase comes in afterwards (once temperatures rise) to finish the action.

**and polysaccharides (e.g., dextrins).** It is unable to completely reduce branched starch chains. It aids the action of beta-amylase by creating more reducing ends for them to work on.

*Effects on Beer:* **Mashing at temperature ranges which favor Beta Amylase action produces a more dextrinous, less fermentable wort, producing fuller-bodied beer with higher head fullness and retention but lower alcohol levels.**

# Part 2: Mashing and Sparging*‡

## A) Mashing Basics

**What is Mashing?: Mashing is the process of soaking crushed malt in hot water to liberate the sugars and proteins which form the wort.**

**Chemically, this gelatinizes starches and activates hydrolyzing enzymes contained within the malt.** The enzymes act on the starches to create fermentable sugars in the wort and act on proteins to create other products necessary for optimum yeast health and nutrition. **Mashing gives the brewer full control over wort composition.**

**"Rests" at certain temperatures, for certain lengths of time, favor the action of various enzymes, although rest temperature ranges can overlap. Mashing at a lower temperature favors alcohol production at the expense of body and head retention. Mashing at a higher temperature favors body and head formation and retention at the expense of ABV.**

**Mashing Terminology:** Because it is a very old technique, there are many jargon words are used to describe aspects of the mashing procedure.

The process of infusing the crushed malt with water is called <u>Doughing-In</u> or <u>Mashing-In.</u> The mixture of crushed grains and hot water is called the <u>Mash</u> and the container which holds the mash is called a <u>Mash Tun.</u> The water used for mashing is called <u>Mash Liquor</u> and the container which holds it is called the <u>Mash (or Hot) Liquor Tun.</u>

The (usually) hot water meeting the room temperature grain results in a mash which has a temperature someplace in between the two; this is referred to as the <u>Strike Temperature.</u>

The time the mash spends soaking at a particular temperature is called a <u>Rest</u>. Frequently, the mashing process is completed by heating the mash (either directly or by additional infusions of liquor) to 167-170º F in a process called <u>Mashing-Off</u>, <u>Mash-Out</u>, or <u>Doughing-Out</u>.

After the mash has been steeped sufficiently it is transferred to a <u>Lautering Tun</u> or <u>Grant</u> and the liquid portion of the mash is drawn off in a process called <u>Lautering</u>. In most homebrew systems, the mash tun also serves as a lautering tun so the mash isn't transferred before lautering. In most commercial breweries, the mash tun and the lautering tun are separate.

During lautering the grains are usually sprinkled or soaked with additional water to extract extra sugars in a process called <u>Sparging</u>. The water used for this purpose is called the <u>Sparge Liquor</u>. In some cases, the wort and sparge water recirculated through the grains to extract even more sugar, in a process called <u>Recirculation</u> or <u>Vorlauf</u>.

<u>Batch Sparging</u> refers the process of repeatedly soaking the grains and drawing off the sparge water, while <u>Continuous (or Fly) Sparging</u> consists of adding sparge water to the mash at the same rate it is drawn off. The liquid extracted during lautering is referred to as the <u>Run-Off</u>, and once collected in the <u>Wort Tun</u> (AKA <u>Copper</u> or <u>Wort Kettle</u>) it becomes the <u>Wort</u>.

*Milling:* **Milling is a pre-cursor to mashing. It crushes the contents of the kernels, increasing the amount of surface area available for hydolyzation and enzyme action. Crushed grain husks form a filter bed which helps clarify mash run-off during lautering and sparging.**

But, if grains are milled too coarsely (a "coarse crush") the mash will suffer from increased dough-in time, reduced enzyme efficiency and reduced extract yield.

Conversely, if grains are milled too finely (a "fine crush") there is increased risk of stuck mash, potential troubles with wort clarity and the risk of bits of grain husk getting carried into wort during sparging (resulting in polyphenol extraction during wort boil, which causes protein haze and astringency).

*Mash Requirements:* **For optimal mashing, the mash must have the following traits:**

***1) pH range: 5.2-5.8*: The brewer usually needs to adjust water chemistry to get his mashing into this range using additions of mineral salts, acids, or use of dark or acidulated malt, testing the mash pH periodically using pH strips or pH meter.**

**Higher pH levels cause trouble with tannin extraction and reduced enzyme efficiency. Lower pH levels cause reduced enzyme efficiency.**

Some buffering solutions (e.g., Five Star $5^2$™) allegedly get pH into optimum range without need for acid or brewing salt additions. More typically, the brewer "dials in" his water chemistry by calculations and trial and error.

***2) 50+ mg/l Calcium Ions:* At least 50 ppm of calcium ($Ca^{++}$) ions are needed for optimum mash efficiency.**

***3) Starch Conversion Test:* With well-modified malts, a mash of 30-90 minutes guarantees full conversion, but in some cases, the brewer might not be sure that his mash has fully converted its starches to sugars. In such cases, he can use an Iodine test.**

**In addition to lower extract yields, incomplete conversion can result in starch haze.**

***Iodine Test:*** *To perform the iodine test, take a drop of liquid from the mash and put it on a white porcelain plate. Add a drop of iodine solution (Iodophor™ will work) to it. If the sample turns dark purple, starch conversion is incomplete.*

## B) Typical Mashing Techniques

*Note:* one of the potential questions on the BJCP Written Proficiency Exam requires you to describe three different mashing techniques. The three techniques listed below, or two of the techniques listed below and one of the Cereal Mashing techniques listed in Section D are all suitable answers.

**Types of Mashing: There are two basic types of mashing *Single Temperature or Infusion Mashing* where the grains are steeped at a constant temperature and *Temperature Control or Step Mashing* where the mash temperature is held at progressively higher temperatures to favor the activity of certain enzymes at each step along the way. *Decoction Mashing* is a form of Step Mashing.**

Since step-mashing (other than decoction mashing) requires constant, careful temperature control, it is less common among homebrewers, but it is the most common mash method used by commercial brewers since it combines many of the advantages of decoction mashing while saving time and fuel. Some advanced homebrewers also use step-mashing either by adding hot water to progressively raise the mash temperature (a method known as multiple-infusion mash) or by directly heating the mash tun.

Some homebrewers use a system called a HERMS (Heat Exchange Return Mash System) which uses a heater and a pump for step mashing and improved sparging. A simpler homebrew system is the RIMS (Recirculating Infusion Mash System) which just uses a pump to recirculate the sparge liquor during lautering. Both systems have their advantages and disadvantages, the main disadvantages being added expense and complexity and the increased risk of ***Hot Side Aeration*** (oxidization) of the wort during recirculation. With any lautering system, there is always the risk of a ***Set*** (or ***Stuck***) ***Mash***, where the ***Grain Bed*** (the solid part of the mash) becomes so compacted that the liquid portions can't percolate through it.

**1) Infusion Mashing (AKA Single Temperature Mashing):** Infusion mashing is the basic all-grain brewing technique, since even with step-mash techniques, the grains are infused with water at the initial strike temperature. It has been used since antiquity, but in modern times, it is most closely associated with the production British, Scottish and Irish beers, although many commercial breweries in the British Isles now use some form of step mash. Infusion mashing is also used by the majority of homebrewers, since it is relatively easy to do and lends itself ideally to using a picnic cooler or plastic bucket as a mash tun.

**With an infusion mash, the mash liquor is heated to a temperature 160-165 ºF to achieve a strike temperature within proper temperatures for saccharification (140-158 ºF, with 149-155 ºF being the optimal range). It is then allowed to rest at saccharification temperatures for the entire mashing period, typically 30-60 minutes or more.1**

***Advantages of Infusion Mashing:*** Infusion mashing requires a minimum of labor, time, energy, equipment & skill. It is suitable when using well-modified malts (as, historically was the case for most malts produced in the British Isles).

***Problems with Infusion Mashing:*** The main problem with using an infusion mash is that it is only suitable for well-modified grains with lower protein content.[2] It doesn't work well if using grains which require a protein or beta-glucanase rest for optimal performance. Happily, however, most modern malts are suitable for infusion mashes.

A second problem is hitting the proper strike temperature and keeping the temperature steady, since even a change of a few degrees can drastically alter the character of the wort. In practice, however, as long as the temperature is kept with ±2 ºF of the intended strike temperature the results will be satisfactory. Infusion mashes are also 10-15% less effective at extracting sugars than a step mash.

If the strike temperature is too low, additional hot water is used to raise the temperature, as long as the ratio of water to grist doesn't fall below 1.5 quarts of water per pound of grain.

## Infusion Mash Tips

* When using an infusion mash, heat more water than you think you'll need in case you don't hit your strike temperature.

* Since no heat is applied to the mash, it is necessary to have either a large volume of mash or an insulated mash tun to keep the temperature steady.

* To hit your strike temperature more accurately, preheat your mash tun by flooding it with a couple of gallons of boiling water before you add your grist. You can pour off the water or use it as part of your mashing liquor.

* Your grist is less likely to ball and will form a better mash bed for sparging if you add the grain to the mash liquor, rather than vice-versa.

If the strike temperature is too high, a bit of cool or cold water is added.

Another problem is that, unlike a decoction or step mash, which is regularly stirred and which can be transferred to a lautering tun, infusion mashes are not stirred and the mash tun doubles as a lautering tun. Stirring an infusion mash makes it more likely to set during sparging.

A final problem is that infusion mash limits the use of adjunct grains, if they require a cereal mash or protein rest.

**2) Step Mashing (AKA Step Infusion Mash, Temperature-Controlled Mash): Step Infusion Mashing is a technique where the brewer holds the mash temperature progressively higher temperatures for set amounts of time. Step mashing starts with the lowest temperature rest on the schedule. When that rest is completed, the mash is then directly or indirectly heated to raise it to the next rest temperature.**

**The different rests encourage the action of different enzymes which are most active at a particular temperature range.**

Most commercial brewers use some form of step mashing.

***Methods of Step Mashing:*** Step mashing is the trickiest of the three types of mashing, since it requires one of the three methods of temperature control:

1) Directly heating the mash tun. Tricky to manage since the brewer must have extremely good control over temperature control. Step mashing is possible using a stove and stock pot, but it requires constant stirring of the mash and constant monitoring of mash temperature, even more so than for a decoction mash. Professional brewers typically achieve direct heating by either steam-infusion, where steam is used to raise the mash temperature, or by having a jacketed mash tun where the hot water used to increase the mash temperature is contained in a vessel outside the mash tun itself.

2) Progressive additions of hot mash liquor. This can work reasonably well for a homebrewer, as long as the initial mash is very thick so that subsequent water additions don't overflow the mash tun, don't thin the mash too much and, most importantly, don't raise mash pH above the optimal 5.2-5.4 range. Professional brewers occasionally use this method, especially if they wish to thin the mash to achieve better lautering flow.

3) Decoction mashing, described below.

***When Is Step Mashing Appropriate?:*** Most modern malts don't need to be step-mashed. Any malt can be infusion mashed as long as its fine/coarse extract ratio difference is less than

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[1] Palmer suggests at least 1 hour for full starch conversion. How to Brew, p. 167.

[2] Any malt can be infusion mashed if its fine/coarse extract ratio difference is less than 1.8%, if it has a soluble nitrogen ratio (S/T) of 38% or more, and is at least 95% or more mealy. New Brewing Lager Beer,  p. 300.

1.8%, if it has a soluble nitrogen ratio (S/T) of 38% or more, and is at least 95% or more mealy.

In practice, this means you only need to step mash if you are using a large percentage (20% or more) of unmalted grain or non-barley malt, or if you are using predominantly traditional types of U.S. 6-row lager malt or traditional Continental Lager, Pilsner or Munich malt. In any case, you should determine whether to step-mash or infusion mash based on the type of malt you are using, rather than the type of beer you are brewing.

***Advantages of Step Mashing:*** Despite the extra trouble, you can get good results by using a step mash or decoction mash to brew beers which are normally infusion mashed.

1) *Increased Control Over Wort Composition:* A step mash gives the brewer complete control over the composition of his wort, since he can use different rests to encourage the production of certain proteins, starches, sugars and other products. Improved control over your saccharification temperature also allows you to lighten the body of your beer, which is desirable in styles of beer such as pale ale.

*2) Allows Use of Undermodified Malts:* Like decoction mashing, step mashing can compensate for the limitations of undermodified malt.

*3) Allows Use of High-Protein or Gummy Malts and Adjunct Grains:* A step mash can also be helpful if you are brewing a beer with a high percentage (20% or more) unmalted grain or wheat, oat or barley malt, since it allows you to incorporate a protein and/or beta-glucanase rest into your mashing schedule.

*4) Allows Mash-Out Without Adding Water:* This is desirable particularly when brewing low-alcohol beers where you don't want to thin the mash any further, both to avoid problems with tannin extraction (due to pH and specific gravity falling out of desirable sparging ranges) and to hit a specific original gravity reading without having to reduce your volume of sparge liquor or reduce wort volume by boiling.

If using a decoction mash instead of an infusion mash, however, you might also find that the mash extracts too much roast flavor from dark grains, so consider adding them partway through the mashing schedule.

***Disadvantages of Step Mashing:*** There are serious drawbacks to using step mashing.

*1) Requires Extra Time and Labor:* Additional rests increase total mashing time. Unless the mashing equipment is automatically controlled, the brewer can't just leave the mash to convert on its own. He must add water or heat to adjust the temperature upwards.

*2) Requires Extra Equipment:* Step mashing requires some method of heating the mash within the mash tun, which almost requires an all-metal mashing set-up and some method of directly heating the mash. Insulation is also needed to keep the mash tun at the proper temperature. Many homebrewers also incorporate some sort of computerized temperature and flow controls, which adds further complexity and expense. Commercial brewers typically use computer-controlled, double-walled, steam-heated mash tuns.

*3) Directly-Heated Mash Tuns Can Potentially Scorch the Mash:* This is more typically a problem for homebrewers using relatively inexpensive stainless steel kettles or "keggles" (i.e., converted beer kegs) as mash tuns and very powerful propane-fired burners.

*4) Hot Water Can Thin the Mash:* This is a problem only for brewers who step mash by adding hot water. Excess water can result in an excessively thin mash, raise pH out of proper range or result in wort with insufficiently high specific gravity.

**3) Decoction Mashing: This is a simple, traditional German form of temperature-controlled mash where part of the mash is removed from the main mash tun, heated to boiling in a separate container, held there for a certain amount of time and then returned to the mash to raise overall mash temperature.**

**It was developed by brewers in the days before thermometers and modern malting techniques to compensate for imperfect temperature control and to better utilize undermodified malt** (malt with a high degree of complex proteins and unfermentable starches and relatively low levels of enzymes needed to break those compounds down into smaller molecules). It is still used today to achieve the rich, malty flavors of some German and Czech beers.

**Because the necessary enzymes remain in the liquid portion of the mash, they are left behind because the brewer scoops out the thick portion of the grain for the decoction.** The key is to remove the thickest part of the mash, so you get the hard-to-get-at proteins and complex starches hidden inside your grains.

**Practically, decoction mashing is a form of Step Mashing (see below) where the brewer removes a fraction (usually a third) of the moist grain from the mash tun and boils it in a separate container. Once it is heated, the grain is mixed back into the rest of the mash, heating the entire mash. Repeated decoctions progressively increase the temperature of the mash in steps, until Mashing-Out temperature is reached.**

Briefly, the steps are as follows: 1. <u>Dough in</u> at first desired rest temperature. 2. <u>Remove a third of thick portion of the mash</u>. 3. In another kettle, <u>briefly raise the decoction temperature saccharification temperatures (2-5 minutes).</u> 4. <u>Boil the decoction for 15-30 minutes</u>, stirring constantly and adding water as necessary to avoid scorching. 5. <u>Mix the decoction back into the main mash</u> to raise overall temperature. Mix thoroughly to avoid hot spots in the mash. 6. <u>Repeat</u> up to 2 times.

Because the moist grain is boiled in the decoction, decoction mashing breaks down cell walls, giving protease (protein-converting) and amylase (starch-converting) enzymes better access to the contents of each grain of malt. Furthermore, because the decoction is held at starch conversion temperatures before being boiled, the grain in a decoction rest goes through a saccharification rest either two or three times. This means decoction mashing gives the brewer a greater degree of starch conversion than with infusion mashing or other techniques of step-mashing.

***Types of Decoction Mashing:*** Historically, brewers used a variety of different decoction mash schedules.

*1) Triple Decoction Mash (Dreimaischverfahren):* This type of mash was traditionally used for Bohemian Pilsner, Traditional Bock, Doppelbock and Munich Dunkel.

It used a three-step mash where the mash was doughed-in using ground temperature (55-56 ºF) water. The first decoction raised the mash to protein rest temperatures, the second raised it to saccharification rest temperatures, and the third decoction was used to raise the mash to mash-out temperatures.

A variation of the triple-decoction mash was used by Czech Pilsner brewers, who used the same rest schedule, but doughed-in with warm water to get an acid rest.

Triple decoction mashes were necessary to compensate for deficiencies in water chemistry (in the case of Bohemian Pilsner) and/or poorly modified malts. They are not necessary when using modern brewing methods.

*2) Double Decoction Mashes (Zweimaischverfahren):* This is a two-step decoction mash used in the 19th and early to mid-20th centuries to brew other styles of German beer, which took advantage of better quality (i.e., better and more evenly modified) malts. A few German brewers still use it.

Typically, hot water is used during doughing-in to hit a strike temperature suitable for a protein or beta-glucanase rest temperature, then decoctions are used to bring the mash to saccharification rest temperatures and then to mash-out.

*3) Single Decoction Mash (Einmaischverfahren):* A single decoction mash is mostly commonly used to get to mash-out when otherwise using an infusion mash. It is well-suited to modern, well-modified continental lager and amber malts.

Homebrewers sometimes use a single decoction mash where the strike temperature is either at the proper temperature for a beta-glucanase and/or protein rest and a single decoction raises the temperature to saccharification temperatures with no mash out. Or, they hit a strike temperature suitable for saccharification at mashing-in and then use a single decoction to mash-out.

***Advantages of Decoction Mashing:*** In some ways, decoction mashing can be considered an improvement over infusion mashing for the following reasons:

*1) Allows Limited Step Mashing:* It allows you to use step mashing using a mash tun which can't be directly heated, such as a picnic cooler, without needing to increase mash volume and thinning the mash by adding hot water.

*2) Easy to Hit Desired Strike Temperature:* It is easier to hit your desired strike temperature for a particular rest, since you can control the mash temperature by only adding back a portion of the boiled decoction or by quickly heating a bit more mash or by adding a bit of hot water.

You can also dough-in at a lower temperature; automatically getting a doughing-in, protein- or beta-glucanase rest. You can then raise your mash temperature to the critical temperature range where starch conversion occurs.

*3) Aids Starch and Protein Conversion:* The process of heating the decoction aids in the conversion of non-soluble starches (amylase and amylopectin) to soluble starches, such as dextrins, and fermentable sugars such maltose and glucose, by exploding starch granules and breaking down the protein matrix in undermodified malt. This improves brewhouse efficiency (degree of sugar extraction from the malt) by 10-15%, especially when using undermodified malts.

The thickness of a typical decoction mash also favors the production of dextrins over fermentable sugars, increasing the maltiness and mouthfeel of your beer without increasing sweetness. This is particularly useful when brewing with unmalted grains or undermodified malts.

*4) Caramelization and Maillard Reaction Products:* Caramelization (i.e., direct heating of sugars) and Maillard (non-enzymatic browning) reactions occur when the decoction is boiled. This forms melanoidins which darken the color of the finished beer as well as contributing roasted, toasted and savory notes to its flavor and aroma. This aids the development of caramel and toasty notes when brewing beers such as Bocks, Doppelbocks, Dunkelbiers or Oktoberfests.

5) Boiling the decoction slightly reduces pH of the wort (by 0.1-0.15 pH)[3]. In doing so, it prevents tannins from malt husks from leaching into the liquor during sparging. A lower pH mash also makes it easier to brew very pale beers, such as Pilsners, using soft, low carbonate water, such as that from Lake Ontario.

*6) Increased Enzyme Efficiency:* Repeated exposure to saccharification rest temperatures maximizes the efficiency of amylase enzymes, while boiling the decoction gelatinizes starches before the main mash is raised to saccharification temperatures, making them more readily available to amylase during saccharification. This makes undermodified malts, such as traditional Continental base malts like pale lager, pilsner, and Munich, work much more efficiently, since they have only a third of the amylase enzymes found in equivalent British or American pale malts.

*7) Better Protein Breakdown:* Boiling the decoction directly breaks down proteins, increasing Free Amino Nitrogen (FAN) levels and preventing proteins from high-protein or undermodified malts from surviving through the wort boil. In turn, this prevents protein haze in the finished beer and improves its long-term stability.

Boiling the decoction also reduces protein gums which can interfere with sparging, causing a stuck mash. This is particularly handy when brewing with high-protein malts, such as wheat or rye or when working with unmalted grains. (This is true of any step mash schedule which includes a Protein Rest, but is particularly true of Decoction mashes.)

*8) Allows You to Brew Without a Thermometer:* Decoction mashing allows you to brew without a thermometer, since adding a decoction back into the mash naturally elevates it to the next rest on the schedule of acid rest, protein rest, saccharification rest and mash-out.

***Disadvantages of Decoction Mashing:*** There are trade-offs to using a decoction mash, however. In addition to the troubles associated with regular step mashing, problems include:

*1) Extremely Labor and Time Intensive:* Much more time is needed to do a decoction mash correctly, especially if you allow for more than one decoction rest. German brewers who used triple decoction mashing allowed six and a half hours for the entire mashing process, excluding time for sparging, wort boiling, cooling, pitching and cleanup! For this reason, most commercial brewers, even German and Czech brewers, no longer use decoction rests.

*2) Complexity:* It is more complex, since you can't just let the mash sit in the tun as you would with an infusion mash. At times you must monitor the temperature of two separate mashes, while stirring constantly to prevent your decoction from sticking to the pot or burning.

*3) Less Fuel Efficient:* It is more somewhat expensive, not just in terms of time and extra equipment, but also extra fuel. This is another reason why most commercial brewers have abandoned decoction mashing.

*4) Risk of Spoiling the Mash:* You have a greater risk of spoiling your beer by accidentally scorching a decoction and then returning it to the mash tun. This can impart unwanted bitter and smoky notes to the beer. Decoction mashing might

[3] How to Brew, p. 171.

also extract more DMS precursors from the beer. Oddly enough, however, there is little risk of imparting husky astringency if you perform your decoction mashing correctly. Even though you boil a portion of your grains in the decoction, which is normally a good way to extract tannins from grain husks, the low pH and thick mash within the decoction prevents this from happening.

*6) Requires Extra Equipment and Space:* Homebrewers who perform decoction mashing will need an extra stock pot, a sieve or other container, a mash paddle and a directly-heated source to heat the decoction. Homebrewers brewing on a large scale (i.e., 10-gallon batches or larger) might also have trouble pulling large enough decoctions, heating them up properly, and returning them to the main mash tun.

Commercial brewers need an extra kettle and associated directly-heated heat source, which takes up floor space in the brewery. They also need some method of transferring decoctions to and from the main mash tun, which adds additional bulk, expense and risk.

*6) Potentially Unnecessary:* Many of the same malt flavors produced by decoction mashing can be achieved by using modern melanoidin malts in a step or infusion mash, although these some brewers claim that decoction mashing still gives superior flavors. This is still another reason why most commercial brewers have abandoned the practice.

***Equipment Needed For Decoction Mashing at Home:*** Some additional equipment is needed to do decoction mashing.

*1) Time:* The major drawback of decoction mashing, especially double or triple decoction mashes, is that it adds several more hours to your brew day beyond the usual time needed to brew an all-grain beer

*2) Extra Stockpot:* An additional stockpot is needed to boil the fractions of the mash removed from the mash tun. Aluminum stockpots are ideal because they are relatively inexpensive and distribute heat evenly. Alternately, a copper-bottomed stainless steel pot will also work. If money is no object, you can also use a copper pot, which conducts heat even better than aluminum. Be careful when using stainless steel pots, since they can develop hot spots, especially if the bottom is thin.

*3) Mash Paddle:* You will need a mash paddle or some other method of thoroughly mixing the mash, such as a sturdy, long-handled spoon. Not only must the decoction portion of the mash be stirred while it is boiled, but you must also thoroughly stir the heated decoction back into the mash to get an even temperature increase.

*4) Measuring Cup:* You will need a 2-quart heat-resistant measuring cup, preferably made from plastic or Pyrex. You will need to make volume measurements on the fly when determining how much mash you pull for your decoctions.

***Useful Equipment for Decoction Mashing:*** The following items are handy to have, but not absolutely required:

*1. Gloves or Oven Mitts:* You will be carrying boiling hot kettles of mash and you will be stirring boiling hot mash which can splash you. Other protective equipment, such as an apron, proper clothing and proper footgear is also highly recommended when brewing. You are, after all, working around heat and large volumes of very hot liquid.

*2. Flame Tamer:* A 1/8" thick piece of copper or aluminum sheeting placed between your decoction pot and your burner will reduce the risk of hot spots and scorching in your decoctions by spreading the heat evenly.

*3. Insulated Mash Tun:* Any step-mash requires you to hold your mash at a steady temperature during the various rests, but decoction mashing demands an insulated mash tun since you even if you can apply heat to your main mash tun and your decoction vessel simultaneously, you can't easily monitor and control the temperature of both at the same time.

*4. Powerful Heat Source:* Some mashing schedules require you to bring up to several gallons of grain porridge up to a boil in 15-20 minutes. Also, since the length of your brew day is largely determined by how fast you can get wort or water to boil, being able to quickly heat liquid saves lots of time – and decoction mashing takes a lot of extra time to do right.

*5. Probe Thermometer:* You will need to take temperature readings from different parts of the mash to be sure that you have an even temperature. Digital probe thermometers are nice since they record their temperature quickly. Infrared thermometers are not suitable since they only measure temperature of the mash surface.

*6. Volume Measuring Device:* Most calculations for how much mash you should remove depend on volume measurements accurate to the nearest gallon, if not the nearest quart. You can estimate the volume of the mash in your tun by marking the inside or by making marks on a ruler or dowel rod or along the handle of a long-handled spoon (turning it into a charismatic spoon).

*7. Mash Rake:* Decoction mashes are traditionally raked to improve liquor flow during lautering.

***How to Do Decoction Mashing:*** Once you have your equipment, you can start decoction mashing, as with any other skill practice makes perfect.

1) Dough-In using a relatively thick mash[4], but purposely undershoot your normal infusion mash strike temperature by 20-30 ºF. This automatically gives you a doughing-in, beta-glucanase or protein rest (see Step Mashing, below for descriptions of the various rests). Alternately, some German brewers historically mashed-in using ground temperature (56 ºF) water and then used a decoction to raise the mash to protein-rest temperatures.

To get closer to your estimated strike temperature (if you aren't doughing-in using cold water), pre-heat your mash tun by flooding it with several gallons of boiling water, letting the water sit for a few minutes and then pouring it off. Be sure to stir your mash during doughing-in, playing special attention to the sides and bottom of the tun, to break up any balls of dry mash.

2) Take careful note of your mash volume (using a ruler, charismatic spoon or marks on the inside of your mash tun) and then take a temperature reading to estimate how much grain you must remove for your decoction, so that when you return the decoction to the main mash it will increase your mash temperature to the next temperature rest. For example, to have a saccharification rest at 148-155 ºF if your strike temperature is 120 ºF degrees you will need to remove up to a third of the grain. If your strike temperature is 135 ºF, you don't need to remove as much grain.

You can figure approximately how much grain volume you need to remove, as percentage of the mash, by using a

[4] 24-40 fluid ounces per quart of grist, with a doughing-in temperature of 58º F. New Brewing Lager Beer, p. 129. Palmer suggests 0.75-1.00 quarts of water per lb. of grist, but doesn't specify a doughing-in temperature. How to Brew, p. 169.

weighted average calculation, knowing that a boiling decoction has a temperature of 212 ºF:

Decoction Volume = 100% x (T2 – T1)/(212º F – T1)

Where *T1* is your current temperature and *T2* is your desired temperature in degrees Fahrenheit. John Palmer gives much more detailed calculations on p. 72 of ***How to Brew***.

In practice, once you are familiar with your recipe and mashing system, you can skip the calculations and just remove a set amount of grain, usually about a third.

3) After your grain is thoroughly soaked use a measuring cup to remove a portion of the grain. Scoop only the thickest part of the mash out of the main mash tun (see Figure 1) and put it in the additional stock pot (the decoction kettle). You want only the thickest portion because the enzymes are in the liquid portion of the mash and you don't want to destroy them by boiling them!

Take a little bit more mash than you think you'll need, since your main mash will have dropped in temperature a little bit little by the time you get back.

4). Add a little hot water to your decoction pot and apply slow heat, so that the grain doesn't scorch as you heat it.

5) Gently heat the mash to 150 °F, while stirring constantly, being sure to scrape the bottom of the kettle so that the grains on the bottom don't stick or scorch. When you get to 150 °F, shut off the heat to allow the starch enzymes to break down sugars. Hold this temperature for 15 minutes, then resume heating while stirring constantly, until the mash comes to a full, rolling boil (see Figure 2) while stirring the mash vigorously to prevent sticking or scorching. Add more hot water if necessary to prevent scorching. Boil the decoction for up to 20 minutes. The longer the boil, the greater the maltiness your beer will have (due to breakdown of starches).

6) Stop the boil and immediately add the boiled portion back into the main mash, reserving a third of the decoction. Notice the change in color as the decoction is added back in.

7) Using a mash paddle (see Figure 3), stir the mash well to evenly distribute the heated grain. Stir in an elliptical pattern, using two hands if necessary, to thoroughly mix the grain bed, but attempt to splash the mash about as little as possible, to avoid hot side aeration.

8) Take several temperature readings to be sure that your

**Fig. 2. Decoction kettle at a rolling boil. Notice protein formation and breakdown (the tan, foamy area) at upper right.**

**Fig 1. Scoop only the thickest part of the mash, except for your last decoction. Notice liquid being drained away.**

mash has been thoroughly mixed. Once the temperature has stabilized, if your temperature is too low, you can add the reserved portion of the decoction or add hot water to hit your desired strike temperature.

Alternately, you can pull out a few cups of the thick portion of the mash, quickly heat them up in your decoction kettle and add them back in to raise the heat. If the temperature is too high, add a bit of cool or cold water to bring the temperature down. If the temperature is just right, you can wait for the reserved portion of the decoction to cool to the temperature of the main mash and add it back in.

Ideally, if you were attempting to go from a protein rest at 120-135 ºF to a saccharification rest you will now have a mash temperature of 148-150 ºF for light-bodied, drier beers such as pale ale, or a temperature of 153-157 ºF for sweeter beers such as Bocks.

9) Once you have the correct temperature range for your rest, let the mash rest for the proper amount of time (see Step Mashing, below). If you just use decoction mash to go from a protein or beta-glucan rest to saccharification, mash as you would for an infusion mash.

10) If you are doing a double- or triple-decoction mash, repeat steps 2-9. Use the same calculation you used in step 2 to determine how much mash you must remove for the second or third decoction.

For example, if you are attempting to go from a saccharification rest at 153 ºF to mash-out temperature at 170º F, the calculation would look like this: (170 ºF - 153 ºF = 17 ºF) / ( 212 ºF - 153 ºF = 59 ºF) = 0.29 = 29%, meaning you need to remove a bit less than a third of your mash. Again, Palmer gives more detailed calculations in his book.

For most styles of continental lager beer, only a protein rest (at 120 °F), a saccharification rest (typically at a compromise temperature of 153 °F) and a mash-out at 170 °F is necessary. Other methods of step mashing, including combined infusion-decoction mash can also be used to achieve the same effect.

11) If you use a decoction to mash out, for the final decoction take the thinnest part of the wort (since you are attempting to denature enzymes) and go straight to a full boil, since the starches are already converted.

Keep stirring as you bring the mash to a boil! Boil for 15 minutes, and then stir it back into the main mash. Take another temperature reading. If necessary, remove a few scoops of

**Fig. 3. A good mash paddle is necessary to evenly distribute the decocted mash and the main mash to achieve an even temperature. You can make your own mash paddle from a 1" x 4" untreated ash, beech, elm or hickory board. Avoid pine, since it can leach resins.**

mash and boil them to bring the mash up to 167-170 °F, as described in step 9.

Once your mash is the proper temperature, after a 10-minute mash out rest (to denature the remaining enzymes) you can begin run-off and sparging as normal.

## C) Rests

The purpose of any type of step mashing is to allow various rests, which favor the action of certain enzymes which are most active at a particular temperature ranges. **With an infusion mash, only dough-in and saccharification are possible.** Note that not all rests are necessary for every style of beer. From lowest to highest temperature, the various possible rests are:

***1) Acid or Phytase Rest*** **(86-126º F, usually 95 °F, for 60-120 minutes):** This is a variation of Doughing-In (see below). *During this time phytase breaks down phytin, an organic phosphate found in grain husks, producing phytic acid, as well as insoluble calcium and magnesium phosphates. This acidifies the mash water by removing phosphate ion buffers and producing weak acids.*

*The acid rest was developed by Czech brewers before the role of water chemistry in brewing was properly understood. Since they brewed with very low pH water, the acid rest allowed the mash pH to naturally drop to the proper level required for subsequent enzymatic reactions to occur.*

*The acid rest is traditionally used when brewing with undermodified malts and water with low calcium content, as when making Bohemian Pilsner, but is not required if you are using modern malts and can adjust the pH of your mash liquor. Practically, an acid rest is not very effective at adjusting mash pH, since its pH is established fairly quickly at doughing-in and stays relatively stable due to buffering agents within the mash*[5]

***2) Dough-In*** **(95-113º F, typically 104º F for 20 minutes or 10-15 °F higher than first rest temperature):** A rest at doughing-in allows enzymes to be properly distributed throughout the mash, slightly improving brewhouse efficiency, but at the risk of hot-side aeration due to oxidation of long-chain fatty acids through the action of lipoxygenase. Doughing-In at a temperature above 140 ºF avoids this problem since lipoxygenase is denatured at that temperature.[6]

Typically the brewer adds 1.3 quarts water per pound of grist (but sometimes as little as 1 quart or as much as 2), stirring in water and breaking up clumps of dry malt so no dry grist remains, mixing thoroughly to get temperature even.

Unless the grist is already warmed (e.g., if adding material from a Cereal Mash) the brewer must overshoot his desired doughing-in temperature by 15-20 °F since the room-temperature malt cools the hot liquor. Using hotter liquor allows the mash temperature to fall into the desired first rest range.

***3) Beta Glucanase or Starch Rest*** **(95-113º F, typically 104-110 °F for 15-30 minutes):** The same temperatures which optimize enzyme distribution also encourage the action of beta-glucanases and cytases which break down beta-glucans (non-starch polysaccharides) and hemicellulose (glucan hemicelluloses) which are naturally found in cell walls of grain cells. Large quantities of these products are found in unmalted barley, rye, oatmeal and wheat (but not rice or corn), and, if not dealt with, they can contribute to starch haze and a "stiff" or stuck mash.

This sort of rest is only needed for under-modified or high-protein (e.g., wheat, oats) malt, or if you are brewing with a high proportion (more than 20%) unmalted grains in your mash. The Beta Glucanase rest usually runs concurrently with a Protein Rest and/or Ferulic Acid Rest.

***4) Ferulic Acid Rest*** **(111-113 °F for 15-20 minutes, at pH < 5.7):** *This rest liberates ferulic acid, a precursor to 4-vinyl guaiacol, in wheat malt. This slightly aids in production of clove flavor for German wheat beers (although yeast strain and fermentation temperature are more important).*

*Conveniently, the ferulic acid rest is also in the same temperature as the beta-glucanase rest, which is also desirable when brewing such beers. It is optional unless you are brewing a German wheat beer and wish to accentuate the clove notes.*

***5) Protein or Proteolytic Rest*** **(113-152 °F, optimally 120-131 °F, for 15-60 minutes, usually 30 minutes):** A rest at this temperature favors the action of **Protease Enzymes (proteinase & peptidase) which degrade large (albuminate) otherwise insoluble proteins** in the malt into smaller fractions such as polypeptides, and degrade polypeptides into peptides & amino acids. Proteases break down otherwise insoluble proteins in the malt, while peptidases produce Free Amino Nitrogen (FAN) from soluble proteins.

The main purpose of a protein rest is to increase FAN. Its secondary purpose is to break down large proteins which might otherwise contribute to a stiff or stuck mash during lautering, and contribute to protein haze, poor head retention and reduced long-term stability in the finished beer.

[5] Principles of Brewing Chemistry, p. 46.

[6] How to Brew, p. 148.

Protein-reducing enzymes are most active at pH 3.8-4.5, but only about 15% less active at typical mashing pH of 5.2-5.4. Some enzymes remain active for a while at 140-155 ºF, allowing you to get the benefits of a protein rest with an infusion mash. A protein rest can also be combined with a beta-glucanase rest by resting at 113-122 ºF for 15-30 minutes.

A protein rest is desirable when working with undermodified malts or when you are working with well-modified malts with more than 20% malted wheat, rye or oats. In these cases, skipping the protein rest can result in stuck mash or excess body, haze and storage instability in finished beer.

Continental-style lagers made using a decoction mash and traditional undermodified malt usually benefit from a protein rest, although a protein rest is no longer necessary when using well-modified modern malts. Modern German brewers generally don't use a protein rest.

***Caution:*** If working with fully-modified malt, an excessively long (1+ hour) protein rest can result in poor head formation and retention and dull hop flavors.

***6) Saccharification/Starch Conversion Rest:*** **This is actually two different types of rests: Low Temperature Saccharification and High Temperature Saccharification.**

**Both rests favor the action of diastatic enzymes (alpha and beta amylase) which degrade starches into dextrins and fermentable sugars.**

Diastatic enzyme activity produces monosaccharides (glucose, fructose, mannose, galactose), disaccharides (maltose, isomaltose, fructose, melibiose, lactose), trisaccharides (maltriose) and oligosaccharides (AKA dextrins or glucose chains).

The two enzymes work optimally at different temperatures, however, so altering temperature favors one over the other. The exact temperature can have a major effect on the character of your beer. Saccharification at 140 ºF produces 80% fermentable sugars, while saccharification at 149 ºF produces 76% fermentable sugars, and conversion at 158 ºF produces only 65% fermentable sugars. In practical terms, this means a 0.5-1% drop in ABV for a beer of typical strength.[7] **Most brewers ferment at approximately 150 °F to get a balance between the two types of enzymes.**

***Caution:*** Well-modified malts with high diastatic power have a lot of diastatic enzymes. In a mash containing a high percentage of such malts, diastatic action happens relatively quickly, with most starch conversion occurring within just 30 minutes. For this reason, it is necessary to get your rest temperature into the correct range within about 5-10 minutes, particularly if attempting to raise the temperature of the mash using step mashing.

Likewise, using good quality, fully-modified malt, it isn't necessary to hold your mash at starch conversion temperatures for excessive lengths of time (i.e., more than about 45 minutes). The extra time results in very little extra starch conversion. Use the extra time to vorlauf more thoroughly at a slower rate, since this improves extract efficiency more than a long mashing regimen will.

***A. Low Temperature Saccharification or Starch Conversion Rest AKA Beta Amylase Rest*** **(131-149 ºF for 15-90 minutes, typically 149 °F for 30-60 minutes. <u>Denatured at 158 °F</u>):** A rest at this temperature favors the action of beta amylase, which cleaves 1-6 bonds at the reducing ends of starch chains to produce monosaccharides (e.g., maltose). **This yields wort lower in dextrins and higher in fermentable sugars. It produces a thinner-bodied, drier, more alcoholic, more "digestible" beer, with poorer head formation and retention.**

This temperature range also favors the action of limit dextrinase, which breaks down limit dextrins (branched starch chains) freeing up even more starches for the beta amylase to convert.

Note that although beta amylase is active at a range of 131-150 ºF, starch gelatinization, which is necessary if the enzyme is to access the starches it modifies, only occurs at 140-150 ºF (for barley malt, lower for wheat, rye and oats, higher for corn and rice). Thus, the typical temperature given above represents a compromise between optimal starch gelatinization temperature and beta-amylase operating temperature.

Beta amylase will work at temperatures above 149 ºF, but at 150 ºF, it loses 75% percent of its efficiency after 30 minutes and 90% after 60 minutes. It is immediately denatured (inactivated) at 158 ºF. Thus, if you want to make a thin-bodied, higher-alcohol beer, you should undershoot, rather than overshoot, your saccharification rest temperature.

**Low temperature saccharification is recommended for thin-bodied, dry beers such as German Pilsner.**

***B. High Temperature Saccharification or Starch Conversion Rest AKA Alpha Amylase Rest*** **(140-167 ºF, ideally 149-158 ºF, typically 153-155 ºF for 15-90 minutes, denatured at 168 °F):** A rest at this temperature promotes the activity of alpha amylase, which randomly cleaves 1-4 bonds of long-chain starches (amylose and amylopectin) to produce smaller starches (oligosaccharides and dextrins), which can be converted into maltose by beta amylase. Incidentally to breaking down starches, alpha amylase also converts some starches to maltose.

**This yields wort higher in dextrins, and lower in fermentable sugars. It produces fuller-bodied, sweeter and starchier beer with better head formation and retention. but with lower potential alcohol level and a greater tendency to form starch haze.**

**High temperature saccharification is recommended for malty, full-bodied beers, such as Oktoberfest or Bock.**

**7) Glycoprotein Rest (158-165º F, ideally 161-162º F for 15 minutes):** *A rest at this temperature allows glycoproteins (polymers of dextrins and large proteins) to form, which improves head retention.[8] It can run concurrently with a High Temperature Saccharification rest.*

*This sort of rest is desirable when producing beers which are otherwise vulnerable to low head retention, such as American lagers, or beers where high, thick head with good retention is desirable, such as Belgian strong ales.*

***7) Mash-Out AKA Mashing Off or Doughing-Out*** **(167-170º F for 5-30 minutes):** This "rest" denatures enzymes and stops starch conversion, as well as gelatinizing the remaining starches in the mash to the greatest degree possible, reducing viscosity and aiding mash run-off.

Mashing-out makes lautering easier, especially if the mash is thick, either to start with, due to a large percentage of gummy malts or adjuncts, or due to water loss from multiple decoction boils.

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[7] Principles of Brewing Chemistry, p. 48

[8] Ibid.

*Caution:* Mash temperature should not exceed 168-170 °F during this time to avoid extracting tannins from grain husks.

# D) Cereal Mashing

**Cereal mashing is the process of preparing unhulled, unmalted grains so that their starches can be modified by diastatic enzymes present in the main mash at starch conversion temperatures.**

There are several ways to do this, by mashing the cereals with the main mash or by cooking them separately and then adding them to main mash as you would a decoction mash.

American industrial breweries cook their adjunct grains separately, while homebrewers usually add the adjunct grains directly to the mash. The former method allows the adjuncts to be brought to higher temperatures, which results in better starch gelatinization, while the latter method is simpler and lends itself to a simple infusion mash.

**Types of Adjuncts:** When working with adjunct grains, you must first determine if the grains have been previously gelatinized or not.

If they have not been gelatinized, you will need to grind them into grits and then cook them. Gelatinized adjuncts can be ground and then added directly to the mash.

Avoid using whole, un-husked grains. If boiled, grain husks can impart phenols and harsh flavors to your beer and the bran and the germ can impart oils and fats which interfere with head retention and flavor stability.

De-husked whole grains don't impart harsh flavors to the beer, but the lack of husks means that a stuck mash is more likely, while the bran and germ can still impart oils. Like whole grains, they must be ground to grits and then cooked before being added to the mash.

De-branned grains, such as white rice or pearled barley, must still be ground and cooked and can still cause a stuck mash, but can easily be used in brewing.

De-husked, de-branned grains which have been milled into meal are sometimes called grits (as opposed to corn grits, which have been gelatinized). They must also be cooked, but are suitable for brewing.

Flaked grains, such as rolled oats, are cereals which have been moistened and pressed between rollers. The heat from processing gelatinizes them, so they can be added directly to the mash. Torrefied grains, such as puffed rice or puffed wheat, have been gelatinized and then "popped" by exposing them to high heat. They are gelatinized and can be added directly to the mash.

Refined starches, such as cornstarch or potato flour, have undergone extensive processing and are gelatinized. Such starches are very easy to use and can be directly added to the mash, but can easily contribute to a stuck mash.[22]

**Mashing With Adjunct Grains:** There are several different ways of mashing with grain adjuncts.

***1) Adding Grains to Infusion or Step-Infusion Mash:*** As long as your grist consists of no more than 20-50% or so of gelatinized, unmalted grains, you can add them directly to the mash. This method is simple, but doesn't allow the higher temperatures needed for proper gelatinization of certain grains (i.e., rice or corn). To improve starch extraction, however, grind your grains to grits. A coffee grinder or Corona mill works perfectly for this purpose.

The risk of using unhulled grains in any amount is a stuck mash, so you will need to add rice hulls to the mash – either before you start mashing or at the end, just before you mash out. A rule of thumb is to add 1% rice hulls by weight of the total grain bill for every 20% unhulled adjuncts. Excessive levels of rice hulls can cause the same problems as any other grain hull – extraction of phenols and silica compounds which can impart unwanted qualities to your beer, so rice hulls should not exceed more than about 10% of your grist by volume.

The gummier the grain (i.e., the greater the levels of proteins and beta-glucans in the grain), the greater risk of stuck mash, so the greater the need for rice hulls. When mashing with wheat malt, you can get away with up to 50% wheat malt in the grist without needing to use rice hulls. When mashing with flaked corn, you can go as high as 30% corn without needing rice hulls.[23]

High levels of proteins and beta-glucans, which can cause protein or starch haze, respectively, as well as causing other problems. Rice and corn have very little beta-glucan, so there is no need to do a beta-glucanase rest while mashing these grains. Wheat, rye and oats have high levels of both proteins and beta-glucans, so you will need both a protein rest and a beta-glucanase rest when using these materials.

Modern two-base malts have sufficiently high levels of diastatic enzymes that they can easily convert the starches in adjunct grains up to about 40% of the grist (depending on malt variety), so it is not necessary to use highly-diastatic 6-row malt or to add amylase enzymes.

High-protein malt, such as traditional forms of 6-row malt can convert mashes with up to 50% adjuncts, but can also contribute to high protein levels in the beer. If you use a high level of 6-row malt, a protein rest will probably be necessary before you reach starch conversion temperatures.

Be sure to completely mash your grains at proper starch conversion temperatures (~140-167 °F), for a sufficient length of time to convert all the starches. An iodine[24] test might be necessary to determine if starch conversion has finished. Once mashing is completed, mash out by heating the mash to 165-168 °F. In addition to other effects, this keeps the mash as "liquid" as possible.

If there are unconverted starches (due to poor starch conversion or insufficient mashing times), or excessive levels of gums or proteins in your mash, your mash can set if mash temperatures drop below 160 °F or so during run-off and sparging.

***2) Cereal Mashing:*** **Cereal mashing consists of two separate mashes which are blended to reach saccharification temperatures.** The main mash consists of crushed malt, while the second (cereal) mash consists of raw ungelatinized adjunct grains and just a bit of crushed malt.

**The cereal mash boiled for 1 or more hours to gelatinize starches, then added to main mash**, which has

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[22] Papazian gives a list of various adjunct grains and their suggested treatments on pp. 253-256 of *The Complete Joy of Homebrewing*, as does Mosher on pp. 140-144 of *Radical Brewing*.

[23] Ibid.

[24] Note that an iodine test does not measure full conversion. It just measures large branch breakdown of starches into relatively smaller chains, via quick working limit and debranching enzymes. - Kevin Pratt, personal email.

undergone acid and/or protein rests. The increased temperature of the adjunct mash might increase the main mash temperature to saccharification temperatures, but sometimes the main mash must be heated as well.

**Cereal mashing is used to make beers which contain unmalted adjunct grains**, assuming the brewer starts with raw grains, rather than pre-gelatinized grain flakes or grits.

If you are using ungelatinized grains, or grains which require high gelatinization temperatures (i.e., corn or rice), you can conduct as separate cereal mash, just like industrial brewers do. This is necessary if your beer consists of a high level of adjuncts (i.e., more than 20% or so) or if you are using a high percentage of raw corn or rice, which have higher gelatinization temperatures than other grains.

Depending on the type of adjuncts involved, there are several mashing regimes you can use: American Adjunct Mashing, Belgian Adjunct Mashing or a Homebrewer's Step Mashing (AKA "Palmer Mashing"). All of these techniques require a separate kettle for mashing your adjunct grains. As with any directly-heated mash, the grains can scorch easily, so it is recommended that you use an aluminum pot (or a stainless steel pot with a flame-tamer underneath) and stir constantly using a mash paddle.

***A) American Adjunct Mashing (AKA American Double Mashing):*** This mash schedule is designed for beers consisting of up to 60% corn or rice. It was developed in the late 19th century by American brewers in order to dilute the excessive levels of protein found in traditional (pre-1940) strains of American 6-row barley. But, because it allows brewers to make beers with a very high percentage of adjuncts, it has become popular with industrial brewers around the world; even though modern American strains of malting barley can have much lower protein levels.

American Adjunct Mashing can be used when mashing any sort of adjunct grains, but it is necessary if you are brewing a beer which contains a high percentage of American 6-row malt and want to avoid problems associated with excess diastatic enzymes in your mash (i.e., thin body, poor head retention) and excess proteins in your beer (e.g., flavor instability). Conversely, when adjunct grains make up more than 40% of the grist, you will need to add some proportion of highly-diastatic malt, such as American 6-row, to your mash to convert the excess starches in the adjuncts.

The unmalted grain is mixed into a relatively thin mash (2-3 quarts of water per pound of grain) and is mashed in at 122 °F (protein rest temperatures) and held there for 15 minutes, the temperature is then raised to 149 °F (beta amylase rest) and held there for 20 minutes, before being raised to boiling and held there for another 15 minutes. These steps take the adjunct mash through protein and beta-glucanase rests before wholly gelatinizing the starches.

Simultaneously, in the main mash, the barley malt is mashed in at 95 °F and held there for 30 minutes, before being heated to 122 °F. This takes it through a beta-glucanase rest and a protein rest.

When adjunct mash is fully cooked, it is added to the main mash, raising the temperature of the combined mash to 154-155 °F and is held there for 30 minutes. The combined mash is then slightly heated to 158° and held there for 20 minutes before mashing out and sparging at 168 °F.[25]

***B) Belgian Adjunct Mashing:*** This process was described in Belgium about 1900 and is nearly identical to American Adjunct Mashing, although Belgian brewers generally didn't use 6-row malt at that time. It was designed for brewing Witbier, but also works well when brewing any beer which uses unmalted wheat or oats.

It was developed in response to a peculiar Belgian tax law which taxed the size of the mash tun used for barley malt. Since brewers could use a separate, untaxed, mash tun for their adjunct grains, they packed it full!

A modern version of this method uses a small amount (5-10% of the total grist) of 6-row malt, which is added to the adjunct grains. This is stewed at 122 °F for 15 minutes, raised to 150 °F and held for another 15 minutes, and then boiled for 15 minutes.

Simultaneously, the main mash is mashed in at 95 °F and held there for 30 minutes, then raised to 122 °F and held there for 40 minutes. Then the adjunct mash is added to the main mash, heating the combined mash to 155° F. After 45 minutes of mashing, the mash temperature is raised to 170 °F for mashing out.[26] Rice or wheat hulls are added, at the rate of 1 pound per 5 gallons of mash to provide a filter bed.

***C) Homebrewers Step Mash AKA "Palmer Mash":*** This form of cereal mashing is recommended by John Palmer for beers which involve more than 20% adjunct grains. It is simpler than the mash schedules given above.

The adjunct grains, which must be in a pre-gelatinized form, are ground into cereal, and 0.5 to 1 pound of barley malt is added for every 1-4 pounds of cereal. The ratio of cereal to malt should not exceed a 4:1.

This grist is then infused with 2-3 quarts of water per pound of grain and is heated, as a separate mash, to an appropriate mashing-in temperature. Barley, oats, rye and wheat should be started at 113 °F for a combined protein-beta-glucan rest. Corn and rice can be started at 145 °F at the beta-amylase rest temperature.

Hold the mash at beta-glucanase rest for 15 minutes, then heat it slowly, stirring constantly, until you reach starch conversion rest. Barley, oats, and rye are converted at 150-155° F. Corn and rice require temperatures of 165-172° F.

Next, bring the mash to a gentle boil for 10-15 minutes. Add the adjunct mash back into the main mash, using the procedures for a decoction mash, to bring your main mash to protein-rest or starch conversion temperatures.[27]

***Advantages of Cereal Mashing:*** In addition to the advantages described for Step Mashing, there are several benefits to using a Cereal Mash:

*1) Cheaper Ingredients:* Cereal mashing allows you to use less expensive unmalted, unprocessed (or less-processed) grains, which require high gelatinization temperatures (as opposed to pre-gelatinized grain flakes or grits). Industrial brewers use cereal mashing for this reason, since they can substitute inexpensive maize or white rise for some of the grist.

*2) Unusual Ingredients:* Cereal mashing allows you to use unusual varieties of grains which aren't available in malted form, or which can't be added to the main mash due to their high gelatinization temperatures.

[25] Mosher provides a graph on p. 139 of *Radical Brewing*.

[26] Mosher, op. cit., pp. 205-206

[27] Palmer, op. cit., pp. 174-175.

Disadvantages of Cereal Mashing: In addition to the disadvantages described for Step Mashing, there are several unique problems associated with cereal mashing:

*1) Time and Energy Intensive:* The brewer must conduct two separate mashes, which must be timed to more or less coincide. The cereal mash must usually be raised to higher temperatures than the main mash, which requires extra fuel. The brewer must also mill the adjunct grains separately from the malt, since they must be crushed more finely.

*2) Gelatinization Required:* Adjunct grains must be fully gelatinized (by mashing or hot flaking) before they can be added to the main mash.

*3) Limited Styles:* Cereal Mashing is only appropriate for styles of beer which are made using a significant proportion of adjunct grains.

# E) Sour Mashing

***Introduction:*** Sour mashing is the process of allowing lactobacillus bacteria to infect the mash before it is cooked, acidifying the mash so that it naturally reaches proper pH levels required for enzyme action.

This method was traditional among German brewers who brewed pale beers using with alkaline water and who were prohibited from adding acid directly to their mash water due to the Reinheitsgebot, and by Czech brewers, who brewed with very pale malts and very pure water. In both cases, without dark malts or acidic water to bring mash pH into the correct range for mashing, the brewers had to rely on bacterial action.

Modern brewers don't often use this technique, since they can adjust their water chemistry artificially or they can use sour malt. In some cases, however, it is appropriate, especially if you are trying to brew a sour beer such as Berlinerweisse or Kentucky Common.

***How to Do It:*** Several days before you brew, take 5-15% of your mash volume and mash it separately, doughing-in at the appropriate temperature and then heating it to starch conversion temperatures.

Then, let it cool to 130 °F or less, inoculated it with crushed malt (which is naturally covered with microbes), and let the mixture sit, covered, at 95-122 °F for several days. This creates perfect environment for fermentation by Lactobacillus Delbruckii, which sours the mash.

Once the infected mash is reduced to pH 4.0 or lower, it can be added into the main mash at mashing in to bring its pH into the proper range.

The risk is that the mash will be infected by other organisms, especially aerobic organisms, so in addition to good sanitization, it is necessary to eliminate airspace between the fermenting mash and its cover.

If the mash begins to smell at all solventy or rancid, or if the mixture becomes turbid or ropy, or if it otherwise looks "off" in any way, any material on the surface should be skimmed off and the temperature should be raised above 122 °F (even above 140 °F) to destroy any competing mold or bacteria. If the mash goes rancid it must be thrown away.[32]

In theory, the longer you let the mash sit, the sourer it becomes, although in practice this can be problematic, since longer fermentation times can invite bacterial or mold contamination.

[32] Noonan, New Brewing Lager Beer, p. 132.

# Part 2: Off-Flavors

# Astringent

***Detected In:*** Mouthfeel, Aftertaste.

***Described As:*** Mouth puckering, puckery, tannin-like, tart

***Typical Origins:***

***Typical Concentrations in Beer:*** ? mg/l.

***Perception Threshold:*** ? mg/l.

***Beer Flavor Wheel Number:*** 1340

***Discussion:*** See Phenols (Polyphenols), also see Cloudiness.

# Phenolic

***Detected In:*** Appearance, Aroma, flavor, mouthfeel.

***Described As:*** Bitter, fruit skins, fruit pits, grape seeds, grape skins, husky, oaky, roasted, tannic, tea-like, vanilla or woody. Some have an astringent, drying, numbing, prickly, puckering or rough mouthfeel, sometimes detectable only in the aftertaste. Some spicy phenols can also be detected as a prickliness, warming, pepperiness or pain in the nasal passages. Polyphenols can combine with proteins in beer to form chill (protein) haze.

***Typical Origins:*** Yeast, microbial contamination, process faults.

***Typical Concentrations in Beer:*** 0.05-0.55 mg/l.

***Perception Threshold:*** Variable depending on exact chemical; usually about 0.2 mg/l.

***Beer Flavor Wheel Number:*** 0500.

***Discussion:*** Phenols are an enormous family of aromatic alcohols consisting of a benzene ring plus a hydroxyl group and side chains. Technically, they are alcohols.

Unlike esters or fusel alcohols, phenols are largely non-volatile and don't get converted into other compounds. This means that once they're in a beer, they tend to remain in it.

There is genetic variation in the ability to detect certain phenolic compounds and some people are completely insensitive to them.

Common phenols found in beer are given below, along with their specific sensory characteristics and biochemical origins. Also see Bromophenol, Chlorophenol, Iodoform, Smoky, Spicy and Vanilla.

*** Flavanoids (AKA Bioflavanoids, Flavanols):** This is a huge family of phenols with ketone-containing compounds which are naturally found in many plants. They have often little aroma, although they can be precursors to aroma compounds.

They produce flavors ranging from mildly to intensely bitter. Specific flavanoids relevant to brewing have aromas flavors reminiscent of chocolate, cocoa, coffee, earth, nuts and/or roasted or toasted foods. Some have an astringent, drying mouthfeel or aftertaste.

Flavanoids are present in grain husks, and the process of roasting or toasting malt oxidizes or pyrolyzes these compounds during Maillard reactions to produce the distinct flavors of biscuits, bread crusts, burnt grain bitterness, chocolate coffee, roasted grain or toast.

Flavanols are also present in many fruits, especially cherries, citrus and grapes.

* **Polyphenols (AKA Tannins):** These are phenols composed of two or more benzene rings. They have bitter, husky, oaky or vanilla-like aromas and flavors, also sometimes

described as tasting like grape skins or grape seeds. Most also have an astringent, drying or puckering mouthfeel. They commonly occur in woody or husky plant materials.

Polyphenols in beer are mainly extracted from grain husks due to improper grain milling, mashing or sparging technique, but they can also be extracted from water left to stand in contact with decaying plant material, or from hops. Herbs, spices and fruits can also impart polyphenols.

Beer aged in contact with wood will also pick distinct oaky or woody notes from polyphenols. With time, these compounds will react with alcohol to produce vanillin, imparting the flavor and aroma of Vanilla (q.v.).

Beer left on the yeast cake for excessive amounts of time might also pick up polyphenols liberated during yeast autolysis.

Polyphenols can bind with suspended proteins in beer to form protein/chill haze.

They can also form oxidized fusel alcohols due to a reaction with aldehydes, if oxidized by hot-side aeration or poor storage conditions.

Over-attenuation and low dextrin levels (i.e., thin-body) can increase the perception of astringency.

***To Avoid or Control:*** Methods of controlling phenols depend on the exact family of compounds:

*** Flavanoids (AKA Toasty, Roasty, Bitter):** *Causes:* Toasted or roasted malt additions. Fruit, spice or herb additions. *To reduce or avoid:* Reduce or eliminate toasted or roasted malt additions. Reduce or eliminate fruit, spice or herb additions. Avoid scorching grains or wort.

* **Polyphenols (AKA Astringency)**: Also see Cloudiness (Protein Haze). *Causes:* Malt, hops, fruit skins or seeds. *To reduce or avoid:*

- *Don't over-crush grain.*

- *Proper Mash/Sparge technique:* Avoid excessive sparging (stop runoff before it gets below 0.008 S.G.). Avoid collecting alkaline sparge (pH >5.8) liquor. Don't use highly alkaline or sulfated water. Don't let mash-out or sparge liquor temperature exceed ~168 °F.

- *Boil wort with a rolling boil for at least 1 hour* to promote hot break.

- *Get proper hot & cold break separation.*

- *Avoid excessive amounts of hops.* To get high IBU levels use a smaller amount of high alpha acid hops rather than a large quantity of low alpha acid hops. As a rule of thumb, use no more than 8 oz. of hops per 5 gallons of wort. Avoid excessively long boil times (>2 hours) when making beer with a large amount of hops.

- *Avoid Polyphenol Extraction:* Don't heat fruit or grains in water above ~168 °F. Limit time that beer spends in contact with dry hops, fruit (especially fruit stems and husks), herbs and spices (time can range from weeks to months depending on the exact material). For wood-aged beers, reduce exposure to wood and/or increase aging time. Don't leave beer on yeast cake for long periods of time (1 month or more) to avoid yeast autolysis.

- *Reduce Sulfate mineral additions.* Sulfate increases tannin extraction and accentuates polyphenol harshness and bitterness.

***When Are Phenolic Notes Appropriate?:*** Whether phenolic notes are appropriate in a beer depends on the type of phenol:

*** Flavanoids:** Flavanoids which give bready, biscuity, crusty and/or toasty notes are expected in very low to high concentrations in almost all styles of amber or brown beer. Compounds which give burnt grain, chocolate, cocoa, coffee, roasted notes are expected in medium to high concentrations in most styles of dark beer, particularly porters and stouts.

*** Polyphenols:** Balanced low to strong polyphenol (woody, vanilla, oaky) character is expected in wood-aged beers. Subtle peat character is acceptable in Scotch Ale. Harsh or astringent notes are a fault in other styles of beer.

# Sweet

***Detected in:*** Aroma, flavor, mouthfeel.

***Described As:*** Cloying, honey-like, jam-like, jammy, malty, oversweet, primings, sickly sweet, sticky, Sucralose, sugary, syrupy, underattenuated, worty. Specialty sugars or specialty crystal/caramel malts might give sweet aromas and flavors reminiscent of candy, caramel, honey, maple syrup, molasses, toffee or treacle. Technically, sweetness is only detectable in flavor, but esters and VDK compounds commonly associated with sugars and sugary mixtures (i.e., honey) can give the illusion of sweetness in the aroma. High levels of sweetness can increase perception of body in mouthfeel, since they increase beer viscosity.

***Typical Origins:*** Malt, adjuncts.

***Typical Concentrations in Beer:*** ~20-30 mg/l.

***Perception Threshold:*** ?.

***Beer Flavor Wheel Number:*** 0100.

***Discussion:*** Sweetness is one of the basic human senses. Sweetness in beer is caused by the presence of "reducing" sugars such as simple sugars (e.g., monosaccharides) and short chain polysaccharides (e.g., dextrins). Since simple sugars such as glucose, sucrose, fructose, maltose and maltriose are fermented by yeast, non-fermentable sugars, such as lactose, are sometimes used to impart sweetness in brewing. Alternately, the brewer might mash at the high end of starch conversion temperatures (~153-158 °F) to promote dextrin formation in the mash. Sweet beer might be pasteurized or filtered to remove the yeast and then force carbonated at packaging.

The Plato scale corresponds to grams of sucrose per 100 milligrams of water. Degrees Plato (°P) roughly corresponds to S.G. at (1-S.G.)/4. In a finished beer attenuated to 1.008 to 1.010, this works out to 20-30 mg/l.

Unintentional sweetness and poor attenuation in beer is likely due to poor yeast health which resulted in a slow or stuck fermentation. Common causes of slow/stuck fermentation are low FAN levels, low levels of dissolved oxygen in the wort, high gravity worts or high levels of alcohol. Premature flocculation due to shocks to the yeast (e.g., sudden temperature swings) might also result in underattenuation.

***To Increase:*** * Mash at a higher temperature (150-156 °F). * Add non-fermentable sugars (e.g., dextrin, lactose). * Increase wort gravity. * Remove the yeast from partially fermenting wort (e.g., filtering, fining). * Pasteurize or filter beer to remove yeast and add sugar at packaging.

***To Decrease:*** * Practice good yeast management. Choose proper strain for style and wort gravity. Pitch sufficient yeast for wort gravity. Provide sufficient yeast nutrient. Oxygenate wort before pitching yeast. Avoid shocking the yeast. * Mash at lower temperatures (143-149 °F). * Reduce wort gravity. * Reduce or eliminate non-fermentable sugars. * Use more fully-fermentable sugars (e.g., corn sugar, sugar, honey syrup), typically up to about 10-20% of grist. This has the effect of thinning body, however, and might introduce "cidery" notes. * Rouse yeast in beer, while avoiding oxidation, to restart fermentation. * Pitch more yeast (of a higher attenuating or less flocculent strain).

***When is sweetness appropriate?:*** Some degree of sweetness is expected in most beer styles, especially very strong, malty beers. Non-fermentable sugar is sometimes added to beers such as Southern English brown ale and sweet stout to deliberately increase sweetness. Excessive levels of sweetness are considered to be a fault in most beer styles, especially strong, malty beers such as doppelbocks and Belgian strong ales.

**Relative Sweetness of Sugars**

| Sugar | Relative Sweetness |
|---|---|
| Glucose | 0.7-0.8 |
| Maltose | 0.3-0.5 |
| Fructose | 1.1-1.2 |
| Sucrose | 1.0 |

## Syrupy

***Detected In:*** Aroma, flavor, mouthfeel.

***Described As:*** Reminiscent of lightly caramelized (golden) sugar syrup.

***Typical Origins:*** Malt, sugar adjuncts.

***Typical Concentrations in Beer:*** ? mg/l.

***Perception Threshold:*** ? mg/l.

***Beer Flavor Wheel Number:*** 1005

***Discussion:*** See Sweet.

# Part 3: BJCP Category 17 - Sour Ales

## A) Making Sour Beers Sour

There are basically three ways to create a sour beer: Sour Mash, Acid Additions or Microflora Cultures.

***1) Sour Mash:*** This technique is described above. Berlinerweisse and some old-fashioned American regional beers (Kentucky Common, Swanky) are produced using the Sour Mash technique.

Many fermented beer-like beverages native to the tropics are also fermented using a variation of the sour mash process. Such beers use starchy vegetables that the brewers chew up and spit into the fermenter. Human saliva provides both amylase and lactobacillus, while the alcohol produced by the wild yeast which infects the wort sanitizes the final product. Stan Hieronymus' "Brewing With Wheat" gives a good description of how to do this in the section on Berlinerweisse.

**2) *Acid Additions:*** It is possible to add lemon juice, citric acid, distilled vinegar or lactic acid to your cooled wort or raw beer. It is also possible to get a lactic acidic character by using an excess of acidulated malt in your grist.

These are quick and dirty ways of giving a sour tang to a beer without the time, trouble or risk of inoculating your mash or wort with microflora. They are appropriate if you just want to impart a "crisp" lactic or citric tartness to your brew, but artificial acid additions won't produce the complexity of flavors you get from a sour mash or wild fermentation.

***3) Microflora Cultures:*** Whether spontaneously fermented or carefully controlled, microbial action produces the greatest range and complexity of flavors and aromas. It is also the hardest of the three options to control.

The process of brewing beer using this form of fermentation is extremely demanding, requiring time, money, space and special equipment as well as special bacterial cultures. Lambic brewers routinely let their beers sit in secondary for years, so a would-be lambic brewer must have the space and money to buy and store dedicated lambic carboys.

Producing sour beers in this fashion also requires some common-sense precautions to keep the beer-souring bugs from infecting your regular brews. See the Bibliography for references on how to brew sour beers. At the very least, you will either want to read Jeff Sparrow's ***Wild Brews,*** or Jean-Xavier Guinard's ***Lambic*** or look at Jim Liddell's website (http://www.brewery.org/brewery/library/LmbicJL0696.html).

## B) The Microflora of Sour Ales

The amazing thing about sour beers is that sour beer brewers turn what ordinary brewers would consider to be a major mistake into something that tastes wonderful. More typically, infection by these beasties is a sign of a Serious Problem.

This section is a quick guide to what critters can get into your beer and what flavors they impart to the brew. Fortunately, most of this microflora grow slowly and are inhibited by the presence of hops and alcohol. For this reason, they are easily out-competed by ordinary, mild-mannered *S. Cerevisiae*. But, beware wild yeast strains!

Microbes that infect beer generally fall into six genera: *Acetobacter, Brettanomyces, Lactobacillus, Kloeckera, Pediococcus* and *Saccharomyces*. Of these, only four are important in the production of Belgian sour beers, and only one (*Lactobacillus*) is important in producing Berlinerweisse.

***1) Acetobacter:*** *Acetobacter* are genera of bacteria that convert ethanol into acetic acid. Acetobacter are used to make vinegar. They strongly prefer an aerobic environment, so they only appear when infected beer is aerated. Since aeration also promotes oxidation, lambic brewers must be especially careful not to expose the culturing beer to oxygen. To some extent, the pellicles formed by *Brettanomyces* and *Pediococcus* cultures prevent oxygen from getting into the beer.

***2)*** *Brettanomyces (Br.* ***Bruxellensis****, Br.* ***Lambicus****, Br.* ***Clausenii****):* "Brett" is a genera of yeasts most responsible for the flavor characteristics of many Belgian beers. When seen under the microscope, they usually have an ellipsoidal shape, but can also be cylindrical or elongated. Since they often form branched chains as they grow, they can create a waxy- or papery-looking pellicle which floats on the surface of the beer, sometimes with large "bubbles" in it.

Under aerobic conditions, they can metabolize glucose and alcohol into acetic acid but also seem to produce more ethanol under similar conditions. By contrast Saccharomyces produces less alcohol under aerobic conditions. Also unlike Saccharomyces, Brett can digest dextrins, resulting in a slow, constant fermentation over a period of months.

*Brettanomyces* produces characteristic acetic, vinous, cidery, earthy or "horsy" aromas. In normal brewing they can also produce various off flavors described as phenolic, medicinal, smoky, leathery, "mousy," sweaty, cheesy or goaty.

In limited quantities, *Brett* aromas and flavor are a desirable characteristic in some Belgian beers!

B. *Bruxellensis* is the dominant *Brett* strain around Brussels. It imparts rich earthy notes and an acetic finish.

B. *Clausenii* was the first *Brett* species to be isolated, in 1904, by the same Danish researchers who discovered lager yeast. It was isolated from an English "stock" beer (a strong, matured beer, used for blending with younger beers), which is why the translation of the genus *Brettanomyces* means "British sugar fungus. It is hard to get commercially, but some lambic brewers (especially Frank Boon) consider it important, since it imparts fruity characteristics as well as the classic *Brett* "horsiness."

B. *Lambicus* is associated with Belgian countryside breweries. It imparts distinctive flavors and aromas described as "horsy" or "old leather."

***Tips on Using Brett:*** Several strains of Brettanomyces can be cultured form the dregs of Orval beers (several strains of Br. B*ruxellensis*).

There is also some evidence that *Brettanomyces* has an affinity with wood, and produces more flavor when in contact with it. For this reason, homebrewers who ferment wild beers in glass sometimes add a few oak chips to the carboy.

Disturbing the pellicle on a fermenting container of sour beer isn't that big a deal as long as you don't aerate the beer when you do it. Aeration will induce *Brettanomyces* regrowth and make it convert alcohol into acetic acid.

***3) Enteric Bacteria (Enterobacter cloacae, Klebsiella pneumoniae, Escherichia coli, Hafnia alvei, Enterobacter aerogenes and Citrobacter freundii, etc.):*** Various genera of enteric bacteria are some of the first microbes to appear in raw wort, but die off within a month due to increased levels of ethanol and lowered pH (below about 5.0 pH and above about 3% ABV). They are critical in flavor of wild and sour beers. Unfortunately, they are related to some of the microbes that cause food poisoning. Fortunately, the species which grow in beer are harmless, except to people with compromised immune systems. Since enteric bacteria are commonly found in ordinary kitchens (especially on dirty dishrags and sponges), unless you are absolutely fanatical about sanitation, if you brew in your kitchen you probably have some enteric bacteria in your wort. Fortunately, in non-sour beers, a healthy yeast culture quickly outcompetes any enteric bacteria, killing them within hours to days as the wort's pH drops and the alcohol level rises.

*Enterobacteria* are the primarily producers of acetic acid in sour beers. Their metabolism also consumes much of the available glucose in the wort, slowing *Saccharomyces* growth, which in turn allows slow-growing microbes such as *Brett* and *Pediococcus* to survive. They are also important in that when they die, they release nutrients necessary for *Brett* and *Pediococcus*.

They produce odors and flavors described as celery-like, parsnip-like, mushroom-like, smoky or moldy which are not removed by the fermentation process. They can also produce lactic or acetic sourness.

***Tip on Using Enteric Bacteria:*** To infect your brew with enteric bacteria, leave the cooled wort open near a kitchen sink for several hours and then wait 24 hours before pitching your yeast. Delaying yeast pitching lets the bacteria gain a foothold before the drop in pH due to their metabolism, and the increase in ethanol produced by the yeast kills them off.

***4) Kloeckera (K. apiculata):*** This is a genus of yeast which consumes glucose, produces ethanol, and secretes enzymes that break down proteins, releasing amino acids for use by later generations of microbes. It also lowers pH, which in combination with ethanol, tends to inhibit bacterial action. Since it can metabolize only glucose, it dies off early in the fermentation process, allowing Saccharomyces to gradually take over (the lack of glucose inhibits quick Saccharomyces growth).

***5)* Lactobacillus (L. *Delbruckii*):** As its name implies, *Lactobacillus* is a genera of bacteria which produce lactic acid. Some work on lactose, others convert glucose to lactic acid. L. *Delbruckii* is the bacteria used to ferment Berliner Weiss. L. *acidophilus* is used to convert milk into yogurt, while other lactobacillus species are responsible for turning milk into cheese or souring sauerkraut. Some brewers have experimented with using L. *acidophilus* culture by adding yogurt to their beer. Berliner Weiss is traditionally been inoculated with lactobacillus by adding raw, unhulled wheat to the cooled wort.

Beer soured by lactobacillus will have a crisp sour flavor, as opposed to a more astringent and vinous sourness from acetobacter infection.

***Note on culturing Lactobacillus:*** For lambics, it is possible to make a culture of this bacteria (and other microbes) by culturing the dregs of a bottle of Dentergem's Wit or Petrus Oud Bruin. Since *lactobacillus* can grow slowly, this is another starter culture which must be prepared several days beforehand.

***6)* Pediococcus (P. *Cerevisiae*, P. *Damnosus*):** "*Pedio*" is a slow-growing, lactic-acid producing bacteria which prefers warm, anaerobic conditions. It generally appears in conjunction with *Brett* species, since *Brett* produces a pellicle on top of the wort which inhibits diffusion of oxygen into the wort. *Pedio* will also sometimes form a "wrinkly," "ropy," "stringy" or "brain-like" pellicle of its own. It gradually appears over a period of 3-4 months, gradually killing off *Saccharomyces* species as it produces lactic acid.

In traditionally-produced lambics, the increase in *Pedio* growth also coincides with warmer spring and summer temperatures. Without the rise in temperature, the bacteria will not appear, resulting in less sourness.

In addition to producing a lactic sourness, *Pedio* also produces large amounts of diacetyl, detectable as "slipperiness" or "butteriness" on the tongue or the back of the mouth. Diacetyl is also detectable as a vanilla, butterscotch, buttery, or toffee aroma or flavor.

***Tips on using Pediococcus:*** Excluding oxygen is critical when working with *Pedio*. In an anaerobic environment, it will gradually convert glucose to lactic acid, imparting a smooth, complex sourness to the beer. Do not aerate *Pedio* starters and start them at least a week before you intend to brew. Since it is a tricky organism to cultivate successfully, you may need to make two or three starters.

***7)* Saccharomyces (S. *Cerevisiae*, S. globosus, S. dairensis, S. uvarum, S. bayanus, etc.):** Various genera of *Saccharomyces* can metabolize monosaccharides, disaccharides and (occasionally) trisaccharides to produce carbon dioxide and ethanol. Some wild *Saccharomyces* strains can also ferment dextrins. The various strains of yeast produce a vast variety of aroma and flavor byproducts. Strains of yeast used for wild beers can often produce high levels of phenols, producing medicinal, smoky or spicy aromas and flavors. Saccharomyces is the main producer of ethanol in sour beers.

In some sour beers, *Saccharomyces* is the “second wave” of microbes to take over (the first being *Kloeckera* and *Enterobacteria*), first appearing 1-2 weeks after the wort is pitched. As their numbers increase, the ethanol they produce kills off the first wave of invaders. In turn, Saccharomyces is killed off by the increasing acidity brought on by *Pediococcus* and *Brett*, gradually declining over a period of 3-4 months.

# C) Blending

Another factor which makes brewing sour beers at home difficult is the need to blend different batches of beer in order to get just the right flavor. While one batch of spontaneously-fermented beer might taste terrible on its own, it can add complexity to other batches of beer when blended in small amounts.

Although not as well publicized as the art of brewing lambics, the art of blending lambics is almost as complex and demanding; some lambic brewers consider it to be something of a lost art. There are no secrets, just patience and experience in knowing how different batches of lambic are developing, and a skilled and sensitive palate, so you can blend different batches of limbic to best effect.

By contrast, the other styles of sour beer are easier to blend since they have simpler microbiological cultures and develop in a more predictable fashion.

# D) Brewing Sour Beers

Sour beers are the oldest beer style in the world, in that they are brewed using open fermentation using whatever wild microflora are native to the brewhouse. They derive their unique, complex flavors and aromas from the fermentation byproducts of successive yeast and bacterial infections, although acid blends can simulate sourness.

Since high alcohol levels can interfere with the bacterial action, sour beers are low to moderate strength. Due to the nature of the fermentation and aging process, most sour beers have little carbonation, Berlinerweisse and some Gueuzes being the exceptions. Due to the fermentation process and the high proportion of raw wheat used to brew the beer, most sour beers are cloudy.

***The Brewing Process:*** Most sour beers start off as neutral-flavored, low-to-moderate gravity wheat or brown ales, although lambics are brewed with 40% or more raw wheat, since this gives more unfermentable starches which wild yeasts and other microbes can slowly digest.

Because sour and bitter flavors don’t blend well together, and because hops can interfere with bacterial action, hops are used sparingly, if at all, and are included only for their preservative properties. For this reason, hops used for lambics are deliberately aged to allow the essential oils and soft resins found in fresh hops to degrade.

Beyond that, each style of sour beer has unique characteristics:

***1) Berlinerweisse:*** This is the one non-Belgian sour beer recognized by the BJCP Style Guidelines. It is also unusual in that it is a low alcohol, highly carbonated sour beer.

*History: This style of beer dates to at least 1680, and was once popular in and around Berlin, although there were periods where it was more or less popular. It is the best known survivor of a number of northern German sour wheat beers which were popular until the 19th century. In the 18th and 19th centuries, it was sold and consumed very young, within a few weeks of production, but some examples were bottled and aged.*

*It is typically a low-alcohol beer (schankbier - no more than 3% ABV), but some examples could reach 5% ABV (vollbier). Historically, it could be watered down after it was brewed, but this practice was made illegal in the 20th century. A few American and German interpretations of this style are made to the higher of the two alcohol levels.*

*In the 19th century, it was popular to drink Berlinerweisse from large, flat stemmed glasses. In the late 19th and 20th centuries, it was common to sweeten Berlinerweisse with raspberry (himbeer) or sweet woodruff (waldmeister) syrup.*

*In the 21st century, Berlinerweisse is practically extinct commercially, with just one commercial example being produced in Berlin. It accounts for a tiny fraction of beer sales in Germany and is mostly consumed by tourists.*

*Brewing Berlinerweisse:* Berlinerweisse grist consists of German pilsner malt and 25-80% wheat malt (although the one surviving authentic version uses just 25% wheat malt). German grown-hops (although not necessarily noble hops or even German varieties) are used for bittering. Traditionally, at least part of the mash was sour-mashed, although this is no longer done by Berliner-Kindl-Shultheiss, the one Berlinerweisse brewer remaining in Berlin.

An infusion mash was common, but some brewers used up to three decoctions. If decoction mash was used it began at 122 °F, with saccharification at 156 °F.

In the 1950s, brewers boiled the wort for 15-30 minutes, then transferred to a coolship for 20 minutes. It was cooled to 67-71 °F and pitched with yeast. Primary fermentation lasted for 30-48 hours at 64-68 °F. Then, 15% kräusen was added and it was bottled or put into barrels. Kegs left to be conditioned rested at 59 °F.

In all cases, one part of the mash (or mash runoff) - usually half - is inoculated with *Lactobacillus Delbruckii* (and, historically, a number of other Lactobacillus strains). It is not boiled, nor is it hopped.

The other part of the wort is boiled, hopped (bittering hops only, at very low levels), cooled and inoculated with ale yeast (probably a relatively neutral strain, such as German ale yeast). The yeast is pitched at 59 °F, but the temperature is allowed to rise to 77 °F. Fermentation lasts for one week.

The two parts are then blended and cold-conditioned.

Traditionally, Berlinerweisse was very highly carbonated, with bottled examples having up to 4 volumes of carbon dioxide. Modern examples are pressurized to just 2.5 volumes.

Attempting to produce Berlinerweisse using a mixture of yeast and lactobacillus cultures doesn’t work well, since the yeast kill off the bacteria. Historically, Brettanomyces cultures were also present, but since yeast cultures were never stored for long, and since most Berlinerweisse was consumed young, it only became noticeable in aged examples.

*2) Flanders Red Ale:* This is a barrel-aged Belgian sour beer. Its reddish color and tannic and vanilla notes come from extended (up to 3 years) aging in oak barrels.

*History: This is another traditional Belgian sour beer, native to West Flanders. It began to diverge from Flanders Brown Ale in the 19th century, and the difference became even more pronounced in the late 20th century when Flanders Brown Ale started to be aged in stainless steel tanks. It is particularly associated with products of the Rodenbach brewery.*

*Brewing Flanders Red Ale:* Grist for Flanders Red Ale is Vienna, Munich and light to medium crystal and Special B malt, as well as 10-20% maize, to produce a wort similar to that a Vienna lager or Oktoberfest. Hops are continental bittering varieties, to provide 10-25 IBU. Magnesium in the water accentuates the sourness.

The wort is inoculated either with a pure yeast strain or a blend of yeast and other cultures. Trappist ale yeast works well for primary fermentation. Primary fermentation lasts from one to eight weeks. The wort is then racked from the lees into French oak barrels. Secondary fermentation lasts from 18 months to 3 years, with new wort being added to "top off" the barrel as water evaporates.

During secondary fermentation, Lactobacillus strains dominate for the first few weeks, then as they die off Pediococcus strains become dominant after 3-4 months. Finally, Brettanomyces strains take over, becoming dominant after about 8 months. Barrel aging also allows some Acetobacter activity, which gives the beer some acetic sourness. During barrel aging, acidity becomes more dominant and the flavor becomes more complex.

Once aging is complete, the beer is blended, back-sweetened (often with artificial sweeteners such as aspartamine) and bottle-conditioned. More modern versions of Flanders Red Ale will be much sweeter than historical versions, and many commercial versions don't have the same complexity as they once did.

*Flanders Brown Ales:* Flanders brown ales are similar to Flanders Red Ales, except that they are conditioned in stainless steel tanks. They are associated with East Flanders, and with the products of the Liefmann's brewery.

Flanders brown ales are fermented using a mixed culture of yeast, Lactobacillus and Pediococcus and are initially fermented in open squares. They are then racked from the lees and conditioned in stainless steel tanks for up to two years.

Since the tanks aren't gas-permeable, acetic character doesn't develop. Since the tanks are sanitized between batches, there is no place for Brettanomyces or Acetobacter cultures to grow, so there isn't any Brett character, nor is there any acetic sourness.

Finally, since the tanks are stainless steel, the beer lacks the typical barrel-aged notes, such as vanilla, coconut or tannins.

***Belgian Lambic Beers:*** In many ways, the various lambics, Gueuze, Straight Lambic, Fruit Lambic and Faro, are the "kings" of Belgian beer, unsurpassed in complexity.

*History: Sour beers in the Payottenland (Brussels and the surrounding region) date back to the 15$^{th}$ century. Development of the lambic style was encouraged by Belgian tax laws in the 19$^{th}$ century which encouraged brewers to use a high proportion of unmalted grain in their beer, so lambics can have up to 40% unmalted wheat in the grist.*

*Once barrels of fermented lambic were purchased from the brewery by pub owners and lambic blenders, who blended contents of the different barrels together. This practice has largely been lost, however.*

*Lambics remained popular in and around Brussels until the late 20$^{th}$ century. From the 19$^{th}$ century on, however, they were typically blended with sugar or syrup. Pre-blended mixtures of young lambic and sugar are called Faro.*

*After World War 2, lambic became less popular. Other styles of beer, especially the ubiquitous light lagers, stole market share from the lambic brewers and many lambic brewers and blenders closed. Suburban sprawl around Brussels also imperiled the native microflora which the lambic brewers depended on to ferment their beers, and largely swallowed up the cherry orchards used to grow the distinctive Schaerbeek cherries used to make Kriek lambic.*

*Fortunately, the craft beer revolution in the United States, and elsewhere in the world, have helped to revive lambic's fortunes. Most lambic brewers survive due to their export trade (as do many other artisanal Belgian brewers).*

*In 1965, a ceremonial royal decree dictated the proportion of wheat used in the grist and specified that lambic must be spontaneously fermented. Since 1992, the terms Lambic and Gueuze are protected as appellations controlleé by European Community ordinances. Under the terms of this, only spontaneously-fermented Belgian sour ales can properly be called by these names. Properly, beers brewed elsewhere, or beers deliberately inoculated with microflora cultures, must be termed "sour beer." Some home-brewers refer to their products as "pseudo-lambics" or "P-lambics." North American craft brewers often call their creations "lambic-style" beers.*

*Brewing Lambic-Style Beers:* Technically, it is impossible to brew a true lambic unless you live in or around Brussels, Belgium. Most homebrewers produce "pseudo-lambic" or "lambic-style" beers by somewhat different means than the Belgian lambic brewers do.

Grist consists of 30-40% unmalted wheat and 60-70% pilsner malt. "Suranne" (aged) hops, which have been stored at room temperature for up to 3 years to destroy their aroma, flavor and bitterness, are used solely for their antibacterial properties.

Single temperature infusion mash is traditional. Sometimes wheat flour is added to the boiling wort. The mash is typically milky white and is boiled for 3 or more hours.

In authentic examples, wort is cooled overnight in open coolships which are exposed to the airborne bacterial and yeasts of Brussels and the surrounding countryside, allowing spontaneous fermentation to occur. Once the wort is cooled, it is racked into oak barrels (often formerly used for wine) and allowed to ferment and age for 3 or more years.

Since Flemish sour beers are spontaneously fermented they can only be brewed when weather conditions promote the right mix of microbes, traditionally from mid-October to mid-April.

Homebrewers typically ferment the wort normally for several weeks, using any strain of Belgian yeast (Trappist yeast works well). Once fermentation settles down, the raw beer is transferred - lees and all - to a sealed plastic bucket or wooden barrel with an airlock, inoculated with microflora cultured from a commercial lambic, or a commercially-available "lambic blend" of microflora. It is then allowed to age for up to three years.

Belgian aged sour beers are stored in wood or plastic containers which allow oxygen to slowly penetrate. Traditionally, wooden casks also allow some water to evaporate, requiring that more beer or wort be added to top up the volume. This process gives the bacteria a slow, constant source of new sugars to ferment, allowing complex flavors to develop as the beer ages. Lactobacillus imparts crisp, tart sourness. Brettanomyces provides distinctive earthy, leather and barnyard notes, and oxidative yeast strains develop sherry-like notes.

Depending on the character of a particular batch of beer, it can be left to age for up to 3 years.

When the brewer decides that a particular batch of lambic has reached the peak of perfection, he will bottle it, often blending two or more batches to achieve a desired flavor.

Young lambic is sometimes blended with sugar to produce a locally-consumed specialty beer called Faro (pronounced Fah-rho).

Lambics continue to develop in the bottle, improving with age. If aged carefully, some examples can still be good after over a decade in the bottle.

*Different Types of Lambic:* The BJCP recognizes three different varieties of Lambic.

*1) Unblended Lambic:* This is the rarest type of lambic of all. It represents a single batch of lambic which stands on its own without blending. Unblended lambics can be young or old, with old lambics being sourer than young lambics. It usually has almost no carbonation.

*2) Gueuze:* This is a blend of young and old lambic which is allowed to bottle condition. It is produced by blending different batches of lambic, usually of different ages, to increase complexity and to provide a balance between the more intense character of young lambic and the sourness and complexity of aged lambic. Bottle fermentation gives the beer a moderate to high level of carbonation. Blended lambics usually have a better balance between sweet and sour.

*3) Fruit Lambic:* This is straight or unblended lambic to which fruit has been added. Usually, whole or macerated fruit is added to barrels of one year-old lambic and allowed to spontaneously ferment for up to a year. In some cases, the fermenting mix will develop a pellicle of mold and trub on the top, which protects the beer from further infection by unwanted microorganisms. The still-fermenting lambic is then blended and bottled, and bottle-conditioning gives the beer a moderate to high degree of carbonation.

Traditional varieties of fruit lambic are kriek (cherry), framboise (raspberry) and cassis (black currant). Modern lambic producers, especially producers of highly-sweetened products, have produced many other flavors of fruit lambic, from banana to peach.

## The Lambic Fermentation Cycle

During lambic fermentation, a succession of microflora – Enterobacter, Saccharomyces, Lactobacillus, Brettanomyces, Pediococcus and Acetobacter – ferment the wort and metabolize residual starches within the green beer. Periodically, during aging, the barrels are topped up with new wort to keep microflora activity going. Traditional wild-fermented lambics are fermented using over 70 different microorganisms.

This means that spontaneous lambic fermentation relies on a whole microbiological ecosystem, where different microorganisms succeed each other in the same way that different types of plants succeed each other after a forest fire.

The first “colonists” to feed on the fresh word are the Kloeckera and Enterobacter strains. This mixture of microbes consumes glucose and lowers pH. Kloeckera produces ethanol and breaks down proteins, while the enteric bacteria produce acetic acid.

The combination of ethanol and lower pH inhibits further bacterial growth, while proteins made available by yeast action and bacteria autolysis provide nutrients necessary to slow-growing microbes such as Brettanomyces and Pediococcus.

After 1-2 weeks, the bacteria and Kloeckera yeasts die off, allowing the second generation of colonists; Saccharomyces yeasts, to slowly take over, although the lack of glucose and prior bacterial activity inhibit quick Saccharomyces growth. Over a period of approximately 3-4 months they consume about 75% of the fermentable sugars in the wort.

At that point, the third wave of colonists start to appear in noticeable quantities, in the form of slow-growing Brettanomyces yeasts and Pediococcus bacteria. Brett forms a thick “ropy” pellicle on the surface of the beer, inhibiting oxidation, which provides ideal conditions for the Pediococcus, which prefers anaerobic respiration, and inhibits Acetobacter which prefers aerobic respiration. The Pediococcus strains impart lactic sourness, and become dominant after 3-4 months. While the Brettanomyces strains which impart the “earthy,” “horsy, “mousy,” “leathery” or “barnyard” flavors and aromas that make lambics so distinct become dominant after about 8 months. At one year of age, the microflora in the lambic have reached a constant state, although the beer will continue to develop as it is aged.