How Do I Brew Thee? (With apologies to Elizabeth Barrett Browning)

How do I brew thee? Let me count the ways.
I brew thee to the depth and breadth and height
My spoon can reach, when stirring out of sight
For the ends of the pickup tube that's been displaced.
I brew thee to the level of everyday's
Most fervent need, by sun and shoplight.
I brew thee freely, as men strive for Right;
I brew thee purely, in return for Praise.
I brew thee with the passion put to use
Standing in my T-shirt and briefs, and my childhood's faith.
I brew thee from a recipe I seemed to lose
With my patron saint. I shall brew thee without dread,
With smiles, tears, and occasionally my wife! or, if I choose,
I shall but brew thee later before bed.

Sensory Analysis: A Beer is What You Make of It

A beer can be compared to the performance of a symphony orchestra. We are the conductor, the recipe is the sheet music, and the instruments are the ingredients with which we work. A beer can be brewed rigorously to a recipe just like music can be played mechanically to the score. The difference is in the performance.

Everything we do in the brewing process affects the beer we make: the mash, the boil, the equipment we use, the decisions we make to cope with the brewing environment; all is manifest in the flavor of our beer. As brewers we can shape this performance and pull nuances from the ingredients that make a beer truly memorable.

First let's look at the sources of beer's flavor—the ingredients. Most of the flavors come from the malt and other fermentables. The hops add bitterness and a variety of herbal/floral/spicy flavors and aromas, but they usually play a supporting role, an accompaniment. The yeast can have a profound effect on the expression of the flavors, but serve the brewer much like the tempo and musical dynamics. The yeast build flavors from what they are given to ferment, and the brewer directs the fermentation. The barley is malted and kilned to produce a variety of flavors that we broadly describe as malty. These

by John Palmer
Illustration by Rick Hudson

flavors are usually described as warm and toasty, like freshly baked bread, and are the result of Maillard reactions, chemical browning reactions between amino acids and the naturally occurring sugars in the malt. Indeed, Maillard reactions are the source of all malt flavors, including chocolate and roast flavors.

The Mash

The sugars, proteins and flavors of malt are enzymatically extracted during the mash. The extraction is primarily dependent on temperature and pH. At low mash temperatures (113-131° F, 45-55° C), the proteases cleave large insoluble proteins into smaller soluble proteins that greatly enhance the mouthfeel of the beer. For instance, if you rest the mash at 120° F (48° C) for 15 minutes, you will add more soluble protein to the wort that will help build up the body of a beer that uses a high percentage (30 percent) of low protein adjuncts like rice, corn or refined sugar. More soluble protein also seems to aid head retention, although recent research indicates that the real cause may be more complex than that. As the mash temperature passes 150° F (65° C), any remaining beta glucan in the malt (a type of cellulose from the plant cell walls) will become soluble and increase the viscosity of the wort and the apparent body of the beer. Beta glucans add to the mouthfeel of the beer, but can also cause lautering problems in the mash; unmalted wheat and barley are prime examples. Resting the mash at 95-113° F (35-45° C) will break up these beta glucans, reducing viscosity and aiding extraction.

Conversion of the malt starches to sugars occurs most readily at the upper end of the saccharification range at 150-158° F (65-70° C), but the fermentability of the wort can be increased by resting at the lower end of the saccharification range at 140-150° F (60-65° C). Resting the mash in this lower temperature range for 20 minutes will lower the final gravity of the beer, making it drier and less filling. The effect of temperature to enzymes is like voltage to light bulbs; the warmer they are, the faster they will work, but they will also burn out more quickly than they will at a lower temperature. This is especially true of beta amylase, which is very heat- and pH-sensitive, but creates the highly fermentable sugar *maltose*. If the mash temperature is rested at the higher end of the range, beta amylase will be mostly denatured in about 20 minutes, the resultant sugars will be larger and less fermentable, and the beer will be maltier with more residual sweetness. Resting the mash for 20 to 30 minutes in both temperature ranges will yield a more fermentable wort and a slightly higher yield than a single rest mash at 150° F (60° C).

The pH of the mash affects both the enzyme activity and the expression of melanoidin flavors from the malt. The concept of residual alkalinity is the key to understanding the interaction of natural malt acidity and brewing water chemistry that determines the mash pH. There are books such as *How To Brew* that explain the concept more fully than I will attempt to do here. To summarize the concept, the mash pH for all beer styles should always be in the range of 5.4 to 5.8, when measured at room temperature, for highest yield without tannin extraction from the husks. Darker malts, and thereby darker beer worts, are more acidic than lighter malts, and require more alkaline brewing water to balance and achieve the

proper mash pH range. The majority of brewing water across the country (including bottled water) is moderately alkaline, and thus will properly balance with moderately dark beer worts, i.e. amber to brown colored beers. Lighter beer styles need less alkaline brewing water, and darker beer styles need more alkaline brewing water.

If a dark beer is brewed with less alkaline water, the mash pH will be below the recommended range, the beta amylase enzyme will be inhibited, yield will be reduced, and the beer flavor will be acrid. If a light beer is brewed with more alkaline water, the malt and hop flavors will be dull, tannins can be extracted from the grain husks, and the beer can taste astringent and chalky.

The hops are added to the boil for bitterness, flavor and aroma. The melding of the hop character to the malt in a beer can be conducted in a myriad of ways.

The lautering or sparging method can also affect the flavor and body of the beer. The traditional sparging method continuously rinses the grainbed to extract as much of the sugar and soluble extract from the grain as possible. The result is a dilution of the soluble protein and other rich tasting compounds in the wort, and if sparged too long, can lead to higher extraction of silicates and polyphenols from the husks that dull the taste of the beer. No-sparge brewing does not rinse the grain, and the wort comes entirely from the first runnings. The result is a richer, maltier tasting beer that can match the most ardent decoction-mashed effort. Batch sparging is halfway between these two methods. It is less sensitive to the problems of over-rinsing, in effect only rinsing the grainbed once. To batch sparge, drain the wort completely from the mash (this is the first runnings), and then add an equal amount of water back

to the mash, stir, recirculate for clarity, and drain again (the second runnings).

The Boil

Now for an interlude: the boiling of the hops. The hops are added to the boil for bitterness, flavor and aroma. The waxes and oils in the lupulin glands boil off at different rates, and we use this fact to impart different flavors and aromas from different varieties of hops at different times during the boil. Long boiling times result in more of the hop alpha acids being isomerized (and soluble) while the lighter oils and waxes boil away. Shorter boil times preserve more of these aromatic oils in the beer. Hop additions used to be rigorously added at 60, 30 and 15 minutes specifically for bitterness, flavor and aroma, but nowadays brewers achieve a greater spectrum of flavor and aroma with smoother bitterness by adding more of the hops later in the boil, and/or by continuously hopping throughout the boil a few grams at a time. The melding of the hop character to the malt in a beer can be conducted in a myriad of ways.

Fermentation temperature, like the tempo set by the conductor, is one of the most important controls a brewer can exercise in crafting a beer.

Hops also contribute polyphenols to the boil, and these along with malt husk polyphenols will link up with proteins in the boil and precipitate in the hot break. Irish moss helps to link large polyphenols and proteins together to help them settle out and clarify the beer. Studies have shown that less hazy beer is more stable and has less chance of staling. The most common manifestation of protein-polyphenol haze is the "chill haze" formed by small polyphenols cross-linking with protein. These complexes are insoluble when the beer is chilled, but don't have enough mass to settle out effectively and

will dissolve back into solution when the beer is warmed to room temperature. Lagering or cold conditioning the beer will help this haze to settle out. If a beer with chill haze is poorly handled during bottling or kegging, oxygen exposure can cause the small polyphenols to grow into larger polyphenols (and tannins) by polymerization, and the chill haze can become permanent haze.

Maillard reactions come back into play during the boil. The flavor changes are often attributed to caramelization, but this is a misnomer. Caramelization does not actually occur during the boil, even at gravities of 1.100, because the minimum temperature for caramelization of fructose is 230° F (110° C), and most other malt sugars require 320° F (160° C). Maillard reactions occur at a variety of temperatures and produce a bouquet of different flavors from the various amino acids and sugars created in the mash. These flavors can be fruity, nutty, raisiny or caramel-like. Maillard reactions also produce the brown melanoidin compounds that darken the beer and generate spectacular orange and red highlights.

Finally, a vigorous boil helps to drive off the chemical precursors of dimethyl sulfide, an off-flavor similar to cooked corn or vegetables that is most prevalent in beers made from low-kilned malts like pilsner lager malt and pale ale malt. A minimum boil time of 60 minutes is recommended to prevent dimethyl sulfide from being a problem in pale ales and lagers. Malt extract-based beers have fewer problems with DMS than all-grain beers due to the amount of volatilization experienced during dehydration.

Pitching Rate

The yeast pitching rate also affects the aroma/flavor character of the beer. The yeast reproduce rapidly early in the fermentation cycle, producing more fermentation byproducts than at any other time. A low pitching rate causes more total cell growth, more amino acid synthesis, and generally more esters (fruity flavors and aromas), diacetyl precursors (acetohydroxy acids) and fusel alcohols (solvent-like). Lower pitching rates tend to produce more aromatics and esters than

higher pitching rates. High pitching rates mean less total cell growth and generally fewer esters.

However, high pitching rates tend to promote acetaldehyde in the beer. Acetaldehyde is a green-apple-like flavor that is produced early in the fermentation cycle as part of the ethanol production process and is reduced later. It is typically caused by rapid fermentation due to warm temperatures (10° F over nominal), or by over-pitching and under-aeration. It is reduced by conditions that favor the conditioning processes such as warmer lagering temperatures (40-45° F), keeping the beer on the yeast longer, and keeping the yeast suspended. In addition, a less-flocculant yeast strain will allow more time for acetaldehyde reduction.

The fusel alcohols are not reduced by the yeast and will affect the final flavor of the beer, making it seem hot, harsh or solvent-like. While a few fusel alcohols can be esterified, it is a minor path and not a viable means of fusel reduction. Fruity esters are formed by the yeast by combining alcohol and a fatty acid. Fusel alcohol levels are increased by warmer temperatures, excessive aeration and excessive amino acids, or by under-aeration and a lack of amino acids.

Fermentation Temperature

Fermentation temperature, like the tempo set by the conductor, is one of the most important controls a brewer can exercise in crafting a beer. The fermentation temperature can have a big impact on the beer's flavor. Yeast activity and character are highly dependent on temperature. Yeast produce more esters, acetaldehyde and fusel alcohols when stressed. That same temperature/yeast activity level will determine how well the yeast condition the beer and clean up the acetaldehyde and diacetyl byproducts.

Diacetyl is not actually produced by the yeast. The yeast excrete diacetyl precursors throughout fermentation, and these break down chemically into diacetyl, independent of the yeast. Warm temperatures and the presence of oxygen promote this reaction. The yeast absorb and remove the diacetyl as part of the fermen-

Mybock

Partial Mash Recipe

Ingredients
for 5 U.S. gallons (19 liters)

1.0 lb	(0.45 kg) Munich malt
1.0 lb	(0.45 kg) Pilsner malt
1.0 lb	(0.45 kg) Aromatic malt
3.3 lb	(1.49 kg) liquid wheat malt extract
4.0 lb	(1.81 kg) light dry malt extract
1.0 oz	(28 g) Magnum Hops (12% alpha acid) 30 min.
2-3	Activator packs Wyeast 2633 Octoberfest Lager Blend BG for 3.3 gallons

Original Target Gravity: 1.060
IBUs: 29

Directions

Conduct a mini-mash in a 3-gallon (11.35 L) stock pot using a 5-gallon (18.92 L) nylon mesh paint strainer bag from the hardware/paint store. Crush the grain and put it in the mesh bag. Heat 6 qt (5.68 L) water to 165°F (74°C) (ratio of 2.0 qt/lb or 4.18 L/kg), and immerse the grain bag. Make sure all the grain is thoroughly wetted quickly and check the temperature. The mash temperature of the grain and water should now be about 150-155°F (66-68°C). Let mash sit for a half hour. Add heat from the stove while stirring to get the temperature up to 155°F (68°C). Let mash sit for another half hour. Place 2 gallons (7.57 L) of water in a 5-gallon (18.92 L) boiling pot and heat to 165° F (74° C). Lift bag out of the first pot and let it drain for a minute before transferring to the other pot. Swirl the bag in the pot to rewet the grain and let it sit for 5 minutes. Lift the grain bag, drain and discard. Add the wort from the first pot and the 3.3 lb (1.49 kg) of liquid wheat malt extract to the second pot, and begin your boil. Wait for the hot break to occur, then add the hops. Boil for 30 minutes. Add the remaining 4 lb (1.81 kg) of dry malt extract during the last 10 minutes of the boil. Stir to prevent scorching. Chill the wort and dilute in the fermenter to 5 gallons (19 L). Pitch 2-3 Wyeast 2633 Activator packs for a good pitching rate, and aerate well.

tation cycle. The ability of the yeast to remove diacetyl is about 10 times the creation rate, but in the case of lagers, the yeast activity decreases as the temperature is lowered toward the end of fermentation, and cleanup can be a problem. The result is the classic diacetyl artificial butter off-flavor. To remove any diacetyl that may be present after primary fermentation, a diacetyl rest is recommended. This rest at the end of a lager primary fermentation consists of raising the temperature of the beer to 55–60° F (12-16° C) for 24 to 48 hours before cooling it down for the lagering period. This makes the yeast more active and allows them to eat up the diacetyl before downshifting into lagering mode. Be careful to minimize oxygen contact during racking because this will generate still more diacetyl. Some yeast strains produce fewer diacetyl precursors than others; a diacetyl rest is needed only if the pitching or fermentation conditions warrant it.

By brewing a beer with attention to the details of the brewing process, we can craft and shape a beer to an ideal we hold in our minds. We can choose different specialty malts to emphasize particular kinds of malt flavor, or color. We can choose a mash schedule to give the beer more body, or more fermentability, and we can choose a yeast strain and fermentation environment that shapes the flavors and balance. Beer is music for the mouth.

How do I brew thee?
I brew thee for color, for the play of light, to capture the sun
I brew thee for aroma, the smell of home's hearth, and woodland heather
I brew thee for flavor, the warmth of the malt, the bitter kiss of the hop.
I brew thee for the delight of everyday, and for the delight of one.

John Palmer is author of *How to Brew*. As an engineer, he is drawn to the processes of brewing and tries to shape them into the best practices that allow new brewers to obtain consistent, high quality results. His favorite beers are American Amber Ale, American Wheat, Robust Porter, Flanders Red, Flanders Brown, Gueuze and Vienna.

Cherry Dubbel

Partial Mash Recipe

Ingredients
for 5 U.S. gallons (19 L)

1.0 lb	(0.45 kg) Munich malt
1.0 lb	(0.45 kg) Pilsner malt
1.0 lb	(0.45 kg) Aromatic malt
3.3 lb	(1.49 kg) liquid Light malt extract
3.3 lb	(1.49 kg) liquid Amber malt extract
12 fl oz	(0.35 L) Belgian Dark Candi Syrup
12 fl oz	(0.35 L) Traverse City Cherry Juice Concentrate
1.0 oz	(28 g) Fuggle Hops (5% alpha acid) 60 min.
2-3 tubes	Whitelabs WLP500 Trappist Ale Yeast

Original Target Gravity: 1.078
IBUs: 16

Directions

Conduct a mini-mash in a 3-gallon (11.35 L) stock pot using a 5-gallon (18.92 L) nylon mesh paint strainer bag from the hardware/paint store. Crush the grain and put it in the mesh bag. Heat 6 qt (5.68 L) water to 165° F (74° C) (ratio of 2.0 qt/lb or 4.18 L/kg), and immerse the grain bag. Make sure all the grain is thoroughly wetted quickly and check the temperature. The mash temperature of the grain and water should now be about 150-155° F (66-68° C). Let mash sit for a half hour. Add heat while stirring to get the temperature up to 155° F (68° C). Let mash sit for another half hour. Place 2 gallons (7.57 L) water in a 5-gallon (18.92 L) boiling pot and heat to 165°F (74°C). Lift bag out of the first pot and let it drain for a minute before transferring to the other pot. Swirl the bag in the pot to rewet the grain and let it sit for 5 minutes. Lift the grain bag, drain and discard. Add the wort from the first pot and the 3.3 lbs (1.49 kg) of liquid Light malt extract to the second pot, and begin your boil. Wait for the hot break to occur, then add the hops. Boil for 60 minutes. Add the remaining 3.3 lbs (1.49 kg) of liquid Amber malt extract and the dark candi syrup during the last 10 minutes of the boil. Stir to prevent scorching. Chill the wort and dilute in the fermenter to 5 gallons. Pitch 2-3 Whitelabs WLP500 tubes for a good pitching rate, and aerate well. Add the cherry juice concentrate after the third or fourth day of fermentation when activity has slowed.