

Foam Ranger BJCP Class Outline

The main focus for the Foam Ranger BJCP class is to teach the most difficult aspects required for the BJCP exam while providing a self-guided study plan for the less interactive aspects of the exam. The class will focus on palate development, proper score sheeting (including scoring accuracy and writing a complete score sheet), and essay writing. Although, the following topics will be touched on in class (and more importantly, questions will be answered both in class and via email), self-guided study will be required for style guidelines, brewing processes, brewing history, recipe formulation, and brewing ingredient information.

Self Study Topics and Keywords

1. Malts and Malting

- Definitions
 - Grass family, Gramineae
 - 2-row/6-row
 - Basics of anatomy (acrosipire, embryo, husk, endosperm)
 - Proteins (amino acids, peptides, polypeptides)
 - Carbohydrates (simple sugars, dextrans, starches – both amylose and amylopectin)
 - Enzymes (phytase, proteinase, peptidase, beta amylase, alpha amalyse)
 - Modification – definition and effect on mashing regime
 - Diastatic power (degrees Lintner) and levels in each type
 - Color (degrees Lovibond) and color of each type
- Types of Malt/Malt Analysis
 - Pils
 - Pale
 - Vienna/Munich
 - Crystals/Cara-Malts
 - Chocolate/Black Patent/Roasted
 - Wheat
- Malting Process
 - Steeping, Germination, Stewing (for crystals), Kilning, Roasting (for dark malts)

2. Water

- Concepts of pH, alkalinity (buffering), hardness
- Main ions of brewing concern
 - Calcium (2+) – mash pH adjustment, enzyme stability in mash, yeast nutrient
 - Sulfate (2-) – dryness, bittering enhancer
 - Chloride (-) – flavor enhancer
 - Carbonate (2-) and Bicarbonate (-) – buffering
- Water types in various cities and effect on historical brewing styles including Munich, Burton-upon-Trent, Pilsen, Dortmund, Dublin

3. Hops

- Humulus Lupulus
- Anatomy: strobile, strig, bracteole, seed, lupulin glands

- Alpha and beta acids
- Essential oils
- Types, origins, and alpha acid ranges
- Bitterness, IBUs (and calculations)
- Noble Hops (Saaz, Tettnanger, Hallertauer Mittelfruh, Spalt)
- Additions (bittering, flavor/aroma, dry hopping)

4. Mashing/Boiling

- Mashing Process
 - Steps (milling, dough in, mash, rests, lauter)
 - Temperature Rests (acid, protein, saccharification)
 - Enzymes (phytic, proteolic, diastatic (alpha and beta))
 - Processes (infusion, multi-step infusion, decoction)
- Adjuncts
 - Unmalted cereal grains (oats, flaked barley, corn)
 - Non-malt Sugars (rice, corn, beet)
- Key Variables
 - Temperatures
 - pH/Calcium
 - Liquor-to-Grist ratios
 - Enzymes
- Lautering
 - Sparging
 - First Wort Hopping
- Boil/Cooling
 - Isomerizes hop alpha acids for bitterness
 - Sanitation
 - Reduces water volume
 - Coagulates proteins and tannins (hot break, cold break)
 - Evaporates DMS, harsh hop oils
 - Carmelization, formation of melanoidins
 - Cooling – DMS, hot and cold break formation/trub

5. Fermentation/yeast

- Definitions
 - Attenuation (actual and apparent)
 - Flocculation
 - Autolysis
- Starters/Pitch Size
- Aeration/Oxygenation
- Fermentation Cycle (respiration/lag, fermentation (low krausen and high krausen), sedimentation)
- Ale yeast (*s. cerevisiae*) and fermentation schedule/characteristics
- Lager yeast (*s. uvarum*) and fermentation schedule/characteristics
- Lagging
- Unusual brewing systems (Burton union, lambic fermentation, Yorkshire stone squares)
- Nutrients (amino acids, zinc, calcium)
- Yeast off-flavors (ester, phenolics, fusel alcohols, diacetyl, sulfur compounds)
- Bacteria and wild yeasts (including Belgian Lambic and Berliner Weisse)

6. Troubleshooting/Off-flavors

- Light-struck/skunked
- Astringent
- Phenolic/medicinal/band-aid
- Chlorophenolic/Plastic-like
- Diacetyl/Buttery/butterscotch
- DMS/corn-like
- Esters/Fruity
- Grainy/husky
- Metallic
- Oxidized/Stale/Papery/Cardboard/Sherry
- Solvent
- Sour/Acidic
- Salty
- Acedaldehyde/cider-like/green apples
- Vegetal
- Alcoholic/Fusel Alcohols
- Sulfury/Yeasty

7. Beer Styles

- Refer to www.bjcp.org for current LONG style guidelines

Malts and Mashing

Barley is a plant in the grass family, Gramineae. Other species in the Gramineae family that have importance in brewing include wheat, rye, oats, rice, and maize. Barley has been the grain of choice for brewing beer since before recorded history since barley is easily malted, has a well balanced protein and starch structure, is plentiful of enzymes, and its husk is well suited for lautering. Barley is most often grown in milder climates such as northern Europe and northern and central United States.

Barley is a tall grass forming ears (or heads) on the top of each stem. There are two varieties of barley two-row and six-row, each differentiated by the number of seed rows that are grown on each head. A four-row variety also exists but it is not important in the brewing industry.

Even though they are from the same species, six-row barley and two-row barley are different in with regards to the brewing process. Six-row barley benefits from the number of rows present on a head, resulting in a larger yield per acreage. But, the kernels are smaller and have a larger amount of husk per seed (better lautering but more potential from husk astringency). Six-row barley also has a higher protein content which results in a higher enzyme level but can lead to a potential for protein haze (which is why it is often used in American lagers – adjuncts such as corn or rice will dilute the protein level thus reducing haze formation while the high level of enzymes (which are proteins) in the six-row barley converts the enzyme-less rice and corn starches to fermentable sugars). Two-row barley, on the other hand, has larger kernels, less husk per seed, and less enzymes (but still plenty of enzymes to convert its own starches and often other cereal grains as well).

Anatomy of Barley

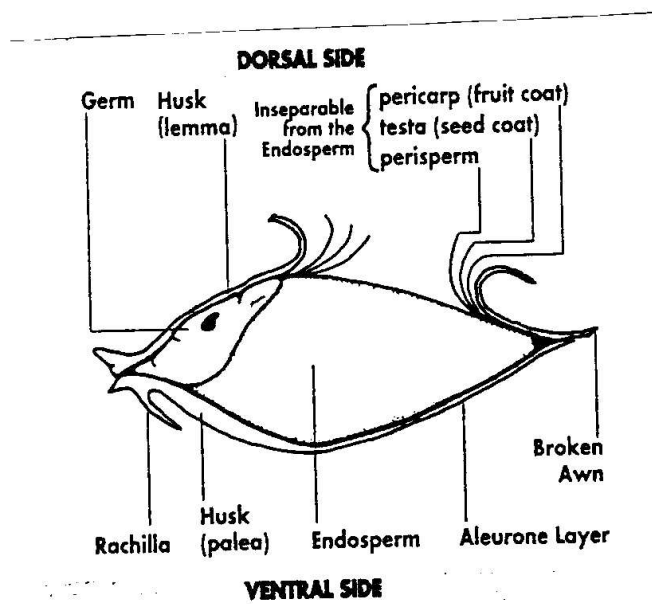


Illustration taken from "Malting and Mashing: Rated G", Zymurgy Special Issue 1995, Ray Daniels

Husk – The husk is the outside protective layer of the grain kernel. The husk is made mainly from insoluble cellulose. The husk contains a large amount of tannins which can cause astringency under the right mash conditions, such as high temperature (higher than 170 F) or high pH (higher than 6). The husk when lightly craked or crushed helps during the lautering stage of mashing by forming a filter bed.

Endosperm – The endosperm is the largest part of the grain kernel. It is the source of starches that brewers are after in the mash. It is converted into malt sugars by the saccharification enzymes during the mash.

Embryo – The embryo is the living part of the kernel that grows during the germination phase of malting. The acrospire and the rootlets grow from the embryo during germination. The rootlets grow on the outside from the base of the kernel while the acrospire grows and consumes the endosperm inside the kernel.

Acrospire – The acrospire is the growing embryo of the grain kernel. The length of the acrospire as it grows inside the grain through the endosperm (relative to the length of the kernel) is a crude estimate of the degree of modification during malting. (Note: in the diagram on the following page, the acrospire is indicated by the darkened part of the kernel while the endosperm is indicated by the white part of the kernel).

Biochemistry of Barley

Proteins – Proteins are chemicals that contain carbon (C), hydrogen (H), oxygen (O), and nitrogen (N). They are made from chains (polymers) of various amino acids. Proteins are broken down during malting and during low temperature mash rests to form smaller proteins and amino acids. Large, complex proteins are known to cause chill haze. Smaller proteins aid in forming body and head retention. Amino acids are yeast nutrients. All of the mash enzymes are proteins.

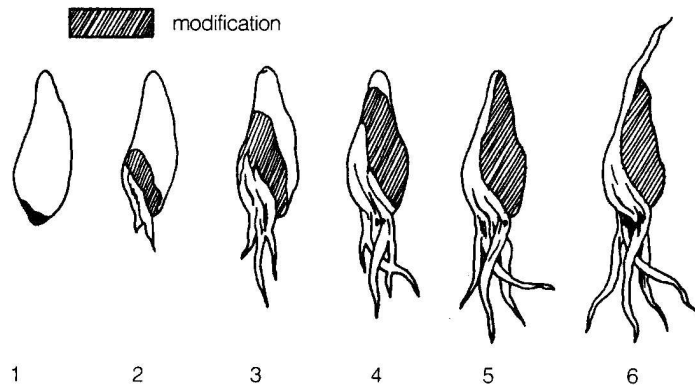
Carbohydrates – Carbohydrates are a large family of chemicals containing carbon (C), hydrogen (H), and oxygen (O). The simplest forms of carbohydrates are simple sugars such as glucose and fructose (monosaccharides). Larger carbohydrates are chains of simple carbohydrates. Maltose, the most common sugar in the wort is a disaccharide (two glucoses connected). Very long chains of simple sugars are starches (straight chain starches are often called amylose and branched chained starches are often called amylopectin). Starches are broken down in the mash by saccharification enzymes to form simple sugars and dextrins. Dextrins are medium sized sugars that are difficult for enzymes to break down further due to the side branching of the chains. Dextrins provide body and mouthfeel, are not fermentable by beer yeast, and provide residual sweetness in the fermented beer.

Malting Process

Raw barley is unsuitable for brewing until it is malted. Malting prepares the malt for the brewer to mash and create wort. Malting reduces the sizes of the complex protein and starch chains so that they are accessible to the enzymes in the mash. Additionally, the enzymes that are critical for mashing are created by the breakdown of complex proteins during malting.

Steeping – Steeping is the first step of malting where the barley is mixed with water (around 60 F). The absorption of water by the grain prepares the barley for growth during germination. This step takes between 1 to 2 days.

Germination – After the barley absorbs water during the steep, the water is drained and the barley begins to germinate (grow). The grain is aerated to provide oxygen for the growth and the temperature is maintained around 60 F for 3 to 5 days. During germination, the acrospire grows depleting nutrients from the endosperm. The longer and more complex proteins and starches are reduced to smaller, less complex, and more manageable sizes for the enzymes to access during mashing. The longer the barley is allowed to germinate determines the modification of the malt.



Modification and growth of acrospire and rootlets during malting. 1) No modification. 2) Rootlets first appear and acrospire begins to grow; modification commences at bottom of grain. 3) Acrospire about half the length of the kernel; modification continues upward and outward. 4) Acrospire about $\frac{3}{4}$ length of the kernel; modification almost complete. Only tip remains hard and "steely." 5) Acrospire fully grown: full modification. 6) Acrospire overgrown: germination has gone too far.

Illustration taken from Dave Miller's Homebrewing Guide, Dave Miller

Kilning - The final stage of malting is kilning. During kilning, the malt is dried to lower the moisture content and temperature ranging from 185 to 450 F depending on the malt being made over a 1 to 2 day period. Kilning is where the malt develops color at the sacrifice of enzymatic activity (higher temperature means more color and less enzymatic activity).

Types of Malted Barley

Base malts (pilsner, pale, Vienna, and Munich) are kilned at low temperatures, make up the bulk of fermentables in the wort, and provide most or all of the mash enzymes. Dark malts (chocolate, black, and roasted) are kilned at high temperatures, are not fermentable, and contribute a roasted, coffee, chocolate, or burnt flavor to the wort. Crystal and Cara

malts (from light to dark) are produced using a steeping kiln process where the kiln is not vented; all of the moisture is retained in the kiln for the duration of the kilning process. This method essentially mashes the grain in the kettle and provides the malt with a caramel flavor that intensifies at higher kiln temperatures (crystal and Cara malts are mostly not fermentable).

Some aspects that are important in selecting malt varieties beyond the type of malting process are modification, color (measured on the Lovibond color scale), and enzymatic activity (also called diastatic power, measured on the Lintner scale).

Modification is the degree that the complex proteins and starches are broken down during the germination phase of malting. Under modified malt has a lower degree of complex protein reduction and thus requires the brewer to perform a protein rest during the mash (most malts produced today are highly modified and do not require a protein rest). Highly modified malts do not require a protein rest, but doing so may result in a higher mash efficiency and reduced probability for chill haze but may result in less body and head retention.

Beer color is mostly influenced by malt color although many other factors influence beer color as well (including boil intensity and time, boil gravity, and wort or beer oxidation). Malt color charts are included in many references but the general order from light to dark is pilsner, pale, Vienna, Munich, light crystal, dark crystal, chocolate, black patent, roasted barley.

Diastatic power is the amount of enzyme power that is available to act on the proteins and starches in the mash. For most mashes, there are plenty of enzymes available. In mashes with a large amount of cereal adjuncts (cereal starches with no enzymes such as flaked rice, flaked barley, flaked oats, or flaked maize), as in the production of American pilsners, the brewer needs to be certain that there are enough enzymes available to convert the large amount of starches (oftentimes, this is where 6-row pilsner malt is used).

Pilsner and pale malts are made from either 2-row or 6-row varieties of barley. Pils and pale malts make up the majority of the grain bill for most styles of beers. Vienna and Munich malts are kilned at higher temperatures and have sufficient diastatic power to convert their own starches as well as that of some adjuncts.

Dark malts and crystal and Cara malts have no enzymatic power, but have little or no fermentables as well. Therefore, they do not need to be mashed but are usually done so for convenience. Since mashing is not required, dark and the crystal and Cara malts are ideal for extract brewers (they only need to be steeped in hot water).

Wheat

Wheat, also from the grass family, is often found in brewing in beer styles such as Bavarian Hefeweizen, Belgian Wit, the Lambic family, Berliner Weisse, and American Wheat. Wheat is most often malted but unmalted wheat is used in Belgian Wits and the Lambic family. Wheat can be used at any proportion in beer but is most often found in ranges from 40 to 60% (for Bavarian Hefeweizen and Belgian Wit) to 30% (for Lambics).

and Berliner Weisse) with any proportion (usually from 30 to 60%) for an American Wheat.

A few principal differences exist between wheat and barley. Wheat has no husk, therefore lautering may be more difficult but tannin extraction will not be an issue. But, wheat has more glutes (a protein that tends to be very sticky) and a higher overall protein level; both aspects lead to a sticky, gummy mash that is more often likely to be “stuck” (where the run-off goes VERY slowly, if at all) and also more likely to result in a cloudy beer. Also, wheat tends to have smaller, harder kernels making them difficult to crush at ordinary mill settings.

Mashing and Brewing Processes

Once the maltster prepares the harvested grain into a malted barley, the brewer still must perform work on the malt in order for it to be fermented by the yeast. This process is called “mashing”. In order to take advantage of the starches, proteins, and enzymes in the malt, the brewer first must crush the grain. When crushing, great care is taken by the brewer to not over-crush or under-crush the kernels. A properly crushed grain will generally leave the husks mostly intact exposing the starchy endosperm. If the grain is under-crushed, many whole kernels will remain uncrushed and will lead to a low efficiency and low starting gravity of the wort. If the grain is over-crushed, the husks will be pulverized which can lead to a stuck run-off and potentially a higher level of astringency from more exposure of the mash to the tannins in the husk.

After crushing, the crushed malt is “doughed-in” with hot water to form the “mash” (the hot crushed malt in water). After doughing-in, the brewer will quickly seek the first (or in some cases, the only) mash temperature. It is during this “mash” that the enzymes act on the malt to breakdown the proteins and starches. A number of mashing schedules are possible, depending on the type of grain, the equipment available to the brewer, and the desired style to be brewed. Additionally, a number of temperature rests can be performed by the brewer to activate a number of enzymes to convert the proteins and starches to smaller fractions. Types of mashing and different temperature rests/malt enzymes will be discussed later.

During the mash, a number of variables are very important to produce a high quality wort with the most important being the temperature. A number of temperatures can be utilized to accomplish a number of results including acidifying the mash, breakdown of proteins and polypeptides, and breakdown of starches into sugars (the most important purpose of the mash). Again, the temperatures and enzymes will be discussed later. A few variables in the mash that are also important are: pH and calcium (both to be discussed in great detail in the water section).

Once the temperature rests are complete (usually 60 to 120 minutes total), the brewer will separate the sweet liquid from the remaining grain particles. This separation is called the “lauter” and the sweet liquid run-off is called the “wort”. Most often, hot water is run over the grain bed to extract more sweet wort from the mash; this is termed “sparging”.

After the wort is collected from the mash, the wort is brought to a boil. During the boil the brewer adds hops for aroma, flavor, and bitterness (the alpha acids in the hops are isomerized to soluble bittering compounds). Also, the boil acts to sanitize the wort,

precipitate haze forming tannins and proteins (termed as the “hot break”), volatilize harsh compounds such as dimethyl sulfide (DMS), reduce the large volume of water collected in the mash, and caramelize the malt to form color and a rich malt sweetness.

Once the boil is complete (usually 60 to 90 minutes), the wort is cooled so that the yeast can be pitched (yeast will not survive the high temperatures of the boiling wort). Additionally, the cooling will further precipitate proteins and tannins and allow the hop particles to settle (collectively termed “cold break”). After the wort is cooled, the yeast is pitched and air or pure oxygen is added as a nutrient for the yeast.

Mash Temperature Rests/Malt Enzymes

There are many enzymes in the malt that are active at various temperature ranges. Each enzyme works only on one specific substrate. Enzymes are always designated with an “ase” suffix with the substrate as the prefix.

Phytase – Phytase is the enzyme that is active at low temperatures during an acid rest. Its active temperature range is from 86-128 F and it converts phytin into phytic acid. The optimum mash pH range is 5.2-5.4. This rest is usually not necessary depending on the water quality and amount of dark malts in the grain bill (dark malts have a high acidity and will bring the pH of the mash down). The optimum mash pH can be achieved by adding acid (usually phosphoric, lactic, or citric) as well.

Peptidase – Peptidase is one of the two major enzymes utilized during a protein rest. Peptidase reduces polypeptides (smaller proteins but not as small as amino acids) to smaller peptides and amino acids. The optimum temperature range for this enzyme is 113-122 F. This rest is usually only recommended for under modified malt; resting at this temperature with highly modified malt will result in too few polypeptides which can hurt body and head formation.

Proteinase – Proteinase is the main protein rest enzyme. It reduces proteins into smaller proteins (polypeptides and peptides) and amino acids. The optimum temperature range is 122-140 F. This rest is mainly used for high protein malts to increase the stability and reduce the potential for chill haze in the finished beer. This rest is often not necessary with most modern highly modified grains.

Beta-Amylase – β -amylase is one of the two saccharification enzymes. β -amylase converts soluble malt starches into simpler sugars and dextrins. The optimum temperature range for this enzyme is 140-149 F. Mash rests low in the saccharification range result in a dryer, more fermentable beer.

Alpha-Amylase – α -amylase is the other saccharification enzyme. α -amylase converts both soluble and insoluble starches into simpler sugars and dextrins. Since α -amylase breaks the long starch chains from the middle (β -amylase works from the ends only), more dextrins are formed resulting in a sweeter, less fermentable beer. The optimum temperature range for this enzyme is 152-158 F.

Mashing Schedules

Infusion mashing – Infusion mashing is the simplest of the mashing programs. The mash temperature is achieved by simply adding hot water to the grain and rested. Only one mash temperature in the saccharification range is used for this method.

Step Infusion Mashing – Step infusion mashing is similar to infusion mashing but multiple temperatures steps are achieved by the multiple additions of hot or boiling water. Direct heating of the kettle can also be used to raise the mash temperature. Most ales are made using either of the two infusion mashing programs.

Decoction mashing – Decoction mashing is much more involved than infusion mashing. Temperature steps are achieved by taking out grain and water from the mash, directly heating and resting it through all of the next temperature rests, bringing it to a boil, and returning it to the mash to raise the bulk mash temperature. Many German and Czech lagers are produced using decoction mashing.

Off-Flavors from Malts and Mashing

Astringency – Astringency is a mouth puckering sensation or a tongue prickling sensation as if you were chewing red grape skins. Astringency is caused by the extraction of tannins from the malt husk in the mash. Astringency can be caused by over-crushing malt (pulverizing the husk), over-sparging (general rule is to not sparge with more water than the mash water or not to let the run-off drop less than 1.008 in gravity), sparging with water too hot in temperature (greater than 170 F), or mashing or sparging with water too high in pH (sparge water should be a pH of 5.8 or less). Some spice additions can cause an astringency if over-used. Hops boiled too long or steeped too long in the secondary or serving keg can cause astringency as well.

DMS – DMS, dimethyl sulfide, has the smell and taste of cooked corn or cream corn. During the boil, an amino acid S-methyl methionine (SMM for short) from the malt is broken down into DMS which is very quickly driven off in the boil. DMS can be carried over into the finished beer if the boil intensity is low, if the boiled is covered, or if the wort is cooled slowly (allowing SMM to breakdown to DMS but not boiled away). Wort spoilage or poor malt quality (high SMM level in malt) can cause DMS as well.

Oxidized – Oxidation can cause aromas or flavors such as sherry-like, wet cardboard, papery (like a spitball!), or nuttiness. Oxidation in dark beers usually manifests itself as sherry whereas amber or light beers usually display a cardboard or papery character. Oxidation can also cause the malt profile in the body to be thin (maltiness disappears soon after you taste it). Oxidation is caused by aeration of the beer after fermentation has begun, such as during racking, secondary fermentation, or bottling/kegging. Storing beer at elevated temperatures will accelerate how quickly the beer will become oxidized.

Water

Beer is made from 90+% water (with some very strong beers obviously being lower in water content). Water is a very simple molecule, but can be very complex in the chemistry involved. It has the chemical formula H-O-H or H₂O (two hydrogens and one oxygen). But water is just not water; there are many other chemicals in most water supplies, mostly inorganic (in other words, salts as opposed to biological forms or

organic carbon-hydrogen forms). When inorganic salts are dissolved into water, the salts dissociate into their ions (some do so more completely than others). For example, table salt (sodium chloride) has one sodium molecule attached to one chlorine molecule (the chemical formula is NaCl). When dissolved in water, the molecules dissociate or float freely about forming a sodium ion and a chloride ion, normally designated as Na^+ and Cl^- (with the + and – designating the electrical charge that they carry). When a number of different inorganic salts are in a water solution, the chemistry can get quite complex. But, despite the complexity, there are three factors when determining how a brewer should treat their water: chlorine/chloramines removal, desired pH, and water salt content in each of the mash and sparge waters, all of which affect the flavors in the finished beer.

Below are the common water salts added in brewing and the ions that they form in water:

| | | |
|---------------------------|-----------------|---|
| Gypsum (Calcium Sulfate) | CaSO_4 | Ca^{2+} and SO_4^{2-} |
| Calcium Chloride | CaCl_2 | Ca^{2+} and Cl^- |
| Calcium Carbonate | CaCO_3 | Ca^{2+} and CO_3^{2-} |
| Epsom (Magnesium Sulfate) | MgSO_4 | Mg^{2+} and SO_4^{2-} |

A concept that is essential in water chemistry is pH (or alternatively acidity/alkalinity). pH is a measure of the acidity or basicity (alkalinity) of the water (formally measured as the negative \log_{10} of the H^+ ion concentration in molarity concentration units for those technical geeks!). Neutral water has a pH of 7, the pH of an acid is less than 7, and the pH of a base is greater than 7. Common acids are beer, milk, battery acid, and Coca Cola. Common bases are bleach, baking soda, and ammonia. Most tap water is slightly alkaline (pH around 8 or 8.5) but some (such as Ozarka Spring water) are slightly acidic at a pH of 6.5. Water pH is best measured by a pH meter but can be measured by pH test strips.

Tap water is treated with chlorine gas (Cl_2), sodium hypochlorite (NaOCl , commonly called bleach), or chloroamine (various structures but commonly NH_2Cl) in order to guarantee that no dangerous microbiology (mainly bacteria and viruses) can survive in the water (coliform bacteria *E. coli* is the usual measurement to determine contamination levels). Tap water is usually treated to between 0.2 and 0.5 ppm of free (unreacted) chlorine. Even at this low level, chlorine can react with phenols in the mash or wort to form very strongly flavored chlorophenolics that are reminiscent of the medicine chloroseptic. For tap water systems where chlorine gas or hypochlorite are used, boiling the water before using it will likely remove any free chlorine. But, most residential water treatment systems use chloroamine which is much more persistent and will only be moderately reduced during a boil. Therefore, to remove chloroamine (and also chlorine or hypochlorite) from tap water, a brewer will need to use activated carbon filtration. (The trick is to know when your activated carbon is no longer active – some homebrew suppliers (and all pool suppliers) sell free chlorine test kits or strips, also carbon filters are huge microbio collectors – never use any carbon filtered water for post-boil uses.) Bottled water is usually treated by both ozone (O_3) and ultra-violet light to remove any microbio present.

The optimum mash pH is 5.2 to 5.4. Most mash grists will have no problem reaching their optimum mash pH for most water sources. The pH reduction by the grain is achieved by the reaction of phosphate in the grain with the calcium in the water and by

the acidity of the darker malts in the grist (the acidity of the malt is usually proportional to the darkness of the malt). The exceptions (or from a brewer's perspective, the problems) occur for very light grists (pilsners, golden ales) where the acidity of the malt is low (even more prominent when the alkalinity of the water is high) – in this case, the malt cannot cause the pH too get low enough resulting in poor mash efficiencies.

Another exception where the optimum mash pH is not reached is for very dark beers (porters, stouts), the acidity from the malt is very high and can result in a very low mash pH which can result in an unbalanced beer (overly harsh, astringent, and acidic finish).

A brewer can achieve the optimum mash pH in a number of ways. The most traditional method is by using an acid rest. An acid rest occurs during the mash at 86 to 128 F for approximately 20 minutes. The enzyme phytase activates the reaction of phytin, which occurs naturally in the malt, into phytic acid. Although, this is not effective for reducing the mash pH to its optimum levels in highly alkaline waters.

Another method to achieve an optimal mash pH is by adding calcium salts (either with gypsum or calcium chloride); the presence of calcium will cause a precipitation of calcium phosphate in the mash, lowering the mash pH. This will work well for moderately alkaline waters. Typical calcium ion concentrations in the mash range from 50 to 100 ppm Ca^{2+} . "Hardness" is often used to summarize the calcium, magnesium, and iron (but most of the hardness is usually calcium).

The most direct method for adjusting pH is to add an acid to the mash water to achieve the acidity level in the water (before mashing) that will result in pH of 5.2 to 5.4 in the mash. Very strong acids may be used in commercial breweries such as hydrochloric acid or sulfuric acid but phosphoric acid or lactic acid are common acids used at the homebrewer level. One last, but uncommon, method is to use sour malt which has been purposefully soured with lactic acid bacteria.

For the sparge water pH, the usual practice is to lower the sparge water pH to around the mash pH. Lowering the sparge water pH to the mash pH will prevent leaching of tannins from the malt husk into the beer. Flavors associated with high tannin levels are a strong astringency, a strong, full tongue prickling sensation (this can often be misinterpreted as either acidic or bitter).

One disclaimer to the brewer: one must know the starting point of the water before adding chemicals. One should know the calcium level or the alkalinity (or acidity) before additions so the additions do not over compensate. Bottled distilled water can generally be considered neutral water where the brewer can start from scratch. Water reports are generally available from municipal water companies and even from suppliers of bottled water.

Flavors Associated with Water Chemistry

Sulfate – Sulfate is most commonly added in the chemical form of gypsum (calcium sulfate) or Epsom salts (magnesium sulfate). High sulfate water is very commonly used in hoppy beers such as Pale Ales and IPAs. High sulfate waters or beers have an accentuated hoppiness and bitterness with a dry finish reminiscent of chalk.

Chloride – Chloride is most commonly added as table salt (sodium chloride) or calcium chloride. Chlorides are flavor enhancers (that why we add table salt to our food). Chlorides will generally bring out the maltiness or sweetness in a beer.

Chlorine/Chloroamine – Free chlorine in beer will give a pool-like water taste or odor. High chlorine in the mash or boil will react with the malt phenols to form chlorophenols which a reminiscent of the medicine Chloroseptic.

Iron – Iron in beer comes from the corrosion of cast iron or mild steels (not stainless steel) by water or beer. In excess, iron in beer will give the beer metallic, tinny, coin-like, or blood-like flavors.

Regional Waters and How it Affects Historical Styles

Burton-upon-Trent, England – Burton is known as the birthplace of the IPA. The waters in Burton have been known to vary quite greatly but all water samples have high amounts of calcium, carbonates, and sulfates (Noonan gives concentrations of 275 ppm, 260 ppm, 450 ppm respectively - actually you may have problems getting all of the salts soluble if you try to duplicate the exact water profile!). For your typical English IPA, the calcium and a moderate amount of colored malt help bring the acidity down to counteract the high carbonate level. The high sulfate level provides a dry finish and compliments the hop bitterness.

Munich, Germany – Munich is well known for light beers such as Munich Helles as well as dark lagers such as Munich Dunkel. Munich's water is well balanced in calcium and carbonates but low in sulfates (75 ppm, 150 ppm, and 10 ppm respectively). The carbonates provide enough balance for a small amount of dark malt but still has a low enough carbonate level for an acid rest to achieve an acceptable mash pH in a lightly colored beer. The low sulfate level provides for a smooth, malty finish.

Pilsen, Czech Republic – Pilsen water is very pure and is very low in all water salts (7 ppm calcium, 15 ppm carbonates, and 5 ppm sulfates). This water profile will give quite a smoothness to the maltiness and no light colored mash should have a problem reaching its optimal mash pH with this low of carbonate level.

Dublin, Ireland – Dublin is the stout capital of the world. The calcium level is moderate and the carbonate level is moderate and the sulfate level is low (75 ppm, 125 ppm, and 55 ppm respectively). The dark malt in the stout adequately balances the moderate carbonate level. The low sulfate level helps keep the maltiness smooth and keeps from drying out the beer in the finish.

Off-Flavors

Metallic – Metallic is a flavor than can be described as tinny (as in the taste associated with a tin can), coin-like, or blood-like. High metal level (as in some well water supplies) in the water supply is a major contributor to metallic flavors. Contact of the wort or beer with mild or carbon steels can also contribute to metallic flavors.

Hops!

In ancient times, blends of spices, often referred to as “gruit”, had been used to flavor beer. This “gruit” also provided a balance for malt sweetness and acted as a preservative against beer spoilage from wild organisms. Hops, although believed as being first cultivated in Babylon in 200 AD, show their first evidence of their use in beer in 1079. Eventually, hops had gained a widespread acceptance in England in the 1500’s and were officially deemed a mandatory ingredient in Germany with the Reinheitsgebot in 1516. Today, almost a hundred varieties of hops are used in beer with an order of magnitude higher number of varieties in development.

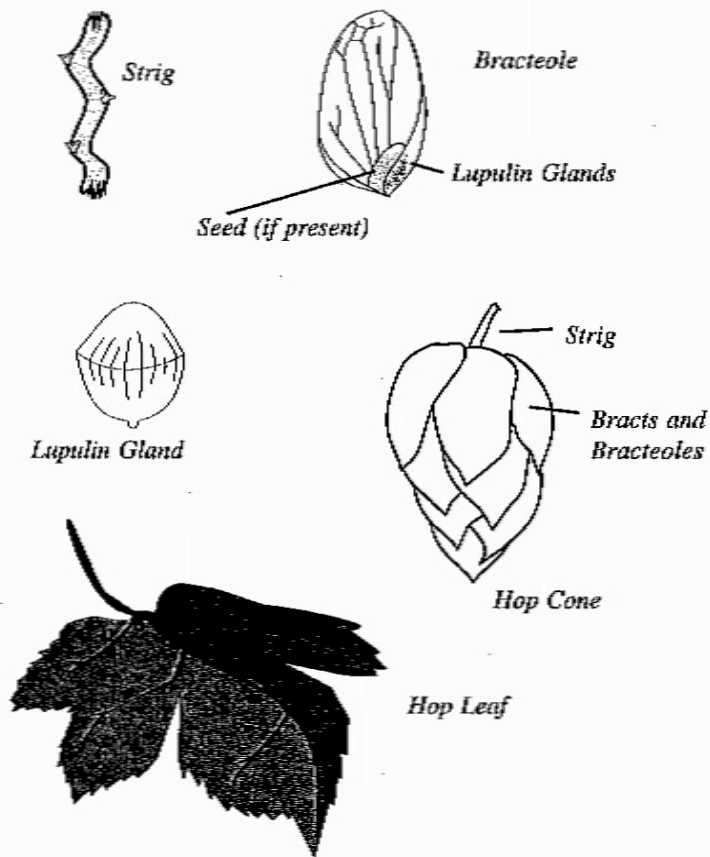
Botanical Basics

The hop plant is a species of flowers with the botanical name “*humulus lupulus*”. Hops are grown throughout the world, most often in the cooler climates such as northern Europe or the northwestern United States. Hops are vertical growing, vine-like plants, usually reaching as high as 15 feet strung along a series of trellises that support the hop vines. They are harvested in the fall season most often using special machines that de-vine and de-leaf the hop cones while leaving the plants in place for the next season.

Hops are cone shaped flowers. The hop plants grow in “bines” along high vertical trellises. The stem that holds the “strobile”, or cone or flower, to the vine is called a “strig”. The petals grow off the strig and are known as “bracts” and “bracteoles”. The bracteoles have small yellow “lupulin glands” at their base that contain the essential oils of the hops that contribute the hop flavors and aromas as well as the bitterness; the bracts have no lupulin glands. For hops that have seeds (primarily UK varieties such as East Kent Goldings), they are also found on the bracteoles.

An interesting fact about hops is that they are a “dioecious” plant. Both male and female varieties exist. But, for the most part, the male hops are rarely grown in the fields; this is due to the fact that the female plants develop a few orders of magnitude more lupulin glands which is the prize of the hop farmer.

Hops are quite vulnerable to diseases (such as *Verticillium* with, downy mildew, mold) and pests (hop aphids); their resistance is quite dependent on variety and location.

Using Hops

Diagrams of a hop strig, bracteole, lupulin gland, hop leaf and a whole hop cone. These are not to scale to one another and of course are highly stylized.

Illustration taken from "Using Hops" by Mark Garetz

Hop Processing

Most hops are picked from the vines using mechanical picking machines. Although, some hops are still hand picked in small regions in Europe. Regardless of the picking method, the hop cones are separated from vines and the leaves and stems are removed. The hop cones are then dried in kilns to reduce the moisture from 80 to 90% down to 8 to 9%. Once dried, the hops are then processed into a number of forms including pellet, plug (large pellet – approximately 1/2" by 1"), brick (usually 11 pounds (which is 5 kilograms)), extracts, or even left in their natural cone (also called whole flower) form.

Hop Constituents

Hops are known to contain over 250 different chemicals that are grouped into a number of groups. Alpha acids (α -acids) are the primary acids that become the bittering components of the hops once isomerized in a lengthy boil; alpha acids ranges are typically found in the range of 2 to 15 % of the hop weight, mainly dependent on variety, region, and seasonal effects. Beta acids (β -acids), often known for their greater stability than their alpha counterpart, also contribute to bitterness but to a lesser degree (and are almost always ignored in bitterness calculations). Essential oils (myrcene, humulene, and caryophyllene), when added late in the boil or as “dry hops” (hops added in the secondary fermenter or after fermentation is complete in a conical fermenter or even in the cask or keg), contribute the many flavors of hops including spicy, fruity, citrus, piney, and resinous. Essential oils include.

Regions, Varieties, and Styles

There are scores of hop varieties in widespread commercial use but only the most popular varieties will be covered here.

Noble Hops

“Noble” is a term given to very traditional hops that are renown for having the finest of aromatic qualities. The four hops that are considered “noble” are Hallertauer Mittelfruh, Spalt Spalter, Tettnang Tettnanger, and Czech Saaz. All of these varieties are low in alpha acid (2 to 5%) and have a low cohumulone and myrcene content. Some other varieties that are sometimes mentioned as being in the same class as these noble hops are: English Kent Goldings, German Perle, and English Fuggle.

German Hops

A number of very fine German hops are available and are widely used in German ales and lagers as well as many of the very delicately hopped styles such as Belgian ales and American lagers. The varieties include those grown in the Hallertauer region (Mittelfruh, Tradition, Hershbrucker), German Perle, German Northern Brewer, Tettnanger, and Spalt. Each of these hops has flavor profiles that can be described as floral, spicy, and herbal.

English Hops

English hops are well known for their fine aromatic qualities but are not usually considered to be of “noble” status. English Kent Goldings is the most popular, being found widely in English styles including Bitters and Pale Ales, English IPAs, and English Brown Ales. Fuggles runs a close second to Goldings in its use; Northdown and Wye Challenger are also widely used. These hops are usually described as giving an earthy, fruity, or spicy flavor to the beer.

Other Continental Hops

There are a number of other hops across Europe that make their way into beers but not necessarily strongly identified with traditional styles. One exception is the Czech Saaz variety which is widely identified with the Bohemian Pilsner style which is known for its very spicy character. Others continental varieties include Styrian Goldings (Slovenia), French Strisselspalt, and Polish Lublin.

US Varieties

There are many US varieties of hops, with dozens more becoming commercially available each year (some recent examples are Simcoe, Santiam, Zeus, and Warrior). Some are even direct descendants of traditional continental hops, including US Saaz, US Hallertauer, and US Fuggles. Many more hops have been bred from naturally found US hops, traditional continental hops, or even experimental cross-breeds.

Today, the most popular US varieties among homebrewers are the “C” hops: Cascade, Centennial, Columbus, and Chinook. These hops are widely known for their aggressive flavors and aromas as well as their higher than normal IBU content (usually from 6% to 12%). As in many US varieties, they are known for their assertive citrus character sometimes accented by highlights of grapefruit, pine, and resinous. These assertive varieties are most often associated with American pale ales and IPAs but can be found in virtually any American brewed style.

Hop Bitterness

To calculate the bitterness of a hop addition, use the following formula:

$$\text{IBU} = (\text{Woz} \times \text{Alpha} \times \text{Efficiency} \times 7489) / (\text{Volume} \times \text{Cgrav})$$

Or to calculate the weight of hops in ounces for a given IBU target:

$$\text{Woz} = (\text{IBU} \times \text{Volume} \times \text{Cgrav}) / (\text{Alpha} \times \text{Efficiency} \times 7489)$$

Where:

IBU = Bitterness in IBU units

Woz = Weight of hops in ounces

Alpha = Alpha acid content of hops in decimal units (9% alpha acid = 0.09)

Efficiency = Efficiency of isomeration which is dependent on a number of factors, most importantly on boil time. Daniels in *Designing Great Beers* suggests for pellet hops, utilizations at 60 min = 30%, 30 min = 24%, 15 min = 15 when using whole hops.

Volume = Wort volume in gallons

Cgrav = Specific gravity correction using the formula $\text{Cgrav} = 1 + (\text{SG} - 1.050) / 0.2$

Factors that affect bitterness in a boil include boil time, hop alpha acid, wort specific gravity, boil vigor, elevation above sea level (atmospheric pressure and boil temperature), and system variations. The longer the time that the hops are in the boiling wort, the higher level of isomeration (hence, bitterness) will occur in the wort. The higher the alpha acid level in the hop, the higher bitterness the hop will give (but the degradation during storage of alpha acid over time and temperature could be significant if the storage temperature was high or if the storage time was long). Higher specific gravities will result in lower solubilities of isomerized hop acid. Vigorous boils will isomerize hop alpha acids more quickly resulting in higher bitterness levels. Higher elevations (lower atmospheric pressures) will lower the boiling temperature of the wort and result in a lower isomerization rate (and lower bitterness). Finally, every homebrew's system will have a unique rate of bitterness conversion that must be accounted for in taste (or by complex analytical methods).

Hop Flavor

Estimating hop flavors is more of an art than a science. Generally, higher essential oil content and later boil additions (usually at 10 and 0 minutes to the end of the boil) will lead to a higher hop flavor in the beer. Dry hopping, the practice of adding hops to the secondary, keg, or cask, will result in a very raw hop flavor that is often desirable in English and American Pale Ales and India Pale Ales.

Off-Flavors

Light Struck – Light struck or “skunky” is indicated by an aroma similar to the scent of a skunk. Light struck is caused by the exposure of the beer to ultraviolet (UV) light and is most prevalent when green or clear bottles are used. The actual mechanism is a reaction of sulfur compounds from the hops with UV light.

Yeasts and Yeast Off-Flavors**Yeast and Yeast Types**

Yeasts are single cell organisms of the fungus family. There are many genera of yeast; the two main types of yeast for fermenting wort are *Saccharomyces cerevisiae* and *Saccharomyces uvarum* (formerly called *Saccharomyces carlesbergensis*). Yeast use metabolic pathways (using a series of enzymes inside the yeast cell) to convert sugars into alcohol and carbon dioxide and a number of other chemicals. The cell wall is quite permeable and allows the cell to absorb oxygen, minerals (such as calcium and zinc), nutrients (mainly amino acids), and sugars. Yeast cells reproduce asexually (by budding, only one cell required) during fermentation.

S. cerevisiae is commonly called ale yeast. Ale yeast is commonly called “top fermenting” because it generally (but not always, depending on the individual strain) forms a yeast cake that sits on the top of the beer (sometimes it is called “top cropping” referring to the breweries with open fermenters that would “skim” or “crop” the yeast off of the top of the fermenting beer). Ale yeast generally does not ferment below 55 F. Ale yeasts ferment all monosaccharides and most disaccharides. Ale yeast can only partially ferment raffinose (a trisaccharide) and cannot ferment melibiose (a disaccharide); this is the technical difference between ale and lager yeasts.

S. uvarum is commonly called lager yeast. Lager yeast is commonly called “bottom fermenting” because it generally settles on the bottom during fermentation. Lager yeasts generally ferment cold, below 55 F. The technical distinction that separates lager from ale yeast is that lager yeast can ferment both raffinose and melibiose. Lager yeast can be broken down into two subdivisions: Froberg and Saaz. Froberg lager yeasts are powdery, ferment very strongly, attenuate well, and are alcohol tolerant. Saaz lager yeasts flocculate well but are poor attenuators and are not very alcohol tolerant.

Wheat yeasts are from the species *Saccharomyces delbrueckii* and are noted for their production of the clove flavored phenolic 4-vinyl guaiacol. Other yeasts of note are *Brettanomyces bruxellinensis* and *Brettanomyces lambicus* which can be found in lambic

brewing and are known for their production of horsey or barnyard character and for their production of lactic acids.

Fermentation Phases

There are three main phases during fermentation: Respiration (including growth), Fermentation (which can be divided into low and high krausen), and Sedimentation (also called post krausen).

Respiration (also called lag phase or aerobic fermentation (fermentation WITH air)), is the first phase of fermentation. After the wort is cooled and the yeast is pitched, the yeast prepare for fermentation. The yeast absorb oxygen, nutrients, and sugars to prepare the cell wall and to generate enzymes for fermentation. During this phase, the yeast absorb oxygen and sugars producing carbon dioxide but no alcohol. This phase lasts between 4 and 24 hours and can be longer when lager yeast and cold fermentation conditions are used.

Fermentation begins after the oxygen is depleted (anaerobic fermentation, fermentation WITHOUT air). The yeast take in malt sugars to form an equal amount of carbon dioxide and ethanol. Low krausen marks the period when the oxygen is depleted and the yeast begin to grow rapidly in numbers via budding and the beer begins to form a yeast cake on the head of the beer. Low krausen is typically 24-48 hours after the yeast is pitched. High krausen marks the peak of fermentation. A thick, rocky head forms on the beer and the yeast population peaks and starts to decline towards the sedimentation phase.

Sedimentation (post krausen) is where the yeast have depleted most of the sugars and nutrients and begin to settle. The yeast cells prepare for dormancy, storing nutrients inside the cell wall. Diacetyl, acetaldehyde, and other off-flavors may be re-absorbed and reduced into ethanol and carbon dioxide during this phase.

Fermentation Terms

Flocculation – Flocculation refers to the tendency of the yeast to settle (or float for true top-cropping strains). Highly flocculent strains usually are low attenuators and can leave some diacetyl (because they don't remain long enough in suspension to reduce the diacetyl to ethanol) but usually produce a very clear beer. Poorly flocculent strains usually attenuate well and reduce diacetyl well but can generate a cloudy yeast haze.

Attenuation (apparent and real) – Attenuation refers to the amount of sugars (or gravity) that is reduced during the fermentation. High attenuation means that most of the sugars were reduced into alcohol and carbon dioxide and that the gravity of the beer was more significantly reduced. Apparent attenuation is the difference in gravity units divided by the original gravity units (for example, a 1050 OG beer fermented to a 1010 FG would have an attenuation of $(50-10)/50$ or 80%). High attenuators generally have an apparent attenuation between 72-80% while low attenuators generally are between 65-72%. Real attenuation is more complex than apparent attenuation. With real attenuation, the lower specific gravity of ethanol is accounted for in the specific gravity reduction during fermentation.

Autolysis – Autolysis is the condition where yeast remains in close contact with each other for a period of time after the majority of the sugars (yeast food) have been depleted.

At this point, the yeast consumes surrounding yeast cells for nutrition (yeast cannibalism) which creates strong sulfury (often like rotten eggs), yeasty, and sometime rubber-like aromas and flavors.

Yeast Health

There are many factors that affect yeast health: temperature, pH, oxygen (during respiration phase only), nutrients, food sources, and viability. Temperature and pH are largely dependent on each individual yeast strain. Nutrients and food sources are provided by the wort (although alcohol tolerances come into play in fermentations with a high malt sugar level – some yeast can tolerate higher alcohol levels while others may go dormant once a given alcohol level is reached). Nutrients include smaller proteins and amino acids (sometimes measured as FAN or free amino nitrogen) as well as essential minerals such as zinc, calcium, and potassium. Oxygen is dependent on the amount of air or pure oxygen introduced to the cool wort. Viability is the measure of the percentage of live cells of the culture pitched into the wort.

Homebrewer's Typical Fermentation Regimes

Ales – Fermented at 66-70 F for a week, racked to secondary and fermented at 66-70 F for one to two weeks.

Lagers – Fermented at 48-54 F for two weeks, optional diacetyl rest at 66-70 F for 2 days, racked to secondary and dropped 2-4 F per day to 34-38 F and held for 1-2 weeks.

Fermenters

Most homebrewers use glass carboy or plastic bucket fermenters. These fermenters are very inexpensive but do not allow direct fermentation control (must have a cool room, refrigerator or freezer, or even be submersed in a tub or water). Also, they normally require the beer to be racked to another fermenter (secondary) to be removed from the trub and yeast sediment.

Most American breweries ferment in stainless steel conical bottom fermenters. The majority of the vessel is a cylinder while the bottom comes to a cone shape. This cone shaped bottom encourages yeast and trub to settle. Nozzles on the bottom of the vessel allow the brewer to remove the sediment without moving the beer. Most conical fermenters are jacket cooled (a cooling solution is able to be pumped around the outside of the vessel to control the fermentation temperature).

Yorkshire Stone Squares – Yorkshire stone squares are used by Samuel Smith's Brewery in Tadcaster, England. These are shallow slate squares that openly ferment (no airlock or pressure vessel is used to contain the yeast). The yeast is top cropping (forms a constant, rocky head on the fermenting beer) but the constant exposure to oxygen creates a noticeable level of diacetyl in the beer.

Burton Union System – The Burton Union system is a series of barrels that ferment the wort with the yeast rising out of the barrels into a common series of troughs that collect the yeast. This system is still in use by Marston's in Burton-upon-Trent, England.

Lambic Fermentation – Lambic fermentations are unique since no yeast is pitched. The cool wort is held in the open air at the top of the brewery over night (in a "cool ship").

During the night, the cooled wort absorbs wild yeast and bacteria from the air. After the initial fermentation, the lambic is then allowed to mature in large wooden casks for up to two or three years. In the wood casks, years of microflora including brewers yeast, wild yeast (*Brettanomyces*), and bacteria (including *Pediococcus* and *Lactobacillus*) continue to ferment and mature the lambic. Oftentimes, fruit such as cherry, raspberry, or peaches are added during the fermentation. Once the fermentation is complete, the lambic is blended to ensure a consistent product.

Choosing Yeast Strains

A very common part of an exam yeast questions is “give five considerations that a brewer should take into account when selecting a yeast strain”. The first one should be obvious: are you brewing a lager or ale? Another would be whether the style requires a special yeast such as lambic, Berliner weisse, Bavarian Weizen, Belgian style or even as simple as American Ale versus English Ale. Next would be the attenuation that is desired (usually coupled with flocculation). Also to be considered is any off-flavors (or signature flavors) that may be produced (or specifically not produced) including esters, diacetyl, acetaldehyde, or phenolics. Alcohol tolerance is also a key decision factor when making big beers (Barleywine!, etc.).

Off-Flavors from Fermentation

Esters – Esters are a by-product of normal fermentation, most often (but not limited to) ale yeast fermentation. Esters are fruity and are usually described as banana, strawberry, rose-like, bubblegum or virtually any other fruit. Esters are usually found in most ales (Scottish ales, Kolsches, and Alts are examples where the ester level should be low to none) and are almost always inappropriate for lagers. Esters are produced in greater amounts at higher fermentation temperatures. Ale fermentations should generally be controlled less than 68 F to keep ester levels in acceptable ranges. Esters when present in very high concentrations can take on solventy aromas and flavors. Some yeast strains are noted for producing more esters (most English strains produce a large amount of esters, Chico/California produces a very low ester level). Higher gravity beers generally produce more esters than a lower gravity beer will with the same yeast strain at the same temperature. Low oxygen levels or very high pitching rates can also cause elevated ester levels.

Phenolics – Phenolics are a large family of chemicals produced from a wide range of sources. Descriptors can be somewhat favorable as peppery or clove to the less favorable as smokey, medicinal, medicine chest, band-aid, plastic-like. Peppery and clove are usually flavors generated by German wheat and Belgian yeasts and a light smokiness can be generated by certain Scottish ale strains. Although favorable in those particular styles, they would be considered off-flavors from wild or inappropriate yeast strains in most other styles. Generally, the other phenolic aromas and flavors are generated by wild yeasts caused by unsanitary conditions or poor handling of yeast cultures.

Chlorophenolics are reminiscent of chloro-septic medicine and are caused by using unfiltered chlorinated water for mashing and sparging. Also, when a strong astringency is present, the phenolic flavors can often be attributed to poor mashing procedures (high mash or sparge pH (greater than 7), high sparge temperature (higher than 170 F), or over-sparging).

Sour/Acidic/Tart – Sourness is almost always caused by bacterial infection (poor cleaning and sanitation). There are a number of wild yeasts and bacteria that may cause acidity. Vinegar-like (acetic acid) is usually caused by *Acetobacter* bacteria or *Pediococcus* yeasts. A cleaner acidity is derived from lactic acid, likely produced by the bacteria *Lactobacillus*. Sourness is acceptable in lambics and Berliner weisse (but Berliner weisses should only have a lactic acidity with no vinegar or horse-blanket like a lambic).

Sulfury – Sulfur chemicals can be perceived as rotten eggs, match-like, or skunkiness. Skunkiness is attributed to exposure to ultraviolet light and is usually proliferated in clear or green bottles. Other sulfury aromas are most likely caused by yeast autolysis. Bacterial infections can also cause sulfury notes but are usually found with a number of other flaws as well.

Acetaldehyde – Acetaldehyde is reminiscent of green apple and usually has a snappy, tangy crispness to the mouthfeel; it can sometimes seem cider-like and be accompanied by acetic acid/vinegar. Acetaldehyde is formed in the metabolic pathway for ethanol production. This is usually evident in young beer or beers where fermentation has stalled prematurely (or where beer has been racked too early). Alternatively, ethanol can be oxidized to form both acetaldehyde and acetic acid. Finally, bacterial contaminations can cause acetaldehyde as well, but will usually be accompanied by a myriad of other off-flavors.

Diacetyl – Diacetyl is described as buttery (like movie popcorn butter or artificial butter), butterscotch, or toffee-like and usually causes a slickness in mouthfeel. Diacetyl is formed during fermentation but is usually re-adsorbed by the yeast to form ethanol. Some yeast strains (Ringwood Ale and Munich 308 or 2308) notoriously produce more diacetyl than other yeast strains. Additionally, since diacetyl is reduced more quickly at higher fermentation temperatures, lagers (or even Scottish ales) can be more prone to diacetyl (thus the need for a diacetyl rest at a higher temperature at the end of the primary fermentation). Diacetyl can be caused by stalled fermentations (or especially premature racking which may also cause oxidation of diacetyl precursors into diacetyl) in a similar manner to acetaldehyde or by weakened/stressed yeast conditions (low cool wort oxygen, low pitch volumes, low nutrient/amino acid levels, high wort gravity, high adjunct usage). Finally, bacterial contamination can cause diacetyl as well.

Fusel Alcohols – Fusel alcohols are a family of alcohols larger in length than ethanol that can include isopropyl, butyl, amyl and dozens of other alcohols that can be perceived as a harsh rubbing alcohol-like aroma and flavor. Fusel alcohols are usually caused by higher fermentation temperatures (but will likely be accompanied by esters as well), low oxygenation of the cool wort, and their production is likely dependent on the given yeast strain. Higher alcohol beers are likely to (but not necessarily) have more fusel alcohols. In high concentrations, fusel alcohols can cause solvent-like aromas and flavors.

Solvent – Solvent is exactly like it sounds: solvent-like (lacquer thinner or acetone) with a strong harshness in mouthfeel, especially in the back of the throat. It can be caused by very high levels of esters and/or fusel alcohols. It also can be caused by wild yeast contaminations.

Vegetal – Vegetal or cooked vegetables (or even rotten vegetables) usually cabbage-like are usually caused by bacterial infections. This should not be confused with DMS (dimethyl sulfide, perceived as cooked corn) which can be caused by a covered or poorly vented boil or slow wort cooling.

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