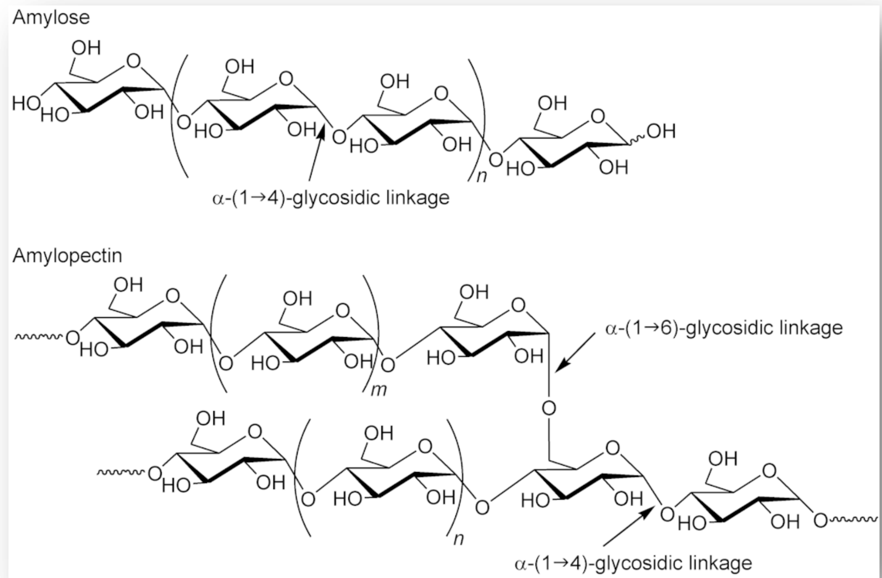
Processes and Techniques

Advanced Recipe Design

The Mash – Chemistry

- Two Major Malt Starches that break down enzymatically:
  - Amylose
  - Amylopectin



https://chemistry.stackexchange.com/questions/58080/bonding-between-amylopectin-and-amylose

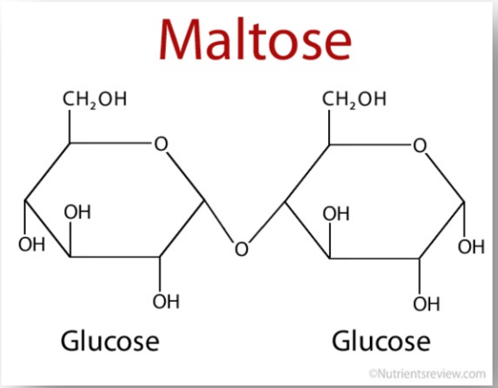
The Mash – Chemistry

- Alpha Amylase
  - High concentrations in pale malt, higher in 6 row barley
  - Chops molecules randomly into longer glucose chains
    - Breaks alpha 1-4 bonds in both amylose and amylopectins
  - Because it chops randomly, it creates both longer unfermentable dextrins as well as fermentables
    - Artificial enzymes are often used in production of "light beer" so you can get it in purified form commercially
  - Peak activity at **5.3-5.7 pH** and a temperature of **70C (158 F)**

Source: John Palmer and https://beerandbrewing.com/dictionary/wyhiNIcbe5/

The Mash – Chemistry

- Beta Amylase
  - Main fermentable producer – chops off maltose molecules from the non-reducing end
  - Breaks down both amylose and amylopectin
  - Also limits dextrins
    - Breaks the alpha 1-6 bond in amylopectin which reduces the body of the beer
  - Peaks a **pH of 5.1-5.3** and temp of **60-65C (140-149 F)**



Source: John Palmer and
https://beerandbrewing.com/dictionary/wyhiNIcbe5/
http://www.nutrientsreview.com/carbs/disaccharides-maltose.html

Mash Temperature Strategies

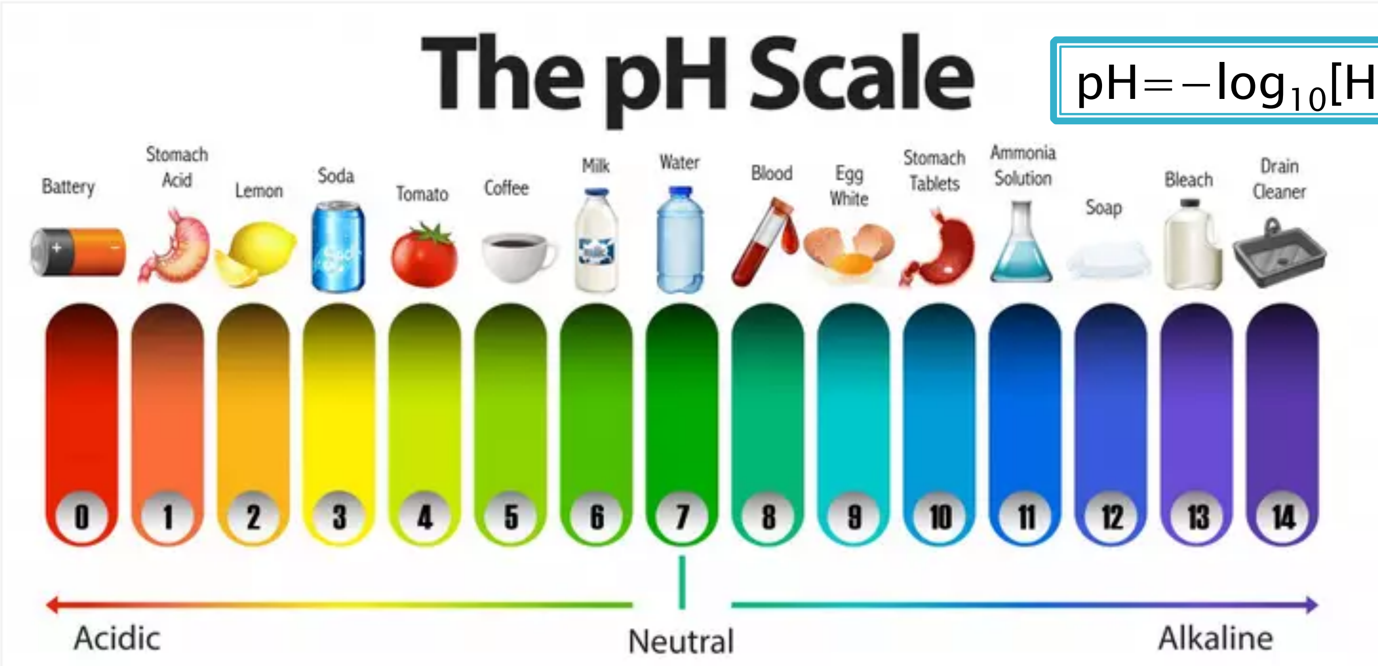
- Full Body Mash
  - Mash around 70 C (156-158F) in the “alpha amylase” range and a slightly higher pH of 5.3-5.7
  - Maximizes production of dextrines/non fermentables for a full bodied beer
- Light Body Mash
  - Mash around 60-65C (140-149F) in the “beta” range and lower pH of 5.1-5.3
  - Maximize fermentable maltose, gives light body beer
- Medium Body Mash
  - Pick a mid temperature 67 C (153 F) for a medium body beer
- Lager Mash – even more fermentables
  - Use two steps – hit both 63C (145 F) and 70C (158F)
  - Results in high attenuation of the finished beer, low finishing gravity

Mash pH Importance

- Mash pH Affects
  - Extraction of sugars
  - Wort viscosity (lowers it)
  - Lauter performance and efficiency
  - Trub drop/formation
  - Color and tannin extraction
  - Physical and chemical stability of wort
  - Fermentation
  - Hop utilization (better/smoother)
  - Flavor (acidity)
  - Long term beer stability

Source: John Palmer CraftBrewersCon Presentation

pH Scale Refresher



$$pH = -\log_{10}[H_{solvated}].$$

Image: https://www.scienceabc.com/pure-sciences/can-ph-have-values-out-of-the-0-14-range.html

Malts are Acidic, and Dark Malts are very acidic

Mash pH Overview

- Target mash pH between 5.2-5.6
  - Recall for alpha amalyse: 5.3-5.7 and beta amalyse ideal is 5.1-5.3
  - pH < 5.7 has additional benefits listed on previous slides
- Generally start with water that is slightly alkaline (> 7)
  - Due to carbonates/temporary hardness in well/surface water sources
- Mix in acidic malts, which lowers grist pH
  - Darker malts are highly acidic, so many dark beers will reach the target pH range without any acid adjustments
  - Lighter beers often need acid additions to reach 5.2-5.6
- We often need acid (lactic, phosphoric, citric) additions to achieve the desired pH range, particularly for light beers

Residual Alkalinity

- Water pH not that important
- Residual Alkalinity (RA): Measure of the buffering capacity of water or how hard it is to change your pH:

$$RA = Alkalinity - Ca/1.4 - Mg/1.7$$
$$Alkalinity = Bicarb * 50/61$$

Ref: Kolbach
Palmer: How to Brew

  - Where Bicarb, Ca and Mg ion concentrations come from water report (in ppm). Gives RA in ppm as $CaCO_3$
- Example: Los Angeles: Ca=70ppm, Mg=30ppm, Bicarb=147ppm
  - Gives RA=53 ppm (as $CaCO_3$), and Alkalinity=120 ppm

High RA means more acid from malts or acid additions needed
Generally your Bicarbonate (alkalinity) and Carbonate dominate

Estimating Mash PH

$$Ph = grist\_ph + SRA * RA/50.0 + ra\_acid$$

- Grist_PH is estimated from weighted average of each malt addition, based on color/type of malt
- SRA is a mash thickness factor and ra_acid is the estimated effective acidity (mEq/l) from acid additions
  - Darker grains will drive a lower grist_ph and pH
  - Thicker mash reduces pH
  - pH varies linearly with Residual Alkalinity
  - There are competing acid models for ra_acid due to the fact that not all acid added directly reduces pH – some of it is buffered by the grains and water

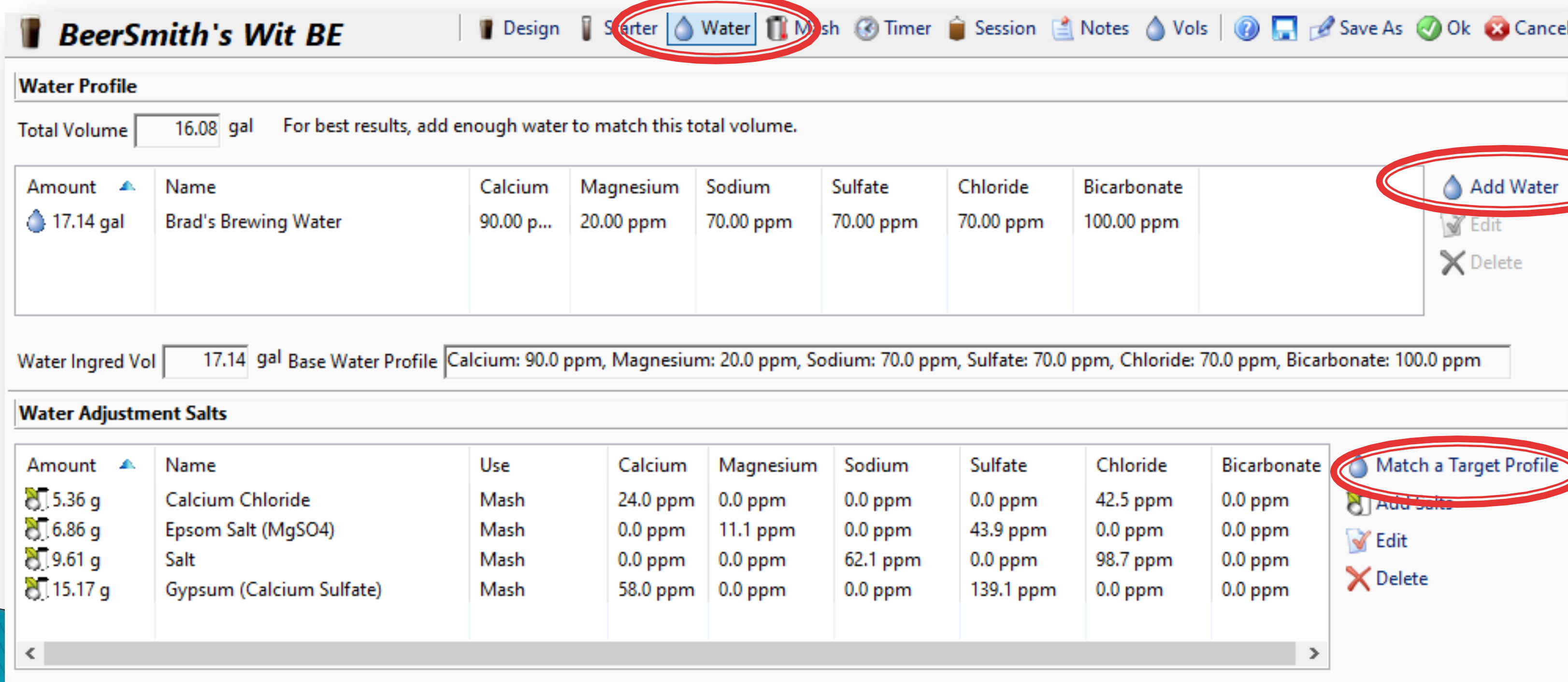
Mash Acid Options

- Acid Options:
  - **Lactic Acid (88%)** – Most common home brew acid – easy to use but some evidence flavor can be detected above 1.5 mL/gal*
  - **Phosphoric (10% or 85%)** – Commercial and homebrew use – recommend 10%
  - **Acid Malt (2%)** – Same as lactic acid as it is made from soured malt
  - **Hydrochloric, Sulfuric**– More commonly used commercially. Very caustic, difficult to handle
  - **Acetic, Citric** – Less common. Could have flavor impact in high concentrations, but more study needed.
  - **Tartaric** – Widely used in wines, often used as a blend to control wine/mead pH. Can be tannic.
- Generally lactic, acid malt or phosphoric are easiest for homebrewers to work with
- **pH too low (Stouts)?** –Potassium Bicarbonate is a good option – add a bit at a time. Older sources recommend Calcium Carbonate (Chalk) but it is not very soluble.

*Brulosophy:
http://brulosophy.com/2019/02/28/water-chemistry-lactic-acid-vs-phosphoric-acid-for-mash-ph-adjustment-the-bru-club-xbmt-series/

Mash pH in Practice: BeerSmith

- Make this the last step when building a recipe: Set up base water

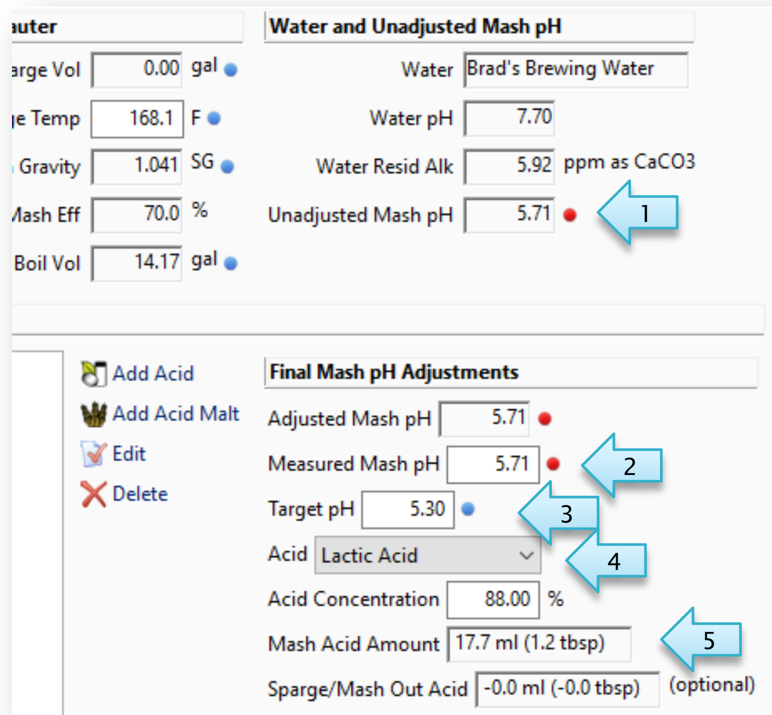


Mash pH in Practice

- The Measuring Mash pH Dilemma
- Competing models for both estimating pH and estimating acid additions needed
  - None of these are perfect
- Recommend using part of estimated mash acid up front, then do an adjustment based on early pH measurement

Mash pH in Practice: BeerSmith

- Go to mash tab after setting water profile/ additions
  1. Unadjusted mash pH is your estimate
  2. Set that to "measured"
  3. Set your target pH
  4. Pick acid to use
  5. This gives you the amount to add



Mash Techniques

- Separating Dark Grains from Mash
  - Anything above 60L can be harsh, and mashing dark malts for 60+ min can draw harsh flavors out
  - Dark grains don't add many fermentables
  - Alternative: Don't mash dark grains, just sprinkle them over the mash/lauter tun before lautering
  - Reduces "harshness" for many styles (Porter, Sweet Stout, Belgians, etc…)
- Varying Mash Thickness
  - Thinner main mash can improve viscosity, extraction, clarity and fermentability (BIAB)

Mash Techniques

- Decoction
  - Traditional for many continental styles (3 stage)
  - Requires additional vessel to decoct, a lot of time
  - Results in "malty" finish from carmelization when boiling grist as well as better clarity, extract
  - Often done at high water/grain ratios – fermentability
  - Maltiness can be simulated with addition of melanoidin malt in single step mash
- Multi-Step Mashes
  - Rarely needed for modern highly modified malts
  - Can improve clarity/extraction/fermentability due to action of various enzymes (phytase rest, protein rest, alpha/beta amylase)
  - "Cereal mash" needed with raw grains that are not torrified/flaked

Boiling Techniques

- Goal is a long, vigorous boil (90 min+)
  - Required for reducing DMS which comes from SMM in the grains (cooked corn off flavor)
  - Also reduces other volatiles that cause off flavors
- Boiler needs proper venting!
  - I've seen a number of commercial setups with a straight pipe vent from boiler to roof
  - Without insulation or a fan, DMS will condense on the vent and fall back into the beer
- Skimming Hot Break
  - You can skim "oily" layer of protein that forms at top of boil to improve clarity

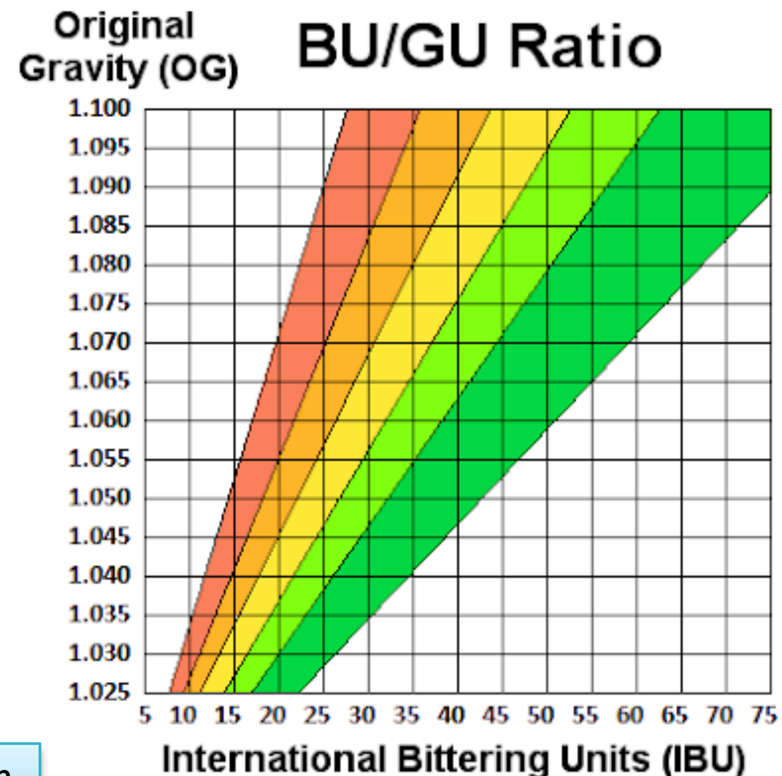
Malt to Hop Balance

- Bitterness Ratio (BU:GU)

  Bitterness_Ratio = IBUs/GU

  - Where GU is the gravity points
- Example:
  - 1.055 IPA at 70 IBUs
  - BU:GU = 70/55 = 1.27
- Varies by style:
  - < 0.5 – malt forward
  - 0.5-0.7 – balanced ales
  - > 0.7 – hoppy!

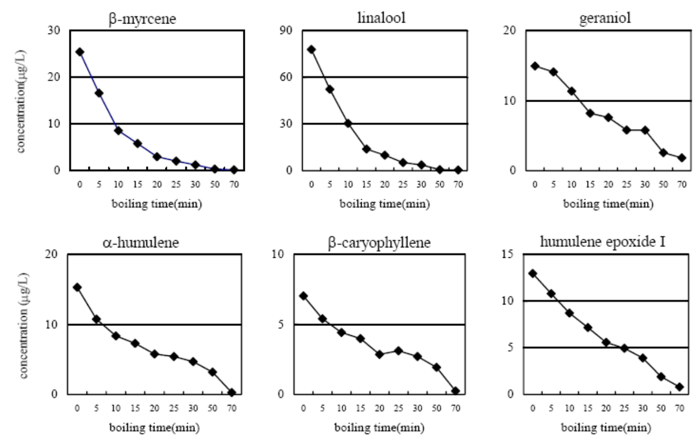
BeerSmith shows bitterness ratio on design screen



Source: http://finnhillbrewing.blogspot.com/2011/04/bugu-ratios.html

Hop Techniques

- Boil Hops
  - Single hop addition – long boil for IBU level desired
  - Moved away from flavor/aroma boil additions
  - Boils > 60 min can result in grassy/vegetal flavors for some varieties
- First Wort Hopping
  - Add hops during lauter – through boil
  - Softens hop bitterness slightly
- Hop Blends
  - Use blend of hop varieties rather than single variety (Firestone Walker/others)
  - Can be used in any phase – boil, whirlpool or dry hop



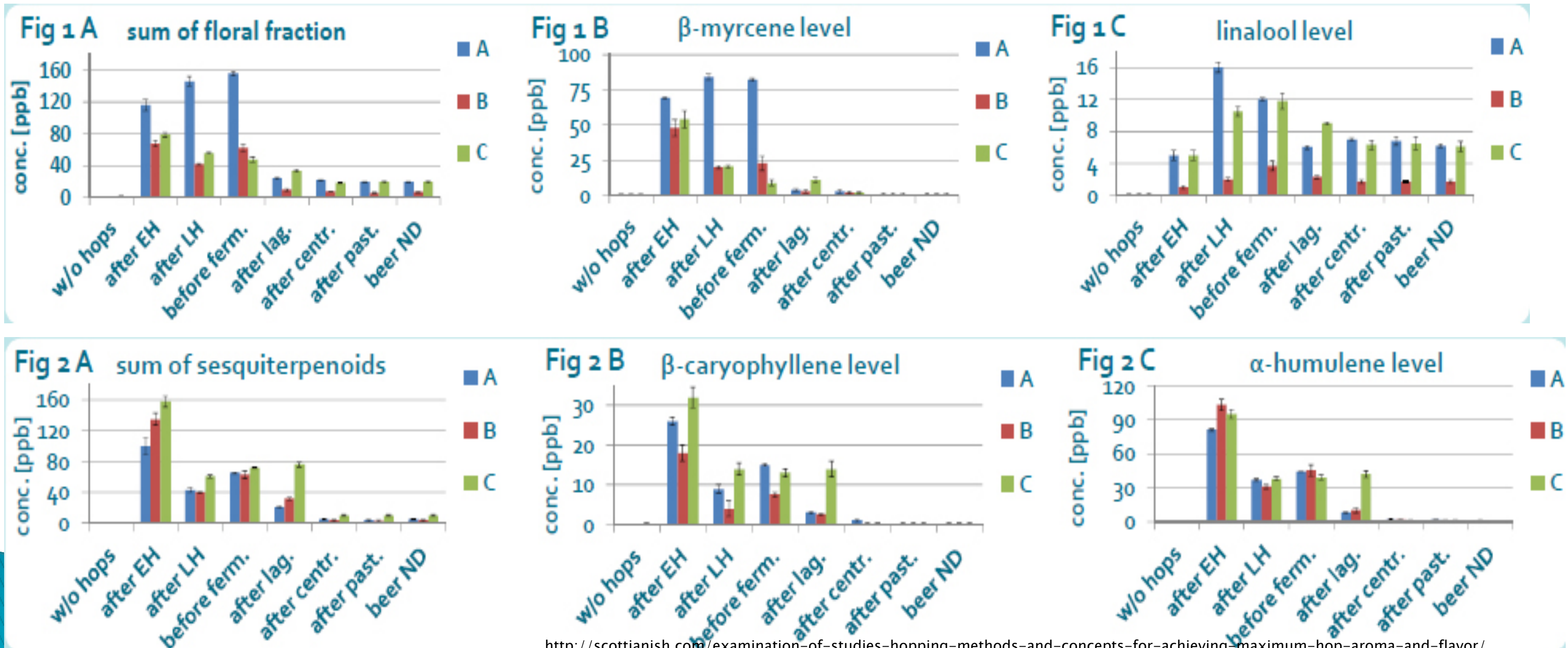
Aroma oils boil off quickly!

Hop Techniques – Whirlpool

- Whirlpool/Steeped Hops
  - Widely used for preserving hop oils
  - Aroma oils are more soluble at whirlpool temps
    - Varies by aroma oil – some are more volatile
  - Considerably more efficient than dry hopping
  - Can add significant bitterness – which must be accounted for
    - BeerSmith does account for whirlpool hop bitterness as well as carry forward bitterness from boil hops
  - Some downsides – as aromatic oils are scrubbed out during fermentation by CO2

Whirlpool Hop Limitations

- A lot of hop oils are lost during fermentation (and Centrifuge here)



http://scottjanish.com/examination-of-studies-hopping-methods-and-concepts-for-achieving-maximum-hop-aroma-and-flavor/

Boil Clarity Aids

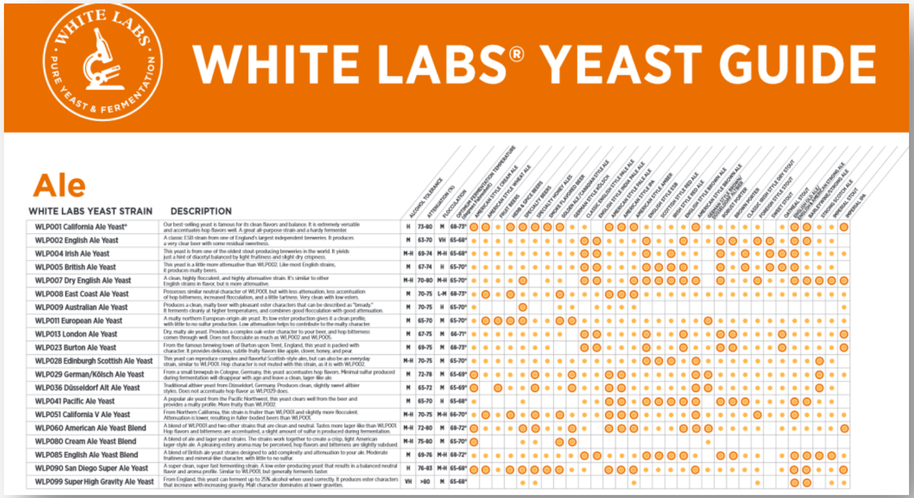
- Irish Moss – Boil 15 min
  - Positively charged ions aid coagulation of both proteins and polyphenols (tannins)
- Whirlfloc Tablets
  - Concentrated carrageenan
  - Similar effect, preferred by many Craft brewers

Post Boil Chilling

- Cold Break with Rapid Chilling
  - Starts forming around 140F (60C)
  - Coagulation of proteins, tannins and hop matter (hop polyphenols precipitate faster)
  - Effective cold break promotes clarity and flavor stability
  - Best to separate the break from the wort if possible before fermenting
  - Rapid chilling reduces chance of infection
- Plate Chillers
  - Large area for heat exchange
  - Commercial as well as home use
  - Best option for anything over about 5 gal (19 l)

Selecting a Yeast Strain

- Match yeast strain to style of beer
- Use “yeast guides” from supplier
- Look at effect you are trying to achieve
  - Sometimes OK to go “out of style”



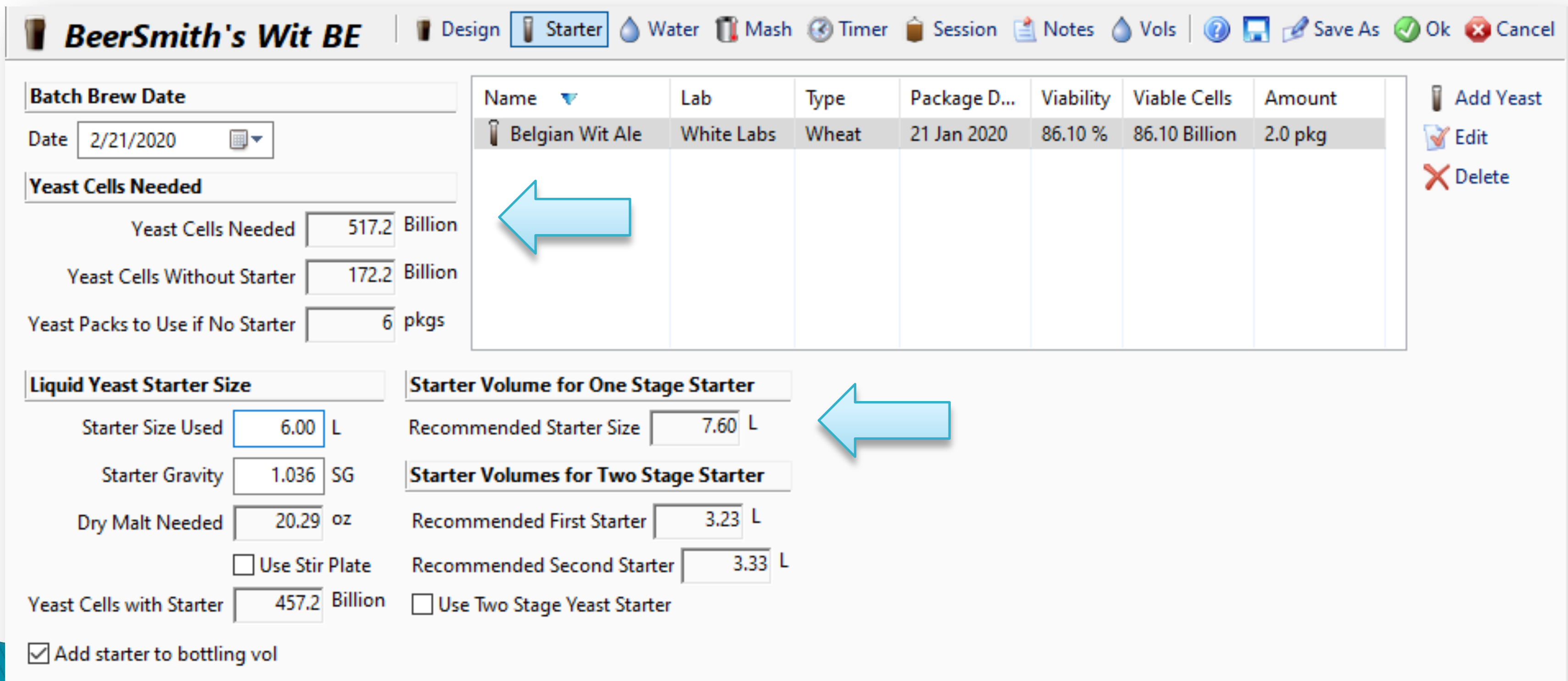
Aeration of Wort

- Goal is 8-12ppm of Oxygen
  - Oxygen aids production of sterols in yeast which aid budding
  - Technically yeast can ferment without oxygen (slower)
  - Overoxgenation can produce VDKs (precursor of diacetyl)
- Pure oxygen needed to reach 8ppm – oxygen wand/tank
  - Splashing/agitation/air pump will only get you to about 6ppm

Yeast Pitch Rates

- Liquid Yeast Pitch Rates
  - Ale: 0.75 billion/liter-Plato
  - Lager: 1.5 billion/liter-Plato
  - Hybrid/Wheat: 1.0 billion/liter-Plato
- Example: 19 l (5 gal) Ale at 12P
  - Cells= 0.75*19*12= 171 billion cells
- Liquid Yeast Viability: 100 bil/pack
  - Decreases 12-20%/month
  - Most liquid yeasts last ~6-9 months
  - Drives you to use a starter in most cases

Yeast Starter – BeerSmith



Fermentation Temperature

- Low Temperatures
  - Extends fermentation, but with fewer off flavors in general
  - Can drive yeast dormant/incomplete fermentation (acetaldehyde)
- High Temperatures
  - Promotes fusel alcohols, diacetyl, excessive ester production
  - Extreme cases can take on solvent, medicinal, band-aid, turpentine flavors
- Raise temp to add more character/complexity
  - Think about English styles
- Lower temp for a cleaner finish
- Temperatures in center of fermenter can be up to 10 F (5 C) higher than surface

Fermentation Techniques

- Pressure Fermentation
  - Commonly done in wine production, as well as beer overseas
  - Significant reduction in the Esters (Ethyl Acetate and Isoamyl Acetate) and Diacetyl with pressures as low as 1 atm (14.7 lb/sq in or 101 kpa) [White/Blichmann]*
  - Lets you create lagers at ale temperatures without excessive ester production
- Diacetyl Rest
  - Diacetyl (butter popcorn flavor) is a byproduct of fermentation
  - Raising temp of beer a few degrees at the end of fermentation and holding it for several hours lets the yeast re-absorb diacetyl
  - Critical for lagers and many ales

*http://beersmith.com/blog/2018/01/17/pressure-fermentation-with-chris-white-john-blichmann-beersmith-podcast-163/

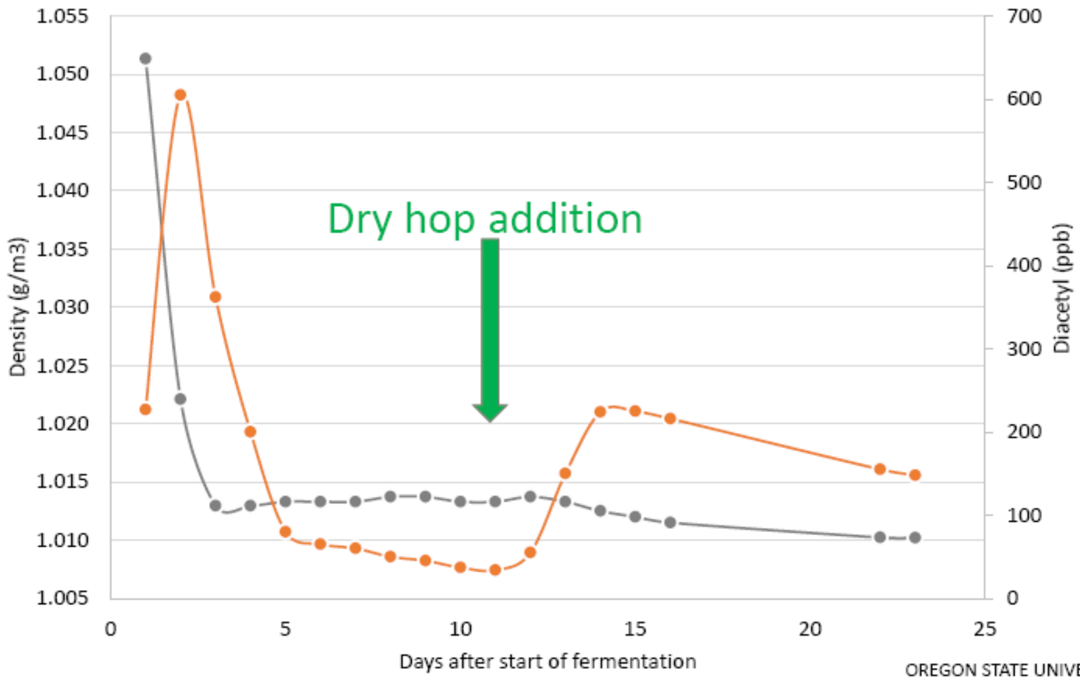
Dry Hopping

- Traditionally done late fermentation with long contact times
  - Recent research indicates 24-72 hours may be better
  - Preserves some oils like myrcene better
- Limits to Dry Hops: Oregon State University*
  - "Dry-hopping rates >800 g/hL (1.1 oz/gal) lead to hop aromas that were more herbal/tea in quality than citrus"
  - Study recommends using a static dry-hopping rate between 400 and 800 g/hL (0.5-1 oz/gal)
  - Use static addition: "Agitation has been shown to change the quality of the hop aroma extracted to more of a herbal/grassy character and promote the extraction of polyphenols, which may increase the astringency of beer"

**Journal of the Institute of Brewing,* by Scott Lafontaine and Thomas Shellhammer:

Dry Hop Creep

- Dry hopping creates fermentables – can result in fermentation after packaging or a high Final Gravity (FG)



OREGON STATE UNIVERSITY

Hop Creep – Latest Research

- Dry hopping liberates fermentable sugars (glucose and maltose, mostly maltose)
- Hops contribute a small amount of sugar themselves
- Dry-hopped beer with high residual extract produces more fermentable sugar
- Enzyme activity varies across varieties (cultivars)
- Longer dry hopping time and higher temperatures result in more sugars

- **Class 1 (high)**: Amarillo 2015, Cluster, Fuggle, Nugget, Perle.
- **Class 2 (low)**: Amarillo 2016, Centennial, Citra, Crystal, East Kent Golding, El Dorado, Galaxy, Hersbrucker, Saazer, Summit.
- **Class 3 (moderate)**: Azacca, Comet, Golding, Kohatu, Mosaic, Mt. Hood, Rakau, Simcoe, Wai-ti, Willamette.
- **Class 4 (moderate)**: Cascade, Dr. Rudi, Moutere, Pacific Gem, Pacific Jade.

Source: Stan Hieronymous "Hop simplified 2020"

Fruity/Tropical Hops

- Research on Achieving Fruity/Tropical Flavors and Aromas
  - Thiols are important – only present in US/Australia/NZ hops and not European
  - Hopping at end of active fermentation
  - Biotransformations:
    - **Geraniol** > Citronellol
    - **Linalool** > Terpineol

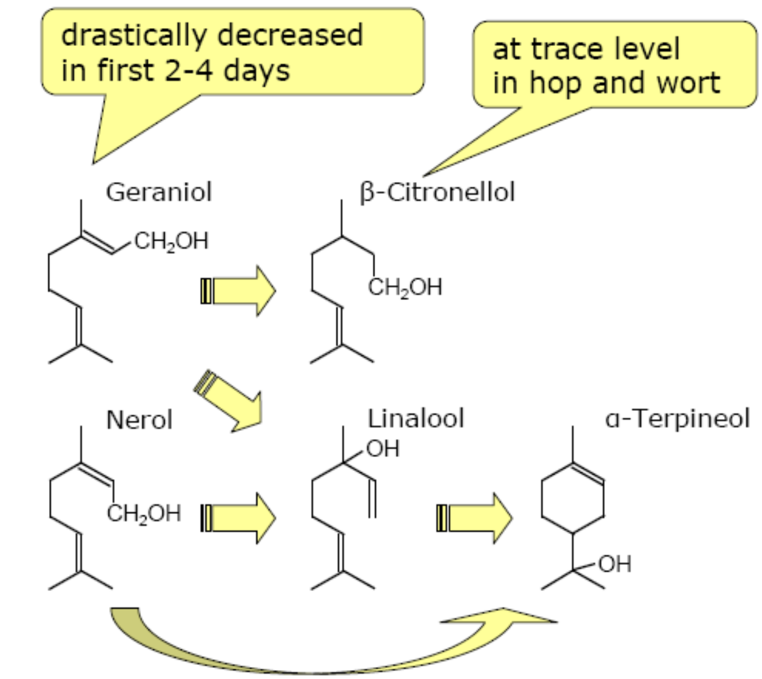


Figure 1. Metabolism cascade of monoterpene alcohols by lager and ale yeast (proposed by King and Dickinson (3, 4)).

Fruity/Tropical Hop Oils

- **Key Oils: Geraniol, Linalool, 4MMP/4MSP and 3MH/3SH (Thiol)**
- **4MMP/4MSP – box tree, broom flavors**
  - **High levels**: Citra, Simcoe, Eureka!, Summit, Apollo, Topaz, Mosaic, Ekuanot, Galaxy, Nelson Sauvin.
  - **Significant levels**: Zeus, Cluster, Chinook, Cascade, Centennial, Amarillo, German Northern Brewer, Hallertau Blanc, German Cascade, Mandarina Bavaria, Polaris.
  - **Measurable but low**: Bravo, Calypso, Denali, Galena, Lemondrop, Sorachi Ace, Super Galena, Willamette, Halltertau Tradition, Herkules, Perle, Taurus, Tettnanger, Styrian Golding, New Zealand Pacific Gem. Perhaps Saaz.
- **3MH/3SH - grapefruit, passion fruit flavors**
  - Nelson Sauvin, Amarillo, Mandarina Bavaria, Mosaic, Citra, Cascade, Calypso, Tomahawk.
- **Geraniol**
  - **Free geraniol dominant**: Bravo, Cascade, Chinook, Citra, Mosaic, Motueka.
  - **Geraniol precursor dominant**: Amarillo, Comet, Ekuanot, Hallertau Blanc, Polaris, Summit, Vic Secret.

Fermentation Clarity Aids

- Gelatin
  - Available in "jello" section at grocery (unflavored) – works on proteins and tannins
  - Prepare 1 pkg for 5 gal (19 l) batch in hot water, add a few days before bottling
- Polyclar (PVPP) Plastic
  - Effective against both proteins and tannins
  - Used both by home and pro brewers (1 tbsp per 5 gal)
- Silica Gels
  - Effective at binding proteins
  - Add 6-10 grams per 5 gal/19 liter batch
  - Can affect flavor/foam if done to excess

Fermentation Clarity Aids

- Isinglass
  - Derived from fish bladders, positive charge
  - Effective at removing yeast cells and proteins
  - Also removes some lipids, which improves foam stability
- Papain
  - Not recommended for beer (wine use only)

Clarity-Ferm/Brewers Clarex (White Labs)
  - Sold as a clarity aid – enzyme breaks down polyphenols to reduce chill haze
  - Also breaks down Gluten protein chains
    - Typically less than 20 ppm (FDA: gluten free)
  - Can be used to create beer that is nearly "gluten free"

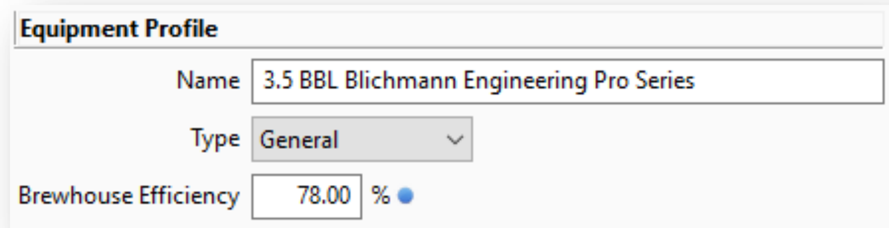
Filtering

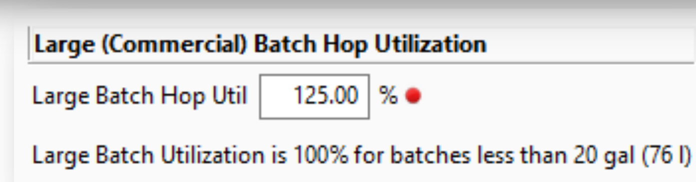
- Cold Filtering (kegging only)
  - Removes yeast, polyphenols and some proteins
  - Wait before filtering –
    - Important changes happen during late fermentation/lagering
  - Most home brewers place filter between two kegs with an inline, cartridge filter
  - Two stage filters (5 micro, 0.5 micron) less likely to clog

Scaling to Commercial Sizes

- **Two Major Considerations**
  - Slightly higher brewhouse efficiency
  - Significantly higher hop utilization (often 125% or more) means you need less hops
- In BeerSmith:
  - Start with pilot batch recipe
  - Build equipment profile for your pro system with correct volumes, efficiency and “large batch hop util”
  - Run scale command to scale pilot batch up to production size

Blichmann Pro 3.5 bbl Equip Profile





Working with Spices/Extracts

- I rarely add spices in the boil anymore
  - Much easier to make a tea or extract with the spices and then “add to taste”
  - A lot of aromatics are lost during the boil and fermentation
  - Use a carefully measured amount of beer and tea/extract on the finished beer
  - After you find the right ratio, simply scale it up to blend the spice tea/extract into the whole batch
  - Once you know the correct amount you can consider adding it in earlier for future batches

Working with Fruit

- Fruit is highly fermentable
  - Reality is that little flavor is left once you ferment fruit – also dilutes beer!
  - Fruits with acid/tannins such as cranberry, currants, blackberries, raspberries (other berries) work best
  - Need residual sweetness to balance fermented fruit acidity/tannins
- Primary or Secondary
  - Don't boil fruit – more aroma in secondary
  - Purees are terribly hard to separate
  - I prefer a grain bag, and remove the fruit when it starts to blanch (about a week)

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Home Brewing

Sour Beer Basics

- Bacteria is added – it produces lactic acid
  - Lactobacillus, Pediococcus, new sour yeasts
  - Lactic acid reduces pH down to the 3.0-3.6 level, creates sour finish
- Two methods:
  - Traditional: Beer is fermented first, then bacteria is added in secondary – extended aging
  - Kettle Sour: Bacteria added to wort up front
    - Wort sours for a day or two (monitor pH), then wort is boiled (or chemically sanitized), then yeast is added to continue fermentation
    - Much faster than traditional method
  - Produce different effects:
    - Kettle souring produces sourness, but low pH also stresses yeast
    - Traditional method takes a long time, but bacteria is added post-fermentation which results in smoother/aged profile

Off Flavors (BJCP Score Sheet)

- Acetaldehyde – Yeast
- Alcoholic – Yeast
- Diacetyl – Yeast
- DMS – Process
- Esters – Yeast
- Grassy – Process
- Skunky – Process
- Metallic – Equipment
- Musty – Process
- Oxidized – Process
- Phenolic – Yeast
- Solvent – Yeast, Water
- Sour– Yeast/Bacteria
- Sulfur – Yeast
- Vegetal – Process
- Yeasty – Yeast

Most Serious Off Flavors are Related to <u>Yeast!</u>
<u>Process Issues</u> (sanitation, oxygen, DMS, mold) are Second

BJCP Scoring

Descriptor Definitions (Mark all that apply):

- ☐ **Acetaldehyde** – Green apple-like aroma and flavor.
- ☐ **Alcoholic** – The aroma, flavor, and warming effect of ethanol and higher alcohols. Sometimes described as *hot*.
- ☐ **Astringent** – Puckering, lingering harshness and/or dryness in the finish/aftertaste; harsh graininess; huskiness.
- ☐ **Diacetyl** – Artificial butter, butterscotch, or toffee aroma and flavor. Sometimes perceived as a slickness on the tongue.
- ☐ **DMS (dimethyl sulfide)** – At low levels a sweet, cooked or canned corn-like aroma and flavor.
- ☐ **Estery** – Aroma and/or flavor of any ester (fruits, fruit flavorings, or roses).
- ☐ **Grassy** – Aroma/flavor of fresh-cut grass or green leaves.
- ☐ **Light-Struck** – Similar to the aroma of a skunk.
- ☐ **Metallic** – Tinny, coiny, copper, iron, or blood-like flavor.
- ☐ **Musty** – Stale, musty, or moldy aromas/flavors.
- ☐ **Oxidized** – Any one or combination of stale, winy/vinous, cardboard, papery, or sherry-like aromas and flavors.
- ☐ **Phenolic** – Spicy (clove, pepper), smoky, plastic, plastic adhesive strip, and/or medicinal (chlorophenolic).
- ☐ **Solvent** – Aromas and flavors of higher alcohols (fusel alcohols). Similar to acetone or lacquer thinner aromas.
- ☐ **Sour/Acidic** – Tartness in aroma and flavor. Can be sharp and clean (lactic acid), or vinegar-like (acetic acid).
- ☐ **Sulfur** – The aroma of rotten eggs or burning matches.
- ☐ **Vegetal** – Cooked, canned, or rotten vegetable aroma and flavor (cabbage, onion, celery, asparagus, etc.)
- ☐ **Yeasty** – A bready, sulfury or yeast-like aroma or flavor.

Troubleshooting Off Flavors

- Off Flavors
  - **Acetaldhyde** [Green Apple] – Incomplete fermentation
  - **Alcohol** [Warm/Moonshine] – Fermenting too warm creates fusel alcohols
  - **Diacetyl** [Butter] – Failing to do a diacetyl rest during fermentation (dirty keg lines)
  - **Dimethyl Sulfide** (DMS) [Cooked corn] – Not doing a vigorous 90 min boil
  - **Esters** [Fruity] – Fermenting too warm
  - **Grassy** [Lawn mower] – Excessive dry hop contact or use of excessive hops
  - **Skunky** [Skunk] – Exposure of finished beer to light
  - **Metallic** [Blood/metals] – Rusty/damaged brewing equipment

Troubleshooting Off Flavors

- Off Flavors
  - **Musty** [Mold] – Mold/mildew often in fermenter or fermenting refrigerator
  - **Oxidized** [Cardboard/Sherry/Wine] – Beer exposed to oxygen
  - **Phenolic** [Clove/Bandaid] – Clorinated water or poor sanitation
  - **Solvent** [Nail polish remover] – Out of control ester production
  - **Sour/Acidic** [Sour] – Bacterial or wild yeast infection
  - **Sulfur** [Rotton egg] – Yeast strain (lagers) – often clears
  - **Vegetal** [Rotten veggies] – Wet or old/bad ingredients
  - **Yeasty** [Green beer] – Yeast stuck in suspension in beer

Off Flavor Tasting

- Sample some “bad” beer