PRO Tech Notes
For Craft Brewers
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Issue 7, Volume 2
8/1/13

Better Living Through Brewhouse Water Chemistry

Joe Walts

Narrows Brewing Company

Tacoma, Washington

Overview

- Many small craft brewers, and even some regional ones, don't pay much attention to water chemistry.
  - For some, the consequence is minimal. Potable surface water (e.g. water from lakes and rivers) is great for brewing.
- Water treatment can be extremely complicated, but simply getting in the right ballpark can ***dramatically improve the flavor and stability of your beer.***
  - However, trying to account for every variable will yield diminishing returns.
- **I'm not a chemist, and some of these calculations are based on a very limited set of experimental data. Your feedback will make us all smarter.**

Fundamental Concepts

- Malt is a pH buffer that's strongest around 5.4-5.8.
  - In general, dark malts are more acidic than light malts.
- Water with carbonate alkalinity is a pH buffer that's strongest at a higher pH than malt.
- The influence of alkalinity will increase as the water-to-grain ratios of your mashes increase.
- Calcium and magnesium will lower mash pH, but not by very much.
- Adding acids to eliminate carbonates will result in lower mash pHs. When carbonates are absent, acids will continue to lower mash pHs.

A Quick Word on Units

- Water reports often give ion concentrations in mg/L or ppm (parts per million). For brewers, the two units are interchangeable.
- The charge-based unit mEq/L (milliequivalents per liter) is convenient for water chemistry. For a given ion:
  - mEq/L = mg/L x Ionic Charge / Molar Mass
- Alkalinity is often given as mg/L as $CaCO_3$, even if the report simply says 'mg/L'. mg/L as $CaCO_3$ is simply equal to 50 x mEq/L.

Baseline Water

- Baseline water = water in your hot liquor tank.
- Low alkalinity will reduce tannin extraction during sparging, as well as chalk buildup in hot water pipes and tanks.
  - 1 mEq/L is a good target because it's near the natural decarbonation limit of water with sufficient calcium, which means that very little chalk will precipitate.
- If you treat your water in a cold or ambient liquor tank, you can use treated water to cool your wort. This will reduce chalk in your heat exchanger

Removing Alkalinity

- My preferred method is to add lactic acid.
- It doesn't precipitate solids, and can therefore be used in hot liquor tanks without causing excessive mineral buildup.
- Unlike slaked lime and phosphoric acid, lactic acid won't deplete your water of calcium.
- It's easy to find and relatively safe to handle.
- In my experience, proper lactic acid treatments give beer a soft mouthfeel.

Step 1: Calculate Lactic Acid Addition to Baseline Water

- $Ab = 1000 \times (S / 100) \times (99.5 / 100) / 90.09 / ((S / 100) / 1.2 + (1 - S / 100))$
  - Acidity of lactic acid for baseline water in mEq/L
  - S = Strength of lactic acid as a mass percentage. 88% is common.
- $Vlab = (TA1 - TA2) \times Vwb \times 117.348 / Ab$
  - $Vlab$ = Volume of lactic acid in mL
  - $TA1$ = Total alkalinity of source water in mEq/L
  - $TA2$ = Target total alkalinity of baseline water in mEq/L
  - Vwb = Volume of baseline water to treat in bbl

Adding Calcium

- Calcium is important for yeast flocculation[1] and beer clarity[2]. Based on vague conventional wisdom, I aim for a minimum concentration of 2.5 mEq/L in my water.
- If needed, calcium can be added to your baseline water or as separate additions to your mash and kettle.
- Two common salts used to add calcium are calcium chloride and calcium sulfate (gypsum).
  - Molar Mass of CaCl2 x 2H2O = 147.02 g/mol
  - Molar Mass of CaSO4 x 2H2O = 172.17 g/mol
- Calcium sulfate is often thought to enhance hop character. This is rubbish[3]. It can make your beer taste more English or lager-like, though.

Step 2: Calculate Calcium Chloride and Calcium Sulfate Additions

- CaN = (Ca1 – Ca2) x Vw x 117.348 x MM / 2 / 1000
  - CaN = Calcium chloride or calcium sulfate to add in grams
  - Ca1 = Initial calcium concentration in mEq/L
  - Ca2 = Desired calcium concentration in mEq/L
  - Vw = Volume of water to treat in bbl. For baseline water additions, Vw = Vwb from Step 1. For mash additions, Vw = mash water volume. For kettle additions, Vw = sparge water volume minus water volume retained by spent grain.
  - MM = Molar mass of $CaCl_2$ or $CaSO_4$ in g/mol

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Optimal Mash pHs

- Brewing scientists hold differing opinions:
  - Bamforth: 5.6-6.1 maximizes extract and fermentability, but 5.0-5.5 maximizes soluble nitrogen and FAN[4]. Most mashes are 5.3-5.5[5].
  - Kunze and Narziss[6, 7]: 5.5 is optimal for starch conversion, but 5.2-5.4 is ideal for beer flavor and stability.
  - DeLange: "the biggest single improvement in my brewing in the last 5 years or so came when I started actively controlling pH to between 5.3 and 5.4."[8]
- Values are for room temperature measurements.
- Common pH strips read low by about 0.3[9].

Mash pH Sampling

- In my experience, pH drops during conversion rests.
  - pH measurements near the end of conversion are repeatable, and are good indicators of kettle wort pH.
  - Controlling pH near the end of conversion results in higher pHs (i.e. better for amylases) when the enzymes are most active.
- If you take pH samples from vorlauf or first runnings wort, your samples may be diluted by lauter tun foundation water.
- Bottom line: my calculations target a pH of 5.4, I pull samples near the end of starch conversion, and I'm happy with measurements between 5.2 and 5.5.

Grainbill Assumptions

- Assume the following:
  - pH of a mash with distilled water and Pilsner malt will be 5.65.
  - Depending on the manufacturer, acidulated malts will drop mash pH by 0.10-0.14 for every % weight of the grainbill they comprise.
  - Dark-roasted malts will drop mash pH by 0.028 for every % weight of the grainbill they comprise.
  - Pale malted wheat will raise mash pH by 0.003 for every % weight of the grainbill it comprises
  - Other types of malt will drop mash pH by 0.00027 for every % weight of the grainbill they comprise per degree Lovibond above typical Pilsner malt (assume typical Pilsner malt is 1.8 Lovibond).
- Note that we're assuming dark-roasted malts contribute a fixed amount of acid regardless of color, while the acidities of "other" malts increase linearly with color[10]. Above ~105 degrees Lovibond, "other" malts are more acidic than dark-roasted malts.

Step 3: Estimate Distilled Water Mash pH of Grainbill

- pHd = 5.65 – 0.1 x PA – 0.028 x PR + 0.003 x PW – Sum(0.00027 x POn x (COn – 1.8))
  - PA = Total weight percentage of acidulated malts in the grainbill
  - PR = Total weight percentage of dark-roasted malts in the grainbill
  - PW = Total weight percentage of pale malted wheat in the grainbill
  - POn = Weight percentage of each other type of malt in the grainbill
  - COn = Color, in degrees Lovibond, of each other type of malt in the grainbill

Residual Alkalinity

- RA = TA – Ca/3.5 – Mg/7
  - RA = Residual alkalinity in mEq/L
  - TA = Total alkalinity in mEq/L
  - Ca = Calcium ion concentration in mEq/L
  - Mg = Magnesium ion concentration in mEq/L
- Assume mash pH shift = 0.059 x Total mEq of RA / lbs of Grain.

Step 4: Calculate Initial Residual Alkalinity of Mash Water

- Simply plug values of your mash water into the general residual alkalinity formula.
- RAi = TAi – Ca/3.5 – Mg/7
  - RAi = Initial residual alkalinity of mash water
  - TAi = Initial total alkalinity of mash water = TA2 from Step 1
  - Ca = Calcium concentration of mash water. If you plan to add calcium salts to your baseline water or mash water, Ca = Ca2 from Step 2
  - Mg = Magnesium concentration of mash water

Step 5: Calculate Target Residual Alkalinity of Mash Water

- This is the residual alkalinity of mash water that will result in your target mash pH.
- RAt = (pHt – pHd) x Wg / 0.059 / (Vwm x 117.348) + 0.05
  - RAt = Target residual alkalinity in mEq/L
  - pHt = Target mash pH
  - pHd = Distilled water mash pH from Step 3
  - Wg = Grainbill weight in lbs
  - Vwm = Mash water volume in bbl

Step 6: Calculate Lactic Acid Addition to Mash

- D = 100 x (1 – 1 / (1 + 10^(pHt – 3.83)))
  - D = dissociation percentage of lactic acid in mash
  - pHt = Target mash pH
- Am = 1000 x (S / 100) x (D / 100) / 90.09 / ((S / 100) / 1.2 + (1 – S / 100))
  - Acidity of lactic acid for mash in mEq/L
  - S = Strength of lactic acid as a mass percentage. 88% is common.
- Vlam = (RAi – RAt) x Vwm x 117.348 / Am
  - Vlam = Volume of lactic acid in mL
  - RAi = Initial residual alkalinity from Step 4
  - RAt = Target residual alkalinity from Step 5

Step 7: Calculate Calcium Carbonate Addition to Mash

- You'll only need calcium carbonate if you want to raise the residual alkalinity of your mash water (i.e. RAt > RAi). If you plan to add acid to your mash, this step will not be necessary.
- CaCO3 = (RAt – RAi) x Vwm x 117.348 x 100.09 / 2 / 0.714 / 1000
  - CaCO3 = Calcium carbonate to add in grams
  - RAi = Initial residual alkalinity from Step 4
  - Vwm = Mash water volume in bbl
- Due to the limited solubility of calcium carbonate as a mash addition, don't use this equation if the target total alkalinity of your mash water exceeds 5 mEq/L[11].

Example: Initial Parameters

- Water supply:
  - TA = 6.78 mEq/L
  - Ca = 3.992 mEq/L
  - Mg = 3.702 mEq/L
- Baseline water volume = 100 bbl
- Mash water volume = 48.4 bbl
- Target total alkalinity of baseline water = 1 mEq/L
- Lactic acid strength = 88%
- Total grainbill = 4,000 lbs
  - Pilsner malt = 3,175 lbs = 79.3% of grainbill
  - Munich II malt (9L) = 770 lbs = 19.3% of grainbill
  - Carafa Special II malt = 55 lbs = 1.4% of grainbill

Example: Steps 1-4

- Acidity of lactic acid = 1000 x (88 / 100) x (99.5 / 100) / 90.09 / ((88 / 100) / 1.2 + (1 – 88 / 100)) = 11.39 mEq/L
- Lactic acid to baseline water = (6.78 - 1) x 100 x 117.348 / 11.39 = 5,955 mL
- Ca > 2.5 -> No calcium salts needed.
- Distilled water mash pH of grainbill = 5.65 – 0.028 x 1.4 – 0.00027 x 19.3 x (9 – 1.8) = 5.57
- Initial residual alkalinity of mash water = 1 – 3.992 / 3.5 – 3.702 / 7 = -0.669 mEq/L

Example: Steps 5-7

- Target residual alkalinity of mash water = (5.4 – 5.57) x 4,000 / 0.059 / (48.4 x 117.348) + 0.05 = -1.979 mEq/L
- Lactic acid dissociation = 100 x (1 – 1 / (1 + 10^(5.4 – 3.83))) = 97.4%
- Acidity of lactic acid = 1000 x (88 / 100) x (97.4 / 100) / 90.09 / ((88 / 100) / 1.2 + (1 – 88 / 100)) = 11.149 mEq/L
- Lactic acid to mash = (-0.669 + 1.979) x 48.4 x 117.348 / 11.149 = 667 mL
- Acid addition to mash -> no calcium carbonate needed.

Additional Resources

- A.J. DeLange's brewing website, which has a lot of information about water chemistry:
  - http://http://hbd.org/ajdelange/
- Kai Troester's website about the affects of pH on brewing processes (note that the targets and assumptions outlined in this presentation do not always match Kai's):
  - http://braukaiser.com/wiki/index.php?title=How_pH_affects_brewing
- My water treatment spreadsheet, which will do the math for you:
  - Download at http://sites.google.com/site/republicbrewpub/
  - File name is Water_Barrels.xlsx

Sources

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- 8: http://www.homebrewersassociation.org/forum/index.php?topic=3657.0
- 9: http://www.braukaiser.com/wiki/index.php?title=ColorpHast_vs_pH_meter
- 10: http://braukaiser.com/wiki/index.php?title=Mash_pH_control
- 11: http://braukaiser.com/wiki/index.php?title=Building_brewing_water_with_dissolved_chalk

Joe Walts is the Head Brewer at Narrows Brewing Company in Tacoma, Washington.

His brewing career began in 2005 at J.T. Whitney's in Madison, Wisconsin and continued at Otter Creek Brewing (Vermont), Fox River Brewing Company (Wisconsin) and Ale Asylum (Wisconsin),where he worked as a brewer and QA manager before relocating to Washington.

Brewing with the highly alkaline water of central Wisconsin has taught Joe more about water chemistry than he ever intended to know, and he hopes that you find the information useful.

Joe welcomes any questions or comments you may have. You can reach him at **jwalts@gmail.com**

Ed Michalski (left) with brother Dave,checking specs for a customer

If you need brewing equipment repaired, or re-engineered to work better, faster or more cost-effectively, contact Ed Michalski, CEO, at PRO Engineering / Manufacturing, Inc.

PRO Engineering and Manufacturing, Inc has a commitment to serving the Craft Brewingindustry through tunnel pasteurizers and batch pasteurizers specifically tailored to craft brewers.

Edward A. Michalski Bio

Ed Michalski started his career in the beverage industry by designing stainless steel, higherflow, spray headers for Pabst Brewing. Along with the header design he also developed a process to produce the new headers.

Ed, along with his brother David, formed PRO Engineering/Manufacturing, Inc. Based on what they learned by re-designing and refurbishing other manufacturers' pasteurizers, Ed and PRO started to offer the pasteurizer marketplace superior newpasteurizers.

Contact Ed Michalski, CEO, at:

(414) 362-1500
ed.michalski@prowm.com Click Here for more information

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