Adjusting Water for Style

Five Star Chemicals Lecture Series

12/12/24

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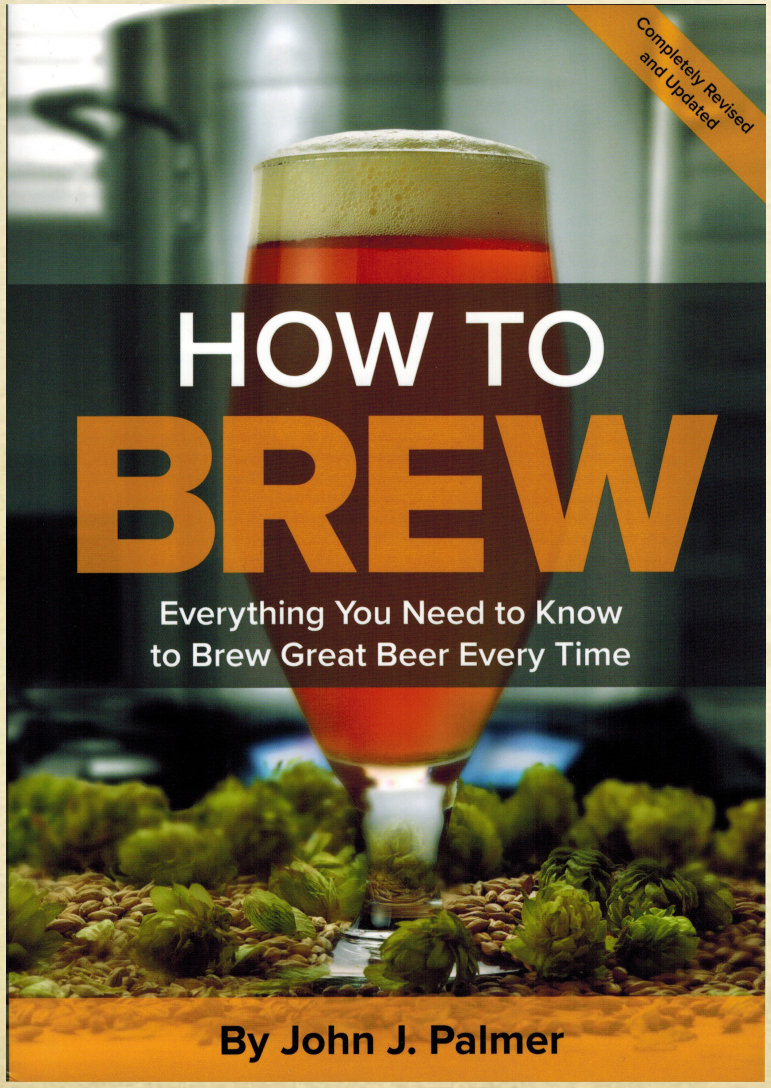
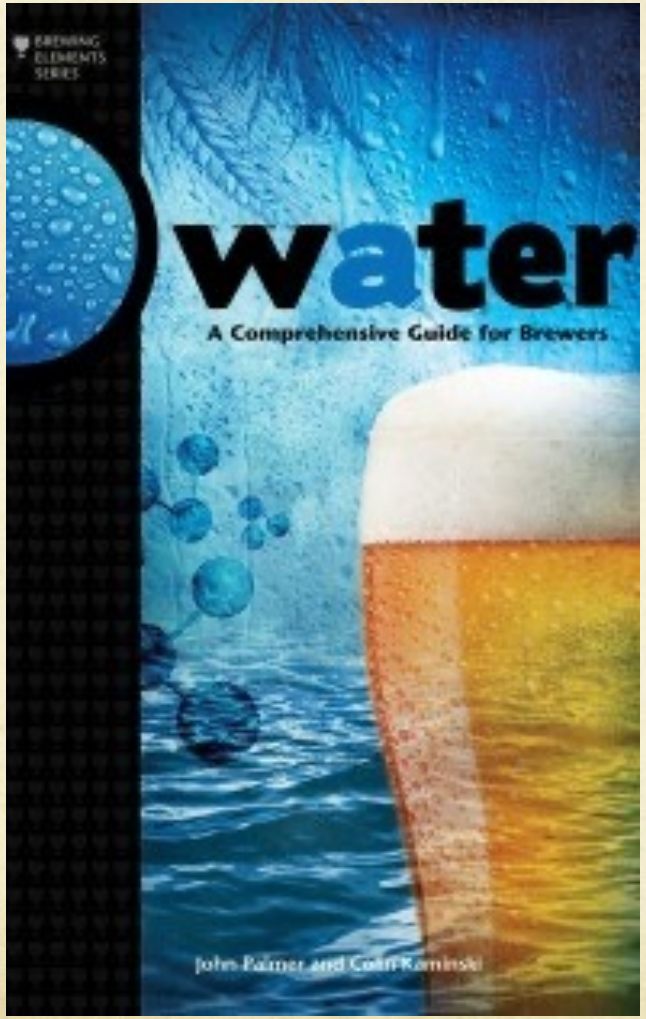
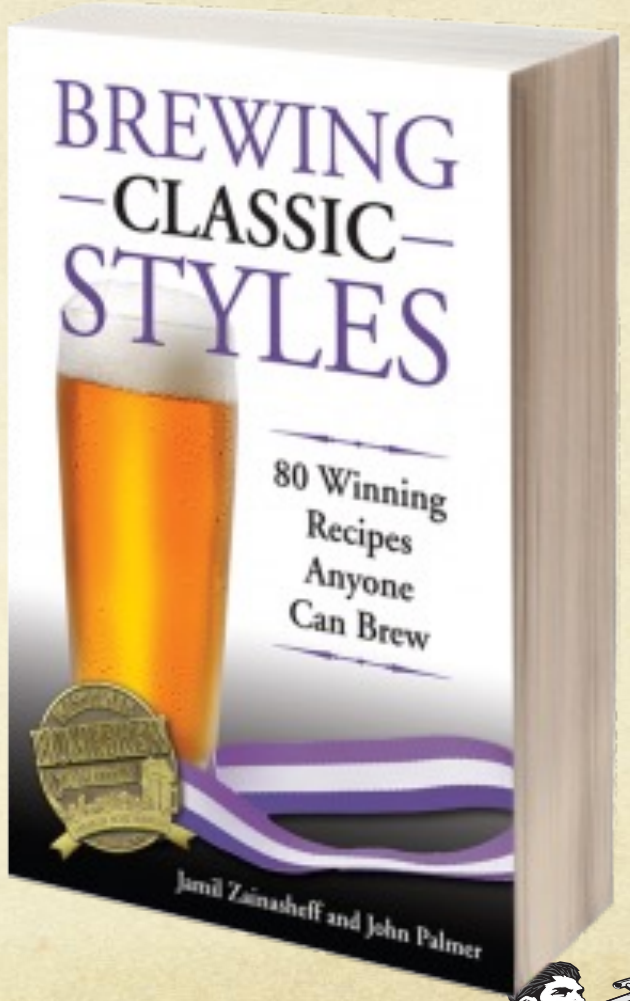






Why Do We Adjust Brewing Water?

- First, to hit our target mash pH, 5.2-5.6
- Second, to improve Beer Flavor
- What do we adjust?
  - Mineral composition, not pH.
- How do we adjust it?
  - Salt additions
  - Acid additions
  - Ion Removal Processes (e.g., Reverse Osmosis)

Two Groups of Ions

- **Affect pH:**
  - Calcium
  - Magnesium
  - Total Alkalinity
    - **Mineral Concentrations**
      - 0-50 ppm is Low
      - 50-100 ppm is Medium
      - 100-150 ppm is High
      - **>150** ppm is a **Problem**
- **Affect Flavor:**
  - Sulfate
  - Chloride
  - Sodium

Know Your Source Water

- Surface Water
  - Low in Minerals, High in Organics
  - Often requires Carbon Filtration to remove taste & odor compounds
- Ground Water
  - High in Minerals, Low in Organics
  - Often requires ion-exchange or RO to reduce Alkalinity
- How is your source water disinfected?
- Does your Source change during the year?

Water Source Comparison

Source	Calcium	Magnesium	Total Alkalinity	Sulfate	Chloride	Sodium	Silica	TDS
Seattle	8	1	22	1	4	2	5	43
Mississippi River	41	25	180	15	23	12	9	280
Lake Michigan	37	12	108	23	15	9	3	172
San Diego, CA	40	18	100	115	86	71	27	480
Lafeyette, IN	100	30	275	70	45	25	30	575
Madison, WI	84	45	**354**	25	81	24	35	648

What is Water Hardness?

- Hardness = The sum of Calcium and Magnesium *measured as calcium carbonate*
  - Brewers WANT calcium and magnesium in our mash/beer.
  - Water Hardness helps lower mash pH
  - Permanent Hardness = Ca/Mg Sulfates & Chlorides
  - Temporary Hardness = Ca/Mg Bicarbonate, Carbonate
  - SOFT = Not Hard. Doesn't describe Alkalinity.

What is Alkalinity?

- Total Alkalinity = the sum of carbonate species in water (from limestone)
  - Alkalinity ≅ Temporary Hardness
  - This is why we say we want to get rid of temporary hardness.
  - Alkalinity raises Mash pH, makes beer less acidic, but duller.

Calcium

- The most important ion in brewing.
- Cofactor for:
  - Mash pH via Residual Alkalinity
  - Protein coagulation, trub formation.
  - Yeast metabolism, flocculation, and beer clarity
  - Oxalate Precipitation
- 50 ppm minimum in the wort for beer clarity
- 100-200 ppm in mash and sparge liquor for stable pH during lautering and better clarity.
- >200 ppm tends to taste minerally.

Magnesium

- The sidekick to calcium, but half as effective at lowering mash pH due to higher solubility of magnesium phosphates.
- A vital yeast nutrient.
  - 5 ppm minimum in the wort needed for yeast.
  - All malt wort (1.040, 10°P) typically has 70 ppm
  - Wort levels of Calcium and Magnesium should be similar!
    - Magnesium s/b at least 40% of (Ca + Mg) in the wort as a rough estimate.
- Recommended level in water is 0-40 ppm
  - >80 ppm tastes sour/bitter in beer
  - Dark beers seem to benefit from ~30 ppm in the water.

Total Alkalinity as $CaCO_3$

- The Villain
  - Keeps the Hero in check
  - Generally should be low, but RA is the key.
  - Bicarbonate is generally 95% of Total Alkalinity
- Alkalinity drives mash pH up
  - Causes more tannin and silicate extraction
  - Results in coarser bitterness from hops
  - But, provides balance for darker, more acidic grainbills
- Recommended range 0-120 ppm as $CaCO_3$, 200 ppm max.

Sulfate

- The Dark Hero.
  - Accentuates hop character, helps dry the beer finish.
  - Tastes minerally with high concentrations of sodium, chloride, and bicarbonate.
- 100-200 ppm in Pale Ales and IPAs improves hop character and finish.
  - Sulfur is generally not desired for German lagers such as Pilsner or Helles, conflicts with soft noble hop character. (≤50 ppm)
- Recommended range is 50-300 ppm for most styles.
  - Do not exceed 800 ppm, preferably 300 ppm.

Chloride

- Imparts a rounder, sweeter, fuller quality to the beer.
- Minimum effective level for accentuating beer mouthfeel and flavor is probably 50 ppm.
- High Concentrations can hurt the beer:
  - >300 ppm can hurt clarity and stability
  - >400 ppm can hurt beer flavor
  - >500 ppm can hurt fermentation
- Recommended range is 50-150 ppm for most styles.

Sodium

- The bastard stepchild of brewing minerals.
  - It's everywhere: sodium chloride, sodium bicarbonate, sodium hydroxide…
  - Can be difficult to remove from water; reverse osmosis removes up to 97%.

- Recommended level is <100 ppm
  - Acts to improve mouthfeel and sweetness of malt.
  - >150 ppm tends to taste salty, especially with significant chloride (<100 ppm).
  - People's sensitivity varies.

Sulfate to Chloride Ratio

- Seasoning Effect: Dryness vs. Fullness
- It is not magic – 40:10 ≠ 400:100
- Useful range is 5:1 to 0.5:1
  - Maximum suggested sulfate is 500 ppm
  - Maximum suggested chloride is 200 ppm
  - Recommend to not exceed combined sum of 500 ppm. (Tastes Minerally)
    - IPA: 250 SO4, 50 Cl
    - NEIPA: 150 Cl, 50 SO4

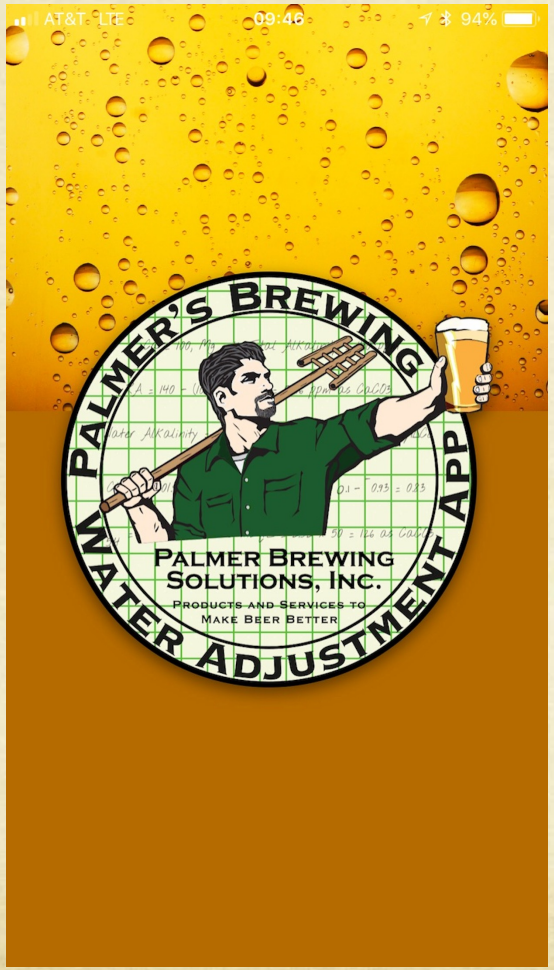
The Water pH is Not Important.

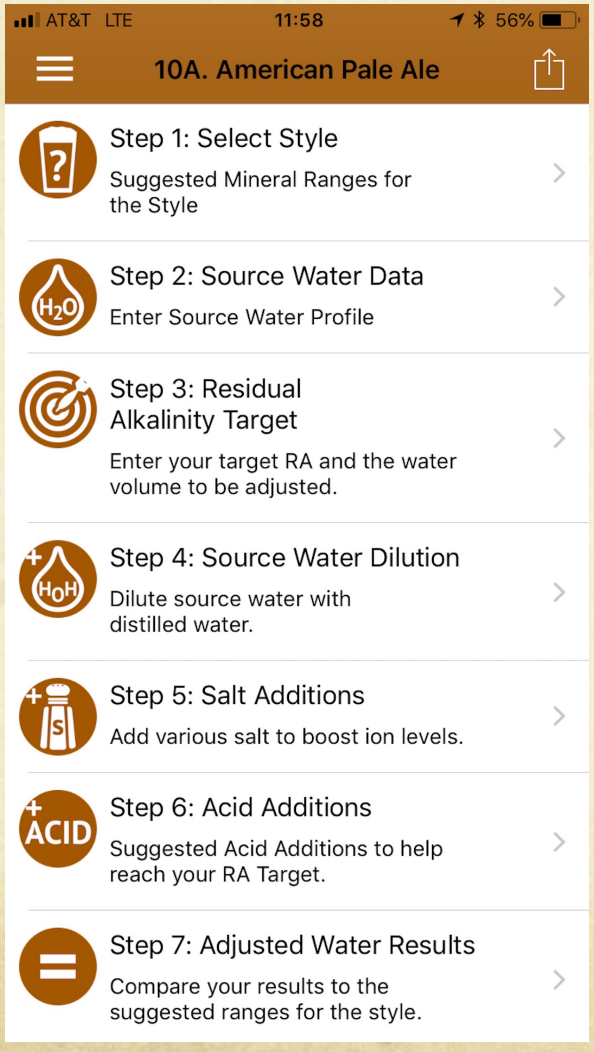
- The water pH is not important.
- The water pH is the chemical equilibrium of the water, i.e., the balance of hardness and alkalinity.
  - Higher pH = more alkalinity than hardness
  - Two different waters can have the same water pH
- High mineral water vs. Low mineral water:
  - Can have same Water pH.
  - Will have different Mash pH.
- Mash pH drives Beer pH, which drives beer flavor!

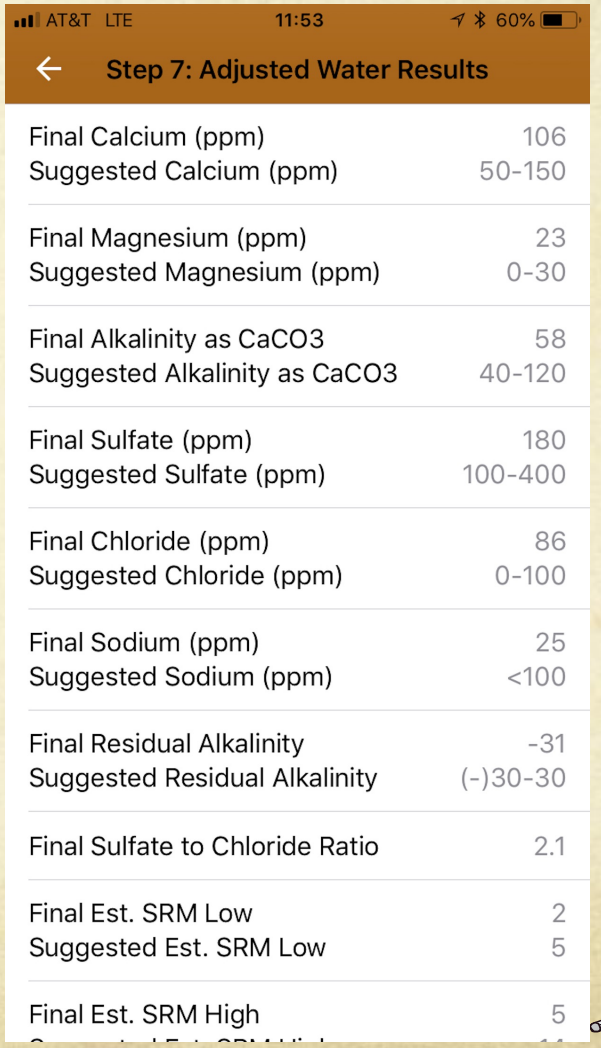
Know What's in Your Water

- Measure the Calcium, Magnesium, Total Alkalinity, Sodium, Chloride, Sulfate, and pH with the BrewLab by the LaMotte Company.

Palmer's Water App







How Water Affects Beer Flavor

- Water Residual Alkalinity drives Mash pH,
  Mash pH drives Beer pH,
  Beer pH drives beer flavor expression.
- Seasoning Balance: Sulfate and Chloride
  - More Sulfate = drier, more assertive hops
  - More Chloride = rounder, fuller, sweeter malt
- Seasoning Level: (Total Dissolved Solids-TDS)
  - TDS is proportional to Calcium salt concentrations…

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Effect of Beer pH on Flavor

- In general, a lower beer pH focuses and brightens the malt and hop flavors.
  - Better for single-malt pale beers.
  - Dark beers can become a singular "roast" character.
- In general, a higher beer pH broadens and opens up malt and hop flavors.
  - Better for multiple-malt dark beers.
  - Pale beers can become dull and harsh.

Seasoning Balance - Sulfate and Chloride

- They affect the flavor balance of the beer –
  Dryness vs. Fullness, Hoppy vs. Malty
- The actual amounts are more important than the ratio.
  - It is not magic – 40:10 ≠ 400:100
- Useful range is 9:1 to 0.5:1
  - Maximum suggested sulfate is 500 ppm, even 100 ppm works.
  - Maximum suggested chloride is 200 ppm
  - Recommend to not exceed combined sum of 500 ppm. (Tastes Minerally)

TDS Effect –Mineral Structure

- Light vs. Heavy Seasoning
- Bohemian Pilsner (TDS = 50 ppm
  - Rich, malty beer backed by large soft bitterness. Smooth finish balanced between malt and hops. No sharp edges.
- German Pils (TDS = 150 ppm)
  - Crisp and bitter hop forward character, followed by clean malt and dry finish. This is a beer defined by clean edges.
- Dortmunder Export (TDS = 750 ppm)
  - Balanced rich malt and firm dry bitterness. A "castle" of beer structure. Lower alcohol but doesn't taste like it

What is Residual Alkalinity?

- **Residual alkalinity is the difference between effects of the Total Alkalinity and Hardness on mash pH.**
  - RA = Total Alkalinity – (Ca + ½ Mg)/3.5
    Note: Units must be mEq/L or ppm as $CaCO_3$
    3.5 factor is dependent on Mash Ratio and Crush
- Calcium and Magnesium react with malt phosphates to produce hydrogen ions and lower mash pH, if there is sufficient calcium….
  - $10Ca^{+2} + 12HCO_3^{-1} + 6H_2PO_4^{-1} + 2H_2O \rightarrow Ca_{10}(PO_4)_6(OH)_2 + 12CO_2 + 12H_2O + \mathbf{2H^{+1}}$
  - Magnesium also reacts, but about half as much.

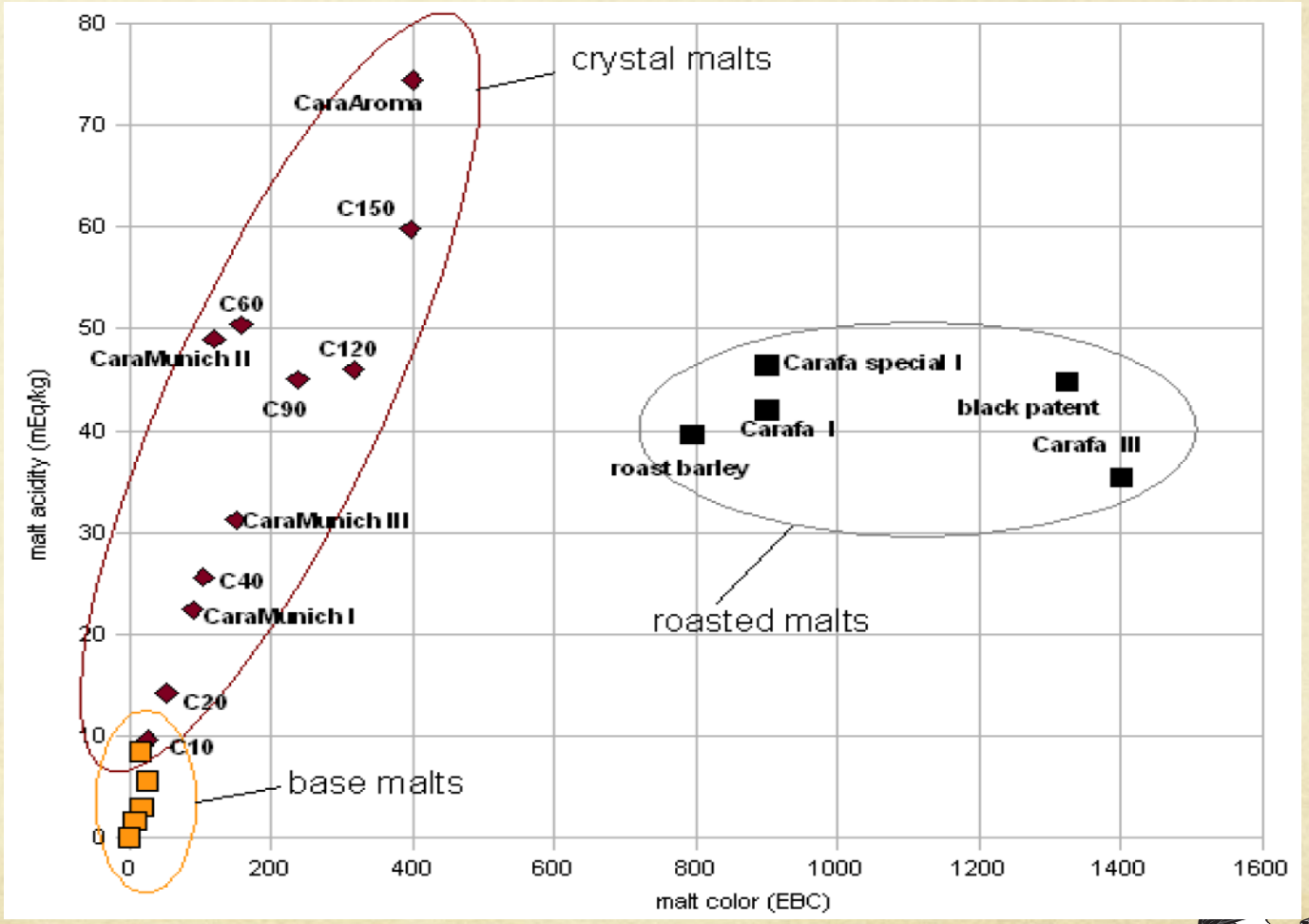
Mash ph is the Equilibrium between Water Chemistry and Malt Chemistry

- The effect of water chemistry in the mash is summarized by Residual Alkalinity.
  - Calcium and malt phosphates react to lower mash pH
  - Alkalinity buffers that reaction.
- Malts are either alkaline or acidic relative to your target pH (5.2-5.6).
  - Base malts are generally alkaline (> 5.6).
  - Specialty malts are generally acidic (< 5.2).

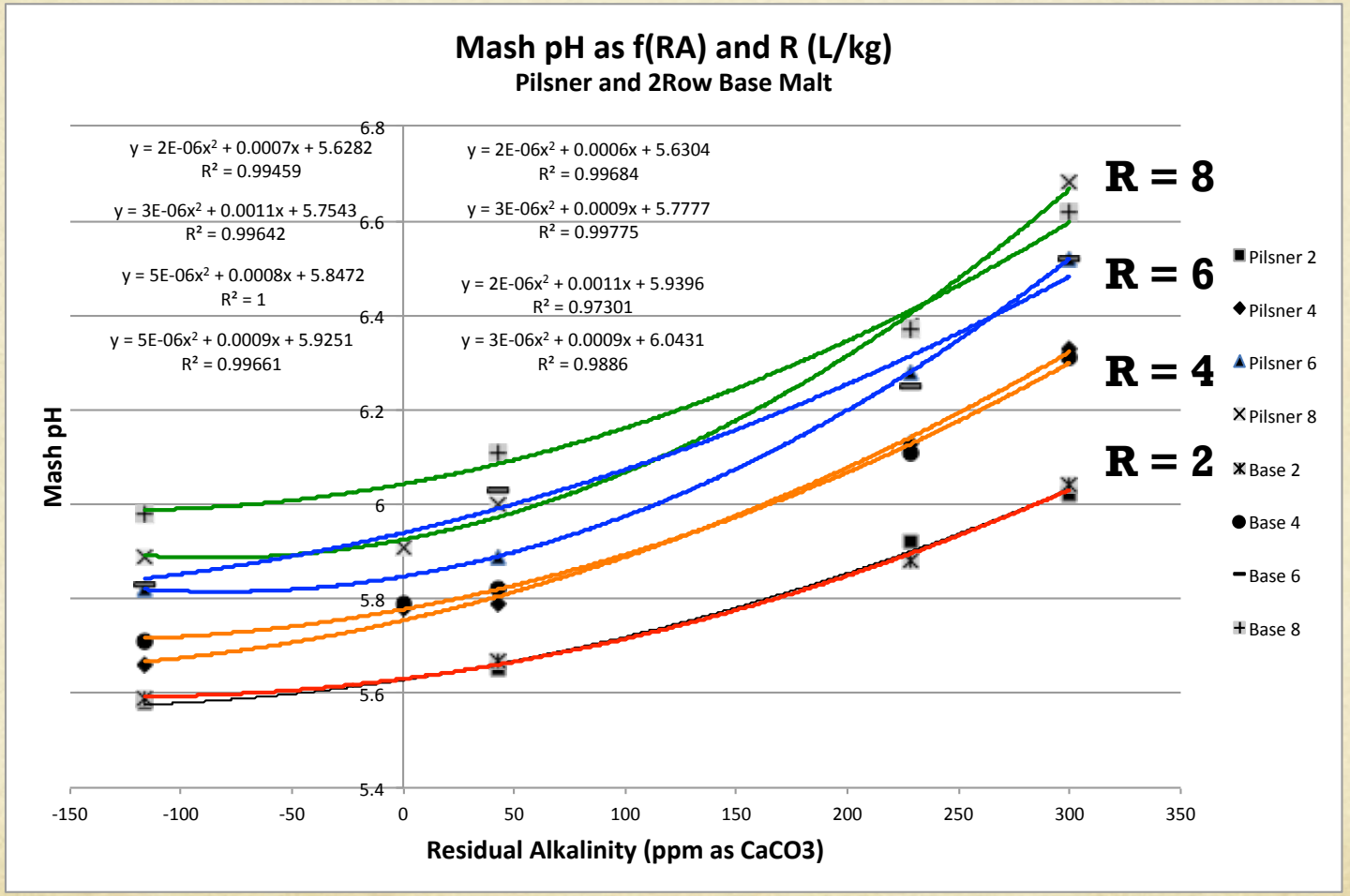
Kilned vs. Roasted Acidity

- Kilned malts get more acidic as color increases.
- Caramel malts have highest acidity.
- Roasted malts have lost acidity.

From K. Troester,
www.braukaiser.com



RA has Increasing Effects



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Water to Grist Ratio vs. RA

- The chemical equilibrium (pH) between water and malt depends on the water to grist ratio (W:G).
  - Lower W:G means less RA effect.
  - Higher W:G means more RA effect.
- Low W:G mash, sparged with +RA water = more sparging, more pH rise.
- Higher W:G, sparged with +RA water = less sparging, less pH rise.

Mash pH: Balancing a Triangle

Base Malt Alkalinity x Weight

+

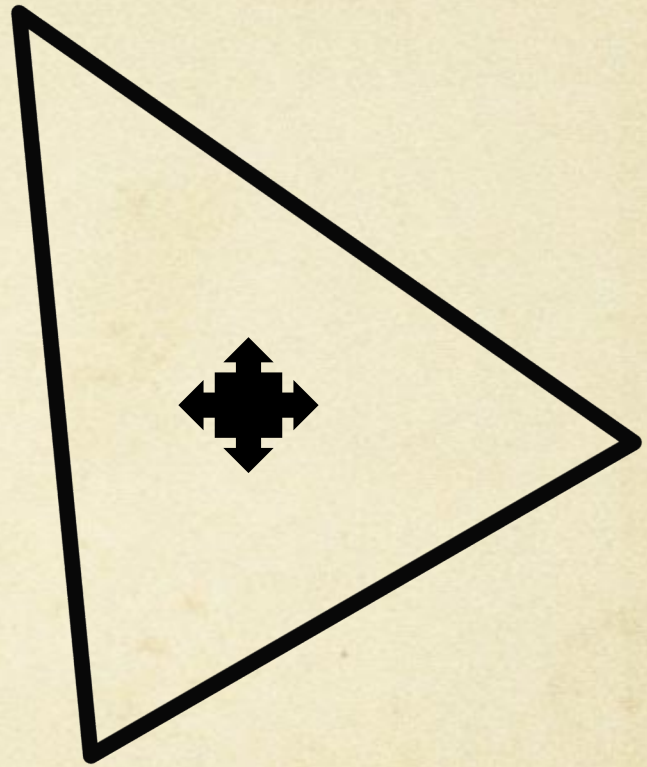
Specialty Malt Acidity x Weight

+

Water Residual Alkalinity x Volume

=

Mash pH



5. The Mash pH Sets Up the Beer pH

- "The key point for control of pH throughout the brewing process is during mashing. This is due to the major influence that can be exerted at this stage on the content and format of the buffer systems that will operate subsequently in the wort and beer."
  - Taylor, D.G., The Importance of pH Control during Brewing, *MBAA Tech. Quart.* 27:131-136, 1990.

Sidebar: What is pH?

- It is the concentration and activity of hydrogen ions in solution.
- But more importantly, it is a measure of chemical equilibrium, which tells us how well the brewing process is proceeding.
- A good analogy is Noise, measured as decibels.
  - You can monitor a process or group of children in the next room simply by paying attention to the noise level.
  - If you want to be serious about controlling your beer, you need to measure pH.

pH Changes with Temperature

- The pH of a solution will change with temperature, due to changes in activity (energy) and buffer response.
- Different worts (styles) will have different activities
  and different pH change with temperature.
- Generally, wort pH lowers by ~0.3 between room (20°C) and mashout temperature (75°C).
  - We use room temperature as a common standard for comparison. (ASBC MOA Beer-9, pH)

pH and ATC

- Most modern pH meters have automatic temperature compensation (ATC).
- The purpose of ATC is to be able to measure a sample at a *different temperature* than the calibration temperature, and give an accurate reading of the pH *at that different temperature*.
  - i.e., it maintains calibration
- It does not compensate for the actual pH change of the solution due to temperature.

What Is the Optimum pH?

- It Depends:
  - There are many enzymatic processes occurring in the mash, each with it's own optimum pH range.
  - The pH optima for proteolysis is lower than for saccharification.
- Therefore, optimum mash pH represents a compromise between priorities: conversion, FAN, lauterability, etc.
  - "Optimum" Mash pH is based on optimum yield.
  - Amylases prefer 5.5-6.0, but pH >5.8 promotes astringency.
  - Therefore, better beer flavor at 5.2-5.6

C. Kaminski's Observations on pH American Pale Ale

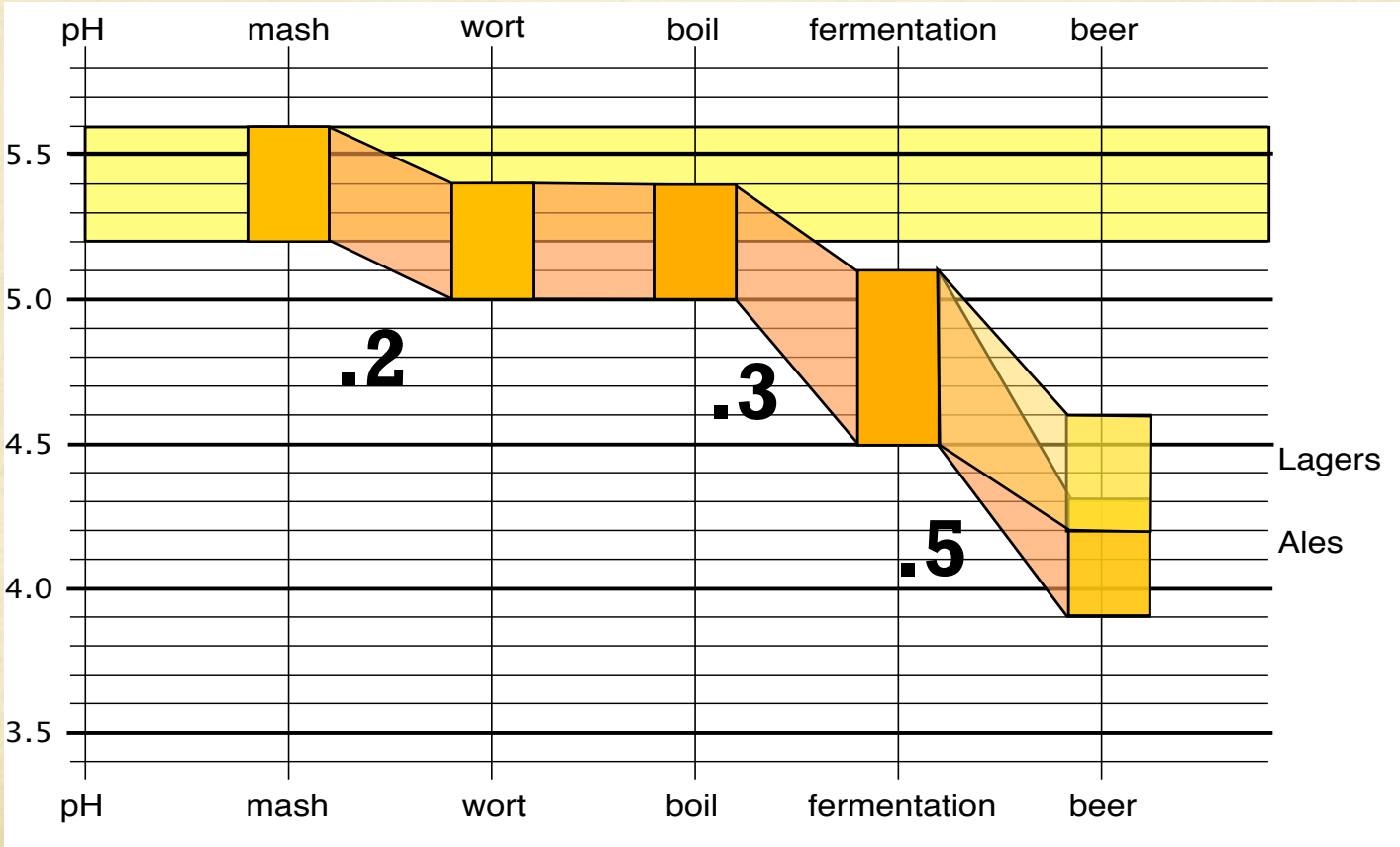
- Boil pH and influence on Hop expression:
  - 5.4 – Strong and Harsh
  - 5.2 – Full and Rich
  - 5.0 – Dull and Flaccid
- Beer pH and Flavor of Pale Ales
  - 4.4 – Soft and Soapy
  - 4.2 – Normal
  - 4.0 – Sharp and Crisp

WHEN & HOW to Measure pH?

- You are looking for a mash pH of 5.2-5.6 @ room temp, for saccharification.
- Measure the pH about 10 minutes into the mash.
- Cool the mash wort sample to room temp on a shallow dish, then measure with a pH meter.
- Note that the mash pH falls throughout the mash.
- If at first you don't succeed, brew again. (you can try to fix it now, but conversion happens quickly, so…)

Mash pH Sets Up Beer pH

5.2-5.6



~4.0-4.6

Style/recipe dependent

Optimizing Beer pH for Flavor

- Every beer recipe has an optimum beer pH, generally in the range of 4.0-4.6.
- Every beer should have a flavor portfolio that includes:
  - malt flavors and aromas,
  - hop flavors and aromas,
  - yeast flavors and aromas.
- If you can't taste or smell *everything*, you are probably not at the optimum beer pH.

Suggested Mash pH Guidelines

- Pale beers: 5.2-5.4
- Amber beers: 5.3-5.5
- Dark beers: 5.4-5.6
  - Always cool a sample and measure at room temperature.
- Water pH is NOT important!
  - Different waters can have same pH.
  - You are putting the cart before the horse if you adjust water pH.

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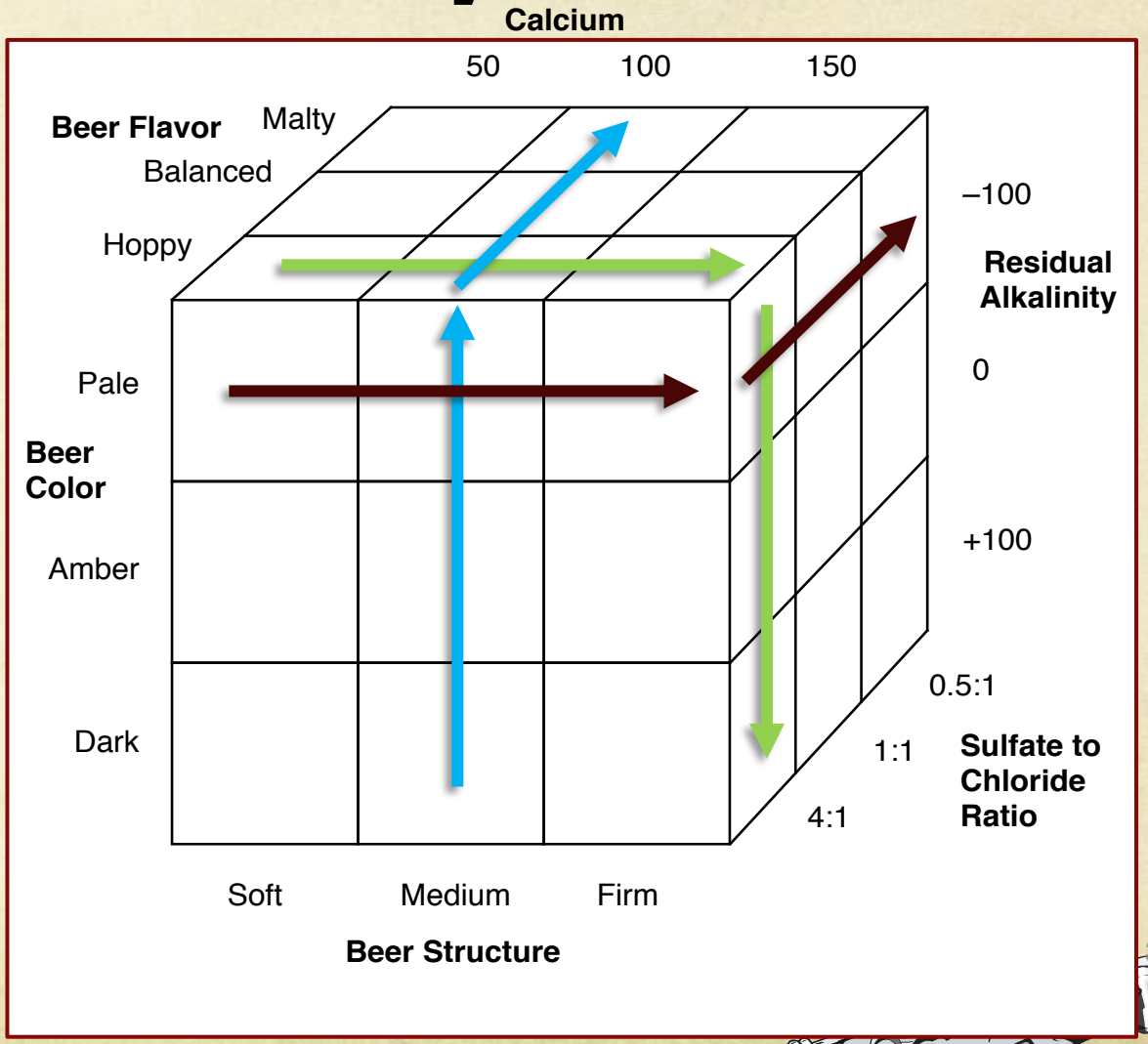
Adjusting Water for Style

- To Adjust water for style, use the cube:
  - Define the style by Flavor, Color, & Structure.
  - Read water profile by Calcium, Total Alkalinity, and Sulfate to Chloride Ratio.
    - Beer Color => Residual Alkalinity
    - Flavor Balance => Sulfate to Chloride
    - Beer Structure => Calcium level



Your Tools for Water Adjustment

- Salts (1 g/10 L)
  - Calcium Chloride: 23 ppm Ca^{+2}, 56 ppm Cl^{-}
  - Calcium Sulfate: 27 ppm Ca^{+2}, 48 ppm SO_4^{-2}
  - Magnesium Sulfate: 9.9 ppm Mg^{+2}, 39 ppm SO_4^{-2}
  - Sodium Bicarbonate: 27 ppm Na^{+}, 72 ppm HCO_3^{-}
- Acids
  - Lactic Acid
  - Phosphoric Acid

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Suggested Salt Additions to RO Water (grams per gallon)

Beer	$CaSO_4$	$CaCl_2$	Baking Soda	Ca	Na	SO4	Cl	HCO_3	RA
Pale Hoppy	1	0.5	0	98	0	147	64	0	-70
Pale Balanced	0.75	0.75	0	100	0	111	96	0	-72
Pale Malty	0.5	1	0	103	0	74	127	0	-73
Amber Hoppy	1	0.5	0.5	98	36	147	64	95	+8
Amber Balanced	0.75	0.75	0.5	100	36	111	96	95	+6
Amber Malty	0.5	1	0.5	103	36	74	127	95	+4
Dark Hoppy	1	0.5	1	98	72	147	64	190	+86
Dark Balanced	0.75	0.75	1	100	72	111	96	190	+84
Dark Malty	0.5	1	1	103	72	74	127	190	+82

Mini-mash pH Results

	Pale Hoppy RA = -70	**Pale Malty** RA = -70	**Amber Malty** RA = +5	**Dark Malty** RA = +80	*Delta*
Pale	**5.7**	**5.6**	**5.8**	**6.3**	*0.6*
Amber	**5.6**	**--**	**--**	**6.1**	*0.5*
Dark	**5.3**	**5.3**	**5.6**	**5.9**	*0.6*
delta	*0.4*	*0.3*	*0.3*	*0.4*	

3 grain bills:

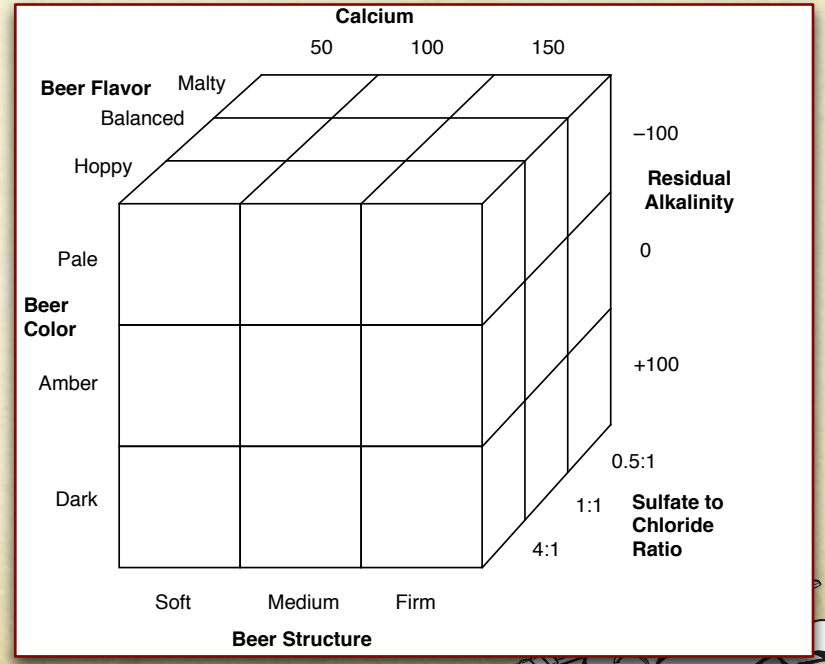
- Pale: Base malt
- Amber: Base and 10% Crystal
- Dark: Base, 10% Crystal, 10% Roast
- Rv = 4 L/kg (2 qts./lbs.)

How Do I Adjust Water for Beer Style?

Ca^{+2}	Mg^{+2}	Alk.	SO_4^{-2}	Cl^{-1}	Na^{+1}	Res. Alk.
40	10	120	40	35	32	86

Dark, Balanced, Soft

1. What are the style characteristics that you want to brew?
   a) Color: Pale, Amber, or Dark?
   b) Flavor Balance: Malty, Balanced, or Hoppy?
   c) Structure: Soft, Medium, or Firm?



Step 1: Add Calcium

Ca^{+2}	Mg^{+2}	Alk.	SO_4^{-2}	Cl^{-1}	Na^{+1}	Res. Alk.
40	10	120	40	35	32	86

Dark, Balanced, Soft

1. Add Calcium based on:
   a) Structure (generally soft or medium) => 50-100 ppm
   b) Color/RA target => Calculate new RA after salt additions.

- For Pale, Hoppy, Medium:
  - Add 1 gram/gallon of calcium sulfate

Ca^{+2}	Mg^{+2}	Alk.	SO_4^{-2}	Cl^{-1}	Na^{+1}	Res. Alk.
102	10	120	187	35	32	42

Step 2: Recalculate RA and Adjust

Ca^{+2}	Mg^{+2}	Alk.	SO_4^{-2}	Cl^{-1}	Na^{+1}	Res. Alk.
102	10	120	187	35	32	42

2. Adjust RA based on beer color/gravity:
   a) Does RA need to decrease (pale)? => Neutralize with acid.
   b) Does RA need to increase (dark)? => Add sodium bicarbonate.

- For Pale, Hoppy, Medium:
  - Add 0.75 ml per gallon of 88% Lactic Acid

Ca^{+2}	Mg^{+2}	Alk.	SO_4^{-2}	Cl^{-1}	Na^{+1}	Res. Alk.
102	10	3	187	35	32	–75

Adjusting Water for Beer Style

Ca^{+2}	Mg^{+2}	Alk.	SO_4^{-2}	Cl^{-1}	Na^{+1}	Res. Alk.
102	10	3	187	35	32	-75

- Final Adjusted Water:
  1. Acidify to neutralize alkalinity first, then add calcium salts.
  2. Do a proportional mini-mash to verify mash pH target.

- When to add salts:
  - First priority is achieving your mash pH target.
  - Add most/all adjustments to HLT to achieve mash pH target.
  - Second priority is achieving Flavor Balance and Structure.
  - Add additional salts or acid as necessary to kettle for flavor.

Maintaining Parity of Ca and Mg

- We need to maintain parity of Ca and Mg for yeast health.
  - If there is too much Ca, then the yeast can't get to the Mg.
- Typical? all-malt wort supplies roughly 30 ppm Ca, 70 ppm Mg.
- If brewing with RO water and salts, add sufficient Mg salts to maintain Mg as at least 40% of (Ca + Mg) in the Wort.
  - Water: 100 ppm Ca, 20 ppm Mg
  - Malt: 30 ppm Ca, 70 ppm Mg
  - Wort: 130 ppm Ca, 90 ppm Mg (90/220 = 41%)

Adjusting Mg (one example)

Ca^{+2}	Mg^{+2}	Alk.	SO_4^{-2}	Cl^{-1}	Na^{+1}	Res. Alk.
102	10	3	187	35	32	-75

- I need to increase Magnesium.
  1. Adding 1g/gallon of MgSO4 = 26 ppm Mg, 103 SO4.
  2. Yields: 290 ppm SO4 total. A little bit too high.
  3. Reduce CaSO4, add CaCl.
  4. 0.5 g/gal CaSO4, 0.5 g/gal CaCl, 1 g/gal MgSO4

Ca^{+2}	Mg^{+2}	Alk.	SO_4^{-2}	Cl^{-1}	Na^{+1}	Res. Alk.
107	36	3	217	99	32	-94

Neutralizing Alkalinity to brew Pale beers

- Acidification to reduce Total Alkalinity is easy.
  - Divide Total Alkalinity by 50 to get mEq/liter.
  - Ex. Total Alk. = 150 ppm as CaCO3 ÷ 50 = 3 mEq/liter.
  - Use 3 mEq/Liter of 1N Acid per liter of water to neutralize the alkalinity.
- 1N solution is 85mL of 88% Lactic Acid added to water to make 1 liter (total).
- Mix acid solution with water in HLT and stir to vent the CO2.
- Mash pH target of 5.2-5.4

Adding Alkalinity to brew Dark beers

- Low mineral water needs alkalinity to buffer dark malts.
- Sodium Bicarbonate works better than Calcium Carbonate.
  - Sodium bicarbonate dissolves easily and reacts more quickly.
  - Hydroxides work faster but may have chemical taste.
- Add sufficient bicarbonate to raise residual alkalinity to:
  - 50-75 ppm as $CaCO_3$ for red and brown beers
  - 75-125 ppm for brown to black beers
  - RA amount depends on depth of color and OG.
- Mash pH target of 5.4-5.6

Adjusting Sparge Water

- Target Mash pH is the first priority.
- The next priority during sparging is to prevent pH rise (>5.8) and prevent astringency.
  - Typically by adding acid to sparge water for pale beers.
  - Do not acidify water based on its pH, acidify based on its alkalinity, i.e., TA=0.
  - You don't need to add alkalinity to Sparge water for dark beers!
- Options:
  - Use the adjusted HLT water to sparge with. Monitor runnings pH.
  - Use low alkalinity water to sparge with. Add salts as needed to kettle.
  - Acidify high alkalinity sparge water to neutralize Total Alkalinity (or Residual) and add salts as needed to kettle.

Capping with Dark Malts

- Capping means to add your Roast malts at the end of the mash.
- This works if you have LOW alkalinity water, or brew with RO or distilled water, but most tap water in the US Midwest is high.
- Most mashes need specialty malts in the mash in order to achieve target mash pH (5.2-5.6), especially if your water has a Total Alkalinity greater than 50 ppm.
  - Low Total Alkalinity (Pale Beers) 0-50 ppm.
  - Medium Total Alkalinity (Amber Beers) 50-100 ppm.
  - High Total Alkalinity (Dark Beers) 100-150 ppm.

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Summary

- #1: Adjust water to achieve good mash pH.
- #2: Adjust water to adjust beer seasoning.
- #3: Brewing is cooking — Don't over-salt, but don't be afraid to adjust it to your taste.

Questions?

- john@howtobrew.com