Brewing Water Treatments

By John Palmer, MBAA Editor-in-Chief
BYO NanoCon, 2020
Why Do We Adjust Brewing Water?

- To Improve Beer Yield – to hit our target mash pH!
- To Improve Beer Flavor
  - And prevent carbonate scale.
- What do we adjust?
  - Mineral composition
- How do we adjust it?
  - Salt additions
  - Acid additions
  - Ion Removal Processes (e.g., Reverse Osmosis)
When do we adjust it?

“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.”

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?
Two Groups of Ions

- **Affect pH:**
  - Calcium
  - Magnesium
  - Total Alkalinity

- **Affect Flavor:**
  - Sulfate
  - Chloride
  - Sodium

- **Mineral Concentrations**
  - 0-50 ppm is Low
  - 50-100 ppm is Medium
  - 100-150 ppm is High
  - >150 ppm is a **Problem**
Palmer’s Water App

10A. American Pale Ale

- **Step 1: Select Style**
  Suggested Mineral Ranges for the Style

- **Step 2: Source Water Data**
  Enter Source Water Profile

- **Step 3: Residual Alkalinity Target**
  Enter your target RA and the water volume to be adjusted.

- **Step 4: Source Water Dilution**
  Dilute source water with distilled water.

- **Step 5: Salt Additions**
  Add various salts to boost ion levels.

- **Step 6: Acid Additions**
  Suggested Acid Additions to help reach your RA Target.

- **Step 7: Adjusted Water Results**
  Compare your results to the suggested ranges for the style.

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**Step 7: Adjusted Water Results**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Calcium (ppm)</td>
<td>106</td>
</tr>
<tr>
<td>Suggested Calcium (ppm)</td>
<td>50-150</td>
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<tr>
<td>Final Magnesium (ppm)</td>
<td>23</td>
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<tr>
<td>Suggested Magnesium (ppm)</td>
<td>0-30</td>
</tr>
<tr>
<td>Final Alkalinity as CaCO3</td>
<td>58</td>
</tr>
<tr>
<td>Suggested Alkalinity as CaCO3</td>
<td>40-120</td>
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<tr>
<td>Final Sulfate (ppm)</td>
<td>180</td>
</tr>
<tr>
<td>Suggested Sulfate (ppm)</td>
<td>100-400</td>
</tr>
<tr>
<td>Final Chloride (ppm)</td>
<td>86</td>
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<tr>
<td>Suggested Chloride (ppm)</td>
<td>0-100</td>
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<tr>
<td>Final Sodium (ppm)</td>
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<tr>
<td>Suggested Sodium (ppm)</td>
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<tr>
<td>Final Residual Alkalinity</td>
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<tr>
<td>Suggested Residual Alkalinity</td>
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<tr>
<td>Final Sulfate to Chloride Ratio</td>
<td>2.1</td>
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<tr>
<td>Final Est. SRM Low</td>
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</tr>
<tr>
<td>Suggested Est. SRM Low</td>
<td>5</td>
</tr>
<tr>
<td>Final Est. SRM High</td>
<td>5</td>
</tr>
</tbody>
</table>
How Water Affects Beer Flavor


- **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…
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!
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 5:1 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)**
- **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.
  
  \[
  RA = \text{Total Alkalinity} - \left(\text{Ca} + \frac{1}{2} \text{ Mg}\right)/3.5
  \]
  
  *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....
  
  \[
  10\text{Ca}^{+2} + 12\text{HCO}_3^{-1} + 6\text{H}_2\text{PO}_4^{-1} + 2\text{H}_2\text{O} \rightarrow \]
  
  \[
  \text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2 + 12\text{CO}_2 + 12\text{H}_2\text{O} + 2\text{H}^{+1}
  \]

- Magnesium also reacts, but about half as much.
RA has Increasing Effects

Mash pH as f(RA) and R (L/kg)
Pilsner and 2Row Base Malt

$y = 2E-06a^2 + 0.0007x + 5.6282$
$R^2 = 0.99459$

$y = 3E-06a^2 + 0.0011x + 5.7555$
$R^2 = 0.99642$

$y = 5E-06a^2 + 0.0009x + 5.8472$
$R^2 = 1$

$y = 5E-06a^2 + 0.0009x + 5.9251$
$R^2 = 0.99661$

$y = 3E-06a^2 + 0.0009x + 6.0431$
$R^2 = 0.9886$

$R = 8$
$R = 6$
$R = 4$
$R = 2$
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

- In general, distilled water mash pH for a specialty malt is proportional to malt color.
  - Darker = lower pH

- Roasting causes pyrolyzation and breakdown of buffers and acids.

- Therefore, dark Caramel malts often have higher buffering power than Roast malts.

- Dark Roast malts often have higher initial acidity, but less buffering power than dark caramel.

Kilned vs. Roasted Acidity

- Kilned malts seem to follow a linear trend.
- Roasted malts appear to be clumped.

From K. Troester, www.braukaiser.com
Kilned vs. Roasted Acidity

- Basically, malt acidity peaks as a function of malt color.
- The highest colored Kilned malts are the most acidic.
- Roasted malt acidity tends to decrease with increasing color (roasting time).

Mash pH: Balancing a Triangle

Base Malt Alkalinity \times \text{Weight} \quad +

\text{Specialty Malt Acidity} \times \text{Weight} \quad +

\text{Water Residual Alkalinity} \times \text{Volume} \quad =

\text{Mash pH}
What Is the Optimum pH?

- It Depends:
  - There are many enzymatic processes occurring in the mash, each with its 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 generally based on optimum yield.
- However, published opinions differ on what the optimum range is…
pH for Best Yield, by Author

- Briggs et al.: 5.2-5.4 (5.45-5.65 at 20°C)
- Bamforth et al.: 5.3-5.8 (5.55-6.05 at 20°C)
- Kunze: (5.25-5.35) 5.5-5.6 at 20°C

Best Yield is therefore 5.4-5.6

Anecdotally, many brewers report better beer flavor with lower mash pH, 5.2-5.6 at 20°C.

Parentheses indicate pH/temperature conversion.
Testing pH

- A good $100 pH meter will give an accurate reading in about 15 seconds.

- Brewers want to differentiate between 0.1 pH units, therefore you need a meter with a resolution of 0.01.

- Every pH electrode typically has a useful life of 1-3 years if well maintained. After that, they tend to drift and are hard to calibrate.

LaMotte Order Code
No. 1741
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.
**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)
Measuring pH

Therefore, the pH measurement temperature must always be stated, and preferably, the measurement should be conducted at room temperature for best accuracy and easy comparison.
Mash pH Sets Up Beer pH

5.2-5.6

~4.0-4.6

Style/recipe dependent
Adjusting **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.
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
### Suggested Salt Additions to RO Water (grams per gallon)

<table>
<thead>
<tr>
<th>Beer</th>
<th>CaSO₄</th>
<th>CaCl₂</th>
<th>Baking Soda</th>
<th>Ca</th>
<th>Na</th>
<th>SO₄</th>
<th>Cl</th>
<th>HCO₃</th>
<th>RA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pale Hoppy</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>98</td>
<td>0</td>
<td>147</td>
<td>64</td>
<td>0</td>
<td>-70</td>
</tr>
<tr>
<td>Pale Balanced</td>
<td>0.75</td>
<td>0.75</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>111</td>
<td>96</td>
<td>0</td>
<td>-72</td>
</tr>
<tr>
<td>Pale Malty</td>
<td>0.5</td>
<td>1</td>
<td>0</td>
<td>103</td>
<td>0</td>
<td>74</td>
<td>127</td>
<td>0</td>
<td>-73</td>
</tr>
<tr>
<td>Amber Hoppy</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>98</td>
<td>36</td>
<td>147</td>
<td>64</td>
<td>95</td>
<td>+8</td>
</tr>
<tr>
<td>Amber Balanced</td>
<td>0.75</td>
<td>0.75</td>
<td>0.5</td>
<td>100</td>
<td>36</td>
<td>111</td>
<td>96</td>
<td>95</td>
<td>+6</td>
</tr>
<tr>
<td>Amber Malty</td>
<td>0.5</td>
<td>1</td>
<td>0.5</td>
<td>103</td>
<td>36</td>
<td>74</td>
<td>127</td>
<td>95</td>
<td>+4</td>
</tr>
<tr>
<td>Dark Hoppy</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
<td>98</td>
<td>72</td>
<td>147</td>
<td>64</td>
<td>190</td>
<td>+86</td>
</tr>
<tr>
<td>Dark Balanced</td>
<td>0.75</td>
<td>0.75</td>
<td>1</td>
<td>100</td>
<td>72</td>
<td>111</td>
<td>96</td>
<td>190</td>
<td>+84</td>
</tr>
<tr>
<td>Dark Malty</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
<td>103</td>
<td>72</td>
<td>74</td>
<td>127</td>
<td>190</td>
<td>+82</td>
</tr>
</tbody>
</table>
## Mini-mash pH Results

<table>
<thead>
<tr>
<th></th>
<th>Pale Hoppy</th>
<th>Pale Malty</th>
<th>Amber Malty</th>
<th>Dark Malty</th>
<th>Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pale</td>
<td>RA = -70</td>
<td>RA = -70</td>
<td>RA = +5</td>
<td>RA = +80</td>
<td>0.6</td>
</tr>
<tr>
<td>Pale</td>
<td>5.7</td>
<td>5.6</td>
<td>5.8</td>
<td>6.3</td>
<td></td>
</tr>
<tr>
<td>Amber</td>
<td>5.6</td>
<td>--</td>
<td>--</td>
<td>6.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Dark</td>
<td>5.3</td>
<td>5.3</td>
<td>5.6</td>
<td>5.9</td>
<td>0.6</td>
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<tr>
<td>delta</td>
<td>0.4</td>
<td>0.3</td>
<td>0.3</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>

### 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?

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?
How Do I Adjust Water for Beer Style?

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:
  • Start by adding 1 gram/gallon of calcium sulfate

<table>
<thead>
<tr>
<th>Ca^{+2}</th>
<th>Mg^{+2}</th>
<th>Alk.</th>
<th>SO_4^{-2}</th>
<th>Cl^{-1}</th>
<th>Na^{+1}</th>
<th>Res. Alk.</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>10</td>
<td>120</td>
<td>40</td>
<td>35</td>
<td>32</td>
<td>86</td>
</tr>
</tbody>
</table>

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<tr>
<td>102</td>
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<td>42</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Ca$^{+2}$</th>
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<td>187</td>
<td>35</td>
<td>32</td>
<td>42</td>
</tr>
</tbody>
</table>

2. Adjust RA based on beer color/gravity:
   a) Does RA need to decrease (pale)? => Neutralize with acid.
      - For Pale, Hoppy, Medium:
        - Add 0.75 ml per gallon of 88% Lactic Acid

<table>
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</thead>
<tbody>
<tr>
<td>102</td>
<td>10</td>
<td>3</td>
<td>187</td>
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<td>32</td>
<td>-75</td>
</tr>
</tbody>
</table>

- **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/MT to achieve mash pH target.
  - Second priority is achieving Flavor Balance and Structure.
  - Add additional salts or acid as necessary to kettle for flavor.
Neutralizing Alkalinity to brew Pale beers

- Acidification to reduce Total Alkalinity is easy.
  - Divide Total Alkalinity by 50 to get mEq/liter.
  - Ex. TA = 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 CaCO3 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.

- Do not acidify water based on its pH, acidify based on its alkalinity.

- 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.
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?