Water Chemistry in Brewing

D Schultz – 2005 BJCP Class

Of the four primary ingredients in beer (malt, hops, yeast & water), water usually gets the least attention by the beginning brewer. In its pure form it does not impart any flavor to the beer yet lack of attention to its minor constituents can lead to problematic brewing and less than stellar beer.

Historically, regions with extreme water profiles had to adjust the styles of beers they brewed to the chemistry of the local water. This was before water chemistry was well understood and before water treatment methods were economical. They brewed Stouts in Dublin, malt forward beers in Germany and bitter/hoppy beers in Burton on Trent.

Brewing Related Components in Water

Calcium (Ca^{+2}) – The principal ion that determines water hardness. Calcium plays a part in determining the pH of the water, mash, wort and beer. It promotes clarity, flavor and stability in the finished beer as it is instrumental to many yeast, enzyme and protein reactions in the mash and in the boil. A minimum level of 50 ppm is required to assure sufficient enzyme activity. Brewing range: 50-150 ppm.

Magnesium (Mg^{+2}) – The other primary ion that determines water hardness. It behaves similarly to calcium but is less effective. It is an important yeast nutrient in small amounts (10 to 20 ppm), but amounts greater than 50 ppm tend to give a sour-bitter taste to the beer. Levels higher than 125 ppm have a laxative and diuretic affect. Brewing range: 10-30 ppm.

Sodium (Na^{+2}) – The cation (positively charge ion) half of the salt molecule. At levels of 70 - 150 ppm it rounds out the beer flavors, accentuating the sweetness of the malt. But above 200 ppm the beer will start to taste salty. The combination of sodium with a high concentration of sulfate ions will generate a very harsh bitterness. Therefore, keep at least one or the other as low as possible, preferably the sodium. Water softeners substitute sodium (soft) for calcium (hard). You're better off with the calcium. Brewing Range: 0-150 ppm.

Bicarbonate (HCO_3^{-1}) and **Carbonate** (CO_3^{-2}) – This family of anions (negatively charged ions) exist in equilibrium with each other where the ratio of the two is pH driven. Carbonate increases the pH and neutralizes the acidity of dark malts. Dublin's high levels (>300ppm) of carbonate lends itself to brewing Stouts. Brewing Range: 0-50 ppm for pale, base-malt only beers. 50-150 ppm for amber colored, toasted malt beers, 150-250 ppm for dark, roasted malt beers.

Calcium that is matched by bicarbonates in water is referred to as "temporary hardness". Temporary hardness can be removed by boiling the water while aerating where it forms calcium carbonate ($CaCO_3$) and precipitates as a solid. For home brewers, dilution is the best method. Calcium that is left behind after the temporary hardness has been removed is called "permanent hardness".

Sulfate (SO_4^{-2}) – Combines with calcium and magnesium to contribute to permanent hardness. It accentuates hop bitterness, making the bitterness seem drier and crisper. At concentrations over 400 ppm however, the resulting bitterness can become astringent and unpleasant, and at concentrations over 750 ppm, it can cause diarrhea. Sulfate is only weakly alkaline and does not contribute to the overall alkalinity of water. Brewing Range = 50-150 ppm for normally bitter beers, 150-350 ppm for very bitter beers.

Chloride (Cl^{-1}) – The anion half of the salt molecule does not contribute much to alkalinity. The chloride ion accentuates the flavor and fullness of beer. Concentrations above 300 ppm (from heavily chlorinated water or residual bleach sanitizer) can lead to mediciney flavors due to chlorophenol compounds. Brewing Range = 0-250 ppm.

Iron (Fe^{+3}) – Not an important ion for brewing but it can lead to a metallic or bloodlike off flavor.

Properties of Water

pH – A scientific measure of the water's acidity. A pH below 7.0 indicates acidic water. A pH above 7.0 indicates alkaline, or basic, water. Water with a pH of 7.0 is considered neutral (neither acidic nor alkaline). The pH of the water in brewing is not important. The pH of the mash is important and the ionic make up of the water will play a significant role in determining the pH of the mash. pH is also important in most of the reactions that take place in brewing.

The pH of the mash should be between 5.2 and 5.6 for optimum enzyme activity. Pale malts and relatively soft water will reach this pH naturally. Water that is high in carbonates (alkaline) will drive the pH above the appropriate levels. Addition of calcium or dark malts will drive the pH back down (overly acidic water is very rare). Dark malts drive the pH down. The addition of carbonates will balance the pH into the proper range.

Hardness – A measure of the calcium and magnesium content of the water. See Carbonates above for an explanation of temporary versus permanent hardness.

Water Treatment

Mineral salts can be added to water to drive specific ion concentrations or to balance the pH of the water.

Calcium Carbonate ($CaCO_3$) a.k.a. Chalk – Raises pH. Because of its limited solubility it is only effective when added directly to the mash. Use for making dark beers in areas of soft water.

Calcium Sulfate ($CaSO_4$) a.k.a. Gypsum – Lowers pH. $CaSO_4$ is useful for adding calcium if the water is low in sulfate. It can be used to add sulfate "crispness" to the hop bitterness.

Calcium Chloride ($CaCl_2$) – Lowers pH and is useful for adding Calcium if the water is low in chlorides.

Magnesium Sulfate ($MgSO_4*7H_2O$) a.k.a. Epsom Salt - Lowers pH by a small amount. It can be used to add sulfate "crispness" to the hop bitterness.

Sodium Bicarbonate ($NaHCO_3$) a.k.a. Baking Soda - Raises pH by adding alkalinity. If your pH is too low and/or has low residual alkalinity, then you can add alkalinity. See procedure for calcium carbonate.

Water in Brewing Reactions

Extract Brewing

Water chemistry has only a minor role in extract brewing as the mash was by the extract manufacturer. If dark malts are to be added, adjustment with carbonates is recommend in the boil to bring it to a pH of 5.2 to 5.6. Other mineral salt additions can be used to contribute flavor enhancements.

Mash

Glucanase – Chain shortens beta-glucans in the mash between 95 and 104°F and across a broad range of 4 to 6 pH.

Proteinase – Chain shortens proteins in the mash between 104 and 140°F and a pH of 4.2 to 5.3.

Amalayse (alpha & beta) – Chain shortens starches into a variety of sugars in the mash between 126 and 144°F and 5.1 to 5.3 pH for beta-amalayse and 149 to 153°F and 5.3 to 5.7 pH for alpha-amalayse.

Phytase – Reacts with phytin in the mash to form phosphates. These organic phosphates react with the calcium and magnesium to lower the pH of the mash.

Lautering – As the wort is rinsed from the grist and replacement water is added, the pH of the mash will rise. At a mash pH above 5.8, tannins will be released and result in astringency. This conveniently occurs when the runoff hits a specific gravity of approximately 1.010. pH adjustment of the sparge water prevents the pH from rising and prevents tannins in he wort.

Boil – The pH of the wort should fall into the range of 5.2 to 5.6 at the beginning of the boil and will drop to between 5.1 and 5.4. The pH is setup during the mash. It is not adjusted in the boil.

Beer – The final pH of the beer acts to prevent spoilage by inhibiting the growth of unwanted organisms. Low pH can indicate contamination by Lactobacillus or Pediococcus.

Water Profiles From Notable Brewing Cities

City	Calcium (Ca^{+2})	Magnesium (Mg^{+2})	Bicarbonate (HCO_3^{-1})	SO_4^{-2}	Na^{+1}	Cl^{-1}	Beer Style
Pilsen	10	3	3	4	3	4	Pilsener
Dortmund	225	40	220	120	60	60	Export Lager
Vienna	163	68	243	216	8	39	Vienna Lager
Munich	109	21	171	79	2	36	Oktoberfest
London	52	32	104	32	86	34	British Bitter
Edinburgh	100	18	160	105	20	45	Scottish Ale
Burton	352	24	320	820	44	16	India Pale Ale
Dublin	118	4	319	54	12	19	Dry Stout

References:

How to Brew by John Palmer. www.howtobrew.com

Bull Run Water (April, 2004)

pH: 7.5 to 8.0

Cl^-: 1.4 to 2 ppm

Water Hardness as CaCO3: 2.9 to 11 ppm

$SO4^{-2}$: Less than 0.5 ppm

Alkalinity as $CaCO_3$: 6.1 to 15

Bicarbonate (as $CaCO_3$): 7 to 12 ppm

Calcium: 0.7 to 2.9

Magnesium: 0.28 to 0.91

Sodium: 4.4 to 12