• IV. INGREDIENTS AND THE BREWING PROCESS

Water, ***by Ginger Wotring***

Water constitutes 85-90% of beer, with the remainder being compounds derived from malt, hops and yeast. As a general rule, if it is drinkable, it may be used in brewing, although some adjustments may be needed to mimic the water used in some historical beer styles. Most tap water is also treated with chlorine to inhibit bacterial growth, and this should be removed to produce high-quality beer. Chlorine gas may be eliminated by boiling, but charcoal filtration must be used to eliminate the more commonly used chloroamines. Reverse osmosis is not recommended since it also strips out minerals needed by the yeast. Most water generally also has very low concentrations of nitrogen-containing ions, iron, manganese, copper and zinc; trace amounts of these last four minerals are essential to a healthy fermentation. Finally, most water contains very low concentrations of bacteria, so it must be sterilized by boiling at some point in the brewing process.

Alkalinity, pH and Hardness

Water is a solution of ions with negative (anions) and positive (cations) charges. The water molecules (H_2O) themselves are also partially dissociated into hydroxide (OH^-) and hydrogen (H^+) ions, and the pH (a chemical shorthand term referring to the concentration of hydrogen ions) indicates the relative concentrations of these ions. Neutral water has equal OH^- and H^+ concentrations corresponding to a pH of exactly 7. Lower pH values indicate a higher H^+ concentration and a higher acidity, while higher pH values correspond to a higher OH^- concentration and a higher alkalinity. In brewing, the pH is determined by the hardness, alkalinity and buffering salts derived from the ingredients.

Alkalinity is a measure of the capacity of the dissolved anions to neutralize reductions in the pH value of the solution. The most important anion at the pH of brewing water and wort is carbonate (HCO_2^-), which reacts with Calcium (Ca^{+2}) ions when heated to form a calcium carbonate precipitate and water:

$$Ca^{+2} + 2HCO_2^- = Ca_2CO_3 \text{ (ppt)} + H_2O + CO_2 \text{ (gas)}$$

This removes Calcium ions from the water, reducing the temporary hardness. Permanent hardness is a measure of the cations that remain after boiling and racking the water from the precipitate, and is primarily due to Ca^{+2} and Magnesium (Mg^{+2}) ions. These cations are permanent of they are derived from sulfate or chloride salts and temporary if they originate in carbonate or bicarbonate salts.

An important process in brewing that helps adjust the pH of the mash is the enzymatic degradation of phytin in the malt to form phytic acid and calcium or magnesium phosphates, which precipitate. Most of the phytic acid combines with free Ca^{+2} to form more calcium phosphate, releasing hydrogen ions in the process. This reaction generally takes place during the acid rest and regulates the mash pH to the 5.2-5.7 range, which is appropriate for the breakdown of starches and proteins. Some water supplies are too alkaline for this process to be effective, in which case the pH must be reduced to the proper level by adding lactic or sulfuric acid.

Ions in Brewing

The most important cation in brewing is Calcium, which is essential for reducing the mash pH to the appropriate range, keeps oxalate salts in solution (they form haze and gushing if they precipitate), reduces the extraction of tannins, and assists in protein coagulation in the hot and cold breaks. Magnesium ions participate in the same reactions, but are not as effective. Yeasts require 10-20 ppm as a nutrient, but higher amounts give a harsh, mineral-like taste. Another cation is Sodium, which accents the sweetness at low levels, but tastes salty at higher concentrations.

The most important anion in brewing is bicarbonate, which neutralizes acids from dark and roasted malts, reacts with Calcium to reduce the hardness and promotes the extraction of tannins and coloring compounds. It is normally in solution with the carbonate (CO_3^{-2}) ion, but the bicarbonate is by far the most important component at typical pH values of water and wort. The sulfate (SO_4^{-2}) ion does not play a significant role in the brewing process, but accents hop bitterness and dryness at the high concentrations found in the waters at Burton-on-Trent. Another anion is chloride (Cl^-), which enhances sweetness at low concentrations, but high levels can hamper yeast flocculation.

Famous Brewing Waters

The ions described above are found in different concentrations depending on the source of the water, as shown in the table below for several major brewing centers (data from Greg Noonan's water workshop at the 1991 AHA Conference and are in ppm):

Mineral	Calcium	Magnesium	Sodium	Sulfate	Bicarbonate	Chlorine
Plzen	7	2	2	5	15	5
Dortmund	225	40	60	120	180	60
Munich	75	18	2	10	150	2
Vienna	200	60	8	125	120	12
Burton	275	40	25	450	260	35
Dublin	120	5	12	55	125	20
Edinburgh	120	25	55	140	225	65
London	90	5	15	40	125	20

These water compositions have played an important role in the development of world beer styles. In London, Dublin and Munich, the high bicarbonate content is needed to balance the acidifying properties of the dark and roasted malts used in porters, stouts and bocks. When brewing pale beers with this type of water, the alkalinity generally needs to be reduced through an acid rest, the use of acid malt or directly adding lactic or sulfuric acid to the brewing liquor. The water at Burton is extremely hard, and the high concentrations of sulfate and magnesium ions lend a dryness that accents the hoppiness of English bitters and pale ales from this region. On the other end of the spectrum is Pilsen, which has very low concentrations of dissolved ions (which is not the same as being very soft). The adoption of decoction mashing may have been in part due to the lack of minerals in the water, along with the use of undermodified malts. The elaborate series of temperature steps in a decoction mash helps the various enzymatic reactions proceed at a reasonable rate, even though the enzymes are working slowly due to the lack of calcium.

Water Adjustment

The waters at these brewing centers may be reproduced by adding various salts to locally available water. For additions meant to improve the buffering capacity of the mash, use the volume of your mash for your calculations. For salt additions to change flavor in the finished beer, the target volume of the finished beer should be used. The most common salt additions are gypsum ($CaSO_4.2H_2O$ = $CaSO_4$ hydrated with two water molecules), Epsom salts ($MgSO_4.7H_2O$), non-iodized table salt (NaCl), calcium carbonate ($CaCO_3$) and calcium chloride ($CaCl_2$). The addition of gypsum and Epsom salts is known as Burtonizing, since it elevates the hardness and sulfate concentrations to levels similar to that found at Burton-on-Trent. Other salts may be used, but these are by far the most common additives in brewing.

Further Reading

- Dave Miller, Dave Miller's Homebrewing Guide (Garden Way Publishing, Pownal, VT 1996).
- Gregory J. Noonan, New Brewing Lager Beer (Brewers Publications, Boulder, CO, 1996).
- George Fix, Principles of Brewing Science (Brewers Publications, Boulder, CO, 1989).