Water Chemistry and Beer Flavor

Andy Hejl

Water and Ions

- Water is a critical component of beer and life
  - ~85 – 90% of beer is water
  - Ions are charged atoms or groups of atoms
  - Most salts consist of pairs of ions in water
    - Cations – positively charged ions
    - Anions – negatively charged ions
  - NaCl (table salt), dissolves to give Na^+, Cl^-

- Ions in brewing frequently measured in ppm, (mg/L)

Mineral Content Effect on Beer

- Pure water (Distilled or RO) is poor for brewing
- Dissolved ions play several key roles in brewing
  - Allow for proper enzyme function in mash
  - Vital for yeast activity
    - Many trace metals play a role
  - Ions in finished beer affect flavor

pH

- Water spontaneously breaks into small numbers of ions

$$H2O \rightarrow H^+ + OH^-$$

- pH is a measure of the amount of H^+ in solution

pH Value	Characteristic
<7	Acidic, more H^+
7	Neutral, even
>7	Alkaline, more OH^-

- pH important at several steps in brewing process
  - Mash pH for enzyme activity
  - Final pH of beer

Alkalinity

- Measure of the capacity of solution to neutralize acid
- Mainly due to the presence of bicarbonate (HCO_3^-)

$$HCO_3^- + H^+ \rightarrow H_2O + CO_2$$

- Higher alkalinity resists change in pH – “buffer”
- >100 ppm HCO_3^- is considered alkaline

- Alkalinity is more important than the absolute pH
- High alkalinity makes it more difficult to achieve proper mash pH (5.2-5.7)

Hardness

- Hardness is a measure of the amount of Ca^{2+} and Mg^{2+}

- Alkalinity can be removed by boiling

$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + H_2O + CO_2$$

- CO_2 is driven out of solution by boiling
- Boiled water racked off of precipitated $CaCO_3$
- Reduces the mineral content of Ca^{2+}
  - Reduction of Ca^{2+} is *temporary hardness*
  - Remaining Ca^{2+} and Mg^{2+} *permanent hardness*

- Easiest to think of all ions in terms of absolute amounts!

Reduction of Alkalinity

- Boiling to remove CO_2, precipitate $CaCO_3$
- Dilute with distilled water
- Addition of acid to the water
  - Hydrochloric acid, HCl
  - Phosphoric acid, H_3PO_4
  - Lactic acid

Municipal Water Treatment

- Water in the US is disinfected with chlorine source
  - Cl_2, free chlorine
  - Chloramine, NH_2Cl
- Chlorine sources in brewing react to form chlorophenols
  - A medicinal (“band-aid”) off flavor
  - Can also form with residual bleach
- Removal of chlorine sources
  - Boiling – can remove Cl_2
  - Carbon Filtration – Removes Cl_2 and Chloramine
  - Campden tablet (Potassium metabisulfite)

Water Report - Example

pH	8.0
Total Dissolved Solids (TDS) Est	416
Electrical Conductivity, mmho/cm	0.69
Cations / Anions, me/L	7.2 / 7.2

	ppm
Sodium, Na	24
Potassium, K	1
Calcium, Ca	66
Magnesium, Mg	34
Total Hardness, $CaCO_3$	307
Nitrate, NO_3-N	0.9 (SAFE)
Sulfate, SO_4-S	12
Chloride, Cl	82
Carbonate, CO_3	6
Bicarbonate, HCO_3	234
Total Alkalinity, $CaCO_3$	201

Ions in Brewing – Calcium, Ca^{2+}

- Calcium is the most important ion in brewing
  - Reduces mash pH
    - Reacts with phosphates in the malt
  - Improves hot and cold break
  - Improves mash enzyme activity, stability
  - Gelatinizes starches, helps lautering
  - Provides nutrients for the yeast
  - Improves clarity in the finished beer
- Typical levels: 5-200 ppm (50-100 best)

Ions in Brewing – Magnesium, Mg^{2+}

- Magnesium is closely related to calcium
- Second ion of permanent hardness

- Not as effective as calcium in reducing mash pH
- Important yeast nutrient
- Typical levels: 2-50 ppm (10-30 best)
- High levels have negative consequences
  - >50 ppm gives astringent bitterness
  - >125 ppm acts as a diuretic

Ions in Brewing – Sodium, Na^+

- Low levels can accentuate sweetness
  - Add a “roundness” or “fullness” to palate
- Typical levels: 2-100 ppm (<50 ppm best)
- Elevated levels affect fermentation and taste
  - High levels can be sour or salty
  - High levels also inhibit yeast performance

Ions in Brewing – Iron, $Fe^{2+/3+}$

- Iron is not a desirable ion in brewing beyond trace levels
- Not often a problem in city water
- More frequently found in well water
- At low levels can affect the flavor of beer (0.05 ppm)
  - Metallic, blood-like flavor

Ions in Brewing – Trace Metals

- These ions are all important at very low levels
  - Not something you need to add to beer
- Copper, Cu^{2+}
  - High levels can contribute to haze
- Manganese, Mn^{2+}
  - Similar to iron in unpleasant taste
- Zinc, Zn^{2+}
  - Critical for yeast performance
  - Advisable range 0.1-0.2 ppm

Ions in Brewing – Bicarbonate, HCO_3^-

- Primary contributor to alkalinity
- Directly related to carbonate (CO_3^{2-})
- Many negative effects on beer
  - Reduce the lowering of mash pH
  - Inhibits cold break
  - Hurts starch gelatinization (accessibility)
  - Impedes yeast activity in fermentation
- Contributes harsh, bitter flavors in subtle pale beers
- Difficult to work with unless using dark malts

Ions in Brewing – Sulfate, SO_4^{2-}

- A very weakly basic anion, not alkaline
- Gives beer a dryer, fuller flavor
- Has a major effect on perception of bitterness
  - Can make the beer too dry, sharp
  - With more hopped beers, can give a clean bitterness
- In excessively high levels is stongly bitter, harsh

Ions in Brewing – Chloride, Cl^-

- Another very weakly basic anion, not alkaline
- Increases stability, clarity of beer
- Enhances beer flavor and palate fullness
- Ratio of chloride to sulfate is an important consideration
  - Can change perception of bitterness
- High levels give a salty character

Common Minerals to Adjust Water

- Gypsum
  - Calcium Sulfate, $CaSO_4 \cdot 2H_2O$
- Calcium Chloride
  - $CaCl_2 \cdot 2H_2O$
- Calcium Carbonate
  - Chalk, $CaCO_3$
- Table Salt
  - Sodium Chloride, NaCl
- Epsom Salts
  - Magnesium Sulfate, $MgSO_4 \cdot 7H_2O$

Water Adjustment in Extract Beer

- Water adjustment in extract beer is not often necessary
  - Mash is already completed
- Can be used to adjust flavor of final beer
- Difficult to know what original water profile was
  - Extract was already mashed and ions concentrated
- Can use pure water to dilute extract

- Significant salt additions can add too many ions to beer

Famous Brewing Waters

City	Calcium	Magnesium	Sodium	Sulfate	Bicarbonate	Chloride
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

Brewing Water and Style Development

- Many beer styles originated because of water
- High carbonate water, low sulfate
  - London, Dublin, Munich
  - Dark grains help to reduce mash pH
- Very hard water
  - Dortmund, Burton-on-Trent
  - High sulfate accentuates dryness, smooths bitterness
- Low mineral content
  - Plzen
  - High hopping without a harsh bitterness
- These water levels may not be what they use today!

Brewing Cities Associations

A list of styles commonly associated with particular cities

City	Style	City	Style
Düsseldorf	Düsseldorf Altbier	Burton-on-Trent	English Pale Ale
Berlin	Berliner Weisse	Newcastle	No. English Brown Ale
Einbeck	Traditional Bock	Senne Valley	Lambic
Köln (Cologne)	Kölsch	Dublin	Dry Stout
Edinburgh	Scottish 60/-	San Francisco	California Common
Bamberg	Classic Rauchbier	Vienna	Vienna Lager