Water Treatment
by Paul Henderson and Geoff Cooper

Water treatment for is a complicated and tricky subject to get a handle on. People commonly ask the same questions when trying to understand the subject so we have addressed the subject using a Q&A format.

Q. Is this a one stop information point for water treatment?

A. We are covering the key topics and commonly asked questions to provide a good foundation for understanding pH adjustments, but won't go into detail about salt additions and ratios. There is plenty of good information out there on this. First we cover "what" and then we reveal "how".

Q. What kind of treatments are we talking about?

A. Water should be clean and free from contaminants like sediment and bacteria. It should have a clean and pleasant taste and no aroma. Some contaminants can be removed by filtering or chemical reactions (eg. campden tablets). Water pH or more importantly mash pH and sparge water pH can be adjusted to more suitable levels. Also water can be built up by adding salts to create suitable mouth feel and flavour profiles in the finished beer.

Q. I hear talk about different traditional water profiles from traditional brewing cities. Does this mean I'm limited in the beer styles I can make because of my water?

A. Ummm, Yes and No.
Traditional water profiles were important and did influence the style of beer that could be made.
For example: London=Porter, Dublin=Dry Stout (Guinness), Plzen=Bohemian Pilsner, Munich=Malty lager, Vienna=Amber lager.

However you have to remember that these traditional water sources were mostly from well water so likely had a higher concentration of minerals and don't represent modern city water supplies which are sourced from rivers and lakes. So if you want to mimic a traditional beer style it is useful to know what water chemistry they started out with as this influenced their use of malts and process. Traditional water supplies also gave specific character to some beers like Burton Ales which have a distinctive sulphurous nose. Typically you can build up a water profile but it is very difficult to take away from the water to create the soft water required for a style like Bohemian Pilsner.
The point is many modern breweries change the water to suit the style they are creating.

Q. Why might I treat my water?

A. You might not need to. Ordinary tap water will produce some very good beers and, indeed, could be a good choice for some beers styles. For example, London tap water can be suitable for making dark beers. Also, if you are using malt extract (liquid or dry) levels of alkalinity and calcium are minor considerations when not mashing. However, your reasons for treating your water might be:

1. To remove undesirable compounds (eg. Chlorine or chloramine)
2. To adjust its alkalinity level to hit the right mash pH
3. To add desirable compounds (eg. Calcium)
4. To add salts to influence the flavour profile and mouthfeel

Q. Are there any standard treatments that I should be using?

A. There is debate about if this is really necessary but campden tablets or filtering through a carbon filter can be used to remove Chlorine (unstable gas) and Chloramine (a stable form of Chlorine that evaporates very slowly). You want to remove these to avoid TCP/band-aid characteristics in the finished beer. If you aren't worried about pH and alkalinity levels and salt additions then you should at least start with clean water. A carbon filter will also remove other undesirable compounds, such as iron and other heavy metals, but these should not be an issue with domestic tap water.

Use of one campden tablet in 10 imperial gallons (around 50 litres) is more than adequate – any residual sulphite will act as a harmless bacteriostat and anti-oxidant.

Q. What is the difference between hardness and temporary hardness?

A. Hardness is a measure of certain minerals bound in the water, primarily calcium and magnesium. It is normally measured in mg/litre as Calcium Carbonate ($CaCO_3$). This can also be expressed as parts per million (ppm) which is the same as mg/litre.

It might be possible to remove some of the hardness from the total hardness of the water by simply boiling the water. This is known as Temporary Hardness. Temporary hardness is when calcium is present at the same time as the bicarbonate ion (HCO_3^-), in which case calcium can be precipitated as the insoluble carbonate salt (chalk, $CaCO_3$) simply by boiling the water. This is typical of London tap water.

It should be noted that, as the bicarbonate providing the carbonate for the precipitation is the principal component in the alkalinity of the water, this process also reduces the water's alkalinity. The reason we boil is to reduce the alkalinity, not the hardness, as these minerals (especially calcium) are beneficial in brewing and hardness has little effect in the flavour of most beer styles. However, alkalinity reacts with acid compounds and limits the shift in pH. This correlation between temporary hardness and alkalinity can lead to some regarding them as synonymous, which often leads to confusion.

When the calcium and magnesium are present (or added) as the sulphate or chloride salts, the hardness is permanent.

Q. How does pH relate to alkalinity?

A. (source BeerSmith)

- Pure water has a pH of 7.0, which means that it is neither acidic nor alkaline. If you are into chemistry, this means that the free H^+ (hydronium) ions are balanced with the OH^- (hydroxide) ions giving equal concentrations capable of forming H_2O. If water has an excess of H^+ ions, we call it acidic (lower pH), while an excess of OH^- ions gives us alkaline (higher pH) water.
- Now it we take our pure water in the form of rain and run it down through the atmosphere and soil it picks up CO_2 and Calcium from the soil, these elements will bind with the H^+ ions leaving a bunch of free OH^- (hydroxide) ions making our water more alkaline. This increases the pH of the water. Most tap water is slightly alkaline for this reason. Really hard water can be highly alkaline.
- Interestingly all malts (and dark malts in particular) have phosphates in them that react with the calcium and magnesium ions in alkaline water freeing up H^+ ions that make the mixture acidic. Adding malt, especially dark malt, lowers the pH of the malt water mixture in the mash.

The resistance to pH change as measured by the amount of acid added to change the pH is called buffering and is associated with alkalinity. The chemical bonds which hold alkalinity ions are easily broken by adding acid so these ions reform into different associations and need to be exhausted before a change in pH can be measured.

Q. Where does the alkalinity go when I add acid?

A. You are creating chemical reactions. Boiling and adding acid can react to create carbon dioxide gas from the calcium carbonate ($CaCO_3$). Sulphuric acid will also create calcium sulphate and magnesium sulphate so is better for hoppier beers but check the sulphate levels of your water before you start because if you have high sulphate levels already a different acid which doesn't create sulphates may be better. Hydrochloric acid will create calcium chloride from the calcium carbonate so is better for darker/maltier beers. Lactic acid creates calcium and magnesium lactates. Note that if you reduce the alkalinity by boiling your water you will lose calcium and that should be replaced to aid kettle and fermentation flocculation and yeast health.

Q. Which steps during the brewing process is pH important?

A. There are many points where pH is important but you may not be aware unless something goes wrong which highlights a problem in your process. (see also table 1 below)

1. Mash - Getting the mash into the correct range 5.1-5.3 increases mash efficiency, but temperature is more important. In all cases pH needs to be less than pH 6 to avoid tannin extraction.
2. Sparge water - Too alkaline and proteins may coagulate affecting the sparge flow and you risk extracting tannins, lipids and silicates from the grain husk which will present as harshness in finished beer. The pH of the mash must not be allowed to rise above pH 6.0 during the sparge to avoid extracting these compounds.
3. Boil - Correct acidification optimises protein flocculation which occurs best at pH 5.5 but a kettle pH 5.2-5.5 is better for other kettle and fermentation process. Below pH 5.0 protein does not coagulate. Acidification occurs during the boil as calcium phosphate is precipitated and a reduction of 0.2-0.3 from a starting pH of 5.5-5.8 can be expected. At the end of the boil pH should be pH 5.0-5.5 for infusion mashed ale wort and lager wort would be pH 5.0-5.2, but cooled lager wort of 5.3-5.5 is still normal.
4. Fermentation - Fermentation is more successful when it starts at the correct pH and then drops to around pH 4.0 which retards bacterial growth.

In general, if you get 1 and 2 about right by suitable alkalinity and calcium adjustments, then 3 and 4 will look after themselves.

Table 1 - Average pH readings in the brewing schedule - Page 66 of A guide to craft brewing by John Alexander

Untreated domestic supply	pH 6.0-8.0
After liquor treatment	pH 6.0-8.0
Initial mash acidity	pH 5.2-5.5
First sweet worts	pH 4.8-5.2
Second sweet worts	pH 5.4-5.6
Initial copper wort	pH 5.1-5.4
Post coppering	pH 4.9-5.3
Beer, post fermentation	pH 3.7-4.2

Q. What methods are there for adjusting alkalinity?

A. Alkalinity can be reduced by acidification of the liquor (water) or the mash. Here is a list of common and not so common methods. Most refer to adjustments for the mash.

1. Addition of acid to both the mash and sparge water.
   - Lactic acid
   - CRS (Carbonate Reducing Solution), a commercial blend of acids
   - Phosphoric, Sulphuric or Hydrochloric acids – each has their pros and cons
2. Calcium in the mash. Either CaCl (Calcium Chloride) or CaSO4 (Gypsum) additions can drop the pH by a reaction with phosphates in the malt. Dry Liquor Salts (DLS) is a commercial blend of calcium salts.
3. Boiling water - especially if adding calcium to improve the chemical reaction. A 30 minute boil will leave a sediment removing temporary hardness and reducing alkalinity to 30- 50ppm
4. Dilution of mash water with RO (Reverse Osmosis) or distilled water. Compounds in the water are reduced in proportion so combining one part water and one part distilled water will cut alkalinity in half. A ratio of 2:1 will reduce it to one third, and so on.
5. Dark malt - lowers pH by around pH 0.2 in your normal mash. If used at 10% or more of the grist, there should be no difficulty in establishing a proper mash pH. Some examples of malts in distilled water in a laboratory. Lager malt give a pH of 5.7-6.0 in distilled water, Vienna and Munich give pH 5.5-5.7, pale malt pH 5.3-5.7, dark brown and crystal 50 pH 5.3-5.7, chocolate 4.3-4.5 and black malt 4.0-4.2.
6. Acid malt aka sourmalt (looks like normal malt but treated with lactic acid) - Used at around 5-10% of the grist. You can also create your own lactic acid mash. This is made from mashing 5-15% of the total grist then dropping the temperature to 35-50 degC and inoculating with crushed grain which naturally has lactic acid bacteria on it. The mash is held for several days while excluding air allowing the lactic bacteria to grow but air is excluded so the mash does not spoil. Does nothing for the sparge water.
7. Step mash -
   - acid rest, (creates phytic acid) - see How to Brew by John Palmer
     - Before the turn of the (last) century, when the interaction of malt and water chemistry was not well understood, brewers in Pilsen used the temperature range of 86-126°F (30-52°C) to help the enzyme phytase acidify their mash when using only pale malts.
     - Today, through knowledge of water chemistry and appropriate mineral additions, proper mash pH ranges can be achieved from the outset without needing an acid rest.
   - ferulic acid rest: This is a little different from the regular acid rest as this rest is primarily for the generation of ferulic acid which wheat beer yeasts convert to 4VG (4-vinyl-gujacol), which is said to cause the "clove aroma". Ferulic acid is already produced in your mash, but its level can be increased by a ferulic acid rest at ~44°C. For more info see http://braukaiser.com/lifetype2/index.php?op=ViewArticle&articleId=130&blogId=1
8. Decoction mashing lowers the pH
9. Swamping – adding calcium hydroxide (slaked-lime) can react with the temporary hardness. It seems difficult to remove the correct amount without over shooting and increasing the pH.
10. FiveStar 5.2 pH stabiliser - Can be used to put the mash into the correct range.

Q. Where do I find out what is in my water?

A. Your water company publishes a water report for your area. But your water can vary over the year depending on where they source the water from. If you want accurate and up-to-date information then you will have to test it yourself.

Q. How can I find out the alkalinity level of my water? Can I guess it based on other values?

A. Check your water report for an alkalinity CaCO3 value, but it isn't a value that the water company has to provide so it may not be on there. Don't be confused by similar looking "Total Hardness as CaCO3" value on the water report - this can be particularly confusing as hardness and alkalinity are both usually reported as an equivalent of CaCO3 but they are different. You could ask the water company but they may not have the information from the lab that you need. The use of a Palintest, or Salifert aquarium test is your best option to find your alkalinity figure. These give a near enough indication.

Some forums say you can guess the alkalinity given other values. It isn't really possible to do. You might get lucky and get close to the correct value but you really want to know accurately so spend a few quid on a test kit.

Q. How much acid should I use?

A. You need to calculate from the difference from your starting point to your desired level. Note that mg/l is the same as ppm.
For example for a pale ale mash you may want a residual alkalinity of 50ppm. If you start with 180ppm you need to reduce all but 50ppm (180-50=130ppm). So you need to remove 130ppm, but you also need to consider how much water you need to treat. Have a look at the following calculations.

<u>Lactic Acid Example:</u>
Lactic acid comes in different concentrations. The figures below will get you into the correct range.
1ml of 60% lactic acid will neutralise 378mg $CaCO_3$
1ml of 80% lactic acid will neutralise 527mg $CaCO_3$
1ml of 85% lactic acid will neutralise 568mg $CaCO_3$
1ml of 88% lactic acid will neutralise 593mg $CaCO_3$
So if you have 30 litres to treat with each litre containing 180mg/l of $CaC0_3$ that would be 30l x 180mg/l = 5400mg of $CaC0_3$.
If your target is to retain 50mg/l then you need to reduce the amount per litre by 130mg/l (180mg/l - 50mg/l = 130mg/l). So for 30l the total $CaC0_3$ to treat would be 30l x 130mg/l = 3900mg $CaC0_3$.
To neutralise this you want to add (3900mg / 378mg) = 10.3ml of 60% lactic acid or follow the same formula and substitute the other common lactic acid rates to match your bottle.

<u>An alternative lactic acid formula given by Kai Troycer:</u>
Kai says 0.17ml of 88% lactic will treat 100mg $CaCO_3$ in 1 litre.
Therefore if we have to treat 130mg (180mg-50mg residual desired=130mg) of $CaCO_3$ we follow this calculation to convert his base 100mg formula above. 130mg equates to 130% of the value Kai used in his base formula so we need to increase the lactic acid addition from 0.17ml by multiplying by 1.3 (or 130%)
For 32 litres the formula would be
(1.3*0.17)=0.221ml per litre x 32l = 7.075ml (I get 7.015ml when using my 88% lactic acid (593mg) formula above. i.e. 130ppm x 32 litres / 593 = 7.015ml).

Now for an example using CRS:

CRS in millilitres per litre

CRS (ml)	0.35	0.52	0.70	0.87	1.05	1.22	1.40	1.57	1.75
Alkalinity mg reduction	-64	-96	-128	-160	-192	-224	-256	-288	-320

The table shows that to reduce the alkalinity by 128 ppm CRS should be added at a rate of 0.70ml per litre. Thus for a standard 25 litre brew, which will probably require 30 litres of liquor, 30 x 0.7 = 21mls of CRS should be added. After adding CRS, several minutes standing time should be allowed to release the carbon dioxide produced by the neutralisation of the excess acid.

Note. Parts per million is equivalent to milligram per liter (mg/l)l

Q. I want to change my water profile to match a traditional style. What salt additions can I use?

A. The first thing you should ask is "do I need to add anything?" because doing nothing may be the best option. Overloading your brewing water with salts for a subtle change in the finished beer may actually create flavour faults (harshness) in the finished beer. Sulphate and chloride levels are often talked about in terms of a ratio of each to the other for a particular beer style and not total quantity.

Here are some common beer styles with alkalinity and calcium salt levels

- Bitter and Pale Ale. Alkalinity as CaC03 - up to 50 ppm, Calcium - 180 to 220 ppm
- Mild Ale. Alkalinity as CaC03 - 100 to 150 ppm, Calcium - 90 to 110 ppm
- Porter and Stout. Alkalinity as CaC03 - 100 to 150 ppm, Calcium - 100 to 120 ppm
- Pale Lager. Alkalinity as CaC03 - up to 30 ppm, Calcium - 100 to 120 ppm

List of salt products:-

1. Magnesium Sulphate. MgSO4. ***Epsom Salts*** - An important yeast nutrient (10-20ppm) but higher levels (>50ppm) can be bitter and at higher levels still (>125ppm) can be laxative. Enhances hop "crispness".
2. Chloride - CaCl. ***Calcium Chloride Flakes***. Adds chloride which enhances malt flavour and and calcium. Can be mixed into a solution and added to your beer glass to test if this will enhance your beer.
3. Sulphate - CaSO4. ***Gypsum*** - For Burtonising water. Adds calcium and sulphate. Enhances hop bitterness/"crispness" (not to be confused with flavour or aroma enhancement) and can create harshness when over used.
4. Calcium Carbonate - CaCO3. ***Chalk***. Used to raise pH which may be necessary if using dark malts and the base water does not have the carbonates to balance the acidity of the dark malt.
5. Sodium - Na . ***Salt*** - Just like in food it enhances flavour. Bicarbonate of soda may also be used if carbonates and salt are required.

See also Table 2 below which shows what one gram of these common brewing salts will add to one litre, one UK gallon and one US gallon.

Graham Wheeler says in his online calculator (http://www.jimsbeerkit.co.uk/water/watertreatnotes.html#Note5) "Nevertheless sulphate accentuates both dryness and bitterness, whereas chloride accentuates sweetness, mouth-feel and palate fullness, like adding salt to food. It seems that it is the ratio that is important, not necessarily the absolute quantity of sulphate or chloride present. Traditionally Burton-style pale ales had high sulphate to chloride ratios to the extent that the chloride was almost non-existent or insignificant. Modern references suggest that Burton-style pale ales and bitters, these days, have between 2:1 and 3:1 sulphate to chloride ratio; milds about 2:3, and stouts having low sulphate and high chloride, to the extent of having virtually no sulphate at all, perhaps having a ratio of 1:2, 1:3, or even 0:1. However, despite what some references might say, there is no typical; brewers all over the country settle for the ratio they end up with after carbonate reduction, and are producing a range of perfectly satisfactory ales and beers. It would be reasonable aim for a sulphate to chloride ratio of 2:1 for a general-purpose treatment, irrespective of beer type. "

Table 2 - Salt additions - Page 64 of A guide to craft brewing by John Alexander
Errors we spotted in John Alexander's book for this table are corrected below.

One gram of this will add	Compounds	mg/ltr	Imperial gallon	US gallon
Gypsum	Ca SO_4	232 mg 558 mg	51 mg 123mg	61 mg 147 mg
Epsom salts	Mg SO_4	98 mg 390mg	22 mg 86 mg	26 mg 103mg
Calcium chloride	Ca Cl_2	272 mg 483 mg	60 mg 106 mg	71 mg 127 mg
Sodium chloride	Na Cl	393 mg 606 mg	86 mg 133 mg	103 mg 160 mg
Potassium chloride	K CL	523 mg 476 mg	115 mg 104 mg	139 mg 125 mg
Calcium carbonate	Ca CO_3	400 mg 600 mg	88 mg 132 mg	105 mg 158 mg

Q. That is a lot to take in and now my head hurts. Is that normal?

A. Yes, it is quite normal. Water chemistry is an advanced topic and isn't strictly necessary to make beer, but if you want to make better beer then you will need to understand the topic. I suggest working through it one step at a time and don't stress about it. And most importantly relax and have a beer.

Acknowledgements
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John Alexanders "A guide to craft brewing"
George Fix "Brewing Science"
http://www.jimsbeerkit.co.uk/water/watertreatnotes.html#Note5