Water for brewing

Working as a production brewer in various breweries, my time was taken up brewing and packaging beer. Visits to utilities areas were infrequent and normally involved going into to a noisy, enclosed room with pumps, pipes and wires and I never really knew what was going on. This article concentrates on what brewers call 'liquor'.

by ***Paul Buttrick***
Beer Dimensions

The science and engineering involved in modern water treatment is a big topic, so we will look at how water for brewing, that is 'liquor', is treated to brew the range of beer styles available from both large and smaller craft breweries. Because water treatments are so different and specific to individual brewing companies, I leave it to readers to go into the noisy dark rooms and find out for themselves what has been installed and more particularly – why ?

Uses of water in a brewery

Brewery water supplies are normally split into two main streams – water for brewing (liquor) and process water, including boiler feed, cooling towers, process water for cleaning including bottle-washing and large pack cleaning. Water may come from natural sources like on-site boreholes – new or sometimes long-standing – in traditional brewing sites or what brewers tend to call 'town's' or 'mains' water. Supplies for microbreweries most often comes from the 'mains' supply from a local water company.

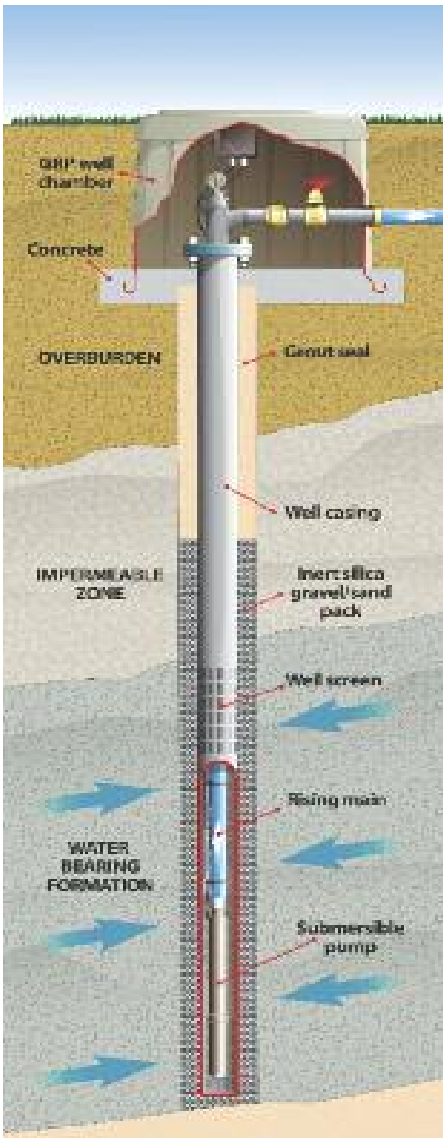
Borehole water

Most large breweries get their water from their own boreholes which tap into copious quantities of fresh ground-water. Consistency, in quantity and quality, is vital for breweries which invest in specialist treatment plant to give the required ionic content for specific brands and styles of beer. An advantage boreholes offer is that they provide a consistent quality of water even if that water requires treatment to provide the right specification for brewing. While mains water will always give 'potable' quality water, the ionic content might sometimes change significantly without warning, depending where the water company sources its water at any one time. This provides an additional challenge – treating the incoming mains liquor to meet the required brewing water specification.

Some breweries treat their water supplies with great reverence and show them off to visitors. Here are the well heads at Budvar in the Czech Republic and Paulaner in Munich.

The geology in the UK is exceptionally variable and sinking a new borehole is a specialist operation where hydrogeological expertise is required to source sufficient water of consistent quality for the brewery's needs.

Boreholes should be designed and carefully constructed to maximise yield, water quality and long-term performance. A good source of water was historically and still is vital in any decision to build a new brewery. For example, water for what was originally a Whitbread



Right: An excellent borehole schematic supplied courtesy of WB+AD Morgan Ltd.

Above: Installing the headworks on a 12 inch, 200m deep well at Diageo's Cameronbridge Distillery.

(Photo: Veolia Water Solutions and Technologies.)

No darkened room here, a general view of CO_2 stripping, tanks and distribution pumps in a modern Dutch brewery.

green-field brewery at Magor in South Wales, comes from the 'Great Spring' which was discovered (and caused havoc and delay) during the building of the Severn Railway tunnel between England and South Wales in 1879. Seventy-five percent of the fresh, high-quality water percolates through limestone rock between the Usk and Wye rivers, the rest from other sources. The high hardness (percolating through the rock) and nitrate content from shallower water courses) necessitate water treatment on site before use.

Water for brewing Marston's famous Burton Ales comes from the Permo-Triassic sandstone which underlie the majority of England's west-midlands and contains groundwater with high concentrations of calcium and sulphate, providing the water for classic Burton style pale ales.

A very informative article by Phil Ham of Envireau Ltd, in the *Brewer and Distiller International* magazine (October 2012), describes the practicalities of installing a borehole. Sinking a borehole is a specialist and costly operation, but the rewards of securing a reliable supply at approximately ten percent of the cost of 'town's' water is a significant benefit for any reasonably-sized brewery. Water from a brewery's own source could be pumped and treated for approximately £0.10/m^3 whereas water sourced from a water company could be £1–£1.50/m^3 depending on locality. For a one million hl/year brewery on a 5:1 water:beer ratio, the difference is in the region of £500,000 per year.

Abstraction of water from boreholes is regulated and licences are required for exceeding a minimum limit. In England this limit is 20m^3/day and the granting of a new licence depends on current water-source availability and the potential impacts a new supply may have on nearby existing extractors or sensitive water-dependent features. The use of borehole water intended for human consumption falls under the Private Water Supply Regulations and local authority environmental health officers may visit sites to collect samples for analysis to ensure compliance at point of use. Equipment needs to be installed to ensure standards are met for both brewing and process use. Water coming from water supply companies must be of potable quality but still often requires further treatment to for brewing beer and other brewery operations.

The requirement that a certain ionic composition for brewing different beer styles on a locational basis is now not necessary and a copious consistent supply is more important than a specific ionic content. However, ionic water specifications are still relevant in brewing beer of a particular style. See Tables 1 and 2.

TABLE 1: Well known to many brewers, this table lists the effect of those ions on brewing and beer quality:

Ion	Typical levels in parts per million – ppm	Brewing/flavour influence
Calcium	c.50 ppm	Stabilises alpha amylase enzyme activity during mashing, helps reduce pH by precipitation of phosphates, precipitates oxalates, plays key role in flocculation and sedimentation of yeast
Magnesium	Should not be >30 ppm	More soluble than calcium, can cause bitter flavour in high concentrations
Sodium/ Potassium	Rarely present at high concentrations	Sodium is thought to have sour/salty taste at levels >200 ppm. No effect on pH because phosphates are soluble
Iron Fe^{3+}/ Fe^{2+}	Should be <0.2 ppm	Gives hash bitter flavour and plays significant role in polyphenol oxidation and haze formation
Copper	<0.1 ppm	An important ion in yeast nutrition
Zinc	0.1 -0.15 ppm	A most important trace element in wort, assists protein synthesis in yeast cells. Zinc deficiency causes slow/poor fermentations.
Manganese	< 0.05 ppm	An important ion in yeast nutrition
Sulphate	Low levels in lagers up to 600 ppm in traditional IPAs	High levels up to 600 ppm in Burton water enhances dry bitter flavour in ales, but harshness in lagers. More normal levels in ales are 2-300 ppm
Chloride	Up to 300 ppm	Contributes to give more mellow and fuller beer palate
Bicarbonate	As a general rule water for lagers should be <50 ppm, ales <150 ppm although levels have been higher in dark beers and stouts.	High levels of bicarbonate lead to higher pH levels throughout the process.
Nitrate	Maximum legal limit 50ppm in potable water and beer	High levels indicate surface water ingress from agricultural land; can come from malt and hops; implicated in the formation of Apparent Total Nitroso Compounds (ATNCs) by nitrate reducing bacteria.
Nitrite	Maximum legal limit 0.1 ppm	Can indicate sewage contamination of water and is toxic to yeast

Pre-treatment of brewery water

Whatever the source of water, it must normally be treated before use in the brewery. Pre-treatment could include removal of particulate matter, followed by removal of metals such as iron and manganese. Water for brewery use other than brewing is normally treated to remove any hardness to avoid plant scale.

Brewing water is treated according to the style of beer and specification of the brands concerned. Lighter lager beers are normally mashed with liquor of low ionic content and have more treatment than ales which are brewed with liquors of higher ionic content (Table 2). Whatever style of beer is brewed, water with high levels of temporary hardness i.e. high levels of bicarbonate (HCO_3^-) is avoided because higher pH beer results in impaired process in terms of mash enzyme activity, final beer stability and in cask beer finings action, as well as a dryer and 'duller' beer flavour.

Liquor treatment choices

The choice of treatment is not simplistic and much depends on particular company

TABLE 2: Typical water analysis in the traditional brewing locations of Pilsen and Burton-on-Trent demonstrates the contribution of key ions to beer flavour and character:

Location	Pilsen	Burton-on-Trent	Comment
Beer Style	Pale lagers	Bitter ales, IPAs	Beer styles traditionally brewed in this location
Calcium	10	352	Brewers must ensure a minimum of 50 ppm
Chloride	5	16	Higher chloride levels bring fullness
Sulphate	4	820	High sulphate is common in ales
Magnesium	1	24	Needs to be <25 to avoid harsh flavours
Bicarbonate	15	320	Bicarbonate is often removed/reduced
Total dissolved solids (TDS)	50	1300	

policies, brand specifications and water source. Ale breweries are often in traditional brewing locations and rely on boreholes reaching down to supplies that have been used for many years. Water quality is regarded as key to that brewery's distinctive flavour and character. These breweries decide only to ensure their water is of potable standard, remove metals such as iron and manganese (if required) and remove temporary hardness from bicarbonate.

This was often done by adding slaked lime (calcium hydroxide) to water in a large stirred tank where calcium carbonate along with other metal ions sediment out leaving the treated water above. Boddingtons Brewery in Manchester was using this method until the mid 1990s; it was a fairly unpleasant process particularly for the operators who had to dig out the sediment every week and man-handle the slaked lime. The slaked lime process was replaced by an acid dosing system followed by a degassing tower to remove the carbon dioxide produced.

Many ale breweries will use filtration only, particularly through activated carbon if they use towns mains water, for the removal of residual chlorine. Dealkalisation using slaked lime is a very old technology and has been replaced by cation dealkalisers and various membrane technologies such as reverse osmosis and nanofiltration. For those who enjoy simple inorganic chemistry, the slaked lime equation:

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 + 2H_2O$$

..and the simple acid dosing equation:

$$H_2SO_4 + Ca(HCO_3)_2 \rightarrow CaSO_4 + CO_2 + 2H_2O$$

Brewing water for lager brewing

Even in the UK, lager beers dominate, with the major brewers and larger independents brewing these beers with softer water. In most cases this necessitates taking water from a regular source and treating it to take out mineral salts to meet the brand specifications. The process choice to do this is by ion exchange or increasingly by reverse osmosis. Some breweries blend back pre-treated raw water with deionised or reverse osmosis treated water to meet brewing specifications, others add back solutions of mineral salts (for instance $CaSO_4$ and $CaCl_2$) to achieve the desired brewing specification.

Ion exchange

Ion exchange plants are easy to use and automate and produce excellent quality water if there is a consistent flow-rate and ionic content. There are two principle types of ion exchange: Twin bed demineralisation, utilises cation and anion resins, where ions are exchanged for H^+ and OH^- ions and base exchange (which exchanges strong cations, principally calcium and magnesium, which cause hardness) with Na^+ ions. This exchange works because the resins have a higher affinity for ions of higher charge and weight.

Ion exchange resins in demineralisation plants remove positive and negative ions from water by exchanging them for H^+ and OH^- ions. Cation and anion resins are typically loaded into separate vessels and regenerated *in situ*, or the resin can be regenerated off site utilising mobile water treatment systems such as Veolia Water's Aquamove service.

Calcium and magnesium and other positively-charged ions are removed by a cation resin, exchanging hydrogen ions for the more heavily charged ions. Once the cation resin is 'exhausted', it is typically regenerated with hydrochloric acid or sulphuric acid. Similarly, negatively-charged ions (chloride, sulphate, etc.) are exchanged with hydroxyl ions. Anionic resins are regenerated with a sodium hydroxide solution. In simple terms, using sodium(+) chloride(-) – NaCl - as the only dissolved salt in the feed water, the hydrogen ion (H^+) regenerated cation resin will exchange the weaker hydrogen (H^+) and stronger sodium (Na^+) ions. This creates a weak hydrochloric acid (HCl) which will then be fed through the anion resin. The hydroxyl (OH^-) ion regenerated anion resin will exchange the weaker hydroxyl (OH^-) ion and the stronger chloride(Cl^-) ion which gives HOH or H_2O (water).

Base exchange with the use of a strong cation ion exchange resin has been a regular choice for softening water by exchanging calcium and magnesium ions for sodium ions. The Ca^{2+} and Mg^{2+} ions which cause hardness are exchanged for Na^+ ions on cationic exchangers. The exchange works because the resin has a higher affinity for ions of higher charge and weight, hence there is a 'pecking order' in affinity which for common ions looks like $Mn^{3+} > Fe^{3+} > Ca^{2+} > Mg^{2+} > Na^+ > H^+$. Once a base exchange resin has become exhausted, it is regenerated by passing through a strong, excess brine (NaCl) solution.

Reverse Osmosis

This is has become a frequently used method for water treatment in recent years, particularly in large breweries. Osmosis is the diffusion of water across a semi-permeable membrane. The reverse osmosis membrane is a percentage rejection technology and will typically remove 96% to 98% of dissolved salts (inorganics) and 99% of organics allowing water to pass across. Osmosis will stop when equilibrium is reached across the membrane, when pressure is exerted on the inlet (concentrate) side of the membrane, osmosis can be reversed, hence reverse osmosis. Reverse osmosis plants involve a

Cation and Anion demineralisation equipment in a modern German brewery.

(Photo: Veolia Water Solutions and Technologies.)

(Photo: Veolia Water Solutions and Technologies.)

A 93% recovery, 60m^3/hr reverse osmosis plant in a modern German brewery.

cross-flow system where pre-treated water is pumped at high pressure (10-25 bar) across the surface of a semi-permeable membrane and treated water is produced. The membranes used in breweries are spirally wound membrane sheets made out of cellulose acetate and typically have flux rates of 15–25L/m^2/hr. A percentage of the water (perhaps 25%) is rejected from the system which becomes more concentrated in salts, organic material and all particulates. Reverse osmosis membranes reject large multi-valent ions such as Ca^{2+}, Mg^{2+} and SO_4^{2-} which are taken out to a greater extent than Na^+ and Cl^-.

It also removes large dissolved organic molecules, colloids, suspended matter and micro-organisms, but dissolved gases such as oxygen and CO_2 pass through. In many larger breweries today the 'reject stream' is passed through secondary reverse osmosis plants and the recovered water used for general cleaning and other processes.

Reverse osmosis is a more flexible option than ion exchange where a steady feed of fairly consistent water is preferred for optimum operation, having said that, ion exchange plants produce a 'cleaner' water. Reverse osmosis performance is monitored by measuring the difference between the conductivities of the feed and concentrate streams divided by the feed conductivity calculated as a percentage. The recovery rate will vary according to the content of the feedwater, the water temperature and the condition of the reverse osmosis membranes. The parameters of the plant operation can be set at different levels as reverse osmosis plants are more flexible, can handle a more variable infeed and are preferred for handling high TDS (total dissolved solids) infeeds.

Membranes become fouled after a period of time and a cleaning and sanitisation routine is run to bring them back up to full efficiency. Key to the design of any reverse osmosis plant is to get the pre-treatment correct so that particulate matter (measured by the silt density index or fouling index test), chlorine and high-level organics are reduced before the membrane. Typically, water treatment companies will suggest that breweries need to budget for membrane replacement every three to five years. With the correct pre-treatment, a good maintenance programme and cleaning regime, membranes have been known to last longer.

The choice between reverse osmosis and ion exchange

Both technologies will produce good quality water, but reverse osmosis is chosen more often nowadays. The choice will depend on the composition of the incoming water, the range and type of beers brewed and a company's view on the different plant operations. Reverse osmosis, although being a more expensive option is more flexible with incoming water, is compact and does not require large quantities of acid and caustic chemicals for resin regeneration. A company may choose a reverse osmosis plant because space is limited and it has a policy of eliminating handling of hazardous chemicals wherever possible.

Other uses of water in breweries

The main focus on brewery water starts with the quality of brewing liquor, but this only accounts for about 30% of the water used on a brewery site. In a brewery, great emphasis needs to be placed on the other 70% to ensure plant is kept in good condition and water is not wasted.

Water for high-gravity beer dilution is the same as is used for brewing. Depending on the method of deaeration, it is usually treated to be microbiologically sound by UV, pasteurisation or sterile filtration. Deaerated water is often carbonated prior to use.

Water used for brewery cleaning tends to go through the same pre-treatment as brewing water. Breweries in soft-water areas may only need to ensure final rinse liquors are sterile, whereas breweries in hard-water areas would need to soften water to avoid scale build-up particularly if alkali or hot cleaning regimes are in place. Chlorine dioxide dosing is a current popular choice for ensuring sterile rinse waters in larger breweries. Ultra violet irradiation is also used, but the water needs to be free from organic and particulate matter to ensure good results.

Water used in flash pasteurisers needs to be softened to guard against scale build-up and water for tunnel pasteurisers and bottle washing is normally treated at the plant itself with chemicals used to avoid scale build-up in pasteurisers and ensure returnable bottles are clean and bloom free. Tunnel pasteurisers are treated to ensure they are free from *Legionella* and slime bacteria build-up.

Boilers running at lower pressures will typically be fed by softened water from a base exchange or dealkalisation process. Modern boilers running at higher temperature and pressures require pure boiler water to run efficiently. The lower the Total Dissolved Solids (TDS) in feed water, the less a boiler is required to 'blow down', wasting valuable water and energy, consequently the choice of treatment before the boiler will significantly effect its running cost. Depending on site water quality, ion exchange treatment (demineralisation) is often used, and some breweries use water from reverse osmosis.

A couple of examples

Wincle Brewery

Wincle brewery on the Cheshire/Staffordshire border in the Peak District National Park upgraded to a 25hL plant in the village of Wincle in 2010. With no mains water supply in the village, the only solution was to sink a borehole next to the brewery. The 60m borehole was sunk by Sonic Drilling who knew the local area and water systems well. Water analysis indicated high manganese and iron, so a small ion exchanger was supplied by Prosep Filter Systems to solve the problem.

In this small installation, a base ion exchange system was chosen instead of the more conventional approach of using a 'manganese green sand' filter since regeneration of the resin with brine solution (NaCl) is easier, cleaner and cheaper to carry out than treatment of the filter with potassium permanganate solution. The resin is regenerated automatically on a pre-programmed five day cycle where iron and

Above: The beautiful setting of Wincle Brewery on the Cheshire/Staffordshire border.

Right: Mashing with their own well water at Wincle Brewery – for those who need to see a bit of brewing.

manganese are displaced on the resin with sodium in the brine. Sediment from the borehole is removed on particulate filters and high bicarbonate levels are reduced with acid addition to brewing liquor tanks. Water for specific beer styles is adjusted with the addition of base salts (gypsum, calcium chloride etc) Also of interest is that the village only has a basic electricity supply, so power comes for an oil powered generator. Waste water is handled by a tank and soak-away system to prevent water contamination of the adjacent river Dane.

Camerons Brewery, Hartlepool

This brewery produces a dozen different brew streams, much of it lager under contract. The brewery is half a mile from the sea and has two boreholes. The brewery pays an annual abstraction licence fee and the local authority tests the supply monthly for microbiological quality and twice a year analytically. Results have shown high levels of various ions including aluminium, fluoride, manganese and sulphate. Reverse osmosis and ion exchange plant was chosen to produce brewing quality and process water. The plant has three 70m^3 reverse osmosis units which are run depending on demand to supply brewing liquor, boiler feed water and deaerated liquor for high gravity dilution. The 'hard' base water is softened for process use and treated with chlorine dioxide at 4ppm (to give at least 1ppm at point of use) which also acts as a terminal sanitiser and replaced peracetic acid.

Water treatment in microbreweries

Water treatment for microbreweries tends to be simpler. Water is normally supplied by the local water company since volumes do not justify the expense of investigating and having a borehole supply. Normally, the local authority will provide analysis data for the brewery's location. A water sample can be sent to a consultant company to analyse the water for ionic content and recommend suitable treatment for different styles of beer. Murphy and Son is a major supplier of microbreweries and have this laboratory service available to brewers.

A 200m^3/hr water softening plant and blending unit with hardness monitoring in a modern Dutch brewery.

Water usage and brewing worldwide

Its impossible to get away from the new 'S' word. In the UK, we are used to having plentiful water around and tend to take it for granted. The global brewers are very focused on water-saving in water-stressed countries – particularly in Africa. They are beginning to have 'sustainability' as part of their social corporate policies. Whereas breweries considered themselves to be 'world class' having a water usage ratio of 5hL/hL of beer, targets are now nearer 3-3.5hL/hL of beer and falling. As a result of stringent target setting, as well as using more efficient processes, breweries are now looking to recover, recycle and reuse process and waste waters.

Companies are starting to realise that water is critical to their products and processes and are now giving it a higher value in their decision making. Veolia Water is encouraging customers to put a 'true price' on the cost of water as companies weigh up their water risks; a 'Water Impact Index' has been developed to help with this assessment. ■

Photo: Camerons Brewery

Reverse osmosis equipment at Camerons Brewery, Hartlepool.

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