Descaling of Water

Limescale (consisting of mainly calcium carbonate, plus calcium sulfate, barium sulfate, calcium phosphate, magnesium hydroxide, zinc phosphate, iron hydroxides and silica, dependent on the geographical area) is a problem in heated water systems wherever water is obtained from limestone or chalk countryside. It is formed primarily because the solubility of calcium carbonate decreases with increasing temperature. Limescale is only a problem if calcium carbonate deposits calcite crystals, which may form directly or subsequent to metastable hexagonal and fibrous vaterite crystal formation. Orthorhombic aragonite crystals have a higher density and, although intrinsically harder, are less prone to form hard scale, but are only about one kJ mol^{-1} less stable [107] and favored at higher temperatures.

Properties of crystalline polymorphs of $CaCO_3$		
$CaCO_3$ crystal		**Density, g cm^{-3}**
Calcite	Trigonal (*R*3*c*)	2.701
Aragonite	Orthorhombic (*Pmcn*)	2.904
Vaterite	Hexagonal ($P6_3/mmc$)	2.560

The mechanism by which the magnetic field produces its effect seems down to the presence of disordered hydrated $CaCO_3$ aggregates [1954],[a] forming liquid emulsions which may be affected by the magnetic field and so convert into different prenucleation clusters and hence different structures on crystallization [1955].

Once formed, crystals are kinetically (if not thermodynamically) stable for hundreds of hours. By drawing water through a static magnetic field (B ~0.1 T , ∇B~10 T m^{-1}, it has been shown that the initial amount of aragonite formed is significantly increased over calcite in samples with and without the presence of dissolved iron [107], although this aragonite eventually changes to calcite [555]. A separate experiment has shown that drawing a pure solution of calcium carbonate and bicarbonate through static magnets (0.16 T) for 5-30 min increases the precipitate formed on degassing the excess dissolved carbon dioxide [1043]. Magnetic treatment has been shown to affect the crystal surfaces of both aragonite and calcite [1689].

The direction and variation of the magnetic field has also been shown to be important [555], with crystal size decreasing with increasing magnetic field [623]. A different group has showed agreement in a recent study where under similar conditions (B = 0.5 T, flow rate = 0.1 m s^{-1}) the magnetic field produces mainly a mixture of aragonite (44%) and vaterite (42%) whereas without it well-crystallized calcite (34%) is formed with little aragonite (14%) [252]. It has been proposed that the smaller water cluster size, being more reactive, hydrates the calcium and carbonate (particularly; see a recent supporting study [793]) ions more effectively and so encourages aragonite nucleation [110]. Alternatively, the magnetic field may cause a surface and/or orientation effects on the growing crystals [980]. It is possible, however, that the major effect is the magnetically induced competitive formation of hydrated silica in suitable solutions that then absorbs calcium ions [353]. The pipe material and its surface were also found to be important [1586].

There are many devices on the market for the magnetic treatment of water for the removal of such limescale. The sales success of these devices would seem to indicate that some work as promoted, at least under some circumstances.

Magnetic treatment of water is claimed to cause four effects: [104]

1. Reduction in the amount of limescale formed.
2. Production of a less tenacious limescale due to a change in the crystal morphology.
3. Removal of existing scale (3 - 6 months).
4. Retention of anti-scaling properties for hours following treatment.

Many tests mainly utilizing single pass systems, however, have proved negative [212]. Recirculatory systems, with prolonged magnetic exposure, give more supportive results. Rapid movement (1200 rpm) in a strong magnetic field (4.75 T) had a significant effect compared with the movement or field alone [105]. A smaller number of larger crystals causes the effect as nucleation is suppressed and crystal growth is enhanced. It is possible that the effect is due to magnetically enhanced corrosion promoting the release of Fe^{2+} that, even at ppm reduces calcite but has no effect on aragonite production; inhibiting the thermodynamic transformation of aragonite into calcite. (Fe^{2+} may be used as a threshold inhibitor by industry). However the amount of dissolution, required by this theory, has not been found. Magnetic treatment devices that create additional turbulence may enhance anti-scaling effect [109], perhaps by encouraging precipitation in the bulk (due to a combination of magnetically modifies hydration and the shifting of charged particles in the magnetic field [645]) rather than by deposition. Another contributing factor may be the lowering of the surface tension, multiple passes producing increased lowering up to about 8% [735]. A potential (= v.B.L where L is the distance between detecting electrodes) is generated when a dilute electrolyte flows (v) through a transverse magnetic field (B, greatest when the flow is orthogonal to the magnetic field). This may increase colloidal coagulation. A recent well-controlled study has shown that scaling can be reduced by a few percent by even one pass though a simple magnetic device but that it is difficult to increase this effect to more than about 20% even with extensive recirculation [259]. This study also showed an optimum in the flow rate as at too high a flow rate the magnetic field was encountered only briefly, an effect recently confirmed [555]. Recently, the presence of dissolved oxygen has been shown important for the production of the magnetic effect for forming aragonite rather than calcite [970], and for initiating scaling [1046]. It may be assumed that many of the studies described on this page did not control for oxygen content, so their effects may have been moderated by the varying dissolved oxygen contents.

There are 'electronic' devices, related to the above purely magnetic devices, that use weak electromagnetic signals utilizing a coil wound around a pipe. A square-wave pattern is often used as it effectively contains many frequencies from a few Hz to 100 kHz [657]. This changes the magnetic field in a manner similar to a number of rapid passes past a very weak static magnet. However the changing electric field will also contribute to the effect, as shown using a pulsed electric field [799]. Recently,13.56 MHz at 2 V has been found to work well [1626].

Footnotes

[a] These sloppy objects are known as DOLLOPs (dynamically-ordered liquid-like oxyanion polymers) [1954].

Source: http://www1.lsbu.ac.uk/water/descal.html