Scale is a layer of solids caused by the deposition of insoluble ions such as calcium carbonate ($CaCO_3$) and magnesium carbonates ($MgCO_3$). Over time, scale deposits cause plugged equipment and a reduction in efficiency as scale forms an insulating layer that limits heat transfer to water.

It is useful to understand the basic chemistry behind the formation of scale in order to understand how different control technologies work. This article provides an overview of scale formation chemistry and discusses a hydrogen-based ion exchange process known as decarbonization.

A Tale of Two Families

All water, irrespective of its source, contains a mix of dissolved minerals. These minerals are grouped into two "families": negative ions and positive ions. The "negative ion family" contains members such as carbonates (CO_3^{2-}), bicarbonates (HCO_3^-), and chlorides (Cl^-). Similarly, the "positive ion family" contains ions such as sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}), among others.

Normally, negative and positive ions are in balance and there are equal amounts of each. Some negative and positive ions, when present, form insoluble and hard solids. For example, when calcium ions (Ca^{2+}) and carbonates (CO_3^{2-}) are present under certain conditions, they form the insoluble calcium carbonate ($CaCO_3$), a major constituent of scale. Other ions simply do not form solids and remain dissolved in solution, such as sodium chloride or table salt ($NaCl$).

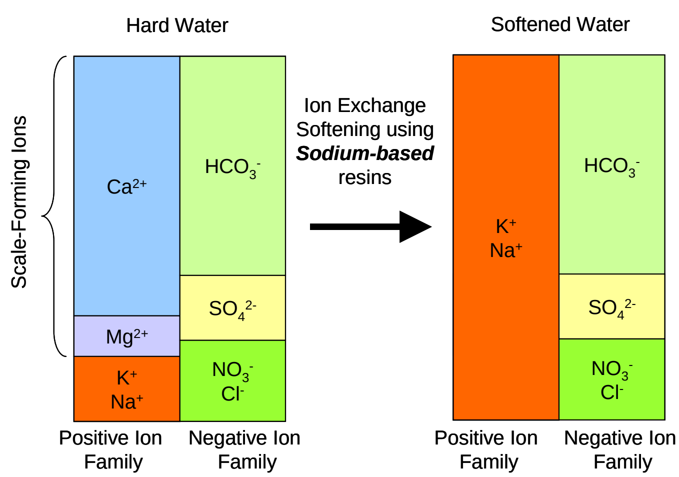
Water is considered either "hard" or "soft" depending on the level of minerals and the potential to form scale. Generally, groundwater is considered hard because limestone and rocks in the ground contain calcium (Ca^{2+}), magnesium (Mg^{2+}) and carbonate (CO_3^{2-}) deposits that dissolve in water and increase the potential for scale formation.

Scale Control Technologies

There are a number of technologies to deal with scale. Some use *polyphosphate*, which is a food-grade, non-toxic additive that keeps scale in suspension and reduces its deposition. Polyphosphate is useful in certain applications and up to a certain level of hardness.

Ion exchange, also known as softening, has been used in different applications for many years. The idea behind ion exchange softening is simple: the positive ions that cause hardness, such as calcium (Ca^{2+}) and magnesium (Mg^{2+}), are replaced with ions that do not form insoluble precipitates such as sodium (Na^{+}). Hence the term "ion exchange"

Typically, the ion exchange softening process occurs in a vessel that contains a sodium-rich resin. When water rich in calcium and magnesium (i.e., hard water) comes in contact with this resin, an automatic ionic exchange process occurs whereby sodium is released from the resin into water, while calcium and magnesium are retained by the resin. The conventional ion exchange process with sodium is depicted on the following schematic.



Conventional Softening Process

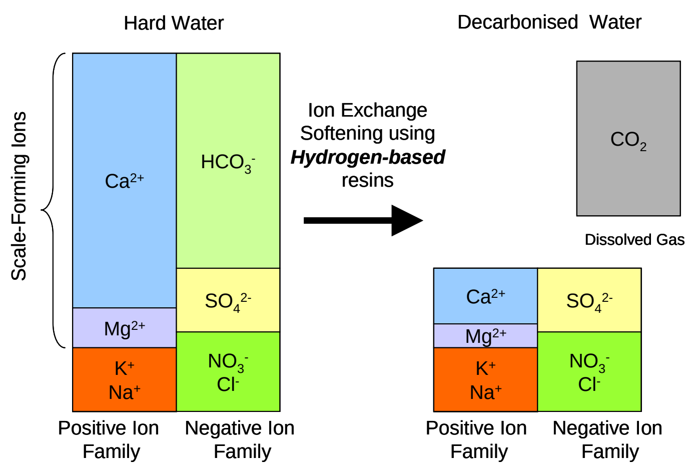
After the softening cycle is over, the hardness-rich resin is replenished with a strong brine solution that typically contains sodium chloride (NaCl) and the resin becomes rich with sodium again. The waste stream containing hardness is then flushed to the drain. This cycle is repeated continuously, hence the need to supply salt on a regular basis.

Conventional ion exchange softening using sodium chloride has its application, yet in some applications it may not be the most suitable. For instance, using softened water rich in sodium ions for coffee brewing slows down the extraction process and leads to over extraction by forming a gelatinous mass around coffee grounds (Boyd Coffee Company, 2010).

Decarbonization using Hydrogen-Based Resins

A new ion exchange process has been developed that utilizes hydrogen-based resins instead of sodiumbased resins. Hydrogen ions (H^+) belong to the "positive ion family" and therefore belong to the same group as sodium (Na^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}). However, hydrogen does not form insoluble deposits with the "negative ions family". In this regard it is similar to sodium ions. Nonetheless, hydrogen has interesting chemical properties that makes it different than sodium.

Hydrogen-based ion exchange resins replace the calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions with hydrogen ions (H^+). Hydrogen ions react with the bicarbonate ions (HCO_3^-) and convert it into dissolved carbon dioxide gas (CO_2). Carbon dioxide is a safe gas when dissolved in water. In fact, all carbonated drinks such as sodas are filled with carbon dioxide. By adding hydrogen (H^+) ions into solution, the formation of bicarbonates (HCO_3^-) and carbonate ions (CO_3^{2-}) is suppressed, and hence the level of scale decreases. The decarbonization process is depicted in the following schematic.



Decarbonization Ion-Exchange Process

In summary, hydrogen-based ion exchange process reduces hardness level in water by removing calcium and magnesium ions, and also converts the negative bicarbonate ions into carbon dioxide. This process produces soft water that is low in sodium and hence is suitable for preparation of coffee and hot beverages.