WATER SOFTENER

A hard water can cause scaling in boilers and household appliances. It will produce curd with soap before it will produce a lather, thus soiling kitchen and bathroom fittings, giving laundry a less clean appearance, and wasting soap. In industrial applications the hardness will cause scaling on heat transfer surfaces, cause stains, discoloration, spots, and other surface defects on many industrial products and off-flavors and poor tastes in food and drinks. It will also cause destruction and waste of various chemicals, such as the soap and alkalis used in washing, dyeing, and similar operations, resulting in undesirable precipitates on textiles being produced or laundered.

Early attempts at removing hardness included boiling to remove that part of hardness which is due to calcium and magnesium bicarbonates, and the commercial process know as Clarke's or lime-softening process. Modifications of the latter are widely used even today but, like boiling, it will not remove calcium and magnesium salts such as chlorides, sulfates, etc.

The first commercial application of ion exchange was the softening of water by Dr. Gans in 1905. Since that time, the ion exchange method of softening has become a widespread treatment process and the original natural and synthetic zeolite type materials were replaced over the years by newer and more versatile ion exchangers, such as the sulfonated coals, the sulfonated phenol formaldehyde (bakelite) type resins and, more recently, by the physically and chemically resistant, high-capacity materials of the polystyrene-divinyl benzene sulfonate bead type. All forms of resins are commonly referred to as zeolite.

Dr. Kunin, of Rohm and Haas Company, drew the sketch on which figure 1 is based, giving his schematic representation of a hydrated strong-acid cation exchanger. As he put it, "In describing an ion exchange resin to the layman, I usually draw the analogy between the crosslinked polymer chains of an ion exchange resin and a plate of spaghetti which has cooled to the point where the individual strands have become glued or cemented together because of the soluble starches. The cementation corresponds in my analogy to crosslinkage. The polymer chains, crosslinks, water of hydration fixed ion exchange sites, and mobile exchangeable ions are shown in this drawing."

The bead itself is an anion with negatively charged exchange sites. The exchange sites hold positively charged cations, such as sodium, potassium, calcium, magnesium, iron, manganese, hydrogen, ammonium, and other metal ions. At the start of a softening run all of the sites on the resin bead have a sodium ion attached. As the water with hardness flows over the resin beads the ion exchange process takes place. The bond between the sites on the beads and the sodium ions is relatively weak compared to the bond between calcium and magnesium ions. The calcium and magnesium ions therefore become attached to the resin bead and the sodium ions enter the water flow. This process works best when the hardness concentration is less than 1000 ppm or 59 grains. As the hardness concentration goes above 1000 ppm, ion exchange becomes less complete and hardness leakage increases. Since there are a finite number of sites on the resin this process will continue only until all of the sodium ions have been exchanged for calcium and magnesium. At this point the resin bed is said to be exhausted and the calcium and magnesium ions have to be replaced with sodium ions so the softening process can be repeated. The process of removing the hardness ions and replacing them with sodium ions is called regeneration.

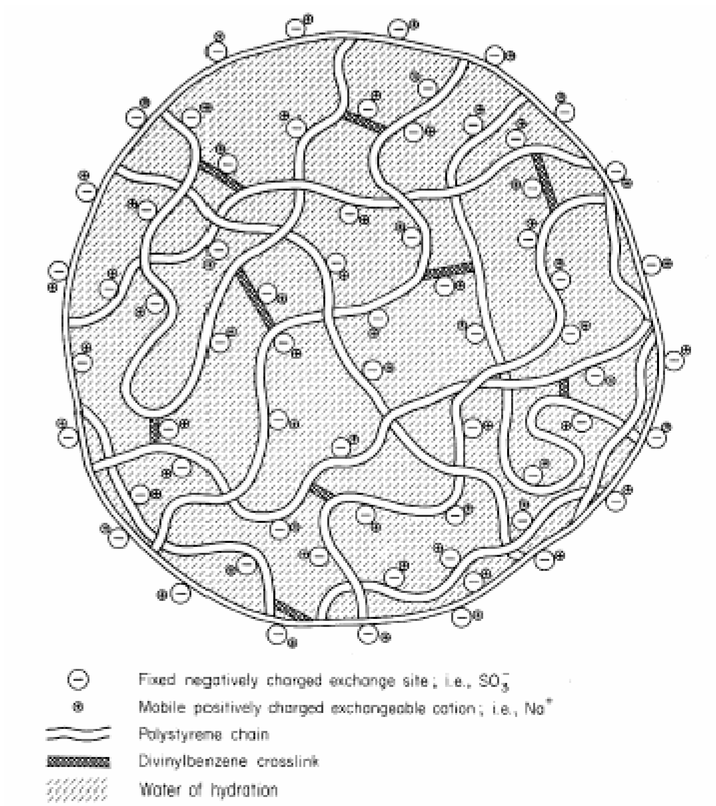

Figure 1
Schematic picture of hydrated strong-acid cation exchange resin

The chemical reaction of softening, written in ionic form, is

$$Na_2^+Z + \left\{\begin{matrix} Ca^{2+} \\ Mg^{2+} \end{matrix}\right. \rightarrow \left.\begin{matrix} Ca^{2+} \\ Mg^{2+} \end{matrix}\right\} Z + 2Na^+ \qquad (1)$$

where Z represents the anionic part of the exchanger. Zeolite is regenerated with common salt (sodium chloride) brine according to the following reactions, written in ionic form:

$$2Na^+ + \left.\begin{matrix} Ca^{2+} \\ Mg^{2+} \end{matrix}\right\} Z \rightarrow \left\{\begin{matrix} Ca^{2+} \\ Mg^{2+} \end{matrix}\right. + Na_2^+Z \qquad (2)$$

This regeneration reaction is simply the reverse of the exhaustion reaction, Eq. 1. The exchanger normally gives up sodium in exchange for calcium or magnesium, as in the exhaustion phase of the cycle, more easily than it does the reverse, but if an excess of sodium in the brine and a considerable strength of brine (5 to 10%) is used for regeneration, the reverse regeneration reaction is facilitated and the sodium cations re-enter the zeolite in exchange for the calcium and magnesium cations previously removed. The latter are then discarded or eluted into the waste brine leaving the zeolite bed.

Our discussion to this point has described the softening reaction in relation to one bead of zeolite resin. In reality the reactions take place in a softener tank that contains millions of resin beads in a bed or column that can be several feet thick. As water containing hardness ion passes down through the resin bed, the ion exchange reactions begin in a reaction zone at the top of the column. Depending on several variables, the hardness ions may penetrate the bed a few inches or as much as several feet before they are removed. The depth of hardness ion penetration is known as the active exchange zone. As hardness ions saturate the upper portion of the bed, the active exchange zone moves steadily downward throughout the run of the softener. Eventually the hardness ions reach the lowest point of the bed and hardness leakage will occur and continue to increase in the outlet water. When leakage increase to a predetermined level, usually dictated by the application the column is considered exhausted and the resin must be regenerated.

Regeneration of a resin column consists of four steps:

a) Backwash
b) Brine draw
c) Slow rinse
d) Fast rinse

In the first step of regeneration the resin column is backwashed. During the downward flowing of raw water in the softening process the zeolite bed has removed suspended matter from the water. Backwashing, an upward flow, expands the bed and releases the dirt, so that the dirt can be discharged to waste. This cleans and loosens the bed and classifies it (separated the large granules from the small), bringing the small granules to the top which aids in proper distribution of the brine through the bed.

The brine draw and slow rinse portion of the regeneration are critical in determining the capacity of the regenerated resin. The exchange capacity of the regenerated resin is influenced by:

a) Salt dosage
b) Brine strength
c) Regeneration contact time

Resin manufacturers suggest brine concentrations between 7% and 14% yield the best regeneration results. A 10% brine solution is considered best. A contact time of 30 minutes is considered optimum. Table 1 shows the exchange capacity of standard softener resin for various salt dosages when regenerating with a 10% solution for 30 minutes.

Exchange Capacity Grains per Cu. Ft.	Salt Dosage Lbs/Cu. Ft.
20,000	6
25,000	10
30,000	15

Table 1
Exchange Capacity

During the brine draw portion of the regeneration fresh water is passed through an eductor which creates a vacuum on the brine draw line thereby drawing brine from the brine tank. The eductor is sized to provide the desired flow of approximately 0.5 gpm per cubic foot of resin. The eductor also dilutes the saturated brine from the brine tank to the required value of 10%. The effect of the time for the 10% brine to be in contact with the resin bed is important for effective regeneration. A contact time of 20 to 40 minutes at a flow rate of 0.5 gpm is satisfactory. After the required amount of brine has been drawn flow from the brine tank stops and the motive flow through the eductor continues a slow rinse through the resin column. At the end of this slow rinse the entire resin column has experienced a contact time of 20 to 40 minutes and all brine has been rinsed from the vessel. After the slow rinse is completed the fast rinse is initiated. The flow for this rinse is normally 2.5-5.0 gpm/cu.ft. This fast rinse flushes out remaining salt pockets and generally lasts 10 to 15 minutes.

Softener controls are generally either time initiated or volume initiated. With time initiated controls the regeneration cycle is initiated after a set number of hours or days have elapsed since the last regeneration. With volume initiated regeneration a flow sensor is mounted in the softener outlet line and when a preprogrammed volume of water has been softened the regeneration cycle begins.