

Kineticco

Water Softening

Fundamentals

INTRODUCTION

Impurities In Water

Water is often called the "universal solvent" as it dissolves a small amount of almost of everything it touches. Rain, nature's purest form of water, does not stay pure very long. Rain begins to pick up dust and gases as soon as it leaves the cloud. Water collects or dissolves a variety of mineral salts, organic compounds and suspended solids as it flows over the earth's surface and through the ground. It dissolves metals as it is stored and distributed from one place to another. These impurities make water undesirable for use in many applications. It is, therefore, important to properly treat or condition the water before using it.

Water impurities are classified as suspended solids, mineral salts in solution, dissolved gases and organic contaminants. Suspended solids, usually referred to as turbidity, consist of clay, silt, sand, iron oxide and other insoluble material.

Mineral salts in solution are chiefly bicarbonates (HCO_3^-), sulfates (SO_4^-), chlorides (Cl^-), nitrates (NO_3^-) or silicates (Si_2O_5^-) of calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^+) or potassium (K^+). Dissolved gases may include oxygen (O_2), carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3) or hydrogen sulfide (H_2S).

Organic contamination consists of animal and vegetable matter, living organisms, oil, sewage by-products and other decayed matter or waste products.

Hardness In Water

Hardness, one of the most common impurities in water, is defined as anything that will react with soap to form a scum or curd. Calcium, magnesium, iron are the most common hardness encountered and all will form soap curd. Conversely, water devoid of these specific minerals is called soft water.

As a result of flowing over and through the earth's surface, most natural water supplies contain some dissolved mineral salts, particularly those of calcium and magnesium, the primary cause of hardness. The degree of hardness is directly proportional to the concentration of these minerals.

Calcium and magnesium may be present as part of several salts. When present as bicarbonate (HCO_3^-) or carbonate (CO_3^-), it is referred to as carbonate hardness. Carbonate hardness can precipitate (become insoluble) and form scale simply by heating it (tea kettle, water heater, etc.). Because of this chemical characteristic, the carbonate hardness is often called temporary hardness.

When calcium and magnesium salts are present as sulfate (SO_4^-), chloride (Cl^-) or nitrate (NO_3^-), the hardness is called non-carbonate hardness. Non-carbonate hardness is less likely to precipitate with the application of heating and thus is sometimes called permanent hardness. Both temporary and permanent hardness can exist together in the same water supply.

Water hardness can be determined analytically by three (3) methods:

1. By titrating with a standardized soap solution until stable suds are formed.
2. By titrating with a chelating agent using a color indicator dye which changes from red to blue.
3. By measuring calcium and magnesium separately with a flame spectrophotometer.

The first method is not an accepted laboratory procedure, but is still used as a field test to quickly check a water softener for basic operation. The soap test is purely a “go or no-go” test. The second method is also used for field testing. The third method is strictly for lab use and employs a sophisticated piece of laboratory equipment.

The Lab Report

Total hardness is the sum of calcium and magnesium. A typical water analysis will show calcium, magnesium, and total hardness in parts per million (ppm) or milligrams per liter (mg/l) or grains per US gallon (gpg). When the term hardness is used, the value is always expressed in terms of calcium carbonate equivalence (as CaCO₃). A Kinetico water analysis report will report calcium and magnesium individually in ppm as the elements, and in grains per gallon expressed as a calcium carbonate equivalent.

Note: 1.0 ppm and 1.0 mg/l are equivalent, ppm & mg/l can be interchanged as they represent the same amount.

Salts disassociate into their respective ions when dissolved into water. Sodium chloride (salt) dissolves and dissociates into sodium ions and chloride ions. As such they are expressed as individual ions on the lab report due to this disassociation. An analysis of a solution containing several different ions cannot be used to predict chemical reactions unless the individual ions are expressed in similar terms. Calcium carbonate equivalence serves as a common denominator so that several ions, all expressed the same way, can be added together and used collectively. Similarly, in mathematics, we use common denominators to calculate fractions. The use of calcium carbonate equivalence is the method of converting the value of each element to a common denominator.

1.0 mg/l of calcium (as Ca) = 2.495 Ca as CaCO₃

1.0 mg/l of magnesium (as Mg) = 4.11 Mg as CaCO₃

Example: A water analysis lists : Calcium (Ca) at 55.0 mg/l
: Magnesium (Mg) at 12.0 mg/l

Conversion: Calcium 55.0 x 2.49 = 137.23 mg/l as CaCO₃

Magnesium 12.0 x 4.11 = 49.32 mg/l as CaCO₃

Total Hardness 186.55 as CaCO₃

186.55 ÷ 17.1 = 10.9 grains per gallon total hardness
(one grain per gallon “gpg” is equal to 17.1 mg/l total hardness as CaCO₃)

Water analyses prepared by different laboratories, or from other countries, may use different reporting systems. They may or may not use the calcium carbonate conversions, or they may only convert a few of the ions to calcium carbonate equivalence. When reviewing an analysis take special care to interpret the values correctly.

The amount of hardness in water supplies can not be predicted and will vary in amount and can vary extensively in a small geographic region. Table 1 gives the U. S. Department of the Interior and Water Quality Association hardness classifications:

TABLE 1

HARDNESS RANGE AS CaCO₃		HARDNESS CLASSIFICATION
Less than 17.1 mg/ or ppm	Less than 1 gpg	Soft
17 - 60 mg/l or ppm	1 - 3.5 gpg	Slightly Hard
61 - 120 mg/l or ppm	3.6 - 7.0 gpg	Moderately Hard
121 - 180 mg/l or ppm	7.1 - 10.5 gpg	Hard
Over 180 mg/l or ppm	Over 10.5 gpg	Very Hard

Advantages of Soft Water

Softened water offers many advantages over hard water. In general, use softened water whenever the use of hard water:

- Would result in scale formation in vessels, containers and equipment used for heating.
- Would consume soap or cleaning compounds.
- Would interact adversely with chemicals used in industrial processes.

In the home, soft water has economic and aesthetic benefits. Clothes are cleaner, softer, and brighter when washed in softened water. Their useful life is extended as the fibers do not become brittle. Hot water heaters and piping remain free of scale, extending their life. Dish washing and household cleaning are more economical and efficient when softened water is used.

Similar benefits are noted on an even larger scale in business and industry. Restaurants, hotels, motels, hospitals, and car washes all benefit from using softened water in their washing and cleaning operations.

Industry uses softened water for process and boiler make-up, the latter being the most predominant application. Food processing plants find softened water useful in cooking, cleaning and boiler operations. The list of potential industrial applications is extensive.

SOFTENING PROCESSES

Definitions

The process of removing unwanted hardness from water is called softening.

There are two well established processes for softening water. They derive their names from the chemical processes used to remove or reduce the hardness. The first and most popular is called ion exchange softening (at one time referred to as zeolite softening.) The second and oldest process is called lime or lime-soda softening. Lime softening is used only in limited industrial applications and therefore is not the focus of this document.

A Short History of Ion Exchange Softening

In 1845 and 1850, two chemists, Thompson and Way, investigated the purifying powers of the soil and its ability to remove color and odor from liquid manures. They began to study soil chemistry and were particularly concerned with the action of water soluble fertilizer salts such as ammonium sulfate and potassium chloride and noted that these salts could not easily be leached out of soil by the action of rain water.

As early as 1852, Way actually prepared a compound called zeolite by the reaction of sodium aluminate with sodium silicate (a method similar to that used extensively in the mid 1900's) and found that it absorbed considerable ammonia.

Professor Robert Gans, in the early years of the twentieth century, became a pioneer in the application of base exchanging silicates to water softening. His work resulted in the famous Gans patent in 1908 for preparing a fused product from kaolin, soda ash, and sand, and extracting with water. To this product he gave the name "Permutite", from the Latin "permuto", meaning to change. It was slow-reacting and it had a capacity of about five thousand grains per cubic foot if soaked overnight in brine. It was not long before another group of products, developed from bentonitic clays, was found to have higher capacity and was easier to regenerate.

United States patents were taken out by Gans in 1909, 1910 and 1916. The first patent was re-issued in 1914. Patent rights were sold to an American group, who established the Permutit Company in 1914.

The New Jersey greensands, which appeared in the early 1900s, provided media with a faster water softening rate and much faster regeneration rate than the early zeolites. They were mined from the only known commercial deposit in the United States. Greensand, made by processing New Jersey marl, is a ferro-alumino-silicate which contains the elements sodium (Na), iron (Fe), aluminum (Al), silicon (Si), and oxygen (O). The greensands, depending on their source and method of processing, had a capacity of 3000 to 5000 grains per cubic foot. They are no longer used for softening water.

In 1920, another type of alumino-silicate zeolite made its appearance and began a highly successful career as a water softening agent. Sodium-alumino-silicate is a true ion exchanger. It is a crystalline structure, man-made, called sodium-alumino-silicate. Solutions of sodium aluminate and sodium silicate are combined and poured on concrete runways. The mixture quickly forms a rigid gel that contains 95% water and 5% solids. Drying in the sun removes 90% of the water, leaving a product containing 50% water and 50% solids. The large chunks were then "harvested" at just the right time and taken to a processing tower for grinding, screening and washing.

The search for improved ion exchangers began in earnest with the discovery that ordinary coal could be converted into a cation exchanger by processing it with either fuming sulfuric acid or sulfur trioxide. The process incorporated sulfonic acid groups into the complex organic compounds present in coal. After sulfonation, the excess acid was washed from the granules of ground coal. Additional treatment with soda ash converted the product to an insoluble sodium salt having ion exchange water softening properties. The product was called carbonaceous zeolite or carbonaceous cation exchanger. The capacity was relatively low, being only about seven thousand grains hardness removal (as calcium carbonate) per cubic foot.

Development of the first truly resinous ion exchangers is credited to two Englishmen, Adams and Holmes. In 1935, they prepared a resinous exchanger by condensing phenol and formaldehyde and sulfonating this resinous material giving it ion exchange characteristics. This material had good stability and capacity for both sodium cycle and hydrogen acid cycle operation.

Its performance was satisfactory when treating or softening acidic or neutral waters. However, some swelling, color-throw and resin instability, with a loss of capacity, occurred when operating on highly alkaline waters. Also, free chlorine and other oxidizing agents harmed the resin. It also was unstable in higher temperature applications.

In 1945, a General Electric chemist named D'Alelio, obtained a patent for preparing resinous ion exchangers by cross-linking polystyrene and divinylbenzene. These resins were extremely stable, had a usable softening capacity of approximately 30,000 grains per cubic foot when regenerated with fifteen pounds of salt per cubic foot, and could be used in the hydrogen cycle (acid regenerated), making them suitable for both softening and deionizing applications.

Before long, anion exchanger resins were prepared on a polystyrene base and anion exchangers having differing strengths and removal characteristics could be manufactured.

Today's softening resins have high capacities, are extremely stable in the presence of oxidizing agents, acids, alkalis and wide variations in temperature. Equipment size has been reduced, salt efficiencies improved, and today's ion exchange water softener provides an extremely economical means of obtaining soft water.

A SHORT HISTORY OF KINETICO WATER SOFTENING

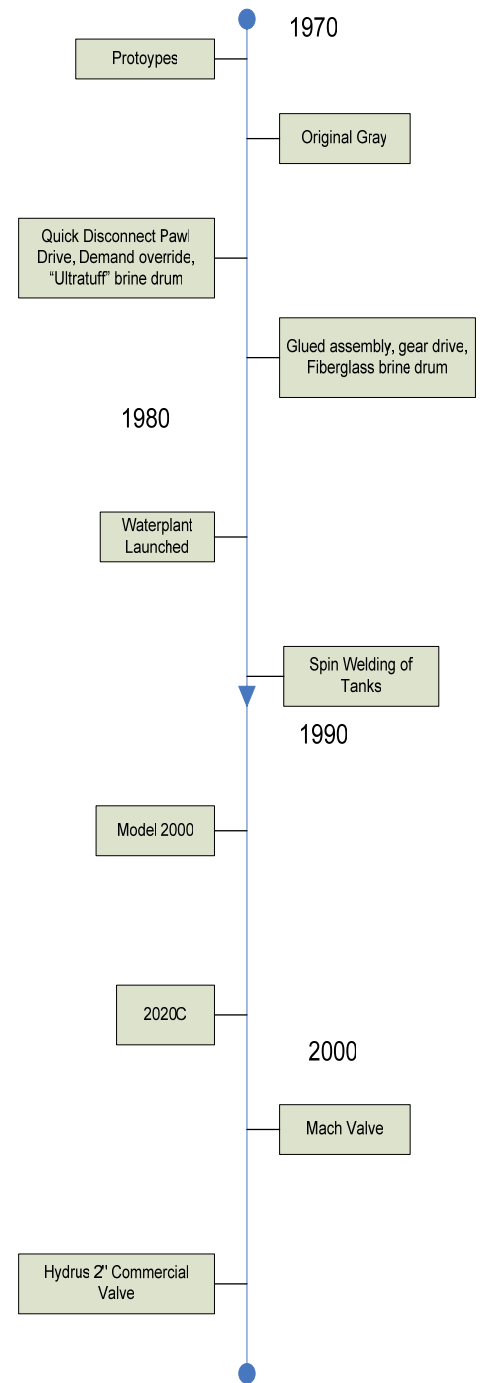
Historical information about Kinetico Incorporated – J.Kewley, Cofounder

“From the very beginning, it was always the goal to develop a non-electric, meter controlled, twin tank design. However, the original design (and prototype) was a tank-in-tank design (one tank inside of the other one vs. two tanks side by side) and the original regeneration design was a 5 cycle design. To this day single tank softeners rely on the common and inefficient 5 cycle design. The tank-in-tank design was abandoned due to the technical difficulty of making a tank with a large diameter opening that would be needed to accommodate the smaller tank that would be inserted into it. This design would also have serious flow distribution and restriction issues.

The Kinetico counter flow regeneration cycle was inadvertently discovered after we had difficulty getting accurate information from our resin supplier (at that time there were only two in the United States). This led us to a meeting with Dr. Lou Wirth of Dow Chemical in Midland, Michigan. Lou was one of the leaders in the ion exchange industry. He provided the basis for design of the Kinetico counter current regeneration cycle that we have always used. The 3 cycle counter current regeneration is far superior to a 5 cycle process and does require twin tanks for it to be properly utilized.

The very first unit ever installed was of a design configuration that we never offered for sale (using 6 inch diameter by 36 inch tall tanks). It was installed in February, 1973, when the Kinetico valve was not quite fully ready for production and it worked well enough until a final production valve was installed on the softener in the fall of 1973. That softener with the original valve is still in service (August, 2006). During its service life it has had two service calls, one in approximately the late 1980’s to add about 3 inches of additional resin to the tanks (it is normal to have a slight attrition of resin for softeners that are vigorously backwashed during regeneration and which do not utilize an upper distributor, which this unit did not). The second service call was in 2005, to replace a small, internal drain valve that was starting to dribble a little water to the drain (but the unit still functioned and provided continuous soft water with the old valve).

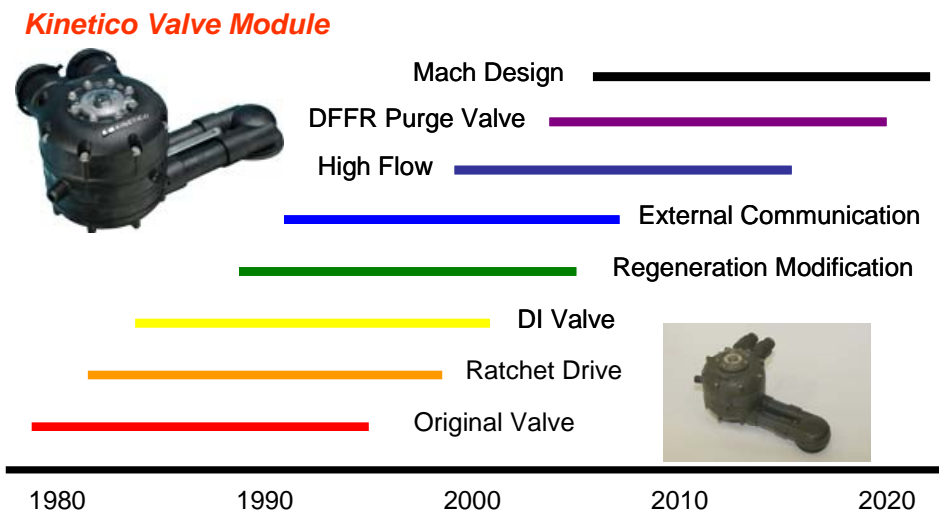
The first softener we sold was our Model 30, quite similar to our current 2030s. Our actual first sale was in November, 1973, made directly to a local consumer. We started selling through a few dealers shortly after that and began actively soliciting dealers in June, 1974. By the end of 1974, we had a total of 318 softeners installed, nearly all within a 200 mile radius of Newbury, Ohio.



During 1974, when soliciting a dealer in western Ohio, we learned that our Model 30 was not large enough to handle the high hardness water in that area. Within a day, our Model 60 (much like our current 2060s) was designed and the first one sold a few days later. Although designed in an extraordinarily short period of time the Model 60 has out sold every other model Kinetico has ever manufactured and was considered the work horse of the product line for many years, and still is today.

In May, 1975, we hired an experienced sales manager to develop sales for us across the U.S. That month, we set a new record for units sold at 101 units. For the year of 1975, we sold a total of 1,980 units. In 1976, we sold 5,656 units, then 10,322 in 1977, and it has been increasing ever since. We started selling in Canada in about 1976, initially using Trojan Technologies of London, Ontario, as our distributor. We did not sell overseas until 1981, after we had experienced success in the North American markets.

Also in 1981, we introduced our Ultra-Kinetic I product. We were the first to use fine mesh resins and packed bed technology to dramatically increase the efficiency of our water softener (even beyond the already dramatic increase in efficiency that our original design had achieved when compared to single tank designs). It was an immediate success in the marketplace and the Kinetico high efficiency units are used around the world in all types of residential and commercial applications.”



Evolution of the Kinetico Valve

PRINCIPLES OF ION EXCHANGE

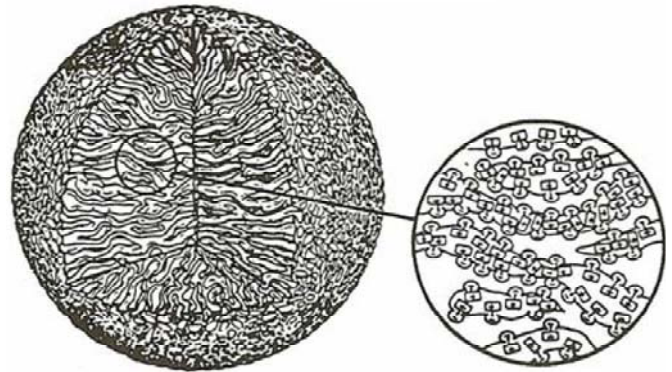
Water softening by ion exchange uses highly efficient sulfonated polystyrene base cation exchange resin. As water passes through a bed, or column, of this resin the hardness ions are removed by the resin and replaced with sodium ions. Thus when hardness is removed the hard water is changed to soft water.

The Resin Bead

Cation exchange water softening resins are insoluble compounds of polystyrene-divinyl benzene sulfonate. It may be visualized as a plastic sphere having tiny pores or microscopic channels through which water can pass. 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.

Figure 1 illustrates in extremely simplified form the porous structure of a cation exchange resin bead with its negative exchange sites holding on to a considerable number of sodium ions.

Figure 1.



The Exchange Process

The number of exchange sites occupied by a single cation depends upon the number of positive charges on the cation. For example, calcium and magnesium each have two positive charges so each occupies two ion exchange sites. Sodium, potassium, ammonium, and hydrogen have only one positive charge so each occupies only one site.

Before the softening process begins, sodium ions occupy all the exchange sites. As hard water passes around the resin beads, the hardness ions displace the sodium ions and occupy the exchange sites previously occupied by sodium. This interchange of ions is called ion exchange.

The process works best when the influent water is less than 1000 ppm total dissolved solids (TDS) because the resin bead has a greater affinity for hardness than it does for sodium. It is assumed that higher TDS waters often contain elevated levels of naturally occurring sodium. As the TDS concentration goes above 1000 ppm and the raw water contains more sodium the ion exchange becomes less complete and hardness leakage increases.

Each resin bead has a fixed number of exchange sites. As water is processed all the sites will become filled with calcium and magnesium ions. At this point the bead is exhausted and the calcium and magnesium ions have to be replaced with sodium so that the softening process can be repeated. The process of removing hardness ions and replacing them with sodium ions is called regeneration.

As noted the cation resin has a natural preference for hardness ions. While ion exchange resin beads are porous and will allow water transport through the structure it is unlikely that flow through the bead occurs in any significant fashion given the high flow rate designs used in today's water softeners. One theory is that the hardness first attaches to the outside or shell area of the resin and as the bead becomes saturated the hardness migrates towards the core of the resin in a transfer phenomenon that goes from outside to inside.

Once the resin is fully saturated with hardness minerals we must recondition or "regenerate" the resin back to the sodium form. To overcome the preference of the resin to hold onto hardness minerals we must use a strong solution (high concentration) of sodium ions. The most common and economical sodium salt is sodium chloride (NaCl) and a brine solution is diluted and passed through the resin bead as approximately a 10% solution.

As noted earlier, hardness removal occurs best when total dissolved solids in the raw water is less than 1000 ppm. A 10% salt brine solution is 100,000 ppm. This high concentration of brine is strong enough to overcome the resin's affinity for hardness and place sodium ions on the exchange sites.

The exact number of exchange sites that sodium can occupy is called the stoichiometric quantity. Regenerating with this exact number of sodium ions that the resin can hold will not place sodium on all the exchange sites. It takes one and a half times the stoichiometric quantity, or 150%, of sodium in a 10% salt brine solution to place sodium on all the sites. Obviously, 100% of the stoichiometric amount is consumed as it sticks to the resin and 1/3rd is wasted. This explains why the softener regeneration waste contains salt.

Affinities

Due to the charge characteristics inherent in ion exchange resins, water softening resin does have preferences for certain ions. This preference is called selectivity or affinity and in general, cation (softening) resin has the greatest affinity for cations which have the largest number of positive charges. Secondly, within a group of ions having an identical number of positive charges, affinity will increase with increasing atomic numbers. For example cation resin will have a greater affinity for aluminum (three positive charges), than for calcium (two positive charges), than for sodium (one positive charge). The sequence below shows the order of affinity of Kinetico cation resin for some common cations.

Al > Ba > Ca > Cu > Zn > Fe > Mg > Mn > NH₄ > Na > H

Any ion in the sequence will displace any ion to its right. This characteristic of ion exchange resins can serve as a useful tool in processes aimed at separating one ion from another. It also creates a problem commonly referred to as breakthrough or leakage. It is quite possible that one ion can be released from the resin bed while another is still being taken on. The release of any unwanted ion can limit the extent of the softening application. For example, Kinetico cation resin holds calcium more tenaciously than it holds magnesium, so magnesium hardness will break through first from the softener.

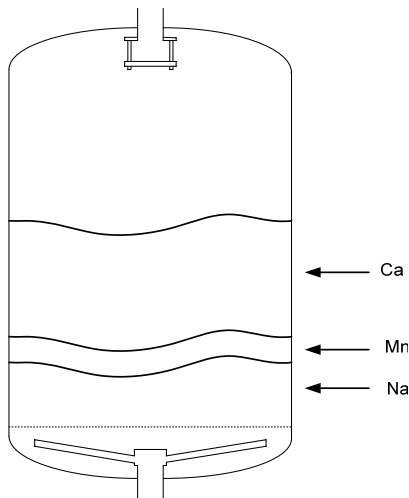
Reaction Zones

A water softener tank contains millions of resin beads in a bed, or column, which can be several feet thick in industrial applications.

As water passes downward through the resin, the ion exchange reactions begin at the top of the resin column in a thin reaction zone. As the top layers become full of hardness, as the bead become exhausted, the reactions continue farther down the column where beads are still in the sodium form. As this reaction zone progresses downward it increases in thickness. The actual thickness of the zone is determined by water velocity (flow rate), water hardness, and resin bead size. The reaction zone will vary and may be only a few inches thick under the right operating conditions.

When the leading edge of the reaction zone reaches the very bottom of the resin column, hardness leakage will occur and will continue to increase. When leakage increases to a predetermined level, usually dictated by the application, the column is considered exhausted and the resin must be regenerated. Ideally the softening process would go off line to regenerate just moments before hardness leakage could be detected.

Recalling the order of affinity the first hardness leakage will be primarily magnesium with some calcium present. Calcium displaces magnesium in the upper exhausted bed area forcing this magnesium to move further down into the resin column to find a new exchange site holding sodium. This calcium-magnesium exchange continues until water flow is stopped. If a vertical sample of the resin bed were analyzed in the lab, the top layers would be rich in calcium, the lower layers would be rich in magnesium, and the resin in between would contain both. This selectivity phenomenon is sometimes called stratification and is similar to chromatographic separation. If water continues flowing through the softener, all magnesium in the bed can eventually be replaced with calcium.



The wave front of hardness moves down through the bed until hardness is detected at the outlet.

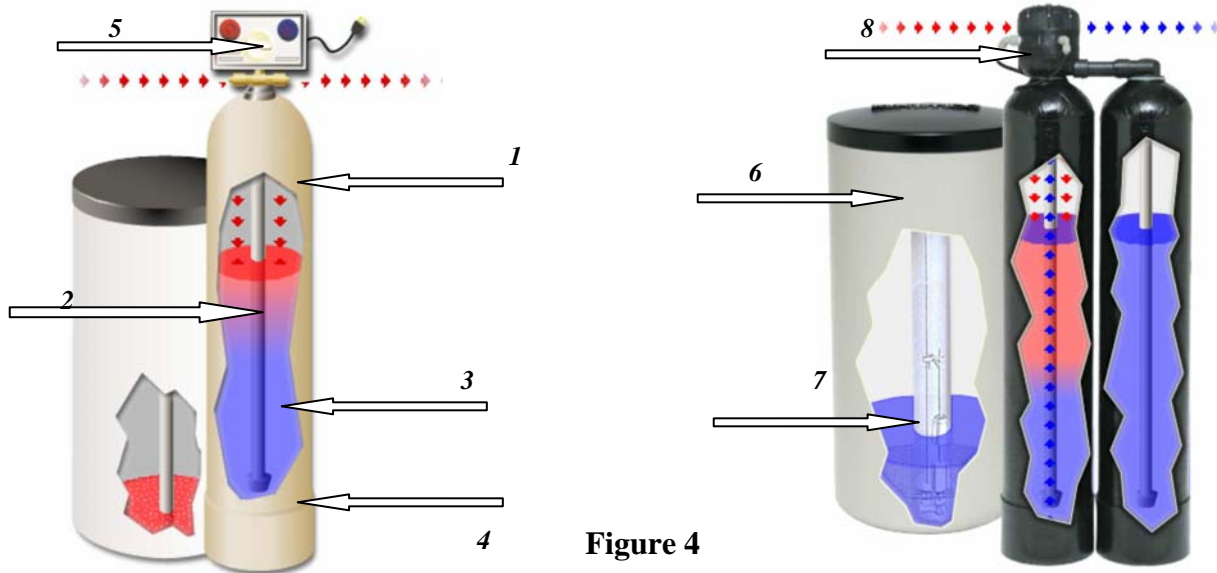
The hardness moves down through the resin in a wave front. The density of the wave front is influenced primarily by flow rate. Under high flow rate conditions the wave fronts spread out and the resin within the wave front is not completely exhausted. Thus under high flow rate conditions the bed will exhaust prematurely and the resin will not be completely exhausted.

To maximize resin capacity, system flow rates would ideally be kept to 5.0 us gallons per ft³ of resin. While this is the ideal flow rate it is common to run softeners up to a maximum of 20 us gpm per ft³ of resin for short periods.

Flow rate affects exhaustion characteristics and therefore it directly influences effluent quality. The higher the flow rate per ft³ of resin the higher the hardness leakage will be. See Hydrus softener sizing guide for guidelines on flow rate per ft³ of resin.

ION EXCHANGE SOFTENING EQUIPMENT

The amount of water to be softened directly influences the quantity of resin required to perform the job. Resin quantity is measured in cubic feet and the resin is placed in a pressure vessel equipped with piping and controls that direct the flow of water through the tank. Such a system will have the following basic components as illustrated in Figure 4:



Single Tank Electric

Kinetico Mach 2060s

1. A tank usually made of steel or fiberglass-reinforced plastic, to contain the resin.
2. A water distribution system in the tank to distribute the incoming water uniformly.
A water collecting system in the bottom of the tank to collect softened water and to uniformly distribute the backwash water.
3. The ion exchange resin bed.
4. Supporting media, or under-bedding, usually gravel, on which the resin rests (gravel can also be used in the brine tank).
5. External piping and valves (called a valve nest, valve harness, or multi-port valve) to direct The incoming water to the top of the tank, to receive softened water from the bottom and direct it to the service outlet, and to reverse the flow for bed cleaning (backwash) and send waste water to drain.
6. A brine system to produce and/or measure saturated brine.
7. Salt for making brine, usually rock salt.
8. Brine piping, eductor piping or pump piping, valves, etc. connecting the brine supply to the softener's external piping.

Tank diameters range from several inches to more than 10 feet. If corrosion is a concern tanks up to 62" inch diameter can be made of corrosion resistant materials, such as fiberglass-reinforced plastic. Larger tanks are typically made of steel and lined or coated internally with chemically resistant materials.

Internal distributors and collectors can be made of galvanized steel or PVC plastic pipe and fittings. Other materials such as stainless steel are generally too costly for most applications.

The external piping, valves, and controls can range from simple, manually operated valves to sophisticated, fully automatic systems involving sensors, meters, recorders, programmable controllers etc. The piping is generally copper or galvanized steel but it can be made from PVC if corrosion is a concern. Other, more exotic materials such as stainless steel, Kynar and PVDF are too costly for most applications.

The brine system can be a simple brine tank made of plastic or can be a large double concrete pit holding truckloads of salt where the brine is transferred by pump.

THE SOFTENING CYCLES

There are two procedures used for resin regeneration, the co-current method, and the countercurrent method.

Standard Kinetico softeners use the counter-current process. This regeneration procedure is simple and effective. It involves four (4) steps:

1. Brine (up-flow) with soft water
2. Slow rinse (up-flow) with soft water
3. Backwash (up-flow) with soft water
4. Purge or fast rinse (down-flow) with hard water

The single tank co-current units use a four step process:

5. Backwash (up-flow) with hard water
6. Brine introduction (down-flow) with hard water
7. Slow rinse (down-flow) with hard water
8. Final rinse or fast rinse (down-flow) with hard water

Note: often valves are called "5-cycle" valves and in this case the Service cycle is being included in the description.

Backwash

During a softening cycle the resin bed may accumulate turbidity or precipitated iron from the water supply. Also, the down flow service cycle compresses the bed somewhat. During the regeneration process there must be a reverse flush (up flow) cycle called backwash. It loosens the compacted bed and washes out collected dirt, sediment and resin fines.

The backwash flow rate must be sufficient to carry the dirt to drain through the upper distribution system, but not so great as to flush the resin out of the tank. Generally a resin bed expansion of 50% will do the job. This bed rise is a function of both flow rate and water temperature.

Brine Introduction

Brine is frequently introduced into the softener by means of an eductor (also called injector). An eductor uses the venturi principle to create a vacuum which draws saturated brine into the eductor where it mixes with water from the nozzle and leaves through the discharge connection. If the eductor is designed with a 2:1 ratio, it will use 2 gallons of water to draw 1 gallon of saturated brine, resulting in 3 gallons brine solution introduced into the softener unit.

Some very large softener systems use a pump to deliver brine to the softener. In that case, a matching dilution water flow is required to dilute the brine before entering the softener tank. This design is most frequently used on large softener installations, usually with bulk salt storage and/or a large saturator or brine pit.

The quantity of brine drawn during regeneration is usually determined by either providing a specific volume of brine at the beginning of the brine cycle, which is drawn in until depleted, or by pumping saturated brine from a bulk container at a set rate for a set length of time until the desired volume has been delivered.

On small to medium sized softeners, brine volume is usually determined by the volume of water sent to the brine tank. Since a specific volume of water will dissolve a specific weight of salt, the volume of brine needed can be calculated from the amount of resin and the salt dosage. Volume can be controlled by a float valve or timed filling at a specific flow rate. Saturated brine can be pumped into a measuring tank, or a specific amount of water can be sent to a combination salt storage/brine measuring tank where the water comes into direct contact with the salt to produce brine.

Slow Rinse

When all brine has been drawn, water flow must continue to push the brine through the resin and eventually, to drain. This slow rinse ensures correct brine contact time by pushing the brine through the resin at the same rate as brine introduction. It allows the regeneration reactions to continue and it displaces the brine with fresh water. A one bed volume displacement (7.5 gallons for each cubic foot of resin), plus additional water equal to the freeboard volume, is adequate for the slow rinse.

Fast Rinse

Prior to a softener going back into service it must go through a “purge” or fast rinse cycle. Water is directed down through the bed at close to the normal service rates and discharged to drain as waste. This fast rinse flushes out any remaining salt. Rinse water in this step could have a continually diminishing amount of salt in the waste stream. After a short rinse the tank can be put back into service.

TYPICAL OPERATING CHARACTERISTICS OF KINETICO SOFTENER RESIN

Typical Types of Cation Resin

There two major types of cation resin, strongly acidic and weakly acidic. The terms "strong" and "weak" refer to the "strength" of the ionic reactions. Ion exchange water softeners use only the strongly acidic type of cation resin. Within the strongly acidic group there are several types based on the amount of DVB (divinylbenzene) used to crosslink the resin. DVB increases the resin's physical strength and its resistance to chemical breakdown from heat and oxidizing agents.

Cross linkage is expressed as a percentage, the most common being 8%, 10%, 12%, and 20%. All have the same basic chemistry of softening but each has slightly different characteristics that can be advantageous in special applications. By far the most widely used resins for water softening are 8% cross linked. The higher the cross linkage of the resin the stronger it is. The higher cross linking also reduces resin capacity as the cross linking structure reduces the number of available exchange sites.

Physical Properties

Kinetico softening resin is manufactured as dark brown spherical beads which are insoluble in all common solvents and the resin is stable at any pH from 0 to 14. Kinetico provides two mesh sizes. The first and most common type is a "standard" mesh resin with a US screen size ("mesh") of 16 by 40 mesh with a minimal amount of "fines" through 50 mesh (no more than 0.5%). This screen sizing results in low pressure loss through the resin bed.

The second type of softening resin used by Kinetico is a fine mesh resin. This finer material has a US mesh screen size range of 30 by 50 mesh. The higher the mesh size numbers the smaller the particle size. Kinetico's finer mesh resins are used in the packed bed, high efficiency products such as the Mach2020c softeners.

Kinetico resin is stable in temperatures up to 138°C (280°F). It is extremely resistant to physical stress and will not impart color or turbidity to the softened water. Standard mesh resin is shipped from the supplier in the sodium form and weighs about 24 kg (52 lbs) per cubic foot. Kinetico fine mesh resin is shipped in the potassium form which allows Kinetico to better pack the softeners at time of construction. The resins, if allowed to become totally dry will develop strains and cracks upon wetting. Therefore the resin should always be kept moist in storage. Freezing of the resin will cause ice crystals to form and expansion of the ice crystals could crack or break resin bead therefore resin should not be allowed to freeze. Frozen resin should be allowed to thaw slowly to minimize thermal shock thus reducing the percentage of resin that breaks.

Counter Current & Co-Current Regeneration

The most common method used to regenerate water softener resin is called “co-current” or down-flow regeneration. Most single tank softeners use raw (hard) influent water mixed with the brine to regenerate resin in a down-flow direction. This method requires the brine to displace all the hardness in the upper parts of the resin bed and “push” that hardness to drain down through the entire bed. If hardness is not entirely displaced through the bottom of the tank some hardness will be retained in the lower portions of the bed. To ensure no hardness persists in the bed the brining step must be complete and a generous amount of brine used.

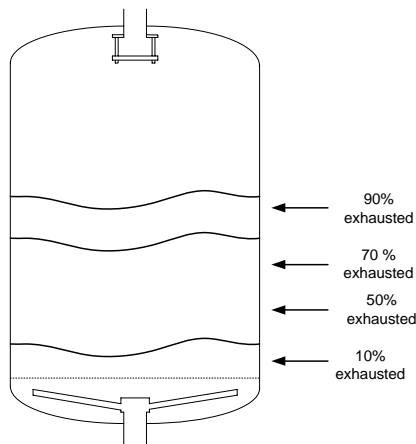
Conversely Kinetico most often uses an up-flow or “counter-current” brine system. Soft water containing the brine solution is introduced at the bottom of the softener vessel during regeneration. This up-flow regeneration eliminates the potential for hardness to be trapped at the lower portion of the bed. The counter current regeneration improves regeneration efficiency resulting in salt savings as well as improved water quality from the softener system.

Co-Current

The co-current regeneration method is the most common for softener regeneration because it is simple to perform in an automated fashion and somewhat effective.

In down flow service, exhaustion occurs when the bottom edge of the reaction zone reaches the bottom of the ion exchange bed. When hardness leakage occurs the resin at the bottom of the tank is only partially exhausted.

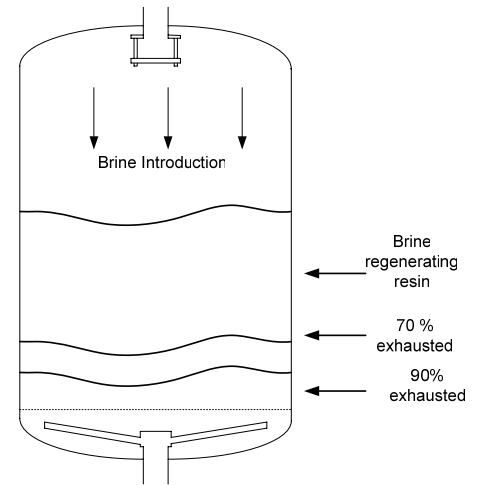
A common misconception is that during regeneration the brine causes the hardness to go into solution as it comes off the resin allowing it to be rinsed directly to drain. In fact during a regeneration brine pushes the hardness down through the resin bed exhausting the resin as it goes downward until it reaches the bottom of the tank then the hardness exits the tank to waste.



During service the softener will have the most exhausted resin at the top of the tank and resin in the lower section of the tank will not be exhausted. The varying degrees of exhaustion in the bed is influenced by water quality and service flow rate.

During the co-current regeneration hardness is pushed down through the bed therefore the resin at the bottom of the tank must be exhausted before all the hardness is pushed out of the tank. If the resin is not fully regenerated then residual hardness will reside in the bottom section of the tank resulting in leakage to service. It should also be noted that the salt dosage must be set to regenerate all the resin in the tank even if the bottom layer is not exhausted at the end of the run.

I.e.: A tank with 10ft³ of resin that requires 6.0 lbs/ft³ will require 60 lbs of salt to ensure a full regeneration even if the service run stops short of exhaustion.

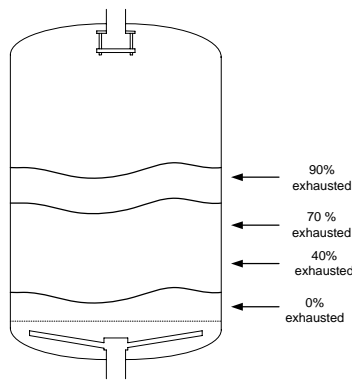


Counter Current

Counter-current regeneration is preferred in applications when an extremely low hardness leakage (better water quality) is required or where salt conservation is desired. Kinetico Mach series & Hydrus multi tank softeners all use the counter-current regeneration method.

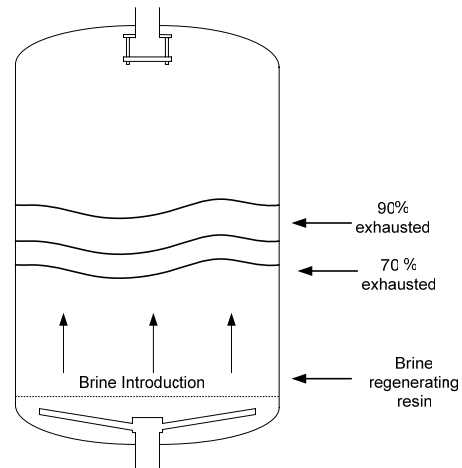
To improve both the efficiency and effectiveness of the regeneration salt must be dissolved in, and diluted with, hardness-free water. This brine is introduced up-flow (service is down flow, hence counter-current.) Slow rinse continues in an up-flow direction also with soft water, followed by backwash. Backwashing must always be done with soft water and the regeneration step is complete following a short down flow fast rinse or “purge”. The purge cycle settles the resin bed and rinses any residual brine that may be trapped in the resin. The purge cycle uses raw or inlet water.

All properly sized multi-tank Kinetico softeners will produce water as little as 1.0 mg/l of total hardness. To achieve the same water quality with a conventional co-current regenerating softener use of a primary softener unit followed by a second polisher unit installed in series is required. Salt dosage levels for co-current units must also be significantly increased to ensure complete regenerations if water quality is of primary importance.



All down flow softeners will exhaust in a similar fashion. Resin at the top of the tank is most thoroughly exhausted while resin at the bottom of the tank is only partially exhausted.

When brining in counter current mode, resin is regenerated starting at the bottom with the least exhausted zones moving up to the most exhausted zones. By moving the hardness up from least exhausted to most exhausted zones salt is used more efficiently. If a unit does not completely regenerate the residual hardness is now at the upper portion of the bed and is less likely to leak to service.



The counter current regeneration capitalizes on the fact the resin in the bottom of the tank is not fully exhausted and this is the core reason the salt use (efficiency) is so great. If a softener tank is completely exhausted (influent equals effluent hardness) the counter current system offers no greater efficiency than a co-current system. A properly operating softener system should never run to total exhaustion therefore the counter current regeneration method will always provide the greatest efficiency.

Capacity

Kinetico standard mesh cation resin has an ultimate (theoretical) capacity of 43,000 grains per cubic foot. However, only about 75% of this capacity can be used efficiently through normal regeneration procedures when installed in equipment. To use any of the other 25% requires excessive amounts of salt and increased regeneration time and would only obtain very small capacity increases making such efforts economically undesirable. As the resin is never fully regenerated back to its “like new” state the resin will always contain residual hardness trapped within the core of the resin. There is no economical way to remove this residual hardness therefore the resin manufacturers advertise a maximum capacity per cubic foot of 30,000 grains. This advertised level of capacity is only obtained with extraordinarily high salt dosages and a system should never be sized at this capacity.

As previously discussed the most common method used to regenerate water softener resin is called “co-current” or down-flow regeneration. Conversely Kinetico most often uses an up-flow or “counter-current” brine system. The counter current regeneration using soft water improves regeneration efficiency resulting in salt savings as well as improved water quality from the softener system. (See Table 2 below)

Water softening resin is most economical to regenerate when it is not completely exhausted. The most efficient setting for regeneration utilizes 66% of the resins total capacity and will regenerate with 60% less salt than if run to exhaustion. In co-current or down flow regeneration systems the resin has a maximum capacity of 30,000 grains of hardness removal (as CaCO₃) per cubic foot when regenerated with 15 pounds of sodium chloride (salt) per cubic foot. When operated at its most efficient level the resin will give 20,000 grains of hardness removal while regenerating with only 6.0 lbs of salt per cubic foot of resin. Running a system at its most economical settings yields definite savings to the owner of the system. The use of counter current regeneration further lowers the salt used per cubic foot thus yielding savings for the operator of the water softener while simultaneously provides better water quality and co-current regenerating units.

Down-flow Brine "co-current regeneration"		
Exchange Capacity as CaCO ₃ Grains per Ft ³	Salt Dose Lbs/ft ³	Salt Efficiency Grains removed / lb of salt
20,000	6	3,333
25,000	10	2,500
30,000	15	2,000

Figures reflect capacity to a 17.1 mg/l leakage (1.0 gpg).

Up-flow brine "counter current regeneration"		
Exchange Capacity as CaCO ₃ Grains per Ft ³	Salt Dose Lbs/ft ³	Salt Efficiency Grains removed / lb of salt
20,000	4.32	4,622
25,000	6.00	4,166
30,000	7.92	3,787

Values taken from Mach2060s softener performance
Counter current systems typically operate at < 3.0 mg/ total hardness leakage.

Economy is important so the efficient use of salt is paramount to reduce operating costs. Salt efficiency is defined as either grains removed per pound of salt or expressed as the pounds of salt used to exchange 1000 grains of hardness. One calculation used is:

$$\frac{\text{Lbs. of Salt}}{\text{Capacity kgr/ft}^3} = \text{Lbs. of Salt/1000 Grains Capacity in Kgr.}$$

Examples:

$$\frac{15 \text{ Lbs. NaCl}}{30.0 \text{ kgr}} = 0.50 \text{ Lbs. of NaCl per 1000 Grains removed}$$

$$\frac{6 \text{ Lbs. NaCl}}{20.0 \text{ kgr.}} = 0.30 \text{ Lbs. of NaCl per 1000 Grains removed}$$

The above calculation shows that when a lower salt dosage is used in a co-current regeneration system capacity is reduced and less salt is used for each 1000 grains of hardness exchanged. In a co-current regenerating softener the lowest practical salt dosage is 6 lbs (2.7kg) of salt per cubic foot because salt dosages lower than this will not adequately regenerate the resin.

With the counter current regeneration of a Kinetico softener we can use lower salt dosages per cubic foot thus saving salt used per 1000 grains removed.

It should be noted that while co-current technology advertises an efficiency of 3,333 gr/ft³ this efficiency is rarely obtainable. Only on waters with < 10 gpg, no iron and at low flow rates might a co-current system be this efficient. While a system may be sold at this advertised efficiency more often than not the salt dose will be increased at time of installation to ensure proper run times and effluent quality.

Operating Costs

Let us assume a water to be softened contains 12 grains per gallon of hardness as CaCO_3 . Each gallon passing through 1.0 cubic foot of resin will consume 12 grains of the resin's capacity. Thus one (1) cubic foot of resin having a 30,000 grain capacity (when regenerated with 15 lbs of salt) will soften 9,500 Liters (2,500 gal) of water.

Capacity :- Total Hardness (gpg) = Gal. of Softened Water

Assume that salt costs \$0.07 per pound.

The salt to regenerate one (1) cubic foot of resin will cost \$1.05

(15 lbs. x \$0.07)

Thus, \$1.05 is the regenerant chemical cost for 2,500 gallons, which is \$0.42 per 1000 gallons of softened water.

\$1.05 :- 2.5 thousand gal. = \$0.42

Based on 30' bed depth, operating at 2 - 3 gpm per cubic foot of resin (gpm/ft^3), and water temperature of 60° F., minimum.

When examining softener economics the use of higher capacity, counter current regeneration will offer direct savings for the system owner. Let us assume a water to be softened contains 12 grains per gallon of hardness as CaCO_3 . Each gallon passing through 1.0 cubic foot of resin will consume 12 grains of the resin's capacity.

Thus one (1) cubic foot of resin having a 30,000 grain capacity will soften 2,500 gal. of water and will consume 8.0 lbs of salt to regenerate. Using the above equation:

Capacity :- Total Hardness (gpg) = Gal. of Softened Water

Assume that salt costs \$0.07 per pound.

The salt to regenerate one (1) cubic foot of resin will cost \$0.56 (8.0 lbs. x \$0.07)

Thus, \$0.56 is the regenerant chemical cost for 2,500 gallons, which is \$0.224 per 1000 gallons of softened water. Note that this is almost half the cost of the co-current system above.

Based on Mach 2060, operating at 2 - 3 gpm per cu. ft., and water temperature of 60° F., minimum.

Factors Causing Capacity Variations

The capacity values presented earlier are based on standard operating conditions. Deviations from those conditions will result in different capacity values. Here are some things that influence capacity:

- 1) Salt dosage per cubic foot
- 2) Brine strength introduced during regeneration
- 3) Regeneration contact time
- 4) Service flow rate
- 5) Bed depth
- 6) Hardness and/or sodium in the raw water
- 7) Temperature

Brine Strength

Research has found that brine concentrations between 7% and 14% yield the best regeneration results. A 10% brine solution is considered optimum in down flow brining and will give reasonable results.

Saturated salt brine contains 26.4% of NaCl by weight. As noted above, this is too strong and must be diluted before contacting the resin bed. The most common dilution method uses an eductor or “venture” to draw up the brine and dilute it at the same time to 10%.

Keep in mind that brine introduced at the top of the softener tank falls through the water in the freeboard area and is further diluted. In a Kinetico softener the counter current brine results in less dilution before contact with the resin. In large industrial softener units, a separate brine distributing manifold is placed about 6" above the resin bed to reduce the freeboard dilution.

A salometer reads in percent of saturation. A 100° salometer reading is obtained at the brine saturation point of 26.4%. A 0° salometer reading is obtained with water only. Table 3, below, gives some salometer readings at various brine percentages and can be used as a guide when testing a brine solution.

TABLE 3

Brine Concentration vs. Salometer Reading

SALOMETER READING	PERCENT BRINE
27°	7%
30°	8%
38°	10%
45°	12%
53°	14%
57°	15%

One gallon of water will dissolve approximately 3 pounds of salt at normal room temperature, yielding a volume of brine somewhat larger than one gallon. One gallon of saturated brine contains about 2.6 pounds of salt.

Brine Contact Time

The effect of brine contact time on ion exchange resins is an important consideration. Contact time is the time elapsed from the moment brine first contacts the resin until the moment the last of the strong brine has been rinsed out of the bed.

When brine introduction starts, all resin beads are full of, and surrounded by, water. As the brine contacts the beads, it enters each bead by the process of osmosis, accomplishing the exchange of hardness for sodium along the way. A significant amount of time (known as the reaction rate) is required for this to happen, hence the great importance of proper contact time. Generally in a brine introduction time of 20-40 minutes at a flow rate of 0.5 gpm per cubic foot is satisfactory.

There is no advantage to soaking the resin in brine and then washing out the salt rapidly. In such a procedure there is a chemical equilibrium set up between hardness within the bead and hardness in the brine surrounding the bead. With hardness remaining in the bead, we can expect less capacity and perhaps more hardness leakage.

Co-current units require the brine solution be introduced above a minimum flow rate or the heavy brine solution coming into the top of the tank will short circuit or “channel” into the resin causing an incomplete regeneration. This phenomenon does not occur with counter-current regeneration allowing for brine to be introduced more slowly.

Flow Rate

The velocity of water past the resin beads affects capacity. As previously noted the velocity of water through the bed affects the thickness of the reaction zone as well as effluent quality. The time required for the softening reaction to take place is always the same for any given temperature. Therefore, water at higher flow rates will flow past more beads, increasing the thickness of the reaction zone.

When the leading edge of the reaction zone reaches the bottom of the resin bed the softening run needs to be terminated. At high flow rates the thicker reaction zone contains more unused capacity and is a larger percentage of the whole resin column than a normal reaction zone is. Higher flow rate means lower capacity. Fortunately this capacity loss is small - usually less than 5% - and frequently is included in the equipment design calculations. However high flow rates will result in increased hardness leakage. In applications where effluent quality is of paramount concern, flow rates per ft³ of resin should be conservative. See Hydrus softener sizing guide for recommended loading rates per ft³.

There are minimum recommended flow rate requirements for ion exchange softener systems. This subject concerns hydraulic performance rather than ion exchange. If the velocity through a tank is too low, there is not enough pressure loss through the resin to cause the water to distribute evenly across the bed. In low flow situations the water will seek a path of least resistance on its way to the bottom of the resin bed and this phenomenon is called channeling. The way to avoid this problem is to use a flow rate greater than by 2.2 gpm per square foot of tank cross-sectional area.

To calculate the area of the tank is $\pi \times r^2$:

(Tank Diameter (ft) \div 2) \times 2 \times 3.14 = tank area in ft²

Area in ft² \times 2.0 gpm/ft² = minimum softener flow

Example:

13" tank (as in a CP213s) has 0.92 ft^2 = therefore 2.0 gpm per tank is the minimum flow

Or

60" diameter tank has 19.6 square feet of area. $19.6 \text{ ft}^2 \times 2.0 \text{ gpm/ft}^2 = 43.0 \text{ gpm}$.

This calculated minimum service rate will assure even distribution across the entire bed area. Short periods of low flow are not the concern but long term operation below minimum flow rates will exhibit higher hardness leakage and premature hardness breakthrough.

If channeling has occurred and leakage is observed, increasing the flow rate at that time will not cure the problem because hard water continues to flow through the exhausted channel. One remedy is a very brief backwash to upset the channel. Otherwise the unit has to be regenerated

Bed Depth

The effect of bed depth can be better understood if we consider reaction zone phenomenon. Under normal operating conditions and at the same temperature, the reaction zone will nearly always be the same thickness no matter where it is in the bed. This means that at exhaustion this reaction zone contains unused capacity which is a certain percentage of the total bed capacity. More resin in a tank simply means more run time to exhaustion. A deeper column of resin also adds hydraulic restriction causing an increased pressure drop through the softener system.

Hardness and Sodium

High TDS and high hardness water causes the normal reaction zone to become thicker. A thicker reaction zone at the termination of a softening cycle results in lower capacity.

Some high TDS waters also contain significant amounts of sodium, sometimes as much as 2 to 9 times more sodium than hardness. When the sodium-to-hardness ratio is high, especially at 800-1000 ppm and above, the sodium has a repressive effect on capacity because it disturbs the equilibrium ratios. The sodium attempts to regenerate the resin at the same time the resin is trying to take the hardness out of the water.

Temperature

Temperature influences all chemical reactions including ion exchange. Colder temperatures slow the reaction rate and a water supply having a temperature near freezing could reduce resin capacity by as much as 12%. Kinetico high temperature softeners are designed to operate at a maximum temperature of 71°C (160°F).

Bed Expansion

When water flows upward through an ion exchange resin bed, it lifts the resin beads until the upward thrust of the liquid (water) is countered by the pull of gravity. The upward movement of the bed is called bed expansion or bed fluidization.

The distance a bed raises above the level of the static bed is called bed rise. Bed rise divided by bed depth multiplied by 100 is the percent bed rise. In other words, the amount of bed rise is given as a percent of the bed depth. If the bed depth is 30" and bed rise is 18", the percent bed rise is 60%. This means a tank with at least 48 inches of side-sheet or side-shell (30" static bed + 18" bed rise) is required to accommodate this expansion.

The amount of bed expansion is a function of the bead size and weight, and the liquid's flow rate, density, and temperature. If the liquid is something other than water, such as brine or sea water, then its greater density will cause greater bed expansion. Temperature also governs a liquid's density.

Bed expansion is used to lift the bed, separate the beads and dislodge any solids or debris caught in the resin bed. In some high efficiency Kinetico softeners the resin beds may be a packed design which eliminates bed expansion during the up-flow brine introduction. By keeping the bed tightly packed during the regeneration the efficiency of the regeneration is improved by eliminating the space between the resin beads. The lack of freeboard in the top of the tank does not allow for accumulation of debris therefore the packed bed Kinetico softeners should be pre-filtered to prevent a build up of contaminants in the softener unit.

Water temperature can vary with the season and geographic location. Cold water is dense and more viscous than warm water and causes greater bed rise than warm water (Figure 3, following page).

For example, at a 5 gpm per square foot up-flow rate, the bed rise at 70°F (21°C) is 45%, but at 40°F (4°) it is 83%. In large industrial applications or tanks that have been filled with little free board assuming those installations having summer to winter temperature swings, the backwash rate should be adjusted seasonally. In normal residential and commercial applications the amount of freeboard is sufficient to accommodate seasonal temperature variations.

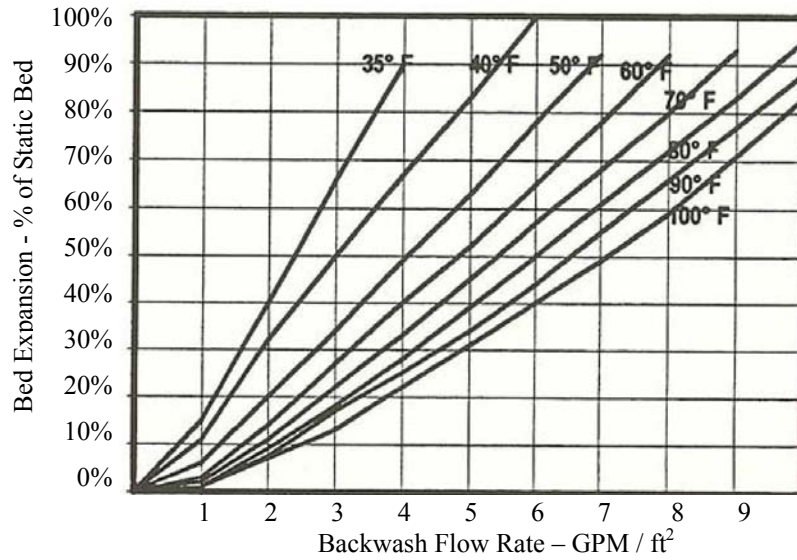
To use the bed expansion curves, select the percent expansion needed, then move to the right to the curve for the temperature of the water. Then drop down to find the flow rate in gallons per minute per square foot. Multiply this rate by the bed surface area in square feet to find the flow rate for backwashing that unit.

Smaller beads are lighter so they rise the highest. Larger beads will not rise as much as the smaller beads. During an up-flow brine operation, the smaller beads migrate toward the top of the resin bed and the larger beads migrate toward the bottom. This stratification of the bed according to bead size and weight can be observed.

Note that resins having different screen grading and/or different density will have a different set of bed expansion curves than the ones listed below. In some cases a tank may be "overfilled" to provide additional operational capacity. Overfilling a tank can cause resin loss during backwash. A counter current softener equipped with an upper distributor will not have resin loss as resin will be retained by the upper distributor. However, resin may lodge into and around the upper distributor during backwash causing poor backwash characteristics for the softener unit. Overfilling should only be done on clean municipal designs if possible.

Bed Expansion Data for Standard Mesh Kinetico Cation Resin

Figure 3



SPECIAL PROCESSES

Iron Removal

Iron most often exists in two ionic forms as well as in its metallic state. In its ionic form, as a cation having two positive charges (ions) it is called ferrous iron. When dissolved in water it is usually present as the salts ferrous bicarbonate, $\text{Fe}(\text{HCO}_3)$, or ferrous sulfate, FeSO_4 . Ferrous iron and both soluble forms of iron.

The second form of iron, found in the oxidized state, is called ferric iron, having three positive electrical charges. Ferric iron usually appears as the oxide or hydroxide in either colloidal or precipitated form. Colloidal iron gives water a persistent rusty color throughout the water while the precipitated iron forms rusty sediment.

Ferrous iron tends to become oxidized (convert to ferric) when exposed to dissolved air. Clear at first, it turns yellowish and slightly hazy (colloidal iron), then continues to become more cloudy and reddish (or rust-colored). If allowed to stand long enough, the rusty ferric iron precipitate grows in particle size until the ferric oxide (or ferric hydroxide) is large enough to settle to the bottom of a container.

Soluble ferrous iron is in solution like calcium and magnesium, and will be removed from the water by a water softener. If the iron exchanged into the resin bead remains in the ferrous form, it can be regenerated off with NaCl during the normal regeneration phase.

Often ferrous iron becomes oxidized to the insoluble ferric form while in the resin column by naturally occurring air dissolved in the water. Oxidized iron coats the surface and plugs the pores of the resin bead. The salt brine used for regeneration becomes ineffective and softening capacity is lost. This type of iron fouling occurs more frequently with well waters which contain more soluble iron than do surface waters.

Obviously, if the iron is already in the insoluble ferric state, it should be removed before entering the water softener. This insoluble iron can be handled by any of Kinetico's Macrolite filtration processes used for turbidity removal.

Occasionally a water supply contains iron that is combined with complex organic compounds, which may be either soluble or in colloidal form. This iron is sometimes called complexed iron or chelated iron. The water can be clear or slightly turbid and may have a yellow cast. This form of iron, even when soluble, will not be removed by softening and this form of iron, over time, can also cause resin fouling. Pretreatment of chelated or complexed iron with strong oxidizing agents (chlorine, potassium permanganate, etc.) can sometimes oxidize the iron to its insoluble ferric (rust) form allowing it to be filtered out.

Ion exchange resin's tolerance for iron is limited. This limit is expressed in the "eight-to-one ratio" rule, which states that there should be no more than 1 ppm of iron for each 8 gpg of hardness in the water supply. Divide the hardness by the iron: if the answer is 8 or more, the ratio is okay and the water can be softened normally. If ratio is less than 8.0 : 1.0 then additional or special treatment is needed.

If the iron content is more than 5.0 ppm the 8:1 rule does not apply. Where the iron content is greater than 5 ppm, but less than 20 ppm the regular use of resin cleaning chemical will protect the resin from iron build-up. In all applications where iron is more than 5.0 ppm filtration to remove ferric iron is recommended. Kinetico softeners have been successfully employed on source waters with up to 50 ppm (mg/l) of total iron. While applying softeners on 50 ppm of iron is not recommended it does further demonstrate the reliability of the counter current regeneration.

Severely fouled resin can be cleaned up by treating it with hydrochloric (Muriatic) acid. Such a procedure has a number of highly undesirable side effects as hydrochloric acid vigorously attacks the tank, controls and piping normally used in water softener construction. This means the resin may need to be removed for treatment. When acid treatment is finished, the resin is in the acid state and must be put back into the sodium form before it can be used. Acid cleaning should be performed only by trained Kinetico service personnel.

An alternate clean-up procedure uses resin cleaning chemical along with brine. Resin cleaner such as metabisulfite is a strong reducing agent that converts ferric iron to the ferrous form, allowing the brine to exchange it off of the resin.

Manganese can also exist in soluble and insoluble forms but behaves quite differently than iron. When present in a water supply it is almost always in a soluble, ionized form and therefore, can be removed by ion exchange. It can also be regenerated off by normal brine regeneration. Manganese is typically not oxidized and precipitated unless the pH is raised to about 9.5 or above.

Special Regenerants

Most softening applications utilize sodium chloride as the regeneration salt. Sodium chloride is readily available and relatively low in cost. In the event that sodium is undesirable in the ion exchange process other salts may be used. Potassium chloride (KCl) has been used as a regenerant in softening water. The dosage must be increased to use 1.28 lbs. of KCl in place of each pound of NaCl to achieve the same capacity. The soft water will then contain potassium ions in place of sodium ions.

MISCELLANEOUS NOTES

Raw Water Quality Limitations

Ion exchange resin is an organic material and, as such, is subject to oxidation by strong oxidizing agents such as chlorine, ozone, hydrogen peroxide, potassium permanganate, and others. These oxidizing substances should be kept away from resin to prevent its deterioration. Free chlorine is widely used in municipal water supplies to kill bacteria and is frequently present in water to be softened. Ion exchange resin is a strong material and can tolerate continuous exposure to low levels of chlorine. Intermittent exposure of up to 4.0 ppm of chlorine is permissible. No limits are available for other oxidizing agents.

Oxidizing agents attack resin by breaking the cross-linking chemical bonds. The net effect of this is the opening up of the internal structure of the resin. When a laboratory resin report shows an increase in water retention capacity it may indicate that the resin has been subjected to oxidation attack. The higher the oxidation potential of the water entering the softener the shorter the resin life will be.

Although not a particularly good mechanical filtration medium, resin can and does filter some turbidity. If too much "dirt" gets into the softener it is difficult, if not impossible, to remove it all. Therefore influent turbidity should be limited to < 5.0 NTU.

Lime Soda Softening

Lime-soda softening removes hardness from water by causing it to precipitate as an insoluble sludge. Lime, or calcium hydroxide - $\text{Ca}(\text{OH})_2$ - and sometimes soda ash, or sodium carbonate - Na_2CO_3 - are added to the water to react with the temporary hardness to produce calcium and magnesium compounds having a low solubility. They precipitate as a sludge which is drawn off and discarded.

This process is slow and requires large open-top, baffle tanks, typically 10 feet high and 10 to 30 feet or more in diameter. Flow rates per unit of area are low. It is a continuously running process that is not started up or stopped easily and if influent water quality varies the process must be adjusted to compensate for the changes.

The lime or lime-soda process can achieve product water quality in the range of 5 to 30 ppm total hardness (as CaCO_3), but it is not uncommon for the water quality to range from 50 to 70 ppm of hardness. The softened water will have elevated alkalinity with a pH over 9.0 possibly up to 10.0. Even though the water is filtered clear, some hardness may precipitate after the water leaves the treatment plant allowing it to collect in distribution piping. To counteract this potential many treatment plants add carbon dioxide a process called re-carbonation. Dissolving CO_2 in water forms weak carbonic acid that reacts with the alkalinity to lower the pH. Such plants usually strive to reduce pH to 8.0 .

The lime or lime-soda process is used only for large volume water treatment, such as municipal treatment plants or large volume industrial water users. Some industrial plants that have a large demand for soft water for boiler feed will install a hot process lime-soda softener particularly if the influent water is very hard. These softeners typically operate at temperatures approaching the boiling point. The high temperature causes faster, more complete chemical reactions and lower operating cost. These hot process units are frequently followed by an ion exchange softener. Such softeners require very special design and construction due to the elevated temperatures. Kinetico does not make such softeners. (Note: standard Kinetico hot water softeners are *not* suitable for this application.)

Other Resins

This document only discusses the use of standard mesh cation softening resin. Newer types of resins such as solid core (or shallow shell) resins may also be used in water softeners. These newer types of resins will have different performance characteristics and exhibit different capacities.

Sizing

Use published sizing guides or contact Kinetico to assist in selecting the right equipment for each application. Gather some basic information before going through a sizing exercise:

1. A water analysis giving total hardness, iron, turbidity, pH, manganese.
2. Service flow rates, minimum, average, and maximum.
3. Gallons of softened water needed per regeneration; or the length of service needed at average flow.
4. Water quality needed.
5. Manual or automatic operation.
6. Continuous or intermittent flow.
7. Pressure available and pressure on the outlet side of the system.
8. Space for the unit - width, depth and height.
9. Access to the installation site, such as widths and heights of doors, aisles and ceilings.

For sizing of a water softener, see the “Hydrus Softener Sizing Guide”