Ion exchange water treatment

Objective

In this laboratory practice we will answer the following questions:

- What is hardness and why is hard water problematic?
- What methods can be used to soften and/or dealinate water?
- What are the advantages and disadvantages of ion exchange desalination?

I. Hard Water

What is Hard Water?

Hard water is usually defined as water which contains a high concentration of calcium and magnesium ions. Measurements of hardness are given in terms of the mg/L or mmol/L, or in calcium carbonate equivalent, which is an expression of the concentration of hardness ions in water in terms of their equivalent value of calcium carbonate. Water is considered to be hard if it has a hardness of 100 mg/L or more as calcium carbonate.

Hard water causes bathtub rings.

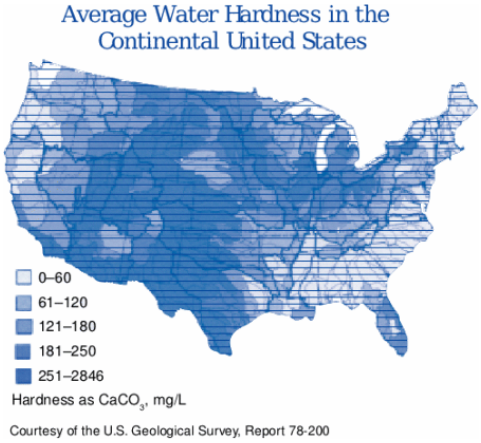
Softening is the removal of hardness from water. This is not a required part of the water treatment process since hard water does not have any health consequences. However, hard water is problematic for a variety of reasons. Hard water makes soap precipitate out of water and form a scum, such as the ring which forms around bathtubs. In addition to being unsightly, the reaction of hard water with soap results in excessive use of soaps and detergents. Hard water may also cause taste problems in drinking water and may shorten the life of fabrics washed in hard water. Finally, hard water harms many industrial processes, so industries often require much softer water than is usually required by the general public.

Calcium carbonate scale on a piece of pipe.

Excessively hard water will nearly always have to be softened in order to protect the water treatment plant equipment and piping systems. At a hardness of greater than 300 mg/L as calcium carbonate, scale will form on pipes as calcium carbonate precipitates out of the water. The scaling can damage equipment and should be avoided.

Sources of Hardness

Hardness generally enters groundwater as the water percolates through minerals containing calcium or magnesium. The most common sources of hardness are limestone (which introduces calcium into the water) and dolomite (which introduces magnesium.) Since hardness enters water in this manner, groundwater generally has a greater hardness than surface water. There are also regional variations in hardness, shown by the example map of USA below.



Since they are the two most widespread and troublesome ions in hard water, it is often said that hardness is caused by calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions dissolved in water. However, hardness can be caused by several other dissolved metals as well, including strontium (Sr^{2+}), iron (Fe^{2+}), and manganese (Mn^{2+}). You will notice that all of the hardness-causing ions are divalent cations, meaning that they have a charge of positive two. Metals such as sodium (Na^{+}) and potassium (K^{+}) with a charge of positive one do not cause hardness.

Types of Hardness As mentioned above, hardness in water is caused by a variety of divalent cations, primarily calcium and magnesium. These cations have a tendency to combine with anions (negatively charged ions) in the water to form stable compounds known as **salts**. The type of anion found in these salts distinguishes between the two types of hardness - carbonate and noncarbonate hardness.

Carbonate hardness compounds	Noncarbonate hardness compounds
Calcium carbonate ($CaCO_3$)	Calcium sulfate ($CaSO_4$)
Magnesium carbonate ($MgCO_3$)	Magnesium sulfate ($MgSO_4$)
Calcium bicarbonate ($Ca(HCO_3)_2$)	Calcium chloride ($CaCl_2$)
Magnesium bicarbonate ($Mg(HCO_3)_2$)	Magnesium chloride ($MgCl_2$
Calcium hydroxide ($Ca(OH)_2$)	
Magnesium hydroxide ($Mg(OH)_2$)	

As you can see in the table above, **carbonate hardness** is caused by metals combined with a form of alkalinity. As you may remember, **alkalinity** is the capacity of water to neutralize acids and is caused by compounds such as carbonate, bicarbonate, hydroxide, and sometimes borate, silicate, and phosphate. In contrast, **noncarbonate hardness** forms when metals combine with anything other than alkalinity.
Carbonate hardness is sometimes called **temporary hardness** because it can be removed by boiling water. Noncarbonate hardness cannot be broken down by boiling the water, so it is also known as **permanent hardness**. In general, it is important to distinguish between the two types of hardness because the removal method differs for the two.

When measuring hardness, we typically consider **total hardness** which is the sum of all hardness compounds in water, expressed as a calcium carbonate equivalent. Total hardness includes both temporary and permanent hardness caused by calcium and magnesium compounds.

Hardness Problems

In addition to having different removal methods, carbonate and noncarbonate hardness can cause different problems. Carbonate hardness is the most common and is responsible for the deposition of calcium carbonate scale in pipes and equipment. The equation below shows how this deposition is formed in the presence of heat:

Calcium bicarbonate → Calcium carbonate + Water + Carbon dioxide

$$\mathbf{Ca(HCO_3)_2 \rightarrow CaCO_3 + H_2O + CO_2}$$

In addition to the scale (calcium carbonate) produced, carbon dioxide resulting from this reaction can combine with water to give carbonic acid which causes corrosion of iron or steel equipment. In contrast, noncarbonate hardness is the culprit in forming soap scum. Noncarbonate hardness reacts with the carbonate alkalinity found in soap and detergents in this reaction:

Calcium sulfate + Sodium carbonate → Calcium carbonate + Sodium sulfate

$$\mathbf{CaSO_4 + NaCO_3 \rightarrow CaCO_3 + Na_2SO_4}$$

Softening Processes

Types of Treatment

There are several types of treatment processes which can be used to soften water. Each type is briefly described below. In later sections, we will discuss the two most commonly used processes - chemical precipitation and ion exchange - in more detail.

In each of the treatment processes, the goal is the same. Softened water should have a hardness of about 80 to 90 mg/L as calcium carbonate. If the water is softened further (as in the ion exchange process) then the hard water must be mixed

with the softened water to achieve the desired hardness. Excessively soft water can be nearly as problematic as excessively hard water since it causes corrosion of pipes.

Chemical Precipitation

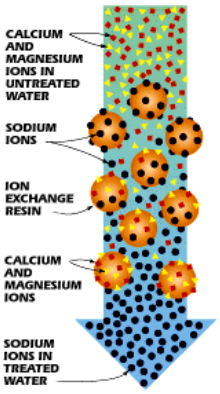
Softening through **chemical precipitation** is similar to removal of turbidity by coagulation, flocculation, and sedimentation. There are many variations, but the typical process involves adding lime to raise the pH of water until it is high enough for reactions to occur which prompt hardness compounds to settle out of the water. The equipment used also resembles turbidity removal equipment - lime is added in the flash mixer, the water is flocculated, and then the hardness compounds precipitate out in the sedimentation basin. As mentioned above, groundwater is more likely to need softening than surface water is. Groundwater also may not need flocculation to remove turbidity, so the softening process can sometimes replace the turbidity removal process. If both turbidity removal and softening are required, then the two processes can occur simultaneously, using the same equipment.

Chemical precipitation using lime will remove carbonate hardness. If soda ash is added as well as lime, both carbonate and noncarbonate hardness may be removed. In either case, chemical precipitation does not remove all hardness from water. The hardness can be reduced as low as 30 to 40 mg/L using chemical precipitation, although the typical goal is 80 to 90 mg/L. We will discuss the chemical reactions which occur in lime-soda ash softening in a later section.

Chemical precipitation is an effective softening process, but it does have some disadvantages. The process requires a lot of operator control to get an efficient result, which may make lime softening too operator-intensive for small treatment plants. The high pH used in lime softening can set colors in water and make them difficult to remove. Finally, lime softening produces large quantities of sludge which can create disposal problems.

Ion Exchange Softening

Ion exchange softening, also known as **zeolite softening**, passes water through a filter containing resin granules. In the filter, known as a **softener**, calcium and magnesium in the water are exchanged for sodium from the resin granules. The resulting water has a hardness of 0 mg/L and must be mixed with hard water to prevent softness problems in the distributed water.

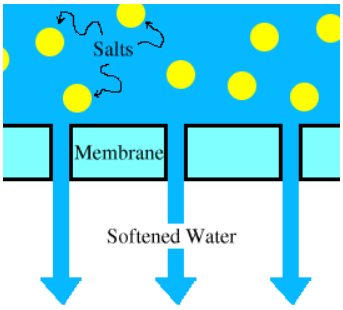


Ion exchange softening does not require the flash mixer, flocculation basin, and sedimentation basin required for lime-soda ash softening. In addition, the process does not require as much operator time. Ion exchange softening is effective at removing both carbonate and noncarbonate hardness and is often used for waters high in noncarbonate hardness and with a total hardness less than 350 mg/L.

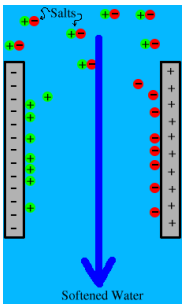
However, ion exchange softening has its disadvantages as well. The calcium and magnesium in the hard water are replaced by sodium ions, which may cause problems for people with health problems who are not supposed to eat any salt. Softeners have to be backwashed in a manner similar to a filter, and the recharge water, known as **brine**, can cause disposal problems.

Other Softening Processes

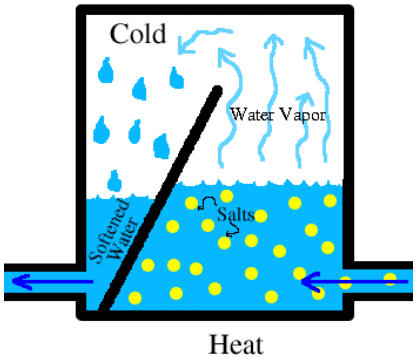
Other processes can be used to soften water, but they are generally expensive and only used in rare circumstances. These alternative processes are listed below.



Reverse-osmosis softening involves water being forced through a semi-permeable membrane. Calcium, magnesium, and dissolved solids are captured while the softened water is passed through the membrane.



Electrodialysis involves passing water between two plates with opposite electrical charges. The metals in the water are attracted to the plate with the negative charge while the non-metals are attracted to the plate with the positive charge. Both types of ions can be removed from the plates and discarded. Electrodialysis is used on very hard water, with a hardness of more than 500 mg/L as calcium carbonate.



Distillation involves the evaporation of water. The evaporated water leaves behind all hardness compounds, softening the water.

Freezing will also remove hardness.

Ion exchange

- reversible chemical reaction
  - insoluble solid (resin) and a solution (wastewater)
  - ions are interchanged
- Used only on dilute solutions

Ion exchange is an effective, versatile means of conditioning boiler feedwater. The term “ion exchange” describes the process:

- as water flows through a bed of ion exchange material, undesirable ions are removed and replaced with less objectionable ones.

For example, in softening processes, calcium and magnesium ions (hardness) are exchanged for sodium ions. In dealkalization, the ions contributing to alkalinity (carbonate, bicarbonate, etc.) are removed and replaced with chloride ions. Other dealkalization processes utilizing weak acid cation resin or strong acid cation resin in

a split stream process, exchange cations with hydrogen. This forms carbonic acid which can be removed in a decarbonator tower.

Demineralization is simply replacing all cations with hydrogen ions (H^+) and all anions with hydroxide ions (OH^-). Ion exchange materials are like storage batteries; they must be recharged (regenerated) periodically to restore their exchange capacity. With proper design and operation, ion exchange processes are capable of removing selected ions almost completely (in some cases to a fraction of a part per million).

The basic types of ion exchangers in use for water conditioning are listed in Table 1.

Table 1 — *Types of ion exchange materials*

Exchangers	Capacity kgr/ft^3
CATION	
Inorganic (zeolites)	
Natural (greensand)	3–5
Synthetic	12–16
Organic	
Sulfonated coal — (carbonaceous)	5–7
Synthetic – (phenolic types)	6–18
(styrene base)	20–30
ANION	
Inorganic	Not widely
Metallic oxides	used
Organic	
Synthetic resins	10–22

Cation exchangers

Cation exchange materials are classified as either weak acid or strong acid depending on the type of exchange group. Strong acid cation exchanger contain $–SO_3^-$ functional, weak acid cation exchanger contain $–COO^-$ functional groups. There has been constant improvement in ion exchange materials since the first use of natural and synthetic inorganic products. Sulfonated coal, styrene-base resins, phenolic resins and acrylic resins are some that have been developed. Exchange capacities were greatly increased with the development of the styrene-base exchangers. These resins are manufactured in spherical, stress and strain-free form to resist physical degradation. They are stable at temperatures as high as 300°F and are applicable over a wide pH range. More dense resins, those having greater degrees of copolymer crosslinking, were specially developed for heavy duty industrial applications. These products are more resistant to degradation by oxidizing agents such as chlorine, and withstand physical stresses that fracture lighter duty materials. Weakly acidic cation exchange resins contain carboxylic and phenolic groups. They remove alkalinity by exchanging their hydrogen ions for the cations associated with the bicarbonate ion (calcium, magnesium, and sodium bicarbonates). Being weakly acidic, they will not affect the cations associated with the anions of strong acids (chlorides or sulfates). Because of almost 100% utilization of the regenerant acid, chemical operating costs will be at a minimum, and there will be little excess acid to produce objectionable waste effluents.

Anion exchangers

Anion exchange materials are classified as either weak base or strong base depending on the type of exchange group. Weak base resins act as acid adsorbers, efficiently removing strong acids such as sulfuric and hydrochloric. However, they will not remove carbon dioxide or silica. They are used in systems where strong acids predominate, where silica reduction is not required, and where carbon dioxide is removed in degasifiers. Preceding strong base units in demineralizing processes, weak base resins give processes more economical removal of sulfates and chlorides. These are two general classes of strong base anion exchangers, Types I and II, denoting differences in chemical nature. Both remove silica and carbon dioxide as well as other anions. Type I is more effective in removing silica, and is used when the combined silica and carbon dioxide content of the water contacting the exchanger is more than 25% of the total anions. When there is contamination of the water with organic matter, a more porous form of Type I resin is recommended. The Type II anion material is used in treating waters where the combined carbon dioxide and silica content is less than 25% of the total anions. This is often the case when carbon dioxide is taken out in a degasifier ahead of the anion exchanger unit.

Table 2 — *Types of ion exchange processes*

Typical Minerals in Influent		Types of Exchanger		Minerals Converted to
(A) $Ca(HCO_3)_2$ $CaSO_4$	→ →	Cation [Na+] Exchanger	→ →	$NaHCO_3$ Na_2SO_4
(B) $Ca(HCO_3)_2$ $CaSO_4$	→ →	Cation [H+] Exchanger	→ →	H_2CO_3 H_2SO_4
(C) $Ca(HCO_3)_2$	→	Cation [H+] Exchanger (Weak Acid)	→	H_2CO_3
(D) Na_2SO_4 $NaHCO_3$	→ →	Anion [Cl−] Exchanger	→ →	NaCl NaCl
(E) H_2CO_3 H_2SO_4	→ →	Anion [OH−] Exchanger	→ →	H_2O H_2O
Conventional softening — process (A)				
Dealkalization by split stream softening — blending effluents from (A) and (B)				
Dealkalization by anion exchange — process (D) proceded by (A)				
Dealkalization by weak acid cation exchanger followed by conventional softening process (C) followed by (A)				
Demineralizing — combination of (B) and (E)				

Resin

Anion and cation resins can be obtained in several different physical forms. They can be obtained with different ions located on the exchange site. This has importance in applications such as mixed beds where minimal leakage rates are required even from

a newly installed bed. Particle size can also be specified. Uniform particle sized (UPS) resins are now available where all beads fit into a very close particle size range. For practical purposes, all of the beads are the same size. Beds of UPS resins have some unique operating characteristics which offer advantages when they are used in mixed bed, layered bed, and packed bed applications.

Macroporous resins are highly porous which give them advantages when used in processes that have high fouling potential.

ION EXCHANGE PROCESSES

Ion exchange processes fall into several categories: softening (including removal of iron and manganese), dealkalization, and demineralization. Examples of these processes are listed in Table 2.

Equipment operation

Ion exchange material is housed in specially constructed tanks (Figure 1) where it forms a bed, usually 30–60 inches deep. In some cases, it is supported by another bed of graded gravel or anthracite filter media. In other cases, some special methods of support, without gravel or anthracite, are used. During normal operation, water enters the top of the tank through a pipe, which distributes it over the surface of the exchanger bed. The treated water is drawn off by collector piping at the bottom. Several newer designs for ion exchange are now coming into common use. These are becoming popular because of their advantages of higher operating efficiencies and lower leakage rates. In countercurrent regeneration procedures, the regenerant flow is opposite in direction to the service water flow. Therefore, the resin located in the bed where the finished water leaves the vessel, is the most highly regenerated. This results in lower leakage rates and slightly higher operating capacities at equal regenerant dosages to cocurrent operated vessels.

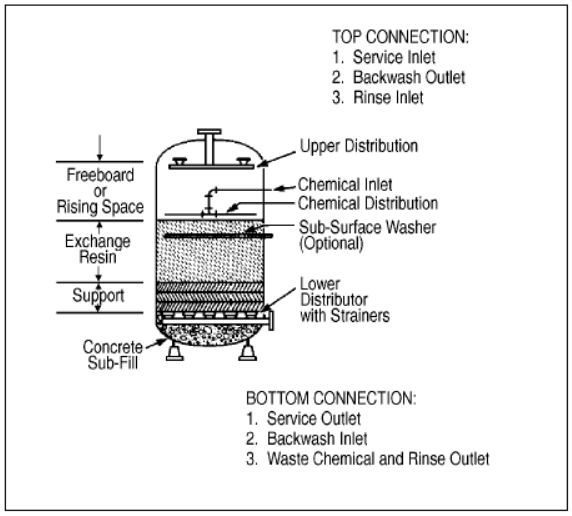


Figure 1 — *Typical ion exchange unit*

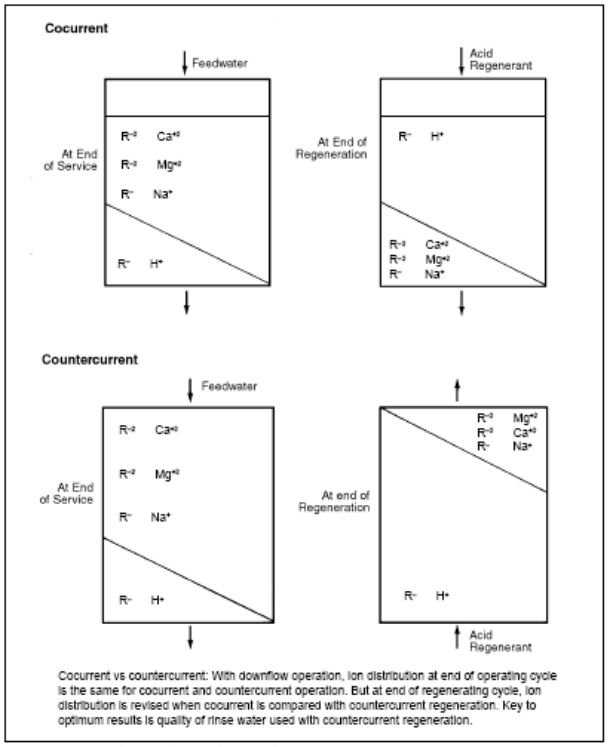


Figure 2 — *Cocurrent vs. countercurrent regeneration*

However, countercurrent vessels are more sensitive to operating problems. The bed must be immobilized during the regeneration process and the influent water must be very low in suspended solids. Figure 2 illustrates what happens in the two regeneration modes at exhaustion and after regeneration. Packed bed systems essentially fill the vessel with resin. The systems are countercurrent in design and offer the low leakage rate advantage. However, packed beds also offer the advantage of reduced waste generation. Since there is no space for proper backwash, packed bed systems usually are built with external backwash tanks which allow the resin to be backwashed after it is sluiced out of the operating vessel. All countercurrent ion exchange systems require feedwater that is very low in suspended solids. **Regeneration of the exchange material involves three steps:**

- backwash,
- introduction of the regeneration chemicals, and
- rinse.

Backwash is simply a reversal of the normal flow to wash out any suspended matter in the bed and to “fluff” the bed, to break up packed areas. This is done just before the unit is regenerated. During regeneration, chemicals are introduced at the top surface of the bed and removed through the bottom outlet. The rinse washes out the last traces of regenerant chemical.

Ion exchange units are usually installed in duplicate to permit continuous service during regeneration. Some typical equipment arrangements are shown in Figure 3.

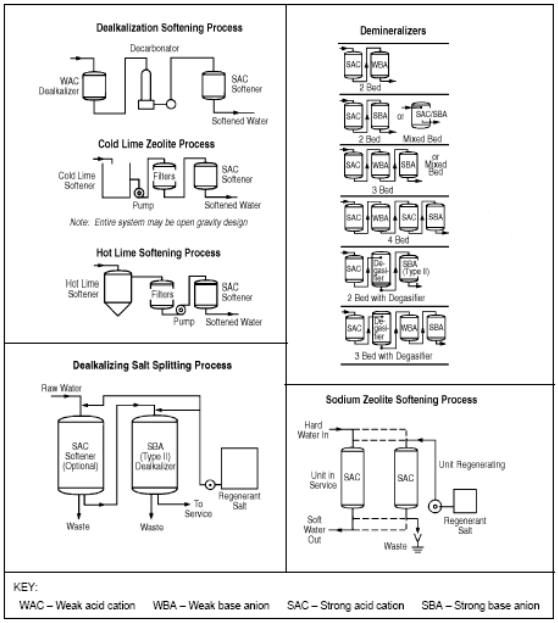


Figure 3 — Valve Typical equipment arrangements

Regeneration procedures

When regeneration is ineffective, the bed is usually fouled with suspended matter. This emphasizes the importance of proper backwash procedures. During backwash, the cation exchanger bed should expand at least 50%, while the anion exchanger bed should expand at least 75%. How much the bed expands depends on the backwash water temperature, backwash rate and density of the ion exchanger. Figure 4 shows the expansion characteristics of typical cation and anion resins.

The capacity of ion exchange material varies according to the amount and concentration of regenerating chemical used and the time the chemical contacts the exchanger. Selecting the optimum dosage level depends mainly on the quality of finished water required, considering both ec onomic and operating factors.

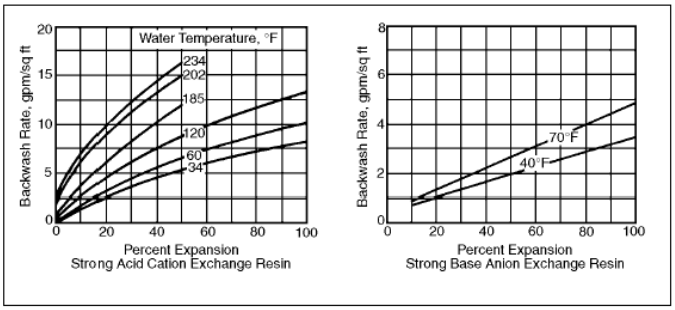


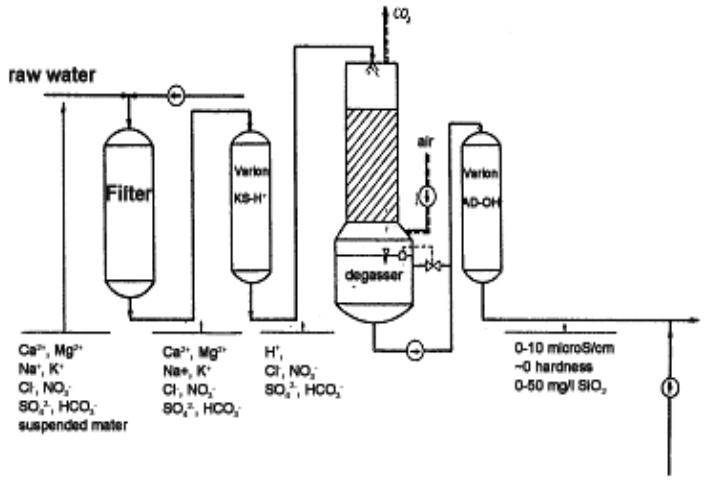
Figure 4 — Expansion characteristics of exchange beds

CONCLUSIONS

The use of ion exchange processes affords numerous efficient and effective means of conditioning feedwater. The proper selection of the specific ion exchange process depends on water quality needs, operating convenience, and economic considerations. For effective results, the system must be carefully selected, designed, operated and maintained. Because the decision is complex, an experienced ion exchange engineer should be consulted to assist in selection and design.

Measurement

Task: ion exchange demineralization of Budapest tapwater with two ion exchage columns. The first column contains 5ml strong acid Varion KS cation exchanger in H^+ form. In this column all cations (sodium, potassium, calcium magnesium etc.) will be exchaged to hydrogen. The effluent contain hydrogen cation and different anions (chloride, sulfate, nitrate, hydrogen-carbonate etc.) e.g. acids (hydrochloric-, sulfuric-, nitric-, carbonic-acids). If the raw water contain high hydrogen-carbonate concentration a degasser can be applied for CO_2 removal before anion exchange. After optional degassing the water flows through an anion exchanger column, filled with 6 ml strong base Varion AD anion exchanger in OH^- form. In this column all anions (chloride, sulfate, nitrate, hydrogen-carbonate etc.) will be exchaged to hydroxide. The excess of hydrogen and hydroxide ions react quickly into water.



Ion exchange demineralization

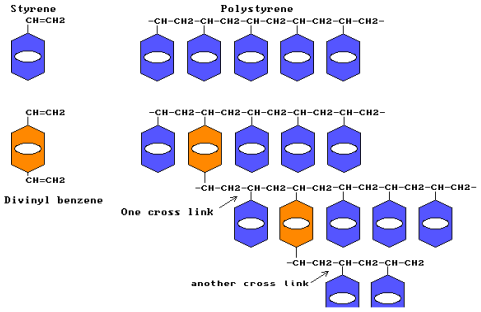
Measuerent:

1. **Start the pump to feed the columns with filtered tapwater**
2. **Measure continuously the effluent pH and specific conductivity after the cation exchange and after the anion exchange column. Register the measured data every 5 minutes together with the volume of the demineralized water in a table (see Appendix).**
3. **Continue the feed until breakthrough**
4. **Draw the volume of the demineralized water-pH and volume of the demineralized water-Specific conductivity curves and estimate the breakthrogh volume.**

Questions:

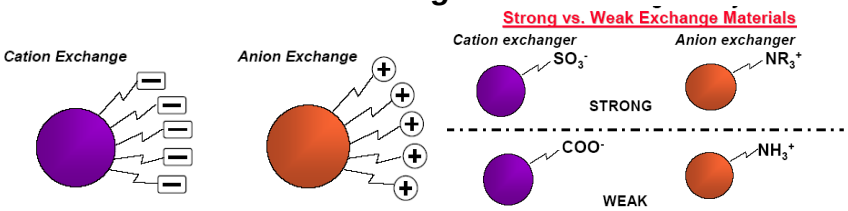
1. **What is the water hardness, and what types are known?**
2. **Sources of hardness**
3. **Softening processes**
4. **Ion exchange resin an process types**
5. **Ion exchange softening**
6. **Ion exchange demineralization**
7. **Sercice and regeneration of ion exchange columns**

Appendix

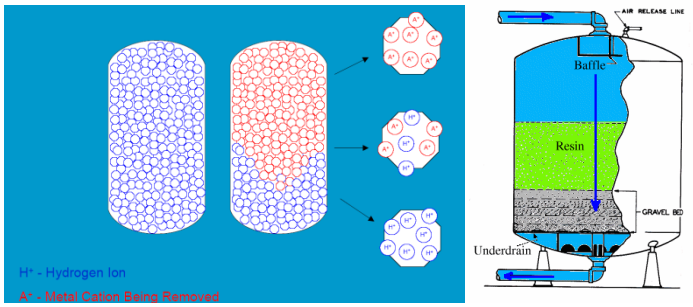


CROSSLINKING TO MAKE ION EXCHANGE RESINS

Ion exchange beads



Ion exchanger types



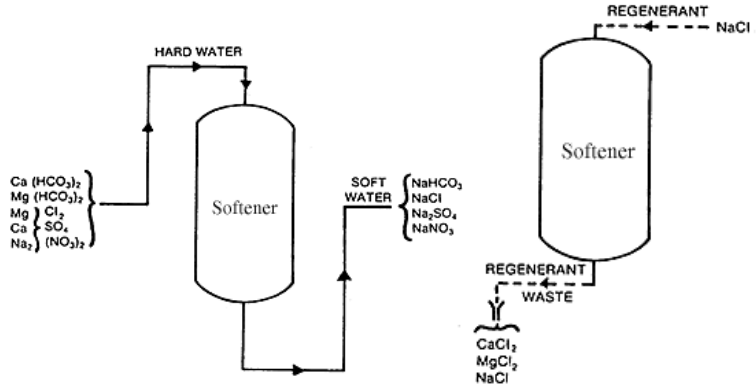
Cation exchange and an ion exchange column

In Order of Decreasing Preference	
Strong acid cation	***Strong base anion***
Barium	**Iodide**
Lead	**Nitrate**
Calcium	**Bisulfite**
Nickel	**Chloride**
Cadmium	**Cyanide**
Copper	**Bicarbonate**
Zinc	**Hydroxide**
Magnesium	**Fluoride**
Potassium	**Sulfate**
Ammonia	
Sodium	
Hydrogen	

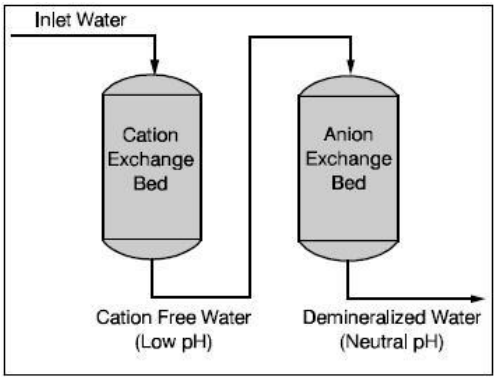
Types of Ion Exchange Operations

- **Batch Operation**
- **Moving-Bed Operation**
- **Fixed-Bed (Column) Operation**

Ion exchange softening



Service **regeneration**



Ion exchange demineralization

Treated Water Characteristics For Various Ion Exchange Systems

	Sodium Zeolite	Strong Acid Cation	Weak Acid Cation	Demin 2-Bed Weak Base	Demin 2-Bed Strong Base	Demin Mixed Bed
TH	0.3	0.1	Ca + Mg NCH	0.1	0.1	0.0
Ca	3.0	0.0	Ca NCH	0.0	0.0	0.0
M Alk	Unaff.	0.0	0.0	0.0	0.0	0.0
SO_4	Unaff.	Unaff.	Unaff.	0.0	0.0	0.0
Cl	Unaff.	Unaff.	Unaff.	0.0	0.0	0.0
SiO_2	Unaff.	Unaff.	Unaff.	Unaff.	0.1 to .20	0.1 to 0.5
PH	Slt. Inc.	2.5-3.5	4.3	5.6	8-10	7.0
Cond.	Slt. Inc.	6.5xTMA	2xTMA	5-20	5-10	0.5 to .25
FMA	0.0	1.0xTMA	0.0	0.0	0.0	0.0
Mg	3.0	0.0	Mg NCH	0.0	0.0	0.0

TMA = Total Mineral Acidity NCH = Noncarbonate Hardness

Table for Measured data

Time(in min)	Volume (in ml)	Effluent of cation exchanger		Effluent of anion exchanger	
		spec. conductivity (in (μS/cm)	pH	spec. conductivity (in (μS/cm)	pH

Conductivity: A measure of water's ability to conduct electricity in cooling water. It indicates the amount of dissolved minerals in water. Conductivity is measured in micro-mhos and can vary from a few for distilled water to over 10000 for saline water.

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pH: pH is the measure of the degree of acidity or basicity of solution. The pH scale ranges from O to 14, with zero being the most acidic and 14 the most basic or alkaline. Control of pH is critical for the majority of boiler water treatment programs.

Key indicators are:

- A change of one pH value represents a change of 10 times in relative acidity or alkalinity. For example, a pH of 4 is ten times more acidic than a pH of 5.
- Acids and alkalis have the effect of increasing the conductivity of water above that of a neutral sample. For example, a sample of water with a pH value of 12 will have a higher conductivity than a sample that has a pH value of 7.
- In general, when pH is below recommended ranges, the chances for corrosion increase and when pH is above recommended ranges, the chances for scale formation increase.
- According to ASME guidelines, the boiler water's level of pH must be maintained above 9.5 to ensure that the proper chemical reaction occurs between the calcium and magnesium ions and the phosphate molecules.

Alkalinity: Alkalinity is a measure of the bicarbonate (HCO_3), carbonate (CO_3), and hydroxyl (OH) ions in water. It is possible for these ions to exist simultaneously; though, only the bicarbonate and carbonate ions are found in natural water supplies.

Key indicators are:

- In boiler feedwater, two forms of alkalinity are the carbonate (CO_3) alkalinity and bicarbonate (HCO_3) alkalinity. Bicarbonate alkalinity is by far the most common.
- M alkalinity, or total alkalinity, is defined as the sum of carbonate, bicarbonate, and hydroxide.
- P alkalinity, or phenophtalein, is defined as one half of the carbonate alkalinity plus all of the hydroxide alkalinity.
- Carbonate and bicarbonate alkalinities can combine with calcium and magnesium hardness to form scale in boiler water systems.
- Alkalinity and pH are related because increase in pH indicates increases in alkalinity and vice versa.
- When water with carbonate or bicarbonate alkalinity is heated, the alkalinity is broken down to carbon dioxide. The CO_2 released, combines with the water to give carbonic acid, which can cause corrosion of the boiler internals. The corrosion products react further with alkalinity and the deposits can build up in the same manner as calcium carbonate scale.

- The presence of silica in boiler water can also lead to hard scale, which can react with calcium and magnesium salts to form silicates which can severely inhibit heat transfer across the fire tubes and cause them to overheat.
- Hardness is measured in grains or parts per million, with one grain of hardness being 17.1 ppm of these elements.
- The hardness is removed from the water by a process known as positive ion exchange. This process is also known as "ion substitution", where soft Sodium (Na+) ions are substituted or exchanged for the Calcium and Magnesium ions, as the water passes through the softener tank.

Hardness: Water is referred to as being either 'hard' or 'soft'. Hard water contains scale-forming impurities while soft water contains little or none.

Key indicators are:

- Hardness is composed primarily of Calcium (Ca++) and Magnesium (Mg++) minerals. These are primarily responsible for scale formation. The sum of these two is the total hardness.
- The total hardness is then broken down into two categories
  - *Carbonate or temporary hardness:* Calcium and magnesium bicarbonates are responsible for alkaline hardness. The salts dissolve in water to form an alkaline solution. When heat is applied, they decompose to release carbon dioxide and soft scale or sludge.
  - *Non-carbonate or permanent hardness:* This is also due to the presence of the salts of calcium and magnesium but in the form of sulphates and chlorides. These precipitate out of solution, due to their reduced solubility as the temperature rises, and form hard scale, which is difficult to remove.
- Hardness, particularly the temporary hardness is the most common and is responsible for the deposition of calcium carbonate scale.
- If the water is alkaline, a proportion of this hardness, equal in magnitude to the total alkalinity (expressed as $CaCO_3$) is considered as alkaline hardness, and the remainder as non-alkaline hardness.

The other important parameters are:

1) **Total Suspended Solids**: The measure of particulate matter suspended in a sample of water or wastewater. After filtering a sample of a known volume, the filter is dried and weighed to determine the residue retained. The amount of suspended solids measured in mg/l
2) **Total Dissolved Solids (TDS):** This represents all the dissolved constituents for e.g. Ca, Cl, and Na etc. It is measured in mg/l. The terms TDS and conductivity of water are interrelated.
3) **Total Cations:** Cations are metallic parts and carry positive charges -calcium, sodium, magnesium are attracted to the cathode.
4) **Total Anions:** Anions are non-metallic and carry negative charges - bicarbonates, carbonate, chloride, sulphate, are attracted to the anode.
5) BOD: Signify Biological Oxygen Demand and is measured in mg/l
6) COD: Chemical Oxygen Demand and is measured in mg/l
7) TOC: Total Organic Carbon and is measured in mg/l
8) Total Silica that is measured in mg/l of SiO_2
9) Turbidity: signify suspended matter in water or wastewater that scatters or otherwise interferes with the passage of light through the water.