

Ion exchange processes

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).

ION EXCHANGE MATERIALS

Ion exchange processes are versatile — specific types of ions can be removed from water depending on the choice of exchange material and regenerant used.

Development

Slightly more than 100 years ago, two English agricultural chemists, H. S. Thompson and J. Thomas Way, noted that certain soils had a greater ability than others to absorb ammonia from fertilizers. They found that complex silicates in the soil performed an ion exchange function. They were able to prepare materials of this type in the laboratory from solutions of sodium aluminate and sodium silicate. In 1906, Robert Gans used materials of this type for softening water. The early materials used were slow in regenerating and lacked physical stability. These first synthetic, inorganic exchangers were called zeolites. Today, zeolites are almost totally replaced by synthetic ion exchange materials. 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) (styrene base)	6–18 20–30
ANION	
Inorganic	Not widely used
Metallic oxides	
Organic	
Synthetic resins	10–22

Cation exchangers

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 cross-linking, 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

Table 2 — Types of ion exchange processes

Typical Minerals in Influent		Types of Exchanger		Minerals Converted to
(A) $\text{Ca}(\text{HCO}_3)_2$ CaSO_4	→ →	Cation Na^+ Exchanger	→ →	NaHCO_3 Na_2SO_4
(B) $\text{Ca}(\text{HCO}_3)_2$ CaSO_4	→ →	Cation H^+ Exchanger	→ →	H_2CO_3 H_2SO_4
(C) $\text{Ca}(\text{HCO}_3)_2$	→	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) preceded by (A)				
Dealkalization by weak acid cation exchanger followed by conventional softening process (C) followed by (A)				
Demineralizing — combination of (B) and (E)				

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.

Physical Characteristics of 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.

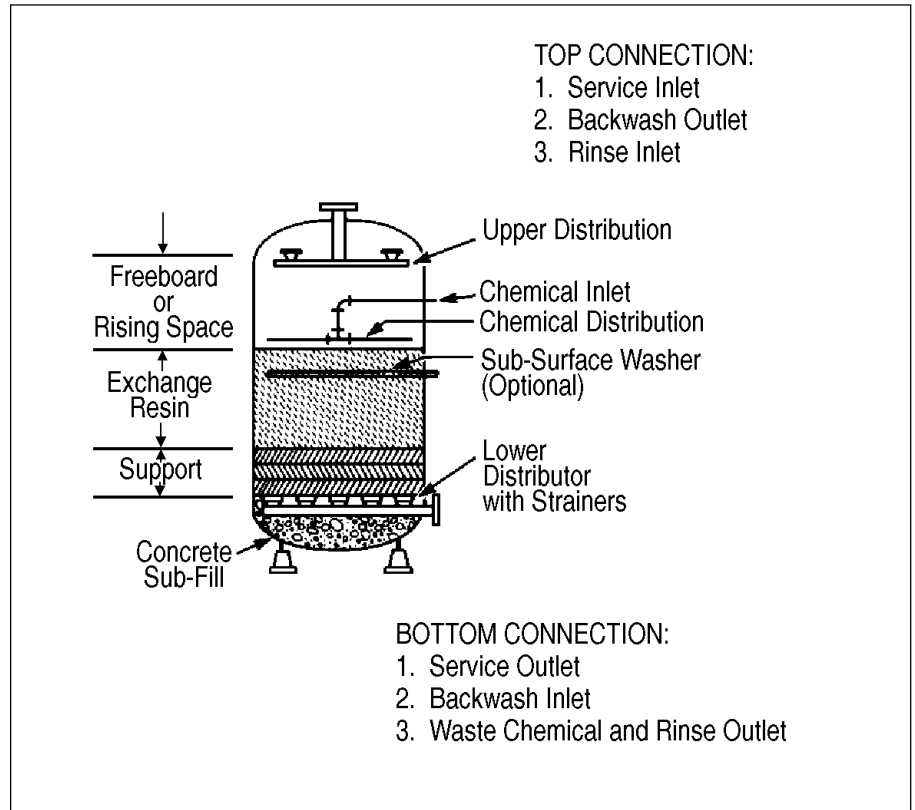


Figure 1 — Typical ion exchange unit

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.

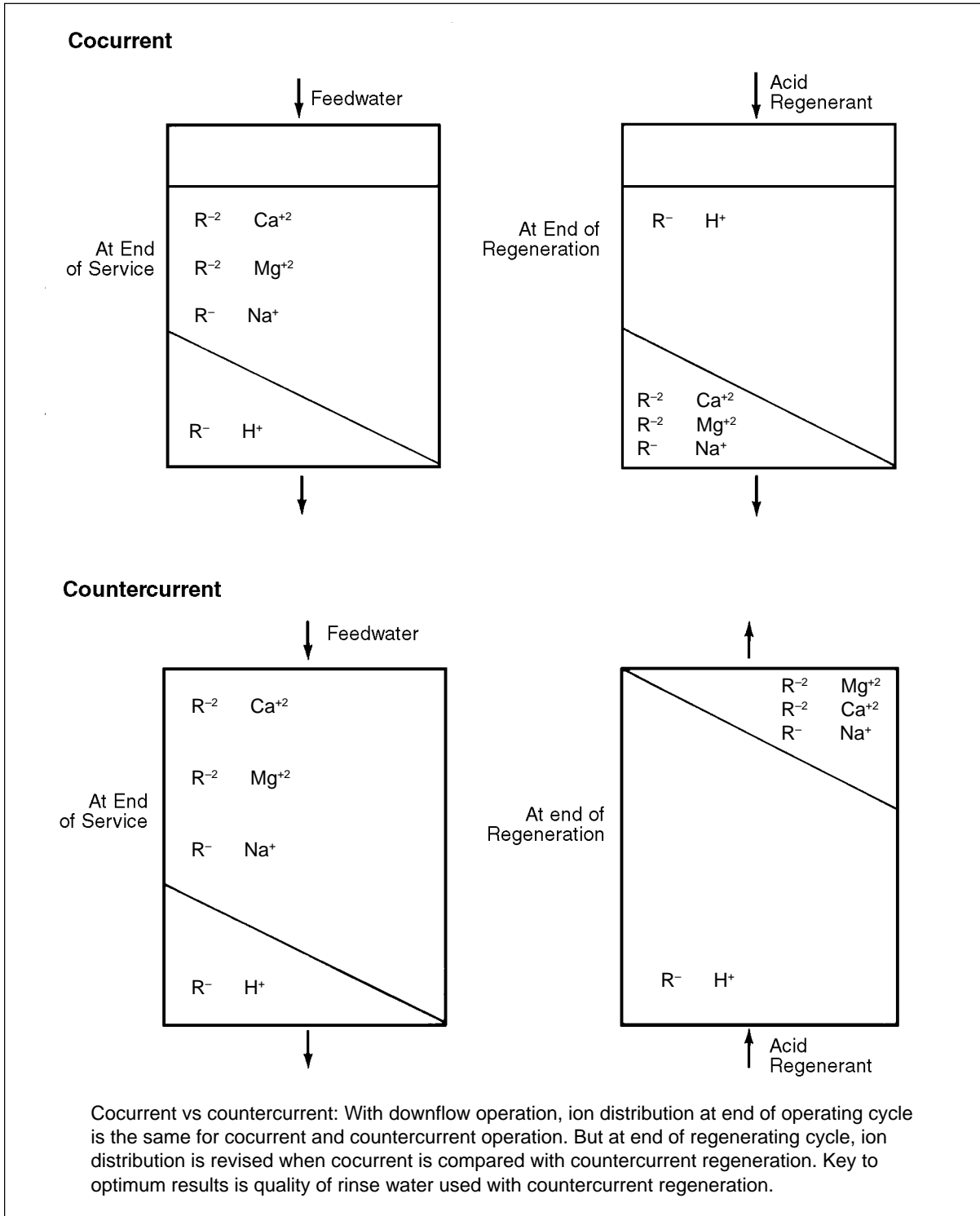


Figure 2 — Cocurrent vs. countercurrent regeneration

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.

Figure 3 shows valve arrangements on a salt regenerated unit. 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.

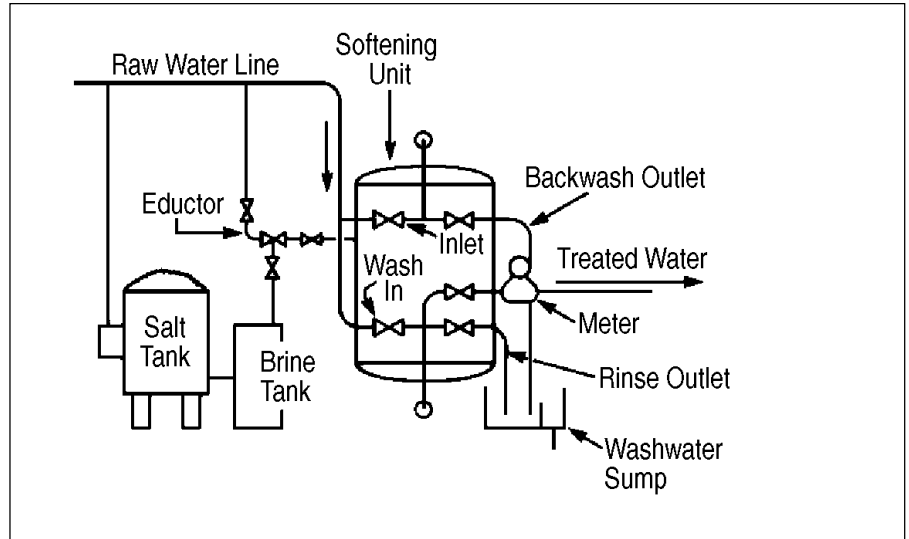


Figure 3 — Valve arrangements for regeneration with salt

Ion exchange units are usually installed in duplicate to permit continuous service during regeneration. Some typical equipment arrangements are shown in Figure 4.

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 5 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. Table 3 shows this variation in capacity with regenerant dosages.

Selecting the optimum dosage level depends mainly on the quality of finished water required, considering both economic and operating factors.

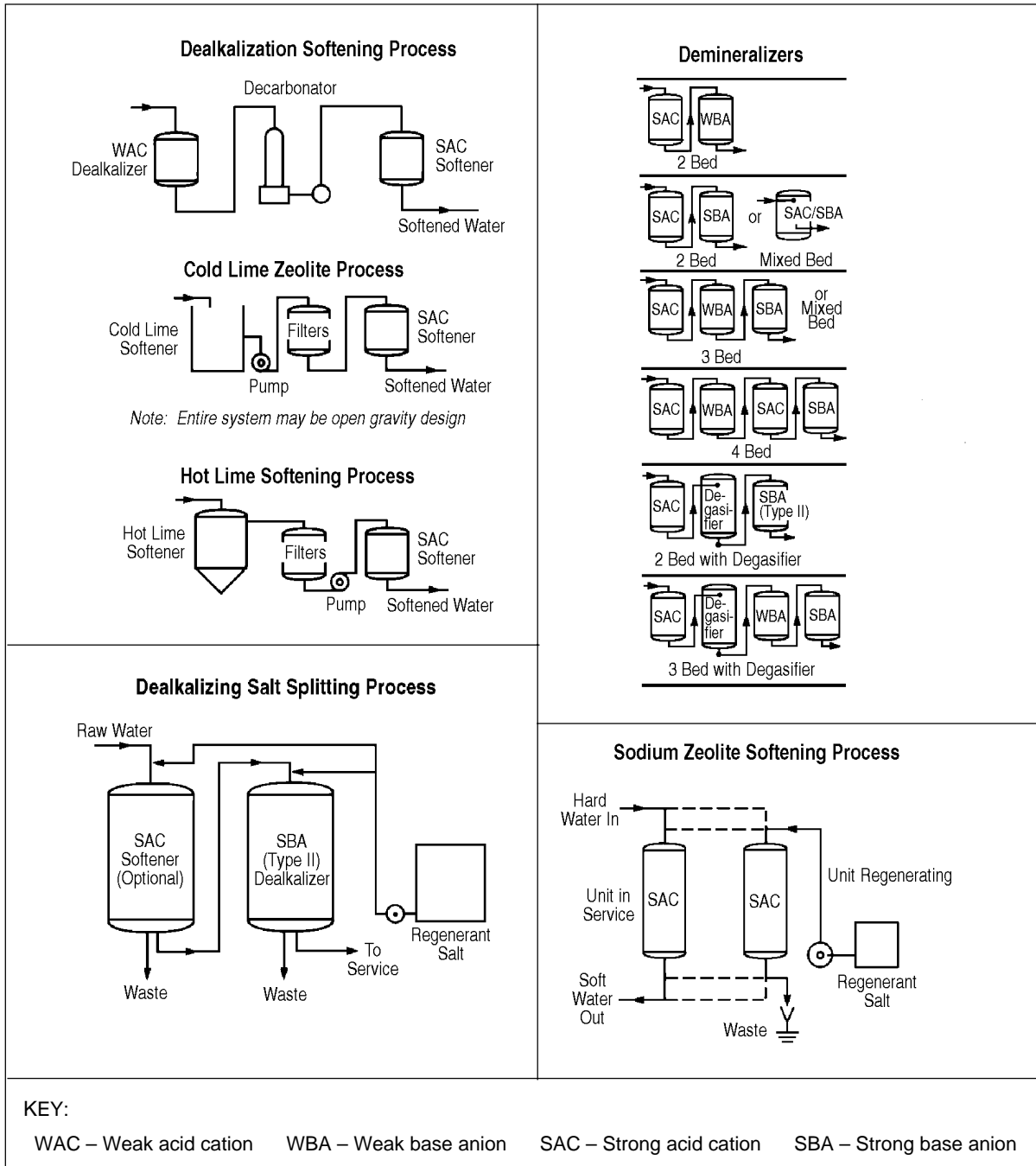


Figure 4 — Typical equipment arrangements

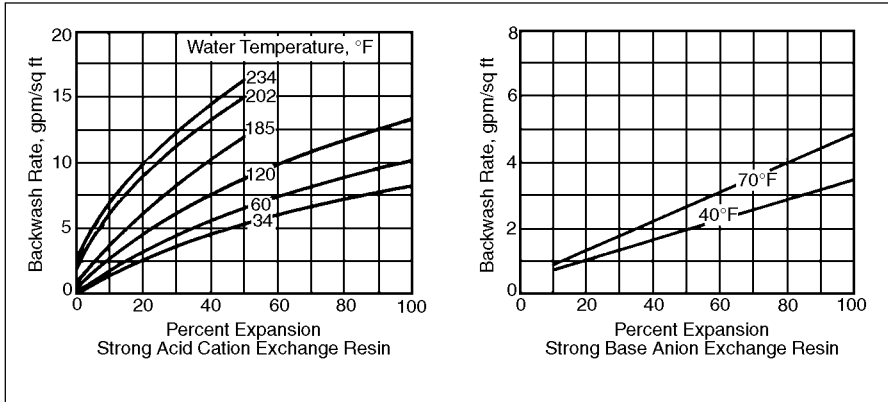


Figure 5 — Expansion characteristics of exchange beds

Table 3 — Effect of regenerant levels on exchange capacity

Exchanger Type	Regenerant	Regenerant Dosage (lb/ft ³)	Operating Capacity (kgr/ft ³)
Cation (high capacity)	Salt	6 – 8	20 – 24
		10 – 15	25 – 30
Cation (high capacity)	Sulfuric acid	4 – 6	10 – 12
		8 – 10	14 – 16
Anion (weak base)	Ammonia	1.5 – 2	20 – 22
	Caustic	3 – 4	20 – 22
	Soda ash	3 – 5	12 – 15
Anion (strong base)	Caustic	3.5 – 5	10 – 12

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.

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