

Boiler Feed Water

Reducing Scale and Corrosion,

Part 1 of 2

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Summary: A big part of ion exchange's use in commercial/industrial applications involves boiler feed water. This series takes a look at treatment methods using salt regeneration in Part 1 and more advanced chemical regeneration and treatment techniques in Part 2.

While taste, color and odor are the primary customer concerns with regard to residential water treatment, water quality is more than a matter of aesthetics when it comes to commercial/industrial uses.

What is clean water?

The truth is, our municipal water is safe for the most part and enhancement is a matter of taste. However, the human body is far more tolerant of many "impurities" contained in our water than are many industrial applications that use water in their manufacturing processes. This series addresses some of the limitations of raw water for use as boiler feed and common methods of treatment for reduction of scale and corrosion. Discussions are limited to treatment by ion exchange.

Water treatment needs

Manufacturers who heat or cool water in their processes soon discover strange things can happen to water when solubility parameters of salts and gasses it contains are exceeded. Ice becomes cloudy, cooling loops fill with sludge, soap curdles, boilers develop an insulating layer of scale, condensers plug with corrosion and foods develop an off taste and color. Most, if not all, industrial processes require some form of water treatment for system efficiency.

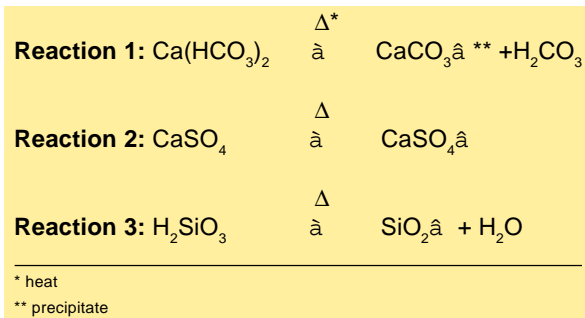
Volumes have been written on the various methods of pre-treating industrial water and none are complete. This article addresses only a few treatment processes—namely softening, dealkalizing and desilicizing raw feed water. The techniques described in this article are also applicable to laundries, ice and beverage production, food processing and others. It basically addresses removal of calcium, magnesium, alkalinity and silica to prevent scale and corrosion.

Causing the problem

The two most important reasons

for pre-treating boiler feed water are for reduction of scale and prevention of corrosion. Scale is caused by the precipitation of hardness and/or silica that's present in feed water. Corrosion is generally caused by presence of alkalinity that converts to carbonic acid in the steam. While corrosion can also stem from dissolved oxygen and/or other acid formers, we won't address those here.

Scale formation can stem from temporary hardness—that is 1) calcium, magnesium or ferrous bicarbonate; 2) permanent hardness, such as from calcium sulfate; or 3) hardness caused by precipitation of silica (see *Reactions 1, 2&3*).



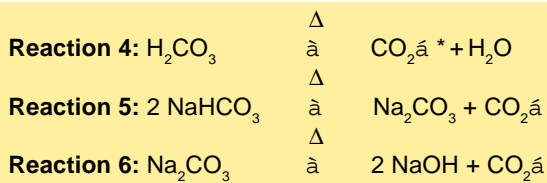
These are explained as follows. Calcium and magnesium bicarbonate decompose to carbonates upon heating. Calcium sulfate di-hydrate (natural gypsum)—which has fair

solubility in cold water (2,400 milligrams per liter or mg/L)—can precipitate out as gypsum scale in hot water above 100°F as it converts to the

(see *Reaction 5*). The carbonate salt can further react to form the hydroxide and CO₂ (see *Reaction 6*).

Therefore, most applications that produce hot water or steam find it's better to limit both hardness and alkalinity and in some cases, silica.

If we consider the purpose of treating boiler feed is to produce high purity steam, we can more readily



* gas

anhydrite form. Silica, which exists as a hydrated substance at room temperature, can form a glassy-like precipitate at elevated temperatures. Silica can also volatilize and carry over with steam.

Further, carbonic acid (from *Reaction 1*) volatilizes as CO₂ gas and water, which can re-condense as carbonic acid in the steam (see *Reaction 4*). Even softened water containing alkalinity (as bicarbonate) will produce corrosive steam, although the resulting Na₂CO₃ won't form scale

appreciate that the higher the pressure and temperature the more likely we are to carry over contaminants to the steam. In addition, we have more energy invested in producing higher temperature steam and would like to minimize the "blow down"—dumping part of the boiling water to reduce total dissolved solids (TDS)—to save money. It follows that the higher the boiler pressure the more we must limit the contaminants in the feed water. Keep in mind that boiling water can concentrate residual salts by a factor

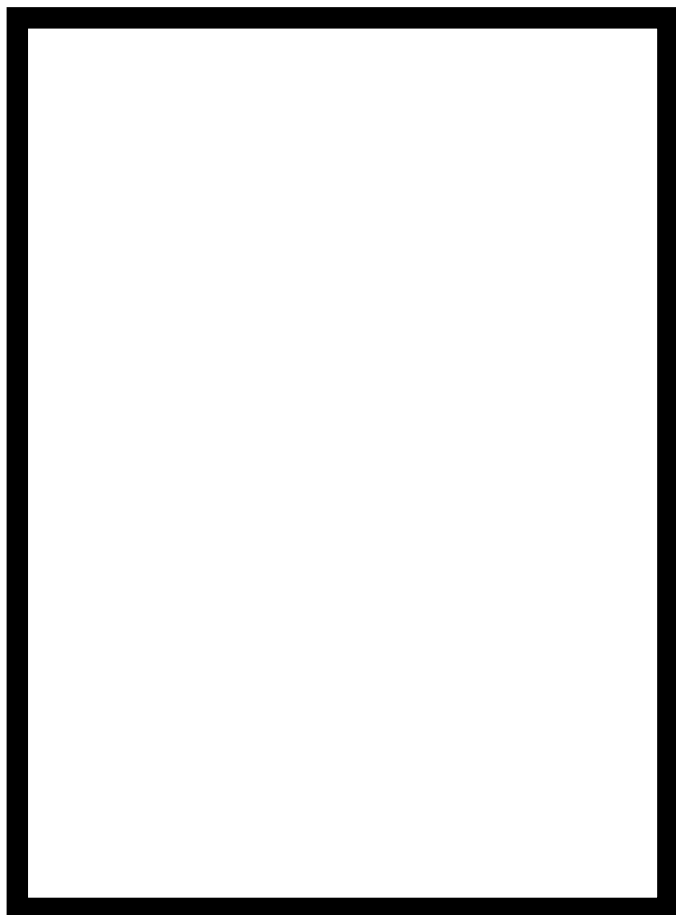
of 20:1 or higher. If we can only tolerate 1 part per million (ppm) of a particular contaminant in the boiler, we can only tolerate 0.05 ppm in the feed to the boiler.

Table 1 demonstrates the guideline requirements recommended by the American Boiler Manufacturers Association—see www.abma.com—for boiler feed water based on a blow down of 5 percent (20:1 concentration):

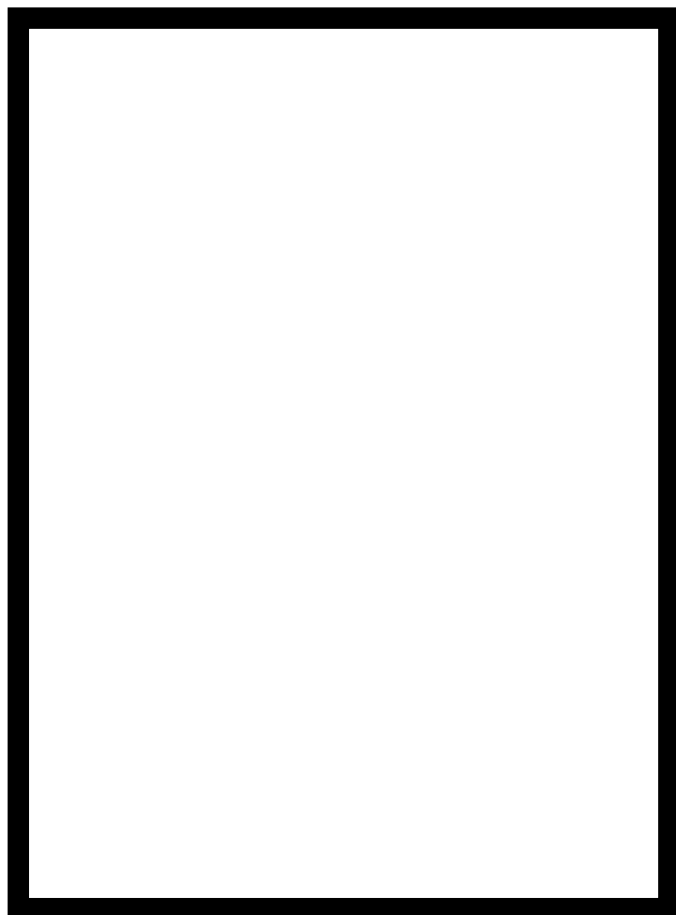
It can be noted that low and medium high-pressure boilers will not require complete demineralization. Scale control via softening or chemical injection with dealcalization will usually suffice. Silica can also be controlled by chemical addition or desilicization by ion exchange.

Hardness & alkalinity sources

Falling rain and surface waters absorb carbon dioxide and other gases to form dilute acids (see *Reactions 7 & 8*). As this water percolates into



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Table 1. Boiler water guidelines (conditions in boiler)

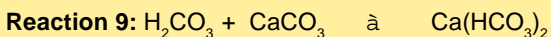
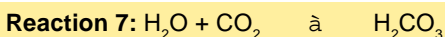
Drum pressure (psig)	Silica (ppm as SiO ₂)	Total alkalinity* (ppm as CaCO ₃)	Hardness (ppm as CaCO ₃)	Conductance (micromhos/cm)
0-300	150	700	0	7000
301-450	90	600	0	6000
451-600	40	500	0	5000
601-750	30	400	0	4000
751-900	20	300	0	3000
901-1000	8	200	0	2000
1001-1500	2	0**	0	150
1500-2000	1	0**	0	100

*Alkalinity not to exceed 10% of specific conductance

** Minimum level of OH alkalinity in boilers below 1,000 psi must be individually specified with regard to silica solubility.

SOURCE: www.abma.com

the soil, it will dissolve minerals and build in TDS (see *Reaction 9*).



Alkalinity represents acid neutralizing or buffering capabilities in water. It can come from the presence of CO₃⁻² or OH⁻ ions as well as HCO₃⁻ in water. With the exception of HCO₃⁻, alkaline salts of divalent ions such as Ca⁺² and Fe⁺² are almost completely insoluble. Therefore, the alkalinity we experience in most feed water with a pH of 6.5 to 8.5 will be HCO₃⁻ if hardness is present. Natural water rarely contains hydroxyl alkalinity (OH⁻). Depending upon pH, the relationship between CO₂, HCO₃⁻ and CO₃⁻² changes (see *Figure 1*).

The hardness associated with bicarbonate alkalinity is termed tempo-

rary hardness. While this may sound like a minor problem, it isn't. When

this water is heated, the HCO₃⁻ ion decomposes to CO₂ and CO₃⁻² ion and the CO₂ goes off with the steam and becomes carbonic acid (see *Reaction 1*). The carbonate that's left behind precipitates as insoluble calcium carbonate scale directly onto the heating surfaces. You now have a scaled up boiler and a corroded heat exchanger (but very little soluble hardness in the blow down). Needless to say, this isn't a good thing. Scale buildup in any heat transfer vessel can reduce the heat exchange efficiency by 50 percent or more. In hot water heaters, the build up of scale will reduce the heater volume over time.

Silica

Silica comes from the partial breakdown of natural aluminosili-

cates contained in the soil. Silica is more soluble in hot water than in cold and generally doesn't present a problem in water heaters or low-pressure boilers. At elevated temperatures, however, silica actually volatilizes with the steam. It can then deposit in condensers or on turbine blades causing mechanical problems and costly shutdowns. The amount of silica contained in the steam becomes significant, above 600 pounds per square inch (psi) of steam pressure. Silica is less soluble in low TDS waters than in high TDS water, thus a boiler requiring deionized (DI) water—generally above 1,000 psi—may also have limits for silica lower than might otherwise be expected.

There are both economic as well as efficiency reasons to soften and dealkalize boiler feed water. Unless there's a need for TDS or silica reduction along with hardness and alkalinity reductions, simple salt regenerated ion exchange provides a complete and economical choice. Silica, however, cannot be removed with a salt regenerated system.

Pretreatment designs

Hardness removal uses a strong acid cation exchanger. Sizing of the softening unit will vary with the flow rate and desired run length (see *Reaction 10*). Calculate grain removal capacity as: gpm × gpg × 60 × hrs = grains removal capacity between cycles. Divide this number by the capacity of the softening resin to get the

Figure 1. CO₂ equilibrium vs. pH.

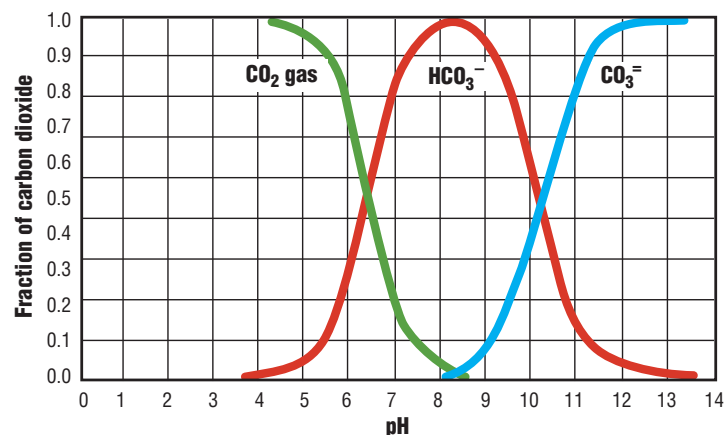
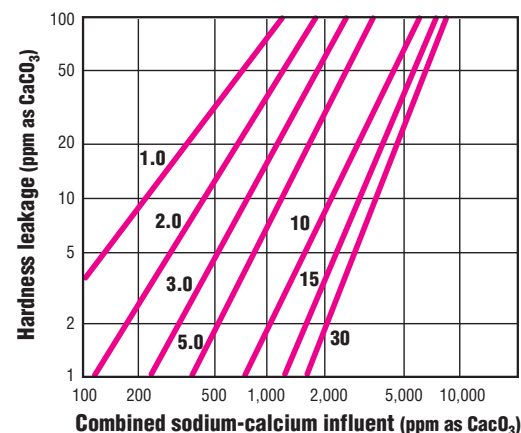


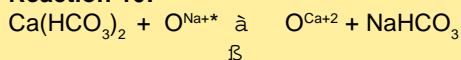
Figure 2. Hardness vs. influent TDS.



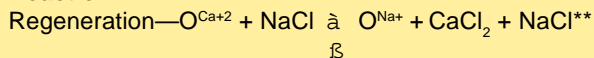
number of cubic feet of resin required (see *Reaction 11*).

pounds per cubic foot (lbs/ft³) or more.

Reaction 10:



Reaction 11:



* O in this case represents an ion exchange resin with Na, Ca, HCO₃ or Cl attached
 ** indicates excess salt

The ability of a softener to produce very low hardness leakage will depend upon the TDS and regeneration salt level. Ten pounds of salt will produce 1 ppm of hardness leakage in water up to about 700 ppm in TDS, and 5 ppm leakage in water up to about 1,600 ppm in TDS. Fifteen pounds or more can be used for lower leakages or to treat water at higher TDS (see *Figure 2*).

Co-current strong acid cation (SAC) softeners are limited to TDS in the feed of about 3,000 ppm but can be run effectively at TDS in excess of 5,000 ppm with high brine doses—30

Because of the complexity and expense of a proper counter-current system, units are often designed with only the polisher of a two-in-tandem softener design. This is referred to as series softening, which utilizes a co-flow primary and a counter-flow polisher. This design has been effectively used for softening “produced waters” from oil field steam floods that are 5,000+ TDS and deliver leakages of less than 1 ppm hardness (see *Figure 3*).

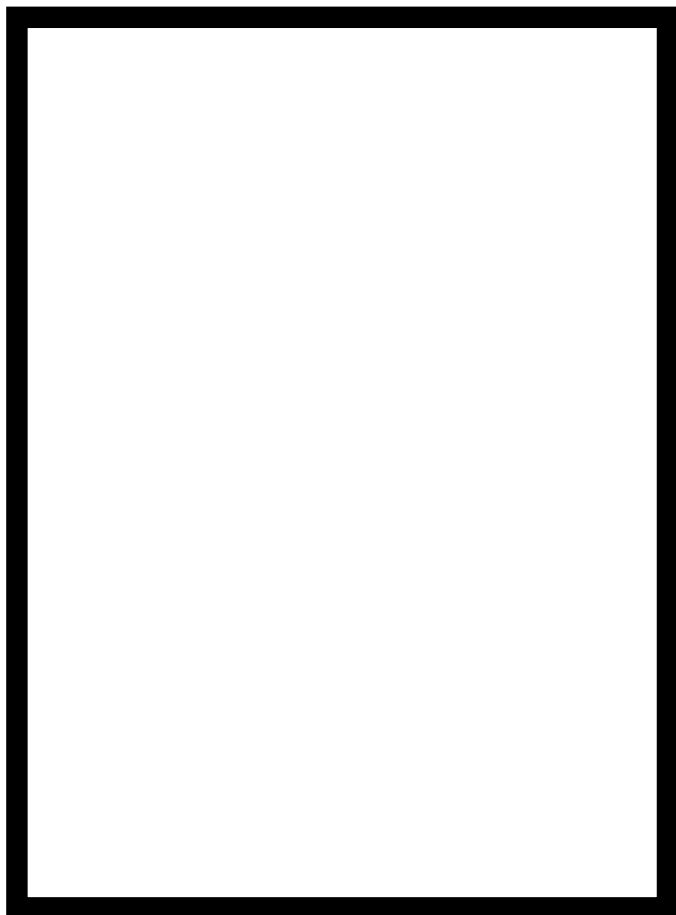
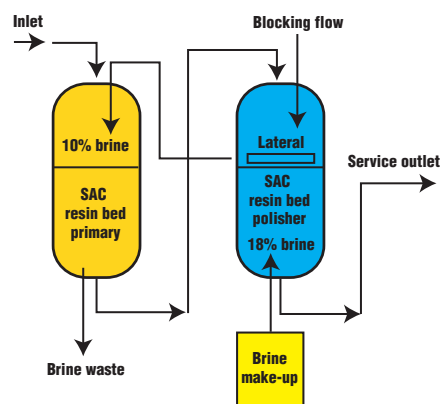
Strong brine at 15-to-18 percent is pumped into the bottom of the polisher. A blocking flow of primary

softened water is pumped to the top. The partially spent and diluted brine is taken off at the regenerant collector (now at about 10 percent strength) and pumped to the top of the primary. The total amount of brine is based on a stoichiometric quantity for the polisher plus the normal level for the primary. The polisher, however, sees all the brine, which is what produces very low leakages. Addi-

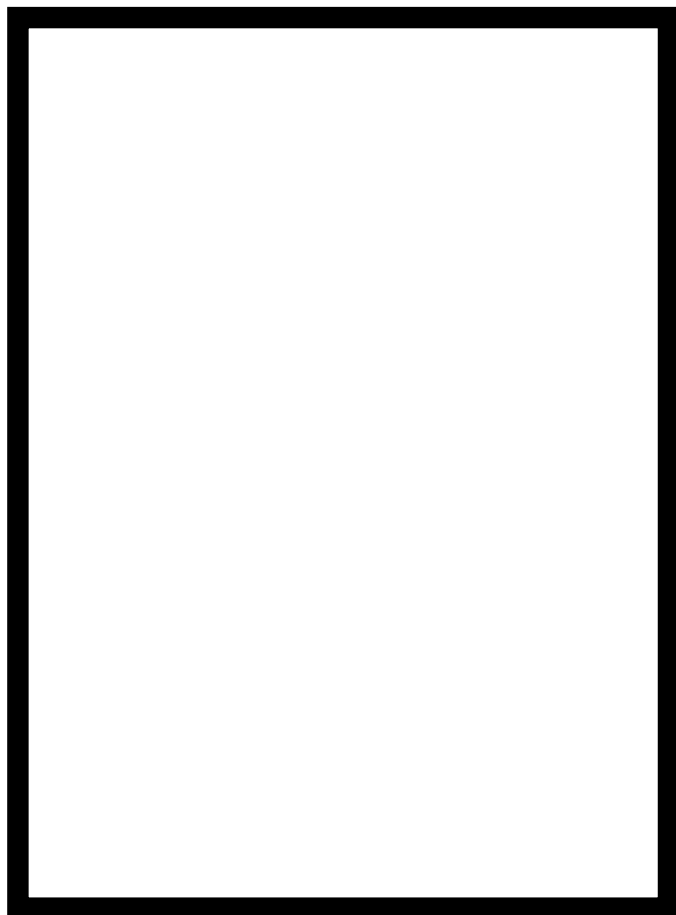
Series softeners

Counter-flow regenerated SAC allows for more effective usage of brine and produces lower leakage in higher TDS feed water.

Figure 3. Series softening



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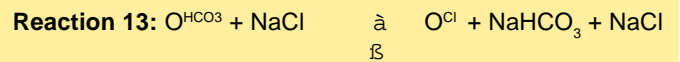
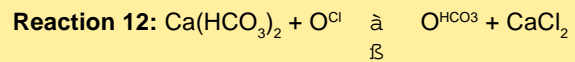
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tional efficiency benefits can be gained by running both the primary and the polisher in a counter-flow mode. Most of the benefit of counter-flow regeneration is lost if the resin bed isn't held in place during brining.

Anion softening

Hardness salts don't form scale unless they have the appropriate counter-ions present (CO_3^{-2} , SO_4^{-2}). The process of using a salt-regenerated strong base anion exchanger to remove those ions has been termed "anion softening." Here, strong base anion (SBA) resins—usually a Type II—in the chloride form will exchange bicarbonates and carbonates (alkalinity) along with sulfates for chlorides (see *Reaction 12*).

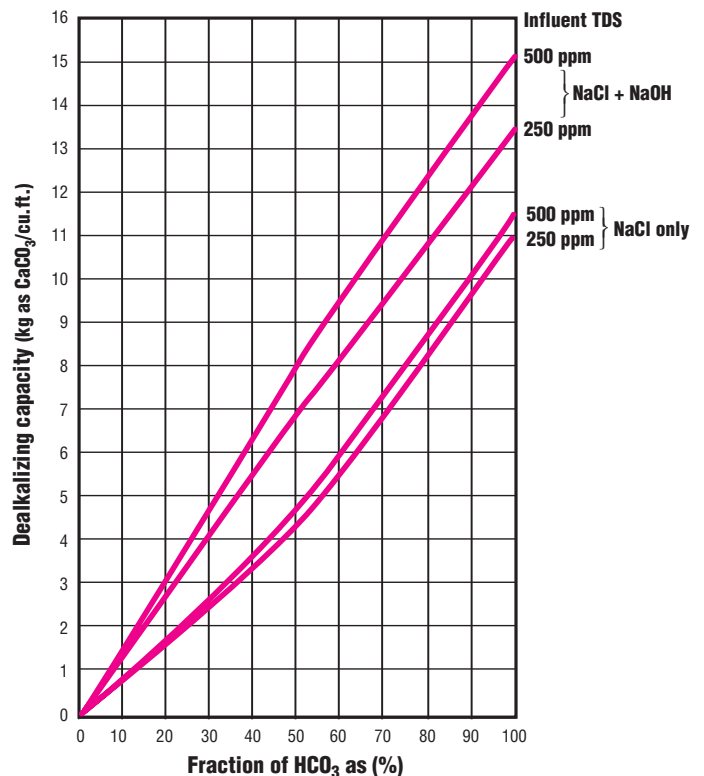
All hardness chlorides are soluble, eliminating scale formers. Plus, alkalinity is reduced. Regeneration is with salt (see *Reaction 13*).



A secondary source of softened water should be used for regeneration to eliminate the possible precipitation of CaCO_3 , CaSO_4 and MgCO_3 .

When an anion softener is used purely for the reduction of alkalinity, it's referred to as a dealkalizer. Here, our service reaction involves only the removal of bicarbon-

Figure 4. Dealkalization capacity vs. alkalinity fraction



ates, although CO_3^{2-} and SO_4^{2-} will still be removed (with reactions similar to *Reaction 12*). Capacity can be enhanced by adding a small amount of caustic soda (NaOH) to the brine. A comparison of capacities for a typical Type II SBA is shown in Figure 4.

Use of a small amount of caustic with regenerant brine will improve performance of a dealkalizer by elevating pH slightly during service. Some HCO_3^- will convert to CO_3^{2-} , which is picked up better by the chloride form SBA resin. Feed water should be pre-softened if your design includes use of caustic with brine for regeneration.

Inclusion of SAC and SBA in the same vessel for simultaneous reduction of hardness and alkalinity in a single tank, although commonly done, is not recommended. The waste regenerant, which will be high in both hardness and alkalinity, will surely precipitate and cause fouling. The same holds true if the same regenerant

is used for regenerating two separate vessels simultaneously. Acidified brine has been successfully employed. If the regenerant pH is held below 5.5 with addition of citric acid (1.0 lbs citric acid/100 lbs of salt), CO_3^{2-} ions will be converted to HCO_3^- and carbonate precipitation can be avoided. HCO_3^- to SO_4^{2-} ratios should be at least 10:1. Otherwise, CaSO_4 precipitation may still occur (see *Reaction 2*).

Conclusion

This article dealt with boiler feed water treatment and scale prevention methods using ion exchange that involve salt regeneration only. Part 2 of this series next month will review use of weak acid resins, de-carbonators and silica removal. □

About the author

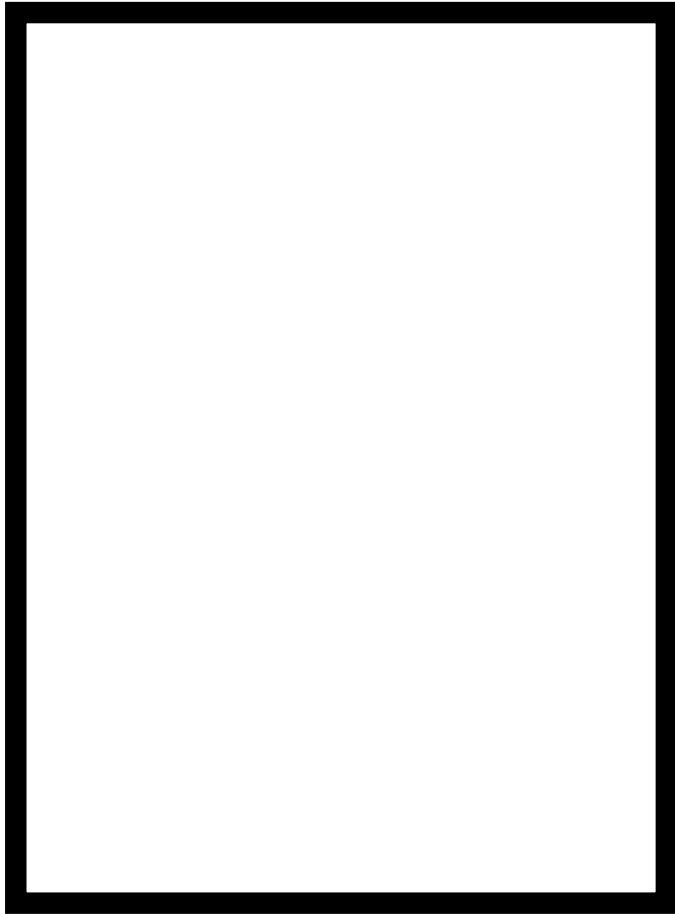
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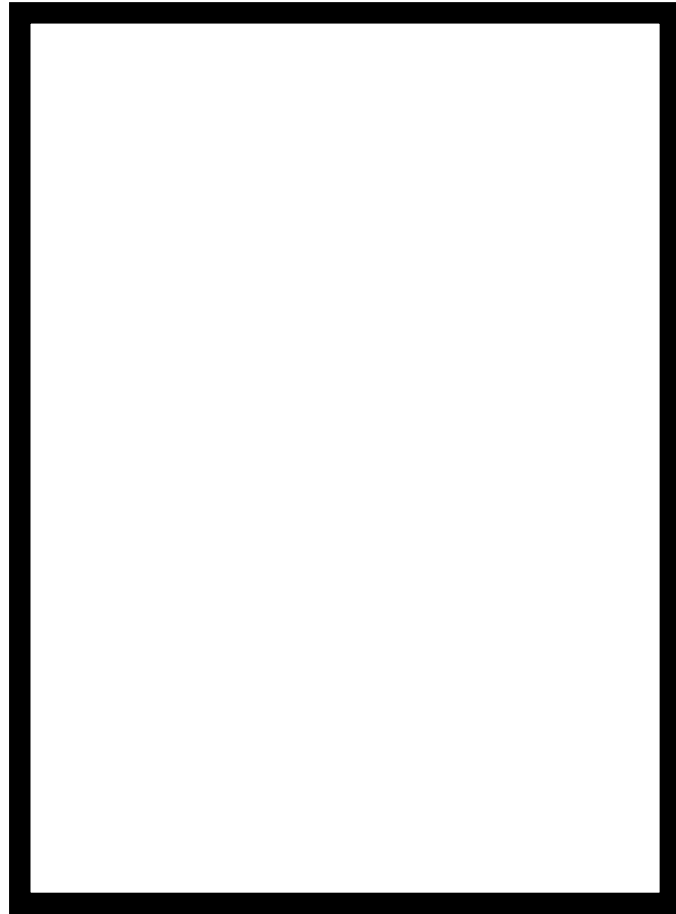
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