Factors Affecting the Brine Efficiency of Softeners— Revisited:

The Quest for Perfection

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Summary: *Communities efforts to extend use of their water supplies—particularly in California—by recycling wastewater creates challenges for water softener dealers being pressured to reduce their contribution of brine to the waste stream to make reuse treatment processes more cost-efficient.*

In a previous two-part series ("Factors Affecting the Brine Efficiency of Softeners," Parts I and II, *WC&P*, August and September 1999), we provided an introductory overview to this topic. The primary influencing factor discussed was the salt setting; however, proper sizing and regeneration techniques also play important roles. If a softener is assembled without some care in protecting its inherent efficiency, its salt efficiency can drop 25 to 30 percent. This adds unnecessary sodium to the wastewater stream and wastes water as well, due to the need for more frequent regeneration.

The need is near

With California's SB1006—the compromise legislation passed in 1999 regarding the softener industry's commitment to improved brine efficiency and California communities' attempts to ban softeners—brine efficiency performance requirements rise from 3,350 grains of hardness removed per pound (gr/lb) of salt used for regeneration to 4,000 gr/lb in January. It may be timely to revisit some of the techniques that can be used to promote higher brine efficiency in the quest for the perfect softener. Perfect in this sense refers to the theoretical limit of the softener to operate at maximum brine efficiency.

Limits of perfection

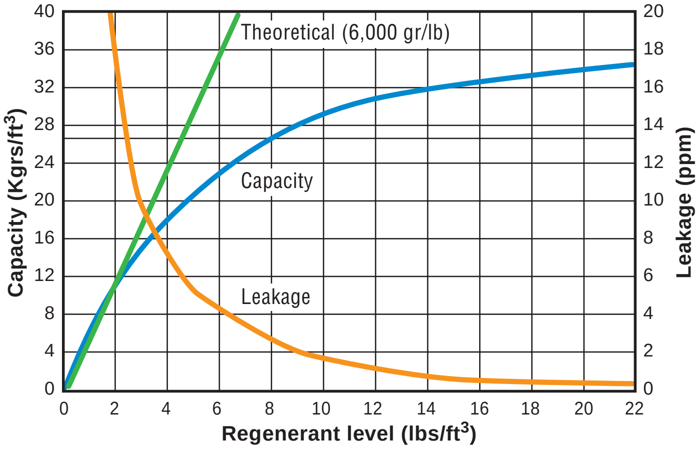
A pound of sodium chloride (NaCl) commonly used in softener regeneration weighs 454 grams (gms). It contains 39.3 percent sodium, or 178.5 gms. If you made up a gallon of brine with this pound of salt, it would have a concentration of 47,159 milligrams per liter (mg/L)—or parts per million (ppm)—of Na^+. Converting this to ppm as calcium carbonate ($CaCO_3$), we have 102,519 ppm (multiply by 50/23) or 5,995 grains of sodium (divide by 17.1). In a perfect world, this amount of salt would regenerate softening resin to the tune of 5,995 grains of hardness/lb salt—the perfect softener. This softener would have no sodium in its regenerant discharge (but it would have elevated chlorides). Consider the same calculation with potassium chloride (KCl). It contains 52.3 percent K, or 237.7 gms; it will remove a theoretical 4,708 grains of hardness per lb of KCl.

Brine efficiency for a water softener is defined as the number of grains of hardness removed per pound of salt used for regeneration. Since typical units produce 20,000 to 30,000 grains of softening capacity with salt (NaCl) doses in the 5 to 10 pounds per cubic foot (lb/cu ft) range, we can calculate that the general recovery of hardness is in the range of 3,000 to 4,000 grains per pound of salt. In other words, they are about 50 to 65 percent efficient.

The ion exchange softening reaction favors hardness removal in dilute solutions typical of well water and city water (200 to 800 ppm total dissolved solids, or TDS). In fact, the preference for calcium is so pronounced that even when the resin is 80 percent in the Ca^{++} form, it still prefers calcium over sodium by 99:1. In the regeneration mode where sodium concentrations can exceed 100,000 mg/L (10 percent brine), however, selectivity for divalent hardness diminishes and the resin actually prefers the monovalent sodium. Hardness is readily displaced and regeneration is very efficient. As the displaced hardness travels down the resin column, however, it's picked up once again by the resin (because the hardness concentration is now very high relative to sodium). Additional sodium is needed to continue the process and keep pushing the hardness down the column and finally out to drain. The trick to getting more of the hardness off the resin is to maintain a fairly high concentration of sodium in the brine—all the way through the column. This results in the need to use excess brine and achievement of something less than "perfect" in terms of regeneration efficiency.

If we examine the regeneration curve (see *Figure 1*) for a typical softening system regenerating with NaCl, we see that the capacity regain increases with increasing levels of salt; however, the incremental gain in capacity diminishes with increased salt dosage. The biggest "bang for the buck" is therefore at the lower end of the chart. Since brine efficiency relates to grains of capacity recovered per pound of salt, the best efficiencies would be with the lower levels of regenerant. Also note the leakage curve in Figure 1. It shows that average leakage (the result of incomplete regeneration) diminishes with an increase in salt dosage. Reducing the salt dosage

Figure 1. Typical softening system regenerating with NaCl



further will increase the brine efficiency but increase the leakage. Since a softener is certified with respect to how much hardness it removes to a certain leakage end point, there comes a point on the curve were the softener no longer works (because the leakage already exceeds the end point).

Resin capacity curves, such as the one in Figure 1, are generated under laboratory conditions with perfect flow and regeneration designs. The ideal system has a 36-inch bed depth and flows at 2 gallons per minute per cubic foot (gpm / cu ft) during service and has 30 minutes brine contact times during regeneration with 10-percent brine. The typical residential system has a 24- to 28-inch bed depth, flows at 8 to 10 gpm / cu ft, and has a 6- to 8-minute brine draw cycle with average brine concentrations of maybe 6 percent. All of these variables take their toll on capacity and brine efficiency.

Converting the values given in Figure 1 to brine efficiency values, we show these numbers in Table 1.

Inherent flaws

It would appear on the surface from the values given in Table 1, all one would have to do to achieve the upcoming 4,000 gr / lb brine efficiency point would be to reduce brine dosage to about 5.5 lbs / cu ft. That's a good start, but can you deliver this value on a test stand? The typical softener will lose 4 percent capacity by being tested at 4 gpm vs. the ideal rate of 2 gpm. If you opt to have your certification run in the winter or early spring, you can lose another 3 percent by having the test done at 65°F, rather than later in the year when one can expect 75°F test water. If you use a 9×48-inch tank for a 1 cu ft system, you'll lose 4 percent capacity by having a 27-inch vs. the ideal 36-inch bed depth. Assum-

Table 1. Brine, capacity and brine efficiency

Brine level (lbs/cu ft)	Capacity (gr/cu ft)	Brine Efficiency (gr/lb salt)
1	6,000	6,000 *
2	11,800	5,900
3	14,700	4,900
4	18,300	4,575
5	21,400	4,280
6	23,100	3,850
7	25,300	3,615
8	26,400	3,300
9	28,000	3,110
10	29,300	2,930

* NOTE: this value has been used for convenience rather than the calculated value of 5,995 gr/lb

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ing an old fashioned, down-flow regeneration design, the freeboard in your system will dilute the incoming brine to an average of 6 percent and cost you another 3 percent in capacity. If you're playing on the safe side by using larger injectors to avoid plugging from crud in your salt tank, you may lose another 5 percent capacity from having a regenerant flow rate of 0.75 gpm vs. the norm of 0.5 gpm/cu ft. If you take all of these potential variables into account, you'll have a total capacity loss of 17.6 percent. To achieve an actual test stand operating efficiency of 4,000 grains/lb of salt, you would actually have to move down the efficiency curve to 4,000—divide by 1.00 minus 0.176, or 0.824—to get 4,855 grains/lb on the salt dose, just over the 3 lb/cu ft level. Expect a leakage of 9 to 10 ppm of hardness—perhaps not a bad tradeoff.

Protecting brine efficiency by simply reducing the salt dosage can prove elusive. In a typical softener design, there's a freeboard above the top of the resin bed that allows for backwashing. The freeboard is generally about 50 percent of the bed depth or roughly half of the bed volume (about 3-3/4 gallons or 1/2 cu ft). Since the total brine introduced is only about 3 gallons (of 10 percent), the brine is further diluted by the head space more than the above example. It's this single factor that makes the practical brine limit level at about 3-1/2 lbs/cu ft and, with all the other variables working against you, the real 4,000 gr/lb salt goal more difficult to achieve than originally thought.

Previous but unpublished work by this author substantiates the belief that reducing brine levels has its limits in co-current systems. During these tests, it was noted than when the total brine level was dropped to 2.64 lbs/cu ft (one gallon of saturated brine), the brine efficiency dropped to a value that was below the same system run at 3.0 lbs. This was due to the effects of dilution of the brine.

So far, all we have done is try to explain why it will be difficult to achieve high efficiency with conventional softener designs and impossible to achieve perfection with any design. But we will try.

Brine efficiency by design

Counter flow regeneration has inherent advantages over co-current flow. First of all, the brine doesn't have to work as hard because it sees the cleanest part of the bed first. Exchange sites still in the sodium form don't use any brine. Co-flow is like washing your car from the bottom up. All the dirt runs down over the bottom (normally the clean part of a conventional softener) and you'll have to reclean it (with extra brine referenced early in the article). Counter-flow brining can boost capacity by 8 to 10 percent over co-flow brining.

Also, the brine isn't diluted by the head space, which preserves the original capacity numbers. Leakages are a fraction (usually 1/10th) of co-flow regeneration, which will lengthen the capacity run. This means one can plow down the curve a little further, lowering the brine dose and boosting efficiency even more. In addition, up-flow brining will be better distributed across the bed than will down-flow. This allows for use of lower flow rate injectors while maintaining good distribution. These four factors—1) inherent efficiency in counter-flow brining, 2) less dilution of the brine, 3) better distribution at lower flow rates, and 4) lower leakages—won't only avoid losses, they'll increase capacity to levels above the normal curve. We can look seriously at the 2 to 2-1/2 lb salt dose and achieve brine efficiencies of 5,500 to 5,900 gr/lb of salt while maintaining an overall capacity of nearly 13,000 grains—enough capacity to handle a two-day supply of 20 gr/gal water for the aver-

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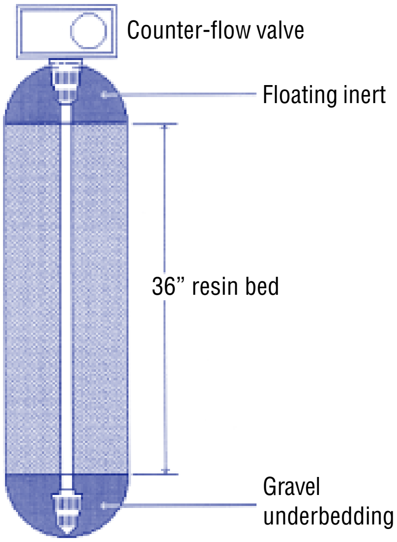
age family while cutting the total brine discharge by half.

Although one can easily reverse the flow of a conventional system by reconfiguring some types of valves to achieve counter-flow regeneration, there are some requirements slightly more difficult to incorporate. First of all, simply flowing brine up through the bed will lift and expand the bed and reduce the regeneration process by allowing brine to flow around the beads rather than through them. Agitating the bed also allows some of the highly exhausted resin from the top of the bed to drop down to the bottom and contribute to higher leakage in the next service cycle. In order to achieve true counter-flow regeneration with all of its advantages, one has to hold the bed in place during brining. Industrial systems use a blocking flow of water from the top and provide an additional take-off distributor just above the bed in order for the brine and the blocking water to exit. This holds the bed in place. Some have used screens to contain the resin and not allow expansion. This also holds the bed in place but it isn't something one can readily do with off-the-shelf parts. Packed beds (tanks completely filled with resin) have no freeboard and would also work for counter-flow systems providing the resin is protected from oxidation and the feed water well filtered. Here are some tips on a potential design to help achieve the quest.

You'll want to use a resin tank that will allow you to use a 36-inch bed depth. One cubic foot of resin in an 8-inch tank will work just fine (see *Figure 2*). If you want to use a 10-inch tank, you'll need about 1-1/2 cu ft. Use an underbedding of 6×12 sand to support the resin bed. For an 8-inch tank, use 7.8 lbs and, for the 10-inch tank, use 14.4 lbs. So far, so good. But how do we propose to hold the bed in place during regeneration? The simplest way is to use a 40-inch tall tank. There should be room to put a few inches of floating inert resin on the top of the bed to keep the fine resin beads away from the upper screen. If not, take out a little resin before trying to add the

Figure 2. One cubic foot of resin in an 8-inch tank



inert. The floating inert is coarser than the resin and doesn't add pressure drop against the upper screen. Most modern valves have electronic packages that allow for a timed brine refill step that will accurately place the required amount of water back into the brine tank after regeneration. Set it to place 0.9 gallons of water back into the brine tank (per cubic foot of resin). This will make up one gallon of saturated brine containing 2.6 lbs of NaCl (per cu ft). Use the smallest brine injector you can find. We're looking for a total draw rate of about 0.3 gpm for the 8-inch tank and 0.4 or so for the-10 inch one.

This design should allow you to achieve an efficiency of 5,250 grains per pound of salt, plus the added advantage of 8 to 10 percent from the counter-flow. We could approach 5,715 gr/lb with this.

Be creative

"Ease of regeneration" is a term rarely associated with conventional softening resins. Fine mesh, uniform bead and shallow shell resins *do* exhibit an "ease of regeneration" when compared to conventional resins. In both co-current and counter-current testing, this has translated into additional capacity because the "ease" translates into shorter rinses and lower leakages—thus preserving more of the resins capacity (long rinses use up capacity). While these resins don't inherently have a higher total capacity per cubic foot, they do allow one to slide up the curve a bit and increase the total column capacity by increasing the regenerant dose (while maintaining efficiency). They do report, however, that improved capacities of 5 percent or more can be achieved by simply replacing the resin. If I've done my math correctly, we left off with a 5,715 gr/lb system. Improve that by 5 percent and we have 6,000 grains per pound of salt—perfection at last.

Conclusion

With growing populations taxing our current water supplies, it's becoming more common to have wastewater recycled. While the need isn't so dire that this water is likely to be coming to a neighborhood near you yet, it's important providers of recycled water be able to hold some sort of tolerance on TDS and chlorides so the water can readily be used for golf courses, roadside irrigation and other purposes. This is creating a stir on the possible banning of residential water softeners on the misbelief that they alone are responsible for the TDS creep over the years.

While it's unlikely water softeners will ever be legally banned, it behooves our industry to do all it can to reduce discharge of excess brine by adjusting all new softeners to salt settings below 4 lbs NaCl per cu ft of resin with Demand Initiated Regeneration (DIR) and re-tune all older units to these levels when service is required.

We encourage readers to take an interest in the salt efficiency issue even if it isn't one in their home areas. It may be sooner than you think.

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