An Inside Look at ION EXCHANGE CAPACITY

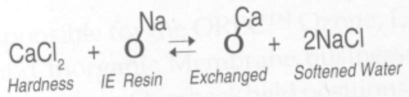
By C. F. "Chubb" Michaud, CWS-V

Summary: *Measuring capacity in ion exchange, whether it's a portable exchange tank for residential water use or deionization tank for residential water use or a more complicated application, can be difficult. Here is a discussion of factors affecting total and operating capacities.*

Ion exchange is an equilibrium reaction. This means the ability of an exchange to take place depends upon ionic concentration both inside and outside the resin bead.

A water softener, for instance, responds not only to how much hardness is in the water (and how much sodium is left in the bead), but also to how much sodium is in the water (and how much hardness is in the bead). Simply stated, the more hardness you have on the resin, the more difficult it is to put more hardness on the resin. Consequently, the more sodium you have in the water, the more difficult it becomes to put more sodium in the water.

Reaction 1



$$CaCl_2 + \overset{Na}{O} \rightleftarrows \overset{Ca}{O} + 2NaCl$$

When we speak of total ion exchange capacity, we are referring to a measurement of the exchanger's ability to remove a certain ionic constituent. Quantitatively, it is an absolute measure of the number of reactive ionic sites per unit volume. This can be expressed as milliequivalents per milliliter (meq/ml), equivalents per liter (eq/L) or kilograins per cubic foot (Kgr/ft^3).

Where... 1 meq/ml = 1 eq/L = 21.87 Kgr/ft^3.

Real world efficiency

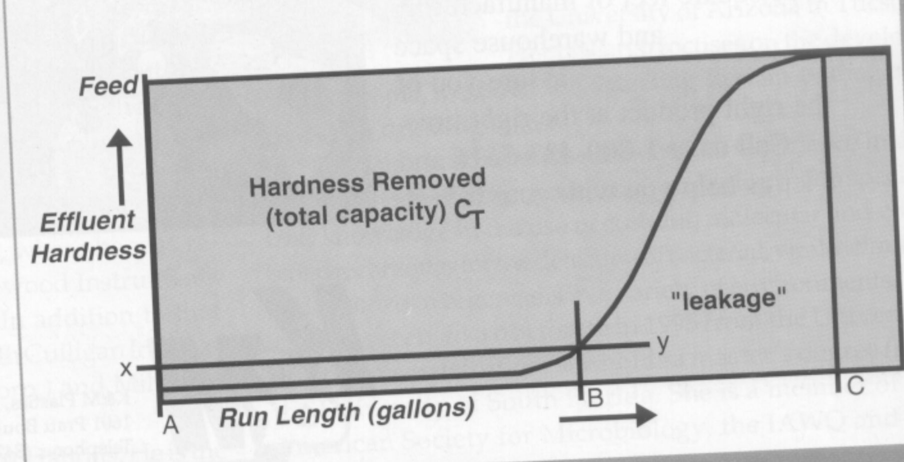
If we observe new resin (100 percent sodium form) in a softener in service for the first time, we note that even after it starts to load up (resulting in "leakage"), we can still remove hardness (see *Figure 1*).

If we run this softener until the effluent residual hardness is equal to the influent hardness (run length = C), we have completely "exhausted" the resin, having used all of its capacity. Therefore, the shaded area, C_T, represents the total amount of hardness removed and can be considered as total capacity.

In reality, it is impractical to operate a softener in such a manner. Nearly half of the run contains a considerable amount of hardness (run length = B-C) and it would require Herculean quantities of salt (50-to-60 lbs.) to restore the resin to a full sodium regeneration each time (see *Figure 2*).

Instead, we pick a regeneration salt dose that provides good recovery economics (5-to-15 lbs/ft^3) and we observe the curve shown in Figure 3. The line "x-y" represents the maxi-

FIGURE 1



mum level of hardness residual we have chosen to tolerate—let's say 10 parts per million (ppm) of hardness. The run length, represented by the interval "A-B," is the time it takes to "rinse down" to quality (fast rinse) and the length "B-C" represents the usable or operating capacity, C_O. If we increase the salt dosage, we can increase the length of C_O, but the return on salt expenditure decreases rapidly (see *Figure 2*)—resulting in less efficiency, for all practical purposes.

Since the influent water has a known grain per gallon loading by measuring the run B-C in gallons, we can calculate the C_O by multiplying the two numbers. For example, if B-C is 1,000 gallons and the feed is 23.5 grains, the C_O becomes 23,500 grains, or 23.5 Kgr. If we have 90 ft^3 of resin in our softener, we can then determine our C_O to be 23.5 ÷0.9, or 26.1 Kgr/ft^3. Note that leakage is assumed to be zero for this calculation.

With normal salt doses of 6-to-8 lbs./ft^3, C_O will be 50-to-60 percent of C_T. New cation resin has a total capacity of 1.9 meq/ml minimum, which is equal to 41.55 Kgr/ft^3. Normal operating capacities are typically 21-to-25 Kgr/ft^3 (50-to-60 percent) with 6-to-8 lbs/ft^3 of salt. This also means that we only utilize 50-to-60 percent of the resin bed. What about the other 40-to-50 percent?

FIGURE 2

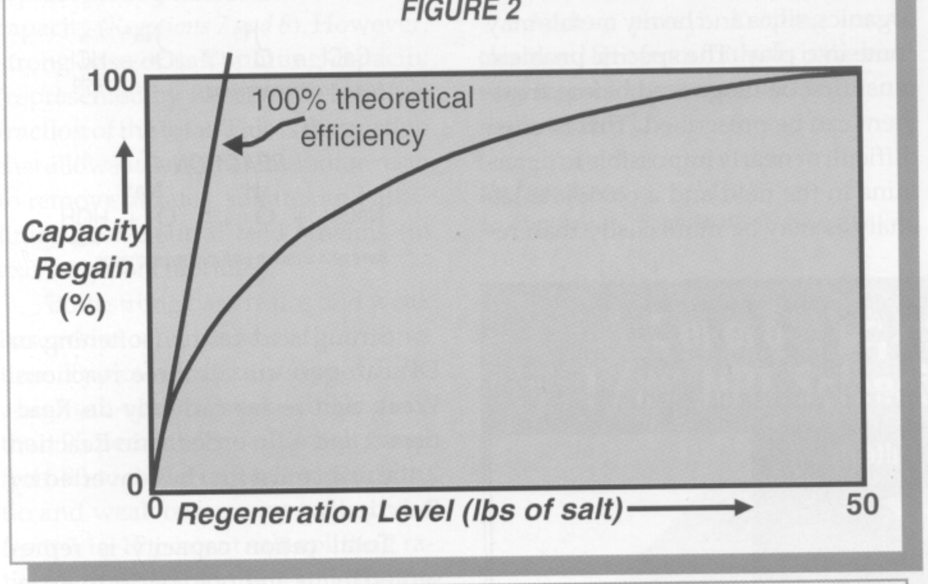
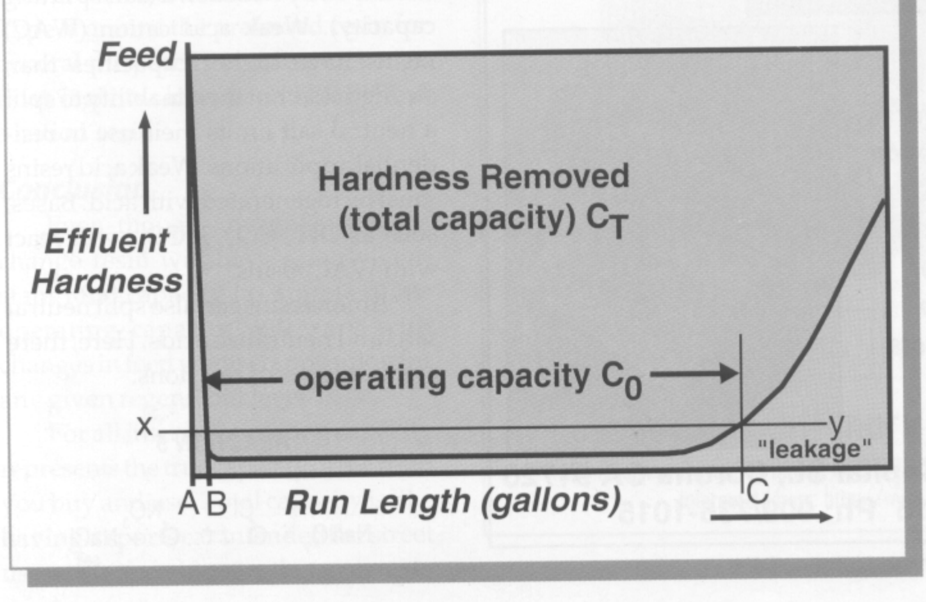


FIGURE 3



As noted in Figure 1, the resin bed still has capacity at point "B," the breakthrough cutoff. In fact, we have 20-to-25 percent of the bed still in the sodium form. However, at that point, equilibrium does not allow for the complete removal of hardness. Leakage occurs and we terminate the run. Regenerating with 6-to-8 pounds of salt restores 50-to-60 percent of the total capacity, which means that our resin bed still contains about 20 percent hardness after regeneration. It is this hardness that, when surrounded by soft water in the next run, leeches out (see *Reaction 1*), and produces background leakage.

Resin aging

With time, our resin oxidizes—due to chlorine or oxygen attack—and swells. Our moisture content has increased from 48-to-55 percent. That same cubic foot of resin now occupies about 1.15 ft^3 (assuming no beads have backwashed out). It still delivers good capacity, but your customer claims the unit doesn't seem to have the same capacity. You decide to have the resin checked by a lab. The lab tells you that the capacity has "dropped" to 1.6 meq/ml from a "new" capacity of 1.9 meq/ml. This is a loss of 0.3 meq/ml or 6.6 Kgr/ft^3. Since you only had 26.1 Kgr/ft^3 to start, you figure you've lost 25 percent of your capacity. To compensate, you adjust the unit to regenerate every third day instead of every fourth day. Later, your customer squawks about using more salt.

You may have acted a tad hastily! The 1.6 meq/ml C_T times the 1.15/ft^3 (swollen) gives a total of 1.84 meq/ml. This represents only a 3 percent loss from the "new" resin. Perhaps the owner's children are using more water now (longer showers, washing Dad's car, more gym socks) or the source water has changed (higher hardness). Maybe all the resin needed was a good cleaning. Perhaps a lesson in water conservation would have been a more appropriate move than upping the salt.

In any case, to cancel the effects of moisture and swelling in the reporting of capacities, capacities are often reported in terms of meq/dry gram—dry weight capacity—instead of meq/ml. Not too surprisingly, the dry weight capacity for cation resins is relatively constant throughout its life. To calculate the meq/ml from the meq/dry gram, we must take into account that there is excess moisture present. Multiply the meq/dry gram by per cent solids—in the above case, 45 percent, or 0.45 (100 percent - 55 percent moisture = 45 percent solids). To convert meq/ml to meq/dry gram, divide by the percent solids (0.45).

Fouling

Often, a resin may pick up something that coats its surface and interferes with the resin's ability to do its job. Oil is an example of this type of foulant.

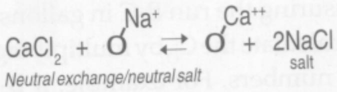
The capacity of the resin is essentially the same. However, the rate at which it can react has slowed because ions now have to diffuse through a layer of oil. We refer to these resins as "fouled," or kinetically impaired. They still work, but they have to be run more slowly. Regeneration is less efficient for the same reason. Leakage goes up and capacities go down. If we define the C_O of a resin over a flow rate range, we are defining its "kinetic capacity." Keeping resins clean avoids a loss of kinetic capacity (which is real capacity).

Should something exchange onto the resin that doesn't want to come off in normal regeneration, we can have a serious fouling problem resulting in a near complete loss of capacity. Iron, aluminum and lead are examples. The resins appear normal although certain types of foulants (like iron) may be visible. Moisture may test low because the foulant makes the bead heavier. Normal regeneration will not restore the bead. In addition to iron, hardness, organics, silica and heavy metals may come into play. The specific problem must first be diagnosed before treatment can be prescribed. This is often difficult or nearly impossible to determine in the field and a complete lab analysis may be more costly than replacement. Often there is some permanent loss of operating capacity plus a loss of kinetic capacity as well—even with successful diagnosis and treatment. Proper pretreatment to prevent fouling is a better strategy.

Function and capacity

Cation resins can split neutral salts (as in softening) and they can neutralize bases, such as caustic sodas and alkalinity. Actually, there are three types of reactions:

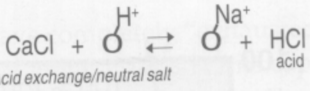
REACTION 2



$$CaCl_2 + \overset{Na^+}{O} \rightleftarrows \overset{Ca^{++}}{O} + \underset{salt}{2NaCl}$$

Neutral exchange/neutral salt

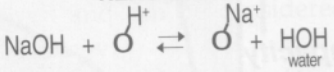
REACTION 3



$$CaCl + \overset{H^+}{O} \rightleftarrows \overset{Na^+}{O} + \underset{acid}{HCl}$$

Acid exchange/neutral salt

REACTION 4



$$NaOH + \overset{H^+}{O} \rightleftarrows \overset{Na^+}{O} + \underset{water}{HOH}$$

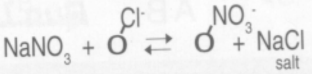
Base neutralization via hydrogen exchange

Strong acid resins (softening or DI) can perform all three reactions. Weak acid resins can only do Reactions 2 and 4. In order to do Reaction 2, the resin must first be converted by Reaction 4.

Total cation capacity is represented by its ability to perform Reaction 4. However, softening capacity is described by Reaction 2 (salt splitting capacity). Weak acid cation (WAC) resins have higher capacities than strong acids, but their inability to split a neutral salt limits their use in residential applications. Weak acid resins must be regenerated with acid. Bases, such as OH^-, CO_3^-, HCO_3^-, will react with WAC resins.

Anion resins can also split neutral salts and neutralize acids. Here, there are four types of reactions:

REACTION 5



$$NaNO_3 + \overset{Cl^-}{O} \rightleftarrows \overset{NO_3^-}{O} + \underset{salt}{NaCl}$$

Neutral exchange/neutral salt

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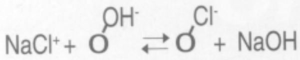
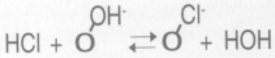
REACTION 6



$NaCl^{+} + \overset{OH^-}{O} \rightleftarrows \overset{Cl^-}{O} + NaOH$

Base exchange/neutral salt

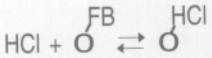
REACTION 7



$HCl + \overset{OH^-}{O} \rightleftarrows \overset{Cl^-}{O} + HOH$

Acid neutralization

REACTION 8



$HCl + \overset{FB}{O} \rightleftarrows \overset{HCl}{O}$

Acid neutralization (weak base only)

Strong base resins can do Reactions 5, 6 and 7. Weak base resins can only do Reactions 5 and 8. In order to do Reaction 5, it must first be converted by Reaction 8. Total anion capacity is represented by its acid neutralization capacity (*Reactions 7 and 8*). However, strong base or salt splitting capacity (represented by Reaction 5) is only a fraction of the total. This is the portion that allows salt regenerated anion resin to remove nitrates, sulfates and alkalinity from neutral feed streams (in exchange for chlorides).

Both strong base resins and weak base resins contain some of both functions. Typical strong base (Type I) have a high salt-splitting ratio—often more than 95 percent. Type II's will range from 80-to-90 percent salt-splitting ratio and weak base resins will exhibit from 0-to-15 percent salt-splitting ratio. With age, anion salt-splitting capacity will be lost, but some of that may convert to weak base sites. This makes Type II anions the preferred resin for general-purpose DI portable exchange float. It gives a long, useful life behind a cation resin.

Conclusion

Even though any given ion exchange resin will have a fairly constant total capacity (as supplied), its operating capacity will vary with changes in feed water composition for any given regenerant level.

For all intents, operating capacity represents the true capacity of the resin you buy and use. Total capacity is like having a sports car intended for street use with a speedometer that goes up to 180 mph. You will never realize that "capacity."

To the contrary, resins with very high "total" capacities may not be good for high kinetics softening. Too tight a structure (high cross-linked, low moisture) may make high operating capacity difficult to realize with a very slow run (1-to-2 gpm/ft^3) and using high salt doses (15+ lbs/ft^3). Save these for your industrial applications. Ease of regeneration, which gives high recovery, is more important.

Salt-splitting capacity is important for full deionization as well as for softening, dealkalization, nitrate removal and all other applications using brine as a regenerant. Total capacity becomes more important in neutralization reactions and DI applications.

And as always, keeping resins clean and free from foulants is the best way to prolong the useful life of any resin system.❑

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About the author

♦Chubb Michaud, CWS-V, earned bachelor's and master's degrees in chemical engineering from the University of Maine and has more than 30 years of professional experience in water and fluid treatment processes. He is a technical specialist with The Purolite Company, a manufacturer of ion exchange resins. Michaud also is a member of the WC&P Technical Review Committee. He can be reached at (909) 396-5253, (909) 396-5258 (fax) or voice mail: (800) 343-1500, Ext. #403.

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