ACHIEVING BRINE EFFICIENCY IN WATER SOFTENING

SOURCE: PENTAIR WATER SOLUTIONS

WHAT IS REGENERATION EFFICIENCY?

There are two measures of regeneration efficiency - brine efficiency and water efficiency. Brine efficiency is a measure of how much salt a softener system uses to remove hardness from the water. The brine efficiency of a system is calculated as the grains of hardness removal capacity per pound of salt used to regenerate the system (grain/lb). Water efficiency is a measure of how much water the system uses to regenerate, and is usually calculated as gallons/regeneration, or gallons of regeneration water/1000 grains hardness removed.

Softeners that are tested to the NSF/ANSI standard 44 for Residential Cation Exchange Water Softeners can be efficiency rated if they use demand initiated regeneration (i.e. meter or sensor initiated, not time clock). Per the standard, efficiency rated softeners must have a rated salt efficiency of at least 3350 grains per pound of salt used for regeneration. Additionally, the salt efficiency for softeners installed in California must be at least 4000 grains per pound. Efficiency rated softeners must also meet a water efficiency of 5 gallons of regeneration water (or less) per 1000 grains of hardness removed.

In an ion exchange water softener, hardness ions in the water - primarily calcium and magnesium - are exchanged on the ion exchange resin for sodium. When all available exchange sites are converted from sodium to hardness, the softener is exhausted and needs to be regenerated. Regeneration is achieved by exposing the ion exchange resin to a brine solution. Sodium chloride is typically used, although potassium chloride may also be used. (We will focus on sodium chloride solutions although the same process takes place when a potassium chloride brine solution is used.) The brine concentration is high enough that the resin replaces the hardness ions on the resin with sodium ions. The hardness ions removed from the resin, along with some excess sodium and chloride ions, are sent to the drain.

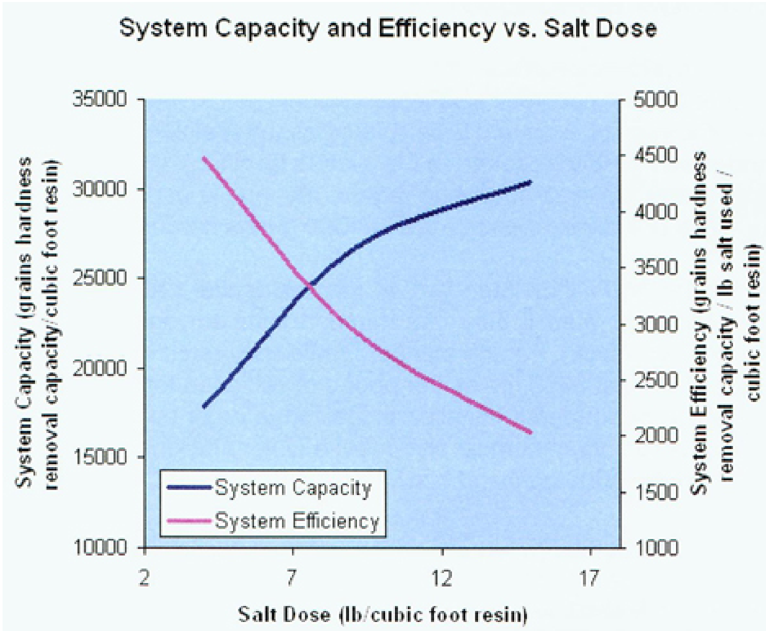
To make the sodium exchange back onto the resin, excess sodium is required. To optimize brine efficiency, the system is designed so that as little excess sodium chloride as possible is discharged to the drain. Optimizing brine efficiency lowers system operating costs and reduces the level of brine discharged into the environment.

There are many ways to optimize the brine and water efficiency of a softener system through system design and operation. Factors affecting brine efficiency include salt dose, brine flow rate, brine flow direction, reserve setting, and others as discussed in this paper.

SECTION 1: BRINING CONSIDERATIONS

SALT DOSE AND CONCENTRATION

Salt dose is the primary variable in achieving brine efficiency. A typical capacity curve and efficiency curve for an ion exchange resin is shown below:



As shown above, the capacity of a softener will increase as the salt does increases. However, it is also shown that brine efficiency decreases as the salt dose is increased because less capacity is gained for each additional pound of salt used. For example, 4 pounds of salt gives a capacity of 17,900 grains. Increasing the salt dose to 9 pounds of salt increases the salt used by a factor of 2.25, while capacity only increases to 26,600 grains, an increase of 1.5 times.

As shown, brine efficiency is higher at a lower salt dose - more hardness is removed per pound of salt used to regenerate the system. Therefore, the system can be run more efficiently by lowering the salt dose. There are practical limits to the minimum salt dosage depending on water characteristics and treated water quality requirements. Theoretically, the maximum efficiency for a softener is around 6000 grains/lb salt. Practically, systems are rarely set up with a salt dose of much less than 3 lb/ft3, and peak efficiencies rarely exceed 5100 gains/lb.

Typically these limits in salt efficiency are determined by the water's tendency to foul the resin and injectors with iron and sediment, and treated water hardness requirements. Low salt doses increase treated water hardness concentration. Removing iron from a softener bed requires higher concentrations of salt. Finally, smaller brine injectors are required for low salt doses as these small injectors are more susceptible to plugging with iron and sediment. Therefore, in applications with iron or where low hardness leakage is required, softeners are seldom run at maximum salt efficiency.

Lowering the softener's salt dose to increase brine efficiency will also decrease water efficiency. At a lower salt dose, there is less capacity per regeneration cycle. Because the system is regenerating more frequently and with minimal change in the regeneration water used in the draw/slow rinse cycle, more regeneration water is used per 1000 grains of hardness treated. So, while significant increases in brine efficiency can be achieved by decreasing the salt dose, its effect on water efficiency should be considered.

EXAMPLE

The following example demonstrates the salts savings achievable by lowering salt dose, and its impact on water efficiency:

A 1 ft^3 softener is installed in a residence with available salt settings of 4, 9, and 15 lbs/ft^3.

Assumptions: 20 Grains per gallon (gpg) of water, 250 gallons per day (gpd) water usage, capacity and efficiency per the chart above.

At a salt dose of 15lbs/ft^3 per regeneration and using the assumptions listed below, the system will have a capacity between regenerations of 30,400 grains. Based on this, the system will regenerate approximately 60 times per year, or once every 6 days. The salt used in 1 year is 900 pounds (15 lbs/regeneration x 60 regenerations/year). The water used for regeneration is 65.97 gallons/cycle or 3958 per year.

The same system is now set at a salt dose of 9 pounds, which gives a capacity between regenerations of 26,600 grains. The system at this setting will regenerate approximately 69 times per year, or once every 5 days. The salt used in 1 year is 620 pounds (9 lbs/regeneration x 69 regenerations/year). The water used for regeneration is 59.98 gallons/cycle or 4139 gallons per year.

Finally, this system can also be set at a salt dose of 4 lbs/ft^3 per regeneration, with a resulting capacity of 17,900 grains. At this setting, the system will regenerate approximately 102 times per year, or once every 3.6 days. The salt used in 1 year with this salt setting is 408 pounds (4 lbs/regeneration x 102 regenerations/year). The water used for regeneration is 54.99 gallons/cycle or 5609 gallons per year.

A salt setting of 4 lbs/regeneration saves 212 pounds per year over a 9 pound salt dose, and 492 pounds per year over a 15 pound salt dose! A salt setting of 4 lbs/regeneration results in an increase in regeneration water used of 1651 gallons per year over a 15 pound salt dose, and an increase of 1470 gallons per year over a 9 pound salt dose.

Salt Dose (lbs/ft^3)	Salt Used Per Year		Water Used Per Year	
	Lbs	Savings	Gallons	Savings
4	408	↑	5609	↓
9	620		4139	
15	900		3958	

Brine concentration also has an impact on softener efficiency. Brine concentration should be between 8-15% NaCl (or 30-57% salometer) upon introduction to the softener for a downflow brining system. Testing indicates that a lower concentration (around 6%) provides the optimum efficiency for an upflow brining system. The brine in an upflow system sees less dilution before it is introduced to the resin bed. In upflow regeneration it is introduced directly to the bottom of the bed, while in downflow regeneration, it passes through the free board area necessary for backwashing and is thus diluted.

Fleck® Control Valve injectors typically produce brine in a concentration range of 6-13% (23-49% salometer), depending on injector size, style, feed pressure, and draw height.

BRINING RATE AND CONTACT TIME

Just as salt dose and brine concentration has an impact on a system efficiency, the rate at which brine is introduced will also have an impact. For a given salt dose and concentration, the brining rate will determine brine contact time with the resin. Increased contact time will increase the capacity and efficiency of the softener system; therefore, the slower brine can be introduced the better. There are practical limitations to how low the flow rate can go. Too low a flow rate will increase the chances of channeling, where the brine isn't flowing evenly through the resin bed but is instead following several lower-resistance paths, resulting in uneven regeneration. In an upflow brining system, a low flow rate is also required to prevent the resin bed from lifting and becoming fluidized, which actually decreases resin-to-brine contact time, thus reducing system efficiency.

Testing has shown that 0.5-0.63 gpm/ft2 is the optimum flow rate for brining and slow rinse of an upflow regenerating softener with standard mesh, 8% crosslinked resin. The table below shows the recommended flows and injector sizes for a variety of tank sizes required to achieve the maximum system efficiency.

Tank Diameter	Flow Range for Upflow Regeneration (gpm)	Recommended Injector Size
8"	0.175 – 0.220	000
9"	0.221 – 0.278	000
10"	0.273 – 0.343	00
12"	0.393 – 0.495	0
14"	0.535 – 0.674	1
16"	0.700 – 0.882	1

There are drawbacks to designing a system at low regeneration flow rates. The system uses smaller injectors which may be more prone to plugging with debris, as previously discussed. The system is more sensitive to changes in inlet pressure which can have an impact on the flow achieved by a small injector. (Injector caps with integrated pressure regulators are available for many Fleck valves to provide a constant feed pressure, therefore keeping the brine and slow rinse rates at the desired rate.) Lower brining and slow rinse rates also mean longer overall regeneration time, which can be an issue if there are multiple water treatment units to be regenerated in a limited period of time.

Decreasing brine flow rate to improve brine efficiency has little impact on softener water efficiency. By decreasing flow rate, the time to draw brine increases but the motive flow-to-brine draw ration remains the same, so approximately the same volume of motive water is required.

SECTION 2: SYSTEM DESIGN CONSIDERATIONS

DOWNFLOW BRINING VERSUS UPFLOW BRINING

An ion exchange softener can be regenerated by either downflow or upflow brining. In downflow brining, the brine flows through the softener from top to bottom, in the same direction that the service flow occurs (co-current).
In upflow brining, the brine flows through the softener from the bottom to the top, in the opposite direction of service flow (counter-current). In general, upflow brining softener systems are more brine efficient than downflow systems. For example, they are generally run at lower brining flow rates which increases contact time as discussed previously. Another reason is the efficiency gains from co-current to counter-current regeneration. Water efficiency is also generally better in upflow systems as these systems will have, on average, more capacity between regenerations with similar water use per regeneration.

At the beginning of a regeneration cycle, the resin highest in hardness is at the top of the bed, and the resin with the least amount of hardness is at the bottom of the bed. In downflow (co-current) regeneration, hardness that is exchanged off of the resin during brining is pushed down the bed, where it continues to exchange on and off the resin until its pushed from the bed. The freshest brine is being used on the most depleted portion of the bed.

In upflow (counter-current) regeneration, the hardness that is exchanged off of the resin during brining is pushed back up the bed, exiting the system at the top of the bed. The freshest brine is being used to regenerated the least depleted portion of the bed. This highly regenerated portion of resin acts as a polisher which decreases hardness leakage. This allows an upflow regenerated softener to use a lower salt dose while achieving the same quality water (i.e. low hardness leakage).

Care must be taken when choosing upflow versus downflow regeneration as upflow regeneration is not suitable for all installations. In particular, brine and slow rinse rates must be maintainable at a level low enough to prevent fluidizing of the resin bed. It is most suitable in cases where feed water has low concentrations of iron and particulates.

Downflow Brining   Upflow Brining

VARIABLE BRINING

Most metered, single tank softeners delay regeneration until the night after the meter reaches its set capacity. To ensure that soft water is available throughout the day, a portion of the capacity equal to a days' usage is reserved.

Variable brining is a control feature available on some upflow softeners. With variable brining, the controller determines how much reserve capacity has been used when the regeneration time is reached. Based on that remaining capacity, the system adjusts the salt dose used for that regeneration.

This salt dose adjustment avoids using salt for resin that is still regenerated. Variable brining systems have brine fill as the first step of regeneration, instead of the last step of regeneration. Fill time is varied to allow the salt dose to be matched to the actual amount of resin that is exhausted.

Variable brining should be used on an upflow brining system with the brining/slow rinse step before backwash. In this case, resin in the bottom of the tank is still in a mostly regenerated state at the start of the brine cycle. Brine will just pass through this portion of the bed and salt will be available when the brine reaches depleted portions of the bed.

Variable brining will not work with downflow brining. With downflow brining, the first resin that is exposed to the brine is the most depleted. As that resin is regenerated, the hardness that is exchanged off of the resin is pushed down the bed ahead of the more sodium-rich brine, and will exchange onto less depleted resin. This resin will now be more fully depleted thus need to be fully regenerated. This continues all the way down the resin bed, so that resin with capacity remaining at the bottom of the bed will actually be depleted by the exchanged hardness before it is regenerated. This means that even if there is still some capacity remaining when regeneration starts in a downflow system, that capacity will be used by the time the full strength brine reaches that portion of the resin bed.

VARIABLE RESERVE

Variable reserve is another means to minimize capacity wasted by the reserve setting. With a variable reserve system, the controller determines what the appropriate reserve for a system should be based on recent water usage patterns. This system increases and decreases the reserve capacity as required, helping to avoid both wasting salt and running out of soft water by optimizing reserve capacity.

Improving brine efficiency by using both variable brining and variable reserve leads to a slight decrease in water efficiency. The salt dose and capacity of these systems are typically lower than a standard system, which increases the regeneration water used per grains of hardness tested.

TWIN TANK SYSTEMS

A softening system is designed to continuously supply soft water. This is achieved in one of two ways. One option is to have a single softener resin tank, regenerating it at times when no one is using water – typically 2 a.m. In order to do this, the softener must have a reserve capacity as discussed previously.

The optimal solution is a twin tank system which provides continuous soft water yet only regenerates when the softener capacity is fully used. In a twin tank system, one tank is online and producing soft water while the other one is regenerated and then waits offline, fully regenerated. When online tank capacity is reached, the offline tank is brought online and the depleted tank is taken offline and regenerated. Because regeneration can occur as soon as the capacity of the system is met, no reserve is required.

EXAMPLE

The following example demonstrates the salt savings achieved by using a twin tank system in place of a single tank system with reserve.

Two softener systems are both set up with 1 ft3 of resin per tank – 1 tank for the single tank system, and 2 tanks for the twin tank system. Both are operating at a salt dose of 4 lbs/ft3. The single tank system has a reserve of 250 gallons.

For the single tank system, it is assumed that (on average) half of the reserve remains when regeneration begins. Based on this, the single tank system will regenerate 118.5 times per year or once every 3 days. This system will use 474 pounds of salt over 1 year.
The twin tank system does not have a reserve – regeneration is immediate when capacity is reached. With this setup, both tanks combined will regenerate 102 times per year or once every 3.6 days. The salt used in one year with this system is 408 pounds.

Assumptions: 20 grains per gallon (gpg) of water, 250 gallons per day (gpd) water usage, capacity and efficiency from the chart in section 1.

System	Salt Dose (lbs/ft^3)	Salt Used Per Year Lbs	Savings
Single Tank	4	474	↓
Twin Tank	4	408	

The twin tank system saves 66 pounds of salt per year over the single tank system with a 1-day reserve.

Using a twin tank system increases water efficiency as well as brine efficiency. Twin tank systems have more capacity between regenerations, with similar water usage per regeneration as a single tank system, thus utilize less regeneration water per 1000 grains of hardness treated.

REGENERATION INITIATION

Softener regeneration can be initiated in several ways, including by a time clock or meter. With a time clock, the softener is set to regenerate after a set period of time regardless of the water volume treated (or amount of capacity used). A metered system is set to regenerate after a specified volume of water has been treated. A metered system offers a better estimate of the resin capacity that has been used. With a time clock system, as demand varies, the softener may regenerate too soon wasting salt by regenerating with capacity remaining. Or the softener may regenerate too late, allowing hard water to pass through the system.

Using demand initiated regeneration increases water efficiency versus a time clock system, as the demand initiated regeneration has (on average) more capacity between regenerations with similar regeneration water usage. This leads to less regeneration water used per 1000 grains of hardness treated.

It should also be noted that, per NSF/ANSI Standard 44, only demand initiated regeneration softeners can be listed as "efficiency rated".

DOUBLE BACKWASH

We have discussed that one upflow regenerated softener benefit is that the most highly regenerated resin is at the bottom (outlet) of the tank, whereas a downflow regenerated softener has the most exhausted resin at the bottom of the tank.

Downflow regeneration with double backwash is a regeneration method that provides some benefits of both upflow and downflow systems. In such a system, the resin bed is backwashed, followed by brine and slow rinse, then the system is backwashed again. The first backwash cleans the resin bed; the second backwash mixes the regenerated bed, more evenly distributing highly regenerated resin throughout the bed. The advantages of this regeneration system include more robust downflow regeneration (no chance of fluidizing the bed, etc.), and that the resin at the bed's bottom is in a higher state of regeneration which lowers leakage and improves capacity.

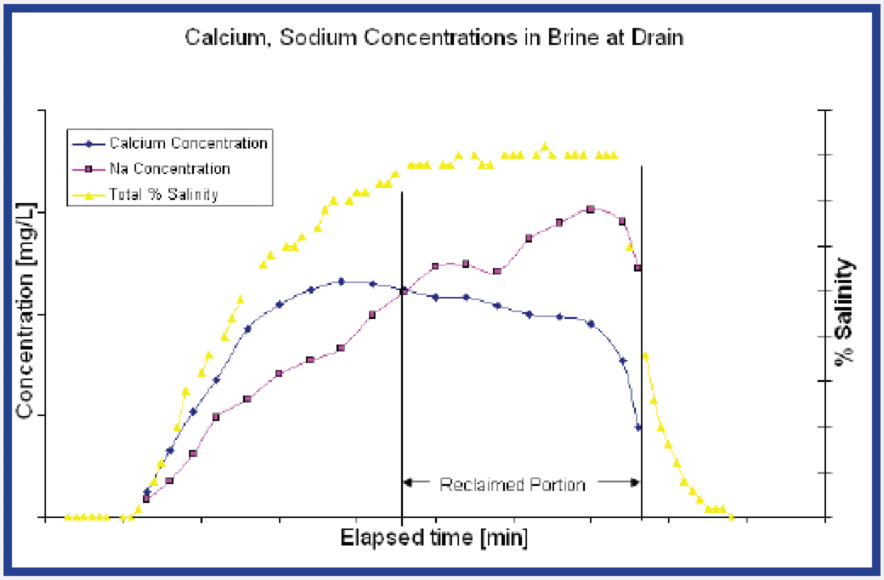
Double backwash will have a negative impact on water efficiency as the extra backwash cycle adds to the water required per regeneration. The second backwash on an electronically controlled unit can be shorter than the first, as it is only necessary to mix the resin rather than clean it.

SECTION 3: BRINE RECOVERY

Brine recovery is another method that claims to improve brine efficiency. In residential applications, brine recovery is typically applied with a simple reclaim and reuse method, where waste brine is redirected to the brine tank in place of a portion of the fill water and then reused. Brine recovery can only be used on high salt dose, and therefore inefficient, systems. This is because there needs to be sufficient salt remaining after the brine has passed through the resin bed to recover, and that salt is not available in an inherently brine-efficient system.

When brine is passed through a softener, brine composition changes as sodium in the brine is exchanged for calcium and magnesium in the resin. Because excess sodium is required to drive calcium and magnesium off of the resin, sodium remains in the brine when it is sent to the drain. The figure below shows the calcium, sodium, and total percent saturation of brine (or salinity of the brine) at the drain during brine and slow rinse cycles. As shown on page 7, calcium and sodium concentrations are rising during the first part of the cycle. In this portion of the cycle, the calcium level is too high for reclaim to occur. In the second part of the cycle, sodium concentration continues to rise, but the calcium concentration starts to drop. This portion of the brine has the most potential for reuse, as the ratio of sodium to calcium increases. In the final portion of the slow rinse cycle, both the calcium and sodium concentrations drop very quickly to levels too low to be useful.

Testing the Theoretical - Recovered + Sweet Brine



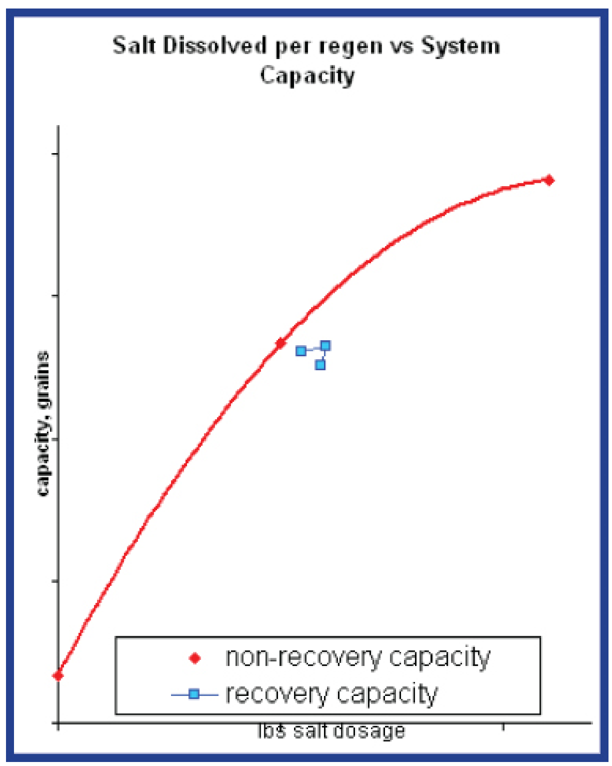
A system was set up in Pentair's water lab to test the efficacy of brine recovery. Brine was diverted from the drain at the peak of sodium concentration and sent back to the brine tank. The majority of the brine is made up from reclaim, except for enough fresh water to dissolve 2 pounds of salt. After regeneration, the total salt dissolved from the brine tank was recorded and plotted against the measured capacity.

The capacity of system with no recovery is shown as the line in the graph below. With brine recovery and claimed salt savings of 20%, expect reclaim system capacity to be above the line. However, our data shows capacities at or slightly below the expected capacity at the tested salt dose.

WHY LOWER CAPACITIES?

As seen in the concentration profile, the concentration of calcium in the brine although declining is still high in the reclaimed portion. This high concentration of calcium hardness in the brine negates the effect additional salt in the reclaimed brine may have by depleting the top of the resin bed.

The net effect is that the capacity and efficiency of the reclaimed brine system is the same or even slightly lower than a standard system at the same actual use salt dose.



APPLIED MEMBRANES INC.

WHERE DOES THE GAIN COME FROM?

Although our tests have not shown that additional capacities are achieved with brine recovery, many people employ this process and actually realize decreased salt usage. This may be due to the fact that many softener capacities are set conservatively to account for anticipated loss in capacity as resin ages or becomes fouled. If the softener is set up with a conservative capacity assuming a gain in efficiency through brine recovery, the net result may be a system “optimized” for the actual salt dosage.

Brine reclaim systems should have a slightly better water efficiency than a system without reclaim. There is a decreased regeneration water volume because the fill cycle is reduced, however, that volume decrease is partially offset by the increase in volume required to draw larger brine volume at the same apparent salt dose. In our example system at left, water savings from brine reclaim is approximately 200 gallons/year.

Until there is an NSF/ANSI standard available to gauge brine reclaim capacity improvements, there will continue to be conflicting opinions regarding the efficacy of brine reclaim.

SECTION 4: WATER EFFICIENCY

The simplest way to gain water efficiency is to optimize backwash, slow rinse, and rapid rinse cycles to be no longer than necessary. In clean water applications, a backwash of 7 to 8 minutes is usually sufficient. Slow rinse cycles only need to be long enough to rinse the excess salt off the resin. This is especially true with larger injectors as slow rinse rates are higher and more water is used for each extra minute of rinse. Additionally, rapid rinse cycles can sometimes be shortened by a couple of minutes. This adds up to significant water savings as these are the highest flow rate regeneration cycles.

EXAMPLE

The following example demonstrates the water savings achievable with an efficient system. In the comparison, the first system is set up with the controller defaults for regeneration cycle times. The second system is set up as to optimize efficiency and is the basis of Pentair's NSF 44 listing.

Cycle	Default	NSF 44
Backwash	40	8
Brine Draw/Slow Rinse	60	65, 83, or 103
Rapid Rinse	10	11

Assumptions: 20 grains per gallon (gpg) of water, 250 gallons per day (gpd) water usage, capacity and efficiency from the chart above.

The two softeners are both set up with 1 ft3 of resin and are operating at a 3.75, 9, and 15 lbs/ft3 salt doses. The default system uses a #1 injector, and the NSF 44 listed system uses a #000 injector. The capacity of the default system is 10% lower than the capacity of the NSF 44-listed system. The systems have regeneration cycle times per the table below:

System	Salt Dose (lbs)	Gallons Per Regeneration	Gallons per 1000 Gains	Gallons per Year
Default	3.75	79.25	5.64	10,293
	9	80.99	3.64	6,096
	15	83.31	2.95	5,384
Efficient	3.75	48.30	3.10	5,658
	9	52.62	1.95	3,559
	15	57.42	1.83	3,340

The default settings system with a brine dose of 3.75 lbs/ft3 uses 79.25 gallons of water per regeneration, or 5.64 gallons per 1000 grains of capacity, or 10,293 gallons per year. The same system at a brine dose of 9 lbs/ft3 uses 6096 gallons per year; at a brine dose of 15 lbs/ft3, it uses 5384 gallons per year. The NSF 44-listed system at 3.75 lbs/ft3 uses 48.3 gallons of water per regeneration, or 3.10 gallons per 1000 grains of capacity, or 5658 gallons per year. The same system at a brine dose of 9 lbs/ft3uses 3559 gallons per year; at a brine dose of 15 lbs/ft3, it uses 3340 gallons per year.

The more efficient NSF-44 listed system will save 4635 gallons per year over the system using default controller settings and the #1 injector.

SUMMARY

There are several ways to optimize water softener efficiency by adjusting regeneration flow rates and cycle durations. However, it should be noted that adjustments to improve brine efficiency or water efficiency often have an impact on one another, and should be both considered and balanced to meet the specific needs of the installation.

Parameter	Change	Impact on Brine Efficiency	Impact on Water Efficiency
Salt Dose	Decrease (i.e. from 9lbs/ft³ to 3 lbs/ft³)	Increase in Brine Efficiency	Decrease in Water Efficiency
Brining Flow Rate	Decrease in Brining Flow Rate	Increase in Brine Efficiency	Little impact on water efficiency as tested when slow rinse volumes remain the same
Upflow vs. Downflow	Upflow Instead of Downflow	Increase in Brine Efficiency	Increase in water efficiency
Variable Brining and Reserve	Use Variable Brining or Reserve	Increase in Brine Efficiency	Slight decrease in Water Efficiency
Twin Tank System	Twin System in Place of Single System with Reserve	Increase in Brine Efficiency	Increase in water efficiency
Regeneration Initiation Method	Use Meter	Increase in Brine Efficiency	Increase in water efficiency
Double Backwash	Implement Double Backwash	Increase in Brine Efficiency	Decrease in Water Efficiency
Brine Recovery	Implement Brine Recovery Process	Little impact on brine efficiency as tested	Slight increase in water efficiency

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