LEARN TO DO IT RIGHT THE FIRST TIME:

Guidelines for Designing Water Softeners

By Robert Slovak

Summary: *Water softener design and setup can be a confusing thing to learn regardless of the application. Here are basic guidelines for engineers and technicians to study to gain a fundamental understanding of this process.*

The following is an introductory article offering practical advice on sizing and setting up water softeners for residential, commercial and non-critical industrial applications. There are significant variations and details not within the scope of this presentation but that deserve further investigation such as alternate methods of brining and regeneration cycle programming. Feel free to surf the *WC&P* "archives" at www.wcponline.com for more on these subjects. Meanwhile, read on.

STEP 1: Select the control valve you want to use based on the service flow requirements of the application—The first objective is to select a valve that offers acceptable pressure drop from the inlet to the outlet of the softener at the service flow required for the application. Use a maximum service flow pressure drop guideline of 15 pounds per square inch (psi)—1 bar—for the valve alone.

STEP 2: Determine volume of cation resin required—The volume of cation resin is generally determined by four things:

a. The service flow rate,

b. Hardness of the water,

c. The volume of water to be treated, and

d. The number of times a day the softener can be regenerated (i.e., valves with flow meters allow multiple regeneration per day). Usually three times is the practical maximum number of regenerations per day because:

- It typically takes up to two hours for regeneration, and
- It takes up to three hours (depending on temperature) to make a saturated salt solution in the brine tank.

Learn this–Resin volume vs. service flow rate

The volume of cation resin required for a given flow rate can be determined two ways: 1) By the volume of resin which concerns contact time, and 2) by the resin bed (the tank) cross section area that concerns pressure drop in the resin bed. See Table 1 to determine the cross section area of the most popular size tanks.

By contact time—Use 5 gallons per minute per cubic foot (gpm/ft^3), or 42 cubic meters per hour per cubic meter ($m^3/h/m^3$), for continuous flow and 7.5 gpm/ft^3 (60 $m^3/h/m^3$) for peak flow. To achieve low hardness leakage as required in applications like boiler water treatment, the flow rate should be limited to 3 gpm/ft^3.

By resin bed area—Use 10 gpm per square foot (ft^2), or 25 m^3/h per square meter (m^2), for continuous flow and 15 gpm/ft^2 (37 $m^3/hr/m^2$) for peak flow. To assure low hardness leakage, limit the area flow to 8 gpm/ft^2.

For example, assume the service flow is 15 gpm—56.8 liters per minute (L/min). Based on the guideline above, the recommended resin volume is 15 gpm/5 gpm/ft^3 = 3 ft^3. The cross section area guideline recommends a resin bed area of 15 gpm/10 gpm/ft^2 = 1.5 ft^2, which corresponds to a 16-inch (") tank (1.4 ft^2) and a resin volume of 4.6 ft^3. You have the choice of using a 16" tank with 3 ft^3 (84.9 L) or use a normal resin volume of 4.6 ft^3 (130.2 L) for added capacity to meet future expansion or increase in hardness.

Bear in mind, the 16" tank with 3 ft^3 of resin produce a bed depth of just under 26 inches (65 cm), which creates the 24" minimum resin bed depth requirement of the resin manufacturer. Also be aware that if the service flow is *too low,* the water can "channel" through the resin bed only using a fraction of the resin's capacity. Use a *lower* flow limit of no less than 1 gpm/ft^3 (8 $m^3/h/m^3$).

Learn this–Resin capacity vs. salt dose

The resin capacity for hardness, or amount of hardness that can be removed by cation resin, depends on how much salt is used (dosage) to regenerate each liter or cubic foot of cation resin. The normal range is 6 pounds of salt per cubic foot (lbs salt/ft^3 or lbs/ft^3) of resin—about 100 grams salt per liter (g salt/L or g/L) of resin—to 15 lbs salt/ft^3 (about 240 g salt/L) for *standard mesh* resin. The capacity for each salt dosage can be approximated in the following:

Low limit salt dosage—6 lbs salt/ft^3 (about 100 g salt/L) resin gives hardness removal capacity of approximately 21,000 grains/ft^3—48 grams of hardness as calcium carbonate ($CaCO_3$) per liter [g($CaCO_3$)/L] or 0.96 equivalents per liter (eq/L).

Medium salt dosage—9 lbs salt/ft^3 (about 150 g salt/L) resin gives hardness removal capacity of approximately 26,000 grains/ft^3—60 g($CaCO_3$)/L or 1.19 eq/L.

High salt dosage—12 lbs/ft^3 (about 200 g salt/L) resin gives hardness removal capacity of approximately 29,000 grains/ft^3—66 g($CaCO_3$)/L or 1.33 eq/L).

Maximum limit salt dosage—15 lbs salt/ft^3 (about 250 g salt/L) resin gives hardness removal capacity of approximately 31,000 grains/ft^3—71 g($CaCO_3$)/L or 1.42 eq/L.

Notice that even though the salt

Table 1. Water softener sizing and performance chart

						Minimum salt dosage 6 lbs/ft³ (100 g/L)		Medium salt dosage 9 lbs/ft³ (150 g/L)		High salt dosage 12 lbs/ft³ (200 g/L)		Maximum salt dosage approx. 15 lbs/ft³ (250 g/L)	
Tank size D" x H"	Tank area ft² (m²)	Resin vol.[1] ft³ (liters)	Backwash[2] @60F & 77F @15C &25C gpm_{60} / gpm_{77} (lpm_{15} / lpm_{25})	Service flow gpm (lpm)	Peak flow gpm (lpm)	Regen. salt lbs (kg)	System capacity[3] grains (kg)	Regen. salt lbs (kg)	System capacity[3] grains (kg)	Regen. salt lbs (kg)	System capacity[3] grains (kg)	Regen. salt lbs (kg)	System capacity[3] grains (kg)
6 x 35	0.19 (0.018)	0.4 (10)	1.0/1.3 (3.6/4.9)	**2.0 (7.6)**	3.0 (11.4)	2.4 (1.0)	**8,400 (0.48)**	3.6 (1.5)	**10,400 (0.60)**	4.8 (2.0)	**11,600 (0.66)**	6.0 (2.5)	**12,400 (0.71)**
7 x 44	0.27 (0.025)	0.6 (15)	1.3/1.8 (5.1/6.8)	**3.0 (11)**	4.5 (16.5)	3.6 (1.5)	**12,600 (0.72)**	5.4 (2.3)	**15,600 (0.90)**	7.2 (3.0)	**17,400 (0.99)**	9.0 (3.8)	**18,600 (1.07)**
8 x 44	0.34 (0.032)	0.8 (20)	1.7/2.3 (6.5/8.7)	**4.0 (15)**	6.0 (22.5)	4.8 (2.0)	**16,800 (0.96)**	7.3 (3.0)	**20.800 (1.20)**	9.6 (4.0)	**23,200 (1.32)**	12.0 (5.0)	**24,800 (1.42)**
9 x 48	0.44 (0.041)	1 (25)	2.2/3.0 (8.3/11.2)	**5.0 (19)**	7.5 (28.5)	6.0 (2.5)	**21,000 (1.20)**	9.0 (3.8)	**26,000 (1.50)**	11 (5.0)	**29,000 (1.65)**	15.0 (6.3)	**31,000 (1.78)**
10 x 54	0.54 (0.051)	1.3 (35)	2.7/3.7 (10.4/13.9)	**6.5 (30)**	9.8 (45.0)	7.8 (3.5)	**27,300 (1.68)**	11.7 (5.3)	**33,800 (2.10)**	15.6 (7.0)	**37,700 (2.31)**	19.5 (8.8)	**40,300 (2.49)**
12 x 52	0.78 (0.073)	2.0 (55)	3.9/5.3 (14.8/19.9)	**10.0 (38)**	(15) (57)	12.0 (5.5)	**42,000 (2.64)**	18.0 (8.3)	**52,000 (3.30)**	24.0 (11.0)	**58,000 (3.63)**	30.0 (13.8)	**62,000 (3.91)**
13 x 54	0.91 (0.085)	2.2 (60)	4.6/6.1 (17.3/23.2)	**11.0 (44)**	16.5 (66)	13.2 (6.0)	**46,200 (2.88)**	19.8 (9.8)	**57,000 (3.60)**	26.4 (13.0)	**63,800 (3.96)**	33.0 (16.3)	**68,200 (4.26)**
14 x 65	1.07 (0.100)	3.0 (85)	5.4/7.2 (20.3/27.3)	**15.0 (57)**	22.5 (85.5)	18.0 (8.5)	**63,000 (4.08)**	27.0 (15.0)	**78,000 (5.10)**	36.0 (20.0)	**87,000 (5.61)**	45.0 (25.0)	**93,000 (6.04)**
16 x 65	1.41 (0.131)	4.0 (115)	7.0/9.5 (26.6/35.8)	**20.0 (76)**	30 (114)	24 (11.5)	**84,000 (5.52)**	36.0 (19.5)	**104.000 (6.90)**	48.0 (26.0)	**116,000 (7.59)**	60.0 (32.5)	**124,000 (8.17)**
18 x 65	1.76 (0.164)	5.0 (140)	8.8/11.8 (33.3/44.8)	**25.0 (95)**	37.5 (143)	30 (14.0)	**105,000 (6.72)**	45.0 (24.8)	**130,000 (8.40)**	60.0 (33.0)	**145,000 (9.24)**	75.0 (41.3)	**155,000 (9.94)**
21 x 62	2.40 (0.223)	6.5 (185)	10.8/14.6 (41.0/55.1)	**32.5 (123)**	48.8 (185)	39 (18.5)	**136,500 (8.88)**	58.5 (30.0)	**169,000 (11.10)**	78.0 (40.0)	**188,500 (12.21)**	97.5 (50.0)	**201,500 (13.14)**

1. The listed resin volumes are nominal values and are subject to change based on user preference and experience.
2. The water temperature determines the backwash flow rate. Colder water temperature requires less backwash flow. Refer to water viscosity charts for other temperatures.
3. These are approximate capacities based on the resin volume. Small inconsistencies may result from rounding off and unit conversions.

SOURCE: AquaCorp. Ltda., Rio de Janeiro, Brazil (aquacorp@aquacorp.com.br)

dosage more than doubles, the hardness removal capacity doesn't. The higher the salt dosage, the lower the salt efficiency.

Bear in mind, the above capacity values are only approximate. Consult the specifications from your resin supplier for more accurate capacity specifications.

Learn this–Resin volume vs. volume of treated water

To determine the volume of resin by volume of water treated and hardness, start by estimating the maximum total grains (or kilograms) of hardness that must be removed each day.

For example, assume the water has a hardness—as ($CaCO_3$)—of 13 grains/gallon [222 milligrams per liter (mg/L), calculated by multiplying 13 grains by 17.1]—and that 20,000 gallons (75.8 m³) of water must be treated. The total hardness is 13 grains/gallon × 20,000 gallons = 260,000 grains—16.9 kilograms (kg)—of hardness per day.

At the medium salt dose, each cubic foot of resin has a capacity of 26,000 grains (each liter of resin can remove 0.060 kg hardness). If you are limited to only one regeneration per day (as with a timer-controlled valve), then a volume of 260,000/26,000 = 10 ft³ (about 283 L) of resin is required. This typically requires a 24" × 72" tank.

Consider multiple regenerations—It's important to understand that multiple daily softener regenerations can reduce system size and cost. If the application is suited for multiple regenerations per day [you need an alternating multiple-tank system or a cistern (reservoir) that can supply treated water for the customer during regeneration], then a more cost effective softener system can be designed. This is an especially good strategy where cisterns are commonly used to store treated water before the points of use (as in Latin America). Consider using three regenerations per day (roughly every eight hours for continuous flow) for the example above. Then, to meet the capacity requirement, only one-third the amount of resin is required or 3 ft³ (85 L) for this example.

But let's check if this reduced volume of resin can meet the service flow rate requirement of 15 gpm. Referring to "Resin volume vs. service flow rate" section, 15 gpm (57 L/min or 1 pm) service flow requires at least 3 ft³ of resin. The flow rate is compatible with the resin volume required for the hardness capacity. Now, instead of a 24" tank with 9 ft³ of resin, the system can be reduced to:

1. A twin-metered alternating softener using 16" tanks with 3 ft³ of resin (each regenerates three times every two days—about every 16 hours) where continuous direct flow of softened water is required

2. A single-metered softener using a 16" tank with 3 ft³ of resin (which regenerates three times per day) where a cistern of treated water is available to supply the customer with a continuous supply of softened water.

STEP 3: Determine the tank size— Generally, the tank is filled to ½ to 2/3 of the total tank volume. The depth of cation resin should be at least 24″ (0.6 m) in smaller tanks and 30″ (0.75 m) in larger tanks. The tank should be tall enough so the resin can expand to at least 50 percent of its normal depth into the void space. Refer to the accompanying chart for standard tank sizes.

STEP 4: Determine the backwash flow rate— The backwash segment of the regeneration removes dirt and debris from the resin and is determined by two things:

a. *Diameter of the tank*—Refer to the accompanying design chart (see *Table 1*) for cross section area.

b. *Temperature of the water*—This determines the water viscosity as an inverse relationship. As water temperature decreases, it becomes more viscous (thicker) and will cause greater expansion of the resin bed during backwash.

Learn this–Backwash flow rate vs. water temperature

This requirement of correct softener design may be the most overlooked factor, especially in warm water regions such as Latin America. The flow must be sufficient to expand the bed at least 50 percent. Use the following guidelines but, for exact backwash flow requirements, refer to the backwash requirements vs. water viscosity chart from your resin supplier.

- 4.2 gpm/ft^2 (10.3 m^3/h/m^2) backwash flow at 10°C (50°F)
- 5.0 gpm/ft^2 (12.3 m^3/h/m^2) backwash flow at 15°C (59°F)
- 5.5 gpm/ft^2 (13.5 m^3/m^2) backwash flow at 20°C (68°F)
- 6.7 gpm/ft^2 (16.4 m^3/h/m^2) backwash flow at 25°C (77°F)

STEP 5: Determine the brine injector size— The injector creates suction for the salt solution. During regeneration, water flows through the injector venturi and creates a vacuum to pull salt brine from the salt tank. The injector is primarily determined by the diameter of the tank. The proper injector selection is found in the manual of the control valve you're using.

STEP 6: Determine the regeneration function times— The regeneration cycle consists of a sequence of functions that correspond to control valve "positions." For most customers who only have to remove hardness, the following sequence of regeneration functions is recommended:

Backwash–Downflow Brine/Slow Rinse–Fast Rinse–Salt Tank Refill–Return to Service

Learn this–Softener regeneration function times

Backwash function—Eight to 15 minutes is recommended depending on the amount of particulate matter (sediment) in the water supply and water scarcity. If iron is present, use the upper range. The backwash flow is regulated by a control orifice that restricts the drain flow to the specified flow rate.

Downflow brine function—It's important to understand that the downflow brine function is only the first part of the complete "downflow brine/slow rinse" task. The control valve remains in the same position for the entire function. During this first part, saturated salt brine solution is sucked ("educted" or "drawn") from the brine tank, mixes with the venturi injector water stream (to a concentration of about 10 to 13 percent), and flows through the resin bed to regenerate it (or chemically displace the hardness removed). The NaCl content of saturated brine is 2.7 lbs/gallon (300 g/L). The brine function time is determined by:

1. The amount of salt required to regenerate the resin bed (refer to accompanying design chart)
2. The flow rate that the injector educts brine into the resin bed (consult the control valve manual for the this specification)

For example, assume you have specified the size of the softener to be a 16″ × 65″ tank with 4.6 ft^3 (130 L) of resin. You decide to choose the medium salt setting of 9 lbs/ft^3 (150 g/L), referring to the accompanying design chart. The amount of salt required is 42.9 lbs (19.5 kg) and the amount of salt brine containing this is 15.9 gallons (60 L) saturated brine. The control valve manual says that the injector for a 16″ diameter tank educts the saturated salt brine at a rate of 0.7 gpm (2.6 L/min). Therefore, the downflow brine time required is 22.7 minutes.

Slow rinse function—As stated above, the slow rinse cycle is actually an extension of the "downflow brine/slow rinse" function"—but with no salt brine being educted. The continued water flow through the injector provides this slow rinse. The recommended guideline is to have the entire downflow brine and slow rinse cycle be three times as long as the brine cycle.

For example, consider the instance above. The brine time is approximately 23 minutes. The total brine and slow rinse cycle should be 3 × 23 minutes = 69 minutes.

Fast rinse function—The fast rinse flows through the backwash flow control so its flow rate is the same. For most applications, the fast rinse time should be 6 to 12 minutes depending on the volume of resin and the application. For instance, most domestic and commercial applications can use the lower range while reverse osmosis (RO) and deionization (DI) pretreatment and boiler feed and industrial process applications should have longer rinse times.

Salt tank refill function—During this cycle, a controlled stream of water flows into the salt tank to make up a saturated brine solution for the next regeneration. The salt tank refill time should be based on the fact that 1 gallon of fresh water dissolves approximately 3 lbs (1 L dissolves 360 g) of salt.

For example, consider the situation above. The amount of salt required for the medium salt setting is 42.9 lbs. (19.5 kg). The manual says the salt tank refill flow rate is 0.5 gpm (2 L/min). The volume of water required to dissolve 42.9 lbs of salt is therefore 14.3 gallons (54.1 L) and the time is 28.6 minutes.

Conclusion

The softener design guidelines outlined in this article and accompanying chart are intended to provide a base of information for general purpose softening applications such as domestic use, commercial and institutional washing and laundry, non-critical industrial processes, low pressure boilers, cooling towers, and RO and DI pretreatment. More demanding applications like high-pressure boilers, medical autoclaves and water sources containing problem contaminants like iron and manganese require additional special considerations. Thus, you should consult your other professional sources for specific application guidelines.

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