



Comparing Resin Options for Nitrate Removal

The task of wading through resin options and available equipment design configurations can be challenging, even for an experienced design engineer. This document will help engineers quickly focus on the best resin.

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Contents

Background	3
Available Purolite™ Resins	4
Municipal and POE Concerns	6
Municipal Plant Choices to Minimize Wastewater and Operating Cost	9
Equipment Design Choices	14
Guidelines for Minimizing Wastewater	16
Resin Vessel Design	18
PRSM™ Software Cases	18
Commissioning	31
Residuals Handling	32
Treated Water Quality	33
Summary	35
References	36
Appendix A	36

Background

The widespread use of nitrate fertilizers has made nitrate the most commonly found contaminant in drinking water supplies globally. Contamination is more acute in areas of high fertilizer use with spring runoffs in colder climates serving to further magnify the problem. Negative impacts on human health (e.g. methemoglobinemia or blue-baby syndrome) are well established. The US EPA and the World Health Organization have set maximum acceptable levels of nitrate in drinking water at 45 and 50 mg/L as NO_3 (~10 and 11 mg/L as N), respectively. Treatment solutions today are expected not only to reduce nitrate to acceptable levels but also to minimize the volume and quality of waste generated so it can be safely and economically disposed of. Additionally, any changes in the quality of the treated water that can potentially increase the corrosivity of the water toward lead and copper in the distribution system are of growing interest.

Brine regenerable strong base anion (SBA) exchange resin has been the workhorse for decades in reducing nitrate in municipal and household point-of-entry (POE) water treatment systems as it represents relatively simple-to-operate technology that can economically and consistently reduce nitrate to acceptable levels. Membrane technology and biological reduction methods are effective in nitrate reduction but have not been widely adopted because of the relatively large volume of waste generated by the former and because the latter require precise on-going control by operators, robustness to handle wide variations in water temperature and downstream control measures to avoid contamination of the treated water by biological matter.

This document is designed primarily to help engineers, water plant operators and regulators to:

- Understand the impact of raw water quality and system design on resin performance
- Choose resin and equipment design options suitable for municipal and point-of-entry systems
- Compare design options using Ecolab's PRSM nitrate software that is available online
- Compare regenerant and wastewater disposal costs for nitrate-selective, Type I and Type II resins
- Understand key factors for proper commissioning and start-up

It is important to recognize that resin selection and equipment design choices for municipal and POE nitrate removal systems are driven by different secondary goals. Municipal plants now focus on technologies that generate minimum wastewater volumes. Disposal of high TDS brine waste to local wastewater treatment plants is increasingly an issue, forcing operators to either haul waste brine offsite for disposal, route it to an offsite evaporation pond or dispose of it via deep well injection to an underground aquifer. The additional cost for these offsite disposal options can amount to more than 80% of the total operating costs. Therefore, the emphasis for new plant designs as well as existing plants is to minimize wastewater volumes as much as possible. The extent of waste minimization will depend highly on (a) the chemistry of the water to be treated, (b) the resin type and grading selected, (c) the type of regenerant use and (d) the equipment design chosen.

In contrast, the focus for POE systems is largely on the safety and aesthetics of the system — both issues are tied to the type of resin selected. A ‘safe’ design minimizes the potential for nitrate dumping to occur. Dumping means that the nitrate concentration in the treated water exceeds that in the raw water. This can potentially occur if a less preferred resin is chosen and the system is run beyond its rated capacity or the household fails to regularly top-up the salt needed for regeneration after a metered volume of water is processed. The aesthetic concern is not a health issue but the potential for the generation of a slightly fishy smell that is related to the amine functionality of some resins — [more on these issues later](#).

Available Purolite Resins

Nitrate removal from drinking water can be accomplished with the following types of resins:

- Nitrate-selective strong base anion (SBA) resin (e.g., [Purolite A520E](#))
- Higher capacity Type I strong base anion (SBA) resin (e.g., [Purolite A600E/9149](#))
- Type II strong base anion (SBA) resin (e.g., [Purolite A300E](#))

Table 1, on the next page, summarizes how to choose from the various type of resins available, based on POE and municipal applications and the relevant design and operating concerns for each sector.

TABLE 1 Resin Type Choices for POE Use: POE Concerns and Application

POE Concern	Resin Name	Resin Type	Performance
Avoiding Potential for Fishy Amine Odor	Purolite A520E	Nitrate Selective	Best
	Purolite A300E	Type II SBA	Acceptable — consider this type of resin with good metering/maintenance.
Avoiding Potential for Nitrate Dumping	Purolite A520E	Nitrate Selective	Best
	Purolite A300E	Type II SBA	Acceptable — consider this type of resin with good metering/maintenance.
Removal of Nitrate and Arsenic	Purolite A300E	Type II SBA	Best — but consider only with good metering and maintenance.

TABLE 2 Resin Type Choices for Municipal Use: Municipal Concerns and Application

Municipal Concern	Resin Name	Resin Type	Performance
Resin Choice for High Sulfate Water	Purolite A520E Purolite PPA520	Nitrate Selective	The general rule-of-thumb is to use a nitrate selective resin for waters with a high sulfate to nitrate ratio (e.g. Purolite A520E). Newer, high capacity Type I A600E/9149 may provide superior results in some cases. It is best to use our online PRSM software to compare operating costs for all recommended resins.
	Purolite A600E/9149	Type I SBA Higher Capacity	
	Purolite A300E Purofine™ PFA300E Puropack™ PPA300E	Type II SBA	
High Priority for Reducing Wastewater Volume and Disposal Cost	Purolite A520E Purolite PPA520	Nitrate Selective	All resin types are acceptable since operator control is better. Uniform grade resins use less rinse water. It is best to use our PRSM software to compare resins and system designs and to calculate wastewater volumes and operating costs.
	Purolite A600E/9149	Type I SBA Higher Capacity	
	Purolite A300E Purofine PFA300E Puropack PPA300E	Type II SBA	
Simultaneous Removal of Nitrate and Arsenic	Purolite A600E/9149	Type I SBA Higher Capacity	Recommended
	Purolite A300E Purofine PFA300E Puropack PPA300E	Type II SBA	Recommended

Please note the resin types shown above are available in various particle size gradings. The specific grading chosen will be dependent on the equipment design chosen and will impact the volume of wastewater generated — [this will be discussed in more detail later](#).

Other resin-based processes for nitrate removal include a CO₂ regenerated system using a combination of strong base anion and weak acid cation resins, a patented weak base anion resin process focused largely on non-potable higher nitrate applications and a special porous resin used as a replacement of granular activated carbon, or GAC, in biologically active filters. Please consult Ecolab for further details.

Municipal and POE Concerns

The concerns shown in Table 1 are more fully discussed below.

Resin selection for POE systems should focus on safety and aesthetic concerns, essentially the potential for a fishy amine odor in the treated water and the potential of the resin to dump nitrate into the treated water.

The influent water should ideally have no chlorine before it enters the ion exchange treatment vessel for nitrate. If softening is also being done on the influent water, the softener should be placed upstream of the nitrate treatment which will dechlorinate the water. Alternatively, a vessel with GAC can be put in front of the nitrate vessel.

Type I SBA resins are manufactured with trimethylamine functional groups and these tend to give off a mild fishy amine smell when initially put into service — this can sometimes be detected by some sensitive consumers when used in POE applications, even at very low parts per trillion concentrations at which it occurs (e.g., [Purolite A600E/9149](#)). Therefore, choosing an odorless resin can be important in household and small community water treatment systems. Type II SBA resins manufactured with a dimethyl-ethanolamine functional group tend to be odorless and were developed to address this need (e.g., [Purolite A300E](#)). In a municipal setting, this is usually not a concern as these plants generally run continuously.

If either Type I or Type II SBA resins are incorrectly operated beyond safe throughput levels (this is unlikely in a municipal plant) or if mechanical or operator issues arise that result in improper regeneration (e.g., no regular salt top-up by the user), then elevated levels of nitrate may enter the treated water system (sometimes referred to as nitrate dumping). Nitrate dumping can occur because nitrate initially loaded on the resin exchange sites can be eventually pushed off the resin by other anions such as sulfate for which the resin shows stronger affinity. In addition to sulfate and nitrate, other major competing anions are usually bicarbonate and chloride. In limited cases, pentavalent arsenic (i.e., arsenate) may be present. The order of affinity of Types I and II SBA resins under these conditions is as follows on the next page.

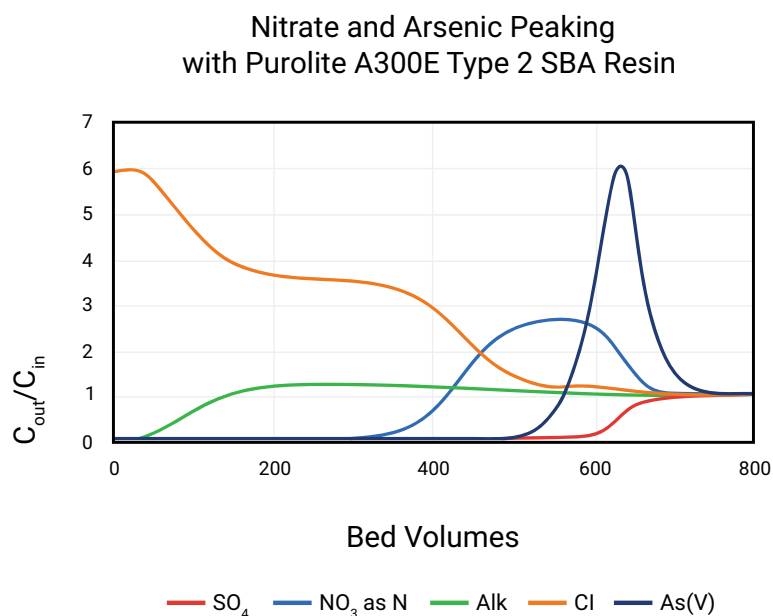
Selectivity of Type I and Type II SBA Resin

Sulfate SO_4^{2-} > Arsenate HAsO_4^{2-} > Nitrate NO_3^- > Chloride Cl^- > Bicarbonate HCO_3^-

The resin, initially in the chloride form, will remove all anions present in the water in proportion to its affinity for each. As more water is treated, the ions of stronger affinity will displace more weakly held anions, so the effluent water will show breakthrough concentrations for some anions that are higher than that in the influent water — this is shown in Figure 1, below. The term bed volume shown on the x-axis represents the amount of water treated by a unit volume of resin. For example, a capacity of 800 bed volumes means that 800 liters of water have been treated by one liter of resin — or 800 cubic feet of water has been treated by one cubic foot of resin.

FIGURE 1

**Nitrate Peaks Before
Arsenic with Type I
& Type II Resins**



If dumping occurs, the nitrate concentration in the treated water can peak at a level higher than the influent level. This will however only occur if the resin is operated far beyond the breakpoint for nitrate. Ecolab's recommendations for operating capacity are intended to stop the service cycle before peaking can occur, usually with an added margin of safety. This potential issue will not occur in well-maintained systems, especially if regeneration of the resin is based on treating a metered volume of water and regenerant salt is topped up regularly. Note that arsenate, if present, will break after nitrate breaks; since arsenic is considered more toxic than nitrate, this can serve as additional safety if the system is designed primarily as a nitrate removal system.

Nitrate selective SBA resins, such as [Purolite A520E](#), were developed in part to address the potential nitrate dumping problem mentioned above as well as to maintain an adequate operating capacity of the resin when the feed water sulfate levels are high. With nitrate selective SBA resins, the selectivity is reversed for sulfate and nitrate compared to Type I and Type II SBA resins as shown below.

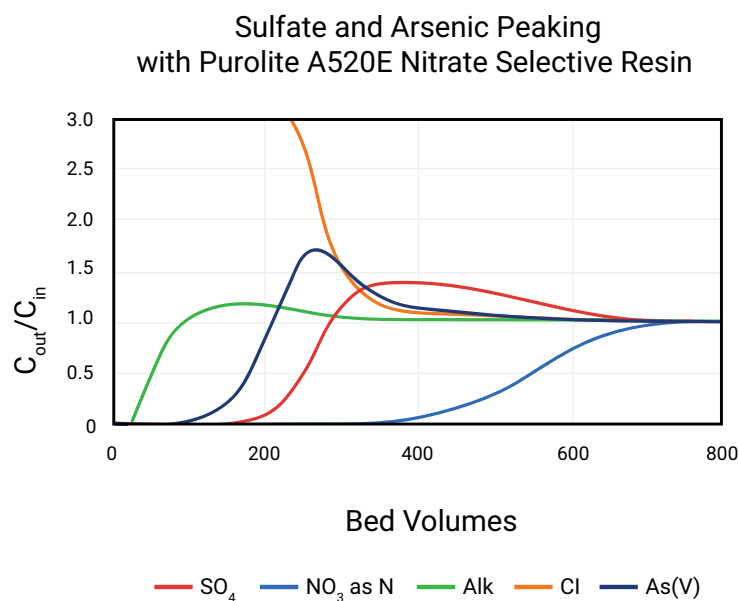
Selectivity of Nitrate Selective Ion Exchange Resin

Nitrate NO_3^- > Sulfate SO_4^{2-} > Arsenate HAsO_4^{2-} > Chloride Cl^- > Bicarbonate HCO_3^-

Figure 2 shows the typical breakthrough curves for nitrate and sulfate with a nitrate selective SBA resin, showing no peaking (or dumping) for nitrate.

FIGURE 2

**Arsenic and Sulfate
Break Before Nitrate
With a Nitrate-
Selective Resin**



Since arsenic is shown to break before nitrate in a nitrate selective resin, such resins are not recommended for joint removal of both arsenic and nitrate. In such cases, the use of either a Type II or Type I SBA resin is better suited. Two examples of this are given in the [project report from the Environmental Protection Agency](#) for plants at Vale, Oregon and the City of McCook, Nebraska — the latter plant uses a special brine regenerated layered bed of resins to simultaneously remove nitrate, arsenic, uranium and total organic matter (TOCs) from the feed water.¹

Municipal Plant Choices to Minimize Wastewater and Operating Cost

For municipal plants with long distribution lines to the consumers, odor is usually not an issue. Because municipal ion exchange treatment plants usually have dedicated operators and have the resources to monitor performance more often, the potential for nitrate dumping is better controlled than in a household environment. Larger treatment plants tend to use a resin that provides the lowest operating cost, therefore Type I, Type II and nitrate selective SBA resins are all popular choices.

In the past, a nitrate selective resin would be chosen if the equivalent ratio of sulfate/(sulfate + nitrate) in the raw water was greater than 60%. However, newer higher capacity Type I SBA resins, such as [Purolite A600E/9149](#), generally show about 12–15% higher operating capacity vs. standard Type I and so it makes sense to economically compare all resins, since the major cost driver for municipal applications, by far, is usually waste disposal.

Equipment Choices

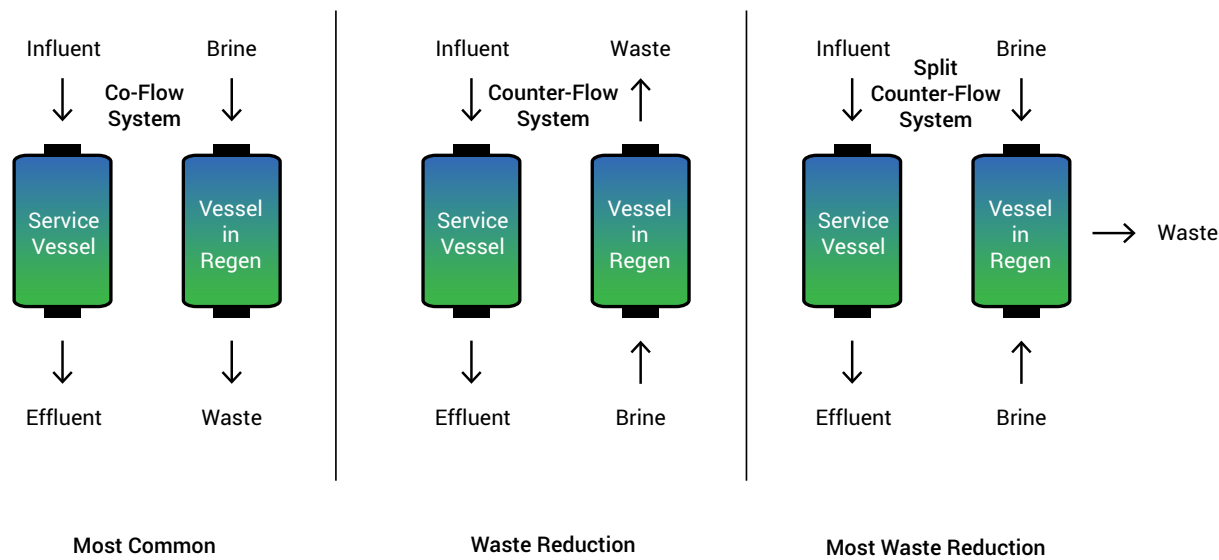
For municipal systems, several design options are available:

- Co-flow regenerated systems
- Counter-flow regenerated systems
- Split-flow counter-flow regenerated systems
- Packed bed counter-flow regenerated systems
- Continuous ion exchange systems (e.g., a carousel of vessels, some in service, some in regeneration)

Figure 3 gives a visual comparison of the service and regeneration modes for co-flow, counter-flow and split-flow counter-flow vessel designs and the impact these have on the reduction of wastewater volumes.

FIGURE 3

Regeneration Designs



For POE systems, only the first two choices are generally used. The equipment used is essentially the same as that used for POE water softeners, using the same hydraulic design conditions and brine supply apparatus. The final design selected will determine if standard particle size resin or uniform grade of resin is needed.

A full raw water chemistry analysis and a good understanding of the needs of the customer is essential for deciding on system design and resin selection. The water analysis should include results of items noted in Table 3. Once complete, it will be easier to evaluate the most appropriate resin for the equipment design.

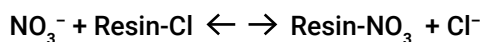
TABLE 3 Water Analysis Checklist

Analyte	Value	Units of Measure (i.e., ppm, meq, or ppm as CaCO ₃)
Calcium	–	–
Magnesium	–	–
Sodium	–	–
Potassium	–	–
Iron	–	–
Manganese	–	–
Sulfate	–	–
Nitrate	–	–
Bicarbonate	–	–
Chloride	–	–
Bromide	–	–
Fluoride	–	–
Arsenic (As V)	–	–
Hexavalent Chromium	–	–
Uranium	–	–
Total Dissolved Solids (TDS)	–	–
Conductivity	–	–
Total Suspended Solids (TSS)	–	–
Total Organic Carbon (TOC)	–	–
Turbidity	–	–
pH	–	–
Water Temperature	–	–

Service and Regeneration

When a strong base anion resin in the chloride form is used to remove nitrate from water, the nitrate and other anions are exchanged for the chloride ion (Cl^-), increasing the chloride concentration in the treated water.

A typical ion exchange reaction is as follows with the dual arrows indicating that the process is reversible:



Because the process is reversible, a simple sodium chloride brine solution can be used to regenerate the resin.

Figure 4 is a general concept for a nitrate removal system using a brine regenerable ion exchange resin system. Water is pumped under pressure through a vessel in which a volume (or a bed) of ion exchange resin is installed. As the capacity of the resin is used up, the nitrate concentration of the treated water will increase until the target concentration of nitrate is reached. At that point, the resin is taken out of service and a sodium chloride brine solution is passed through the resin to release the nitrate and other anions. The resin is then rinsed and returned to service for another cycle. A portion of the incoming raw water is usually bypassed around the treatment vessel and then blended with the treated water. The percentage of water bypassed is set to achieve a combined nitrate concentration below the desired control level.

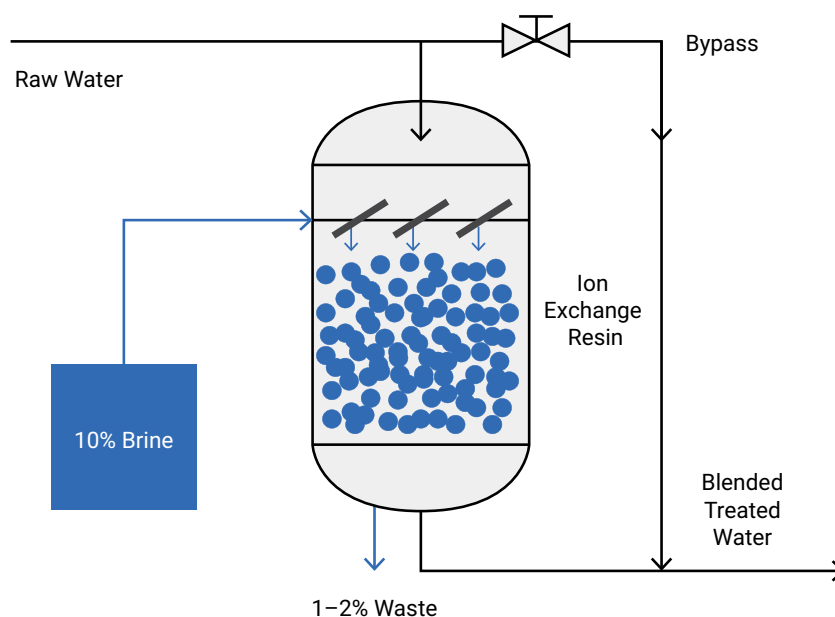
Depending on the equipment design chosen (e.g., co-flow, counter-flow and packed bed systems which will be covered in more detail in the next section), regeneration of the resin will usually include the following generic steps:

- Backwash with raw water — largely to remove particulates and fluidize the bed (done routinely for co-flow systems), as part of each regeneration, typically expanding the resin bed by 50–60% by volume for approximately 10 to 15 minutes. The backwash rate is dependent on the water temperature. Consult technical data sheet for details.
- Regeneration with brine to elute nitrate and other anions — using co-flow or counter-flow systems, typically one to two bed volumes (7.5–15 gallons per cubic foot of resin) using 5–12% brine at a specific flow rate of two to four bed volumes per hour (0.25–0.5 gallons per minute per cubic foot of resin).
- Displacement or slow rinse to gently push out the brine solution while the exchange process continues, typically one to two bed volumes (7.5–15 gallons per cubic foot of resin) of water at a specific flow rate of two bed volumes per hour (0.25 gallons per minute per cubic foot of resin).

- Optional bicarbonate wash to control the pH and alkalinity of the treated water (not often used). Consult Ecolab for details.
- Fast rinse to finish expelling the last traces of the regenerant, typically three to five bed volumes (22–38 gallons per cubic foot of resin) of water at the same flow rate used for the service phase.
- Return of the vessel to service or placement in stand-by mode.

FIGURE 4

**General Concept of
a Nitrate Removal
Process Using Brine
Regenerable Resin in
a Co-Flow System**



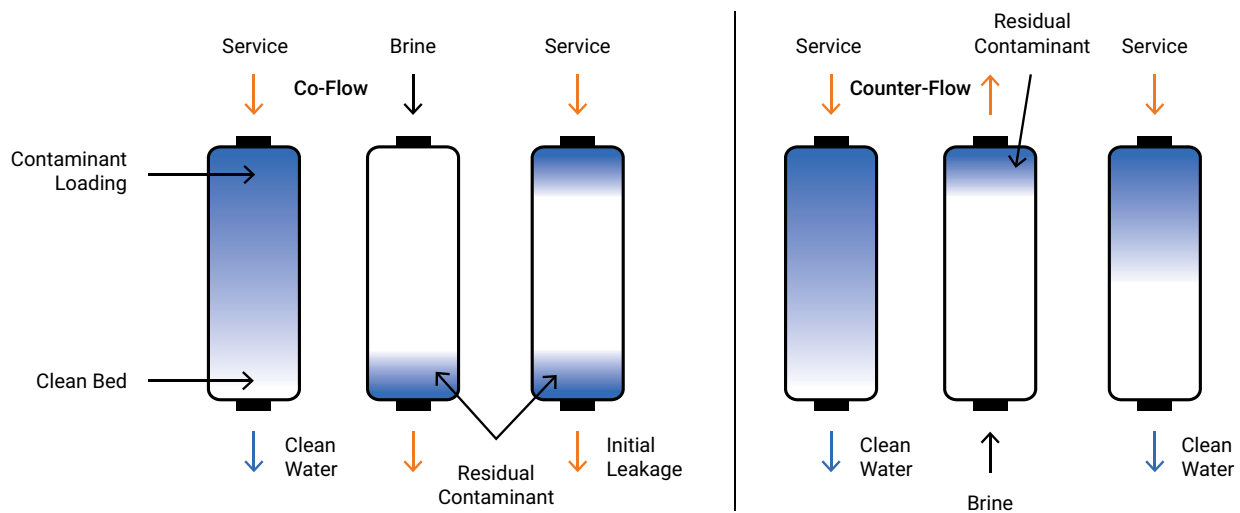
A backwash is generally done for each regeneration process if the system is designed for co-flow regeneration mode. If the system is designed for counter-flow regeneration mode, backwashing is infrequently done (say once per month) — more on this in the next section. Where influent water hardness is greater than 170 mg/L as CaCO_3 (10 grains per gallon), the water used for brine makeup and slow rinse would usually be softened. Consult Ecolab for more advice.

Equipment Design Choices

When waste minimization is a primary goal, a counter-flow regenerated system should be chosen rather than a co-flow system, despite the higher capital cost. Counter-flow regenerated system examples are packed beds, standard counter-flow with either air or water hold-down mechanisms to keep the resin bed compacted during regeneration, or a split-flow design in which part of the brine is passed in an 'upflow' direction through the resin bed while the rest of the brine is simultaneously passed downflow through the bed and both brine stream exit the bed at an intermediate point. Since counter-flow regeneration generally results in lower nitrate leakage, a larger fraction of the water can be bypassed (i.e., untreated) around the ion exchange vessels. It is common practice in large municipal plants to bypass some of the water as the blend of treated and untreated water can be tailored to meet the maximum allowable level in the drinking water while reducing operating costs.

FIGURE 5

Cleaner Resin with Counter-Flow vs. Co-Flow Regeneration Modes



With co-flow regenerated systems, both the service water to be treated and the brine used for regeneration pass through the ion exchange resin bed in the same direction, generally downflow. Sulfate and nitrate tend to load on the resin bed largely at the inlet or top end, while chloride and bicarbonate load largely on the bottom or exit end of the resin bed.

When brine is applied to regenerate the bed in a co-flow mode, the brine strips sulfate and nitrate from the top of the bed and these ions are then pushed by the brine through the resin column to the bottom of the resin bed. As a result, some of the nitrate tends to exchange with and displace the less tightly bound chloride and bicarbonate ions. When the resin bed is returned to the service phase, nitrate that is bound to the lower part of the resin bed contributes to an initial elevated level of nitrate leakage in the treated water (Figure 5).

With counter-flow regenerated systems, feed water and brine enter and leave the resin bed in opposite directions. Nitrate loaded on the resin during service is essentially pushed back out of the bed without traversing the entire bed during regeneration (Figure 5).

Counter-flow regeneration is more efficient, leaving the exit end of the resin bed essentially free of nitrate ions. As a result, nitrate leakage is significantly lower compared to that from co-flow regenerated systems when the bed is returned to service.

Typical equipment design options for counter-flow operated systems include:

- Counter-flow regenerated vessels with air or water hold-down to keep the resin from fluidizing during brining/rinse
- Split-flow designs in which 2/3 of the brine is introduced from the bottom and 1/3 through a top brine distributor
- Packed bed designs where the vessel is almost totally packed with resin (except for the inert resin and the freeboard)

The conventional counter-flow and split-flow options usually allow for enough freeboard in the vessel design to periodically backwash the resin to remove suspended solids accumulated from influent water. Packed bed design allows for a smaller footprint without the need for air or water hold-down, but the resin cannot be backwashed within the vessel — it must be transferred out to an external vessel for backwashing — therefore influent suspended solids must be kept to a minimum.

Guidelines for Minimizing Wastewater

As a general rule, the best way to minimize wastewater volume and the associated disposal cost is to consider the following rules for resin selection and equipment design. In general, relative rinse water needs are as follows:

- Counter-flow (CTF) is better vs. Co-flow (CF) regeneration
 - Purolite (PF) grades are better than Standard (Gaussian) and Puropack (PP) grade
- Higher salt dosages increase salt cost but minimize the frequency of regenerations and rinsing

Table 4 shows the expected rinse requirements for the various grades of resin for co-flow and counter-flow modes.

TABLE 4 Comparing Rinse Water Requirements for Various Resin Grading and Types

Type	Standard Gaussian		Puropack PP Uniform		Purolite PF Uniform	
	CF	CTF	CF	CTF	CF	CTF
Slow Rinse BV	1.5	1.5	1.5	1.5	1.5	1.2
Fast Rinse* BV	5	4	4.5	3.5	4	3
Total Rinse BV	6.5	5.5	6.0	5	5.5	4.2

* Fast rinse can be recycled depending on specific conditions
 1 BV = 7.48 US gallons per cubic foot of resin

Counter-flow regenerated resin will in general give the lowest nitrate leakage. Figure 6 is an example of the large difference in expected nitrate leakage when using counter-flow vs. co-flow regeneration with the same amount of salt (e.g., 120 g NaCl per liter of resin or 7.5 lbs/ft³) and treating the same raw water.

The average leakage for co-flow mode is 5 ppm (or mg/L) nitrate as N while that for counter-flow modes is 0.9 ppm as N.

The average percentage of the water that can be bypassed using counter-flow mode in the example above to achieve a blended nitrate of 8 ppm as N is about 54% bypass.

This can be easily calculated using the formula:

$$\text{Influent Nitrate Concentration} * \text{Fraction of Water Bypassed} + \text{Average Nitrate Leakage Concentration} * \text{Fraction of Water Treated} = \text{Blended Nitrate Concentration}$$

Example: Influent nitrate is 14 ppm as N while average nitrate leakage exiting the resin is 0.9 ppm as N. Desired nitrate in the blended water is 8 ppm as N. Assume the fraction of water bypassed is represented by X; then:

$$14X + 0.9 (1 - X) = 8$$

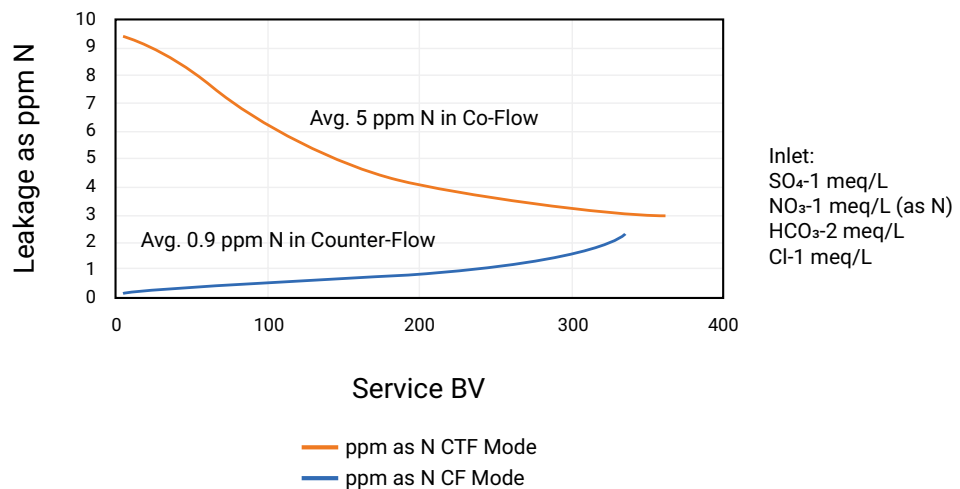
With co-flow mode, the bypass allowed is only 33% to achieve the same target. Therefore, the salt cost using counter-flow regeneration will be about 30% lower than for co-flow regeneration.

Similarly, rinse water disposal cost will be 50% lower with counter-flow vs. co-flow mode.

FIGURE 6

Comparing Co-Flow and Counter-Flow Nitrate Leakage at Same Regeneration Dose

Purolite A300E — Comparing Nitrate Leakage in Co-Flow vs. Counter-Flow Mode at 120 g/L NaCl



Resin Vessel Design

Below are the critical elements for proper vessel design when treating nitrate.

Minimum Bed Depth

- Co-flow regeneration mode: 900 mm (~3 ft)
- Counter-flow regeneration: 1,200 mm (~4 ft)

Linear Velocity Goal: 20–30 m/h (8–12 gpm/ft²)

Specific Flowrate Goal: 8–40 BV/h (1–5 gpm/ft³)

Appendix A provides a more detailed example of how to manually calculate the appropriate vessel diameter, bed depth and resin volume for a specific flow rate. Also shown are details on the regeneration steps and how to calculate backwash and rinse volumes and flowrates.

PRSM™ Software Cases

Below are a few examples of how our PRSM (Purolite Resin System Modeling) software can be used to compare the performance of various resins, in co-flow or counter-flow regeneration modes, considering the cost for the resins, salt, rinse water and disposal of wastewater. Our PRSM software can be accessed via our website at <https://bit.ly/3nIFZR1>.

Two examples are given below to show how to get the maximum out of our PRSM software. In the first example, US units of measurement are used, while metric units are used for the second example.

Example 1: Comparing Two Uniform Resins (Using US Units)

This example compares two Purolite uniform grade resins, [Purolite A600E/9149](#) and [Purolite PFA300E](#) at 1,000 gpm flowrate in co-flow regeneration mode at the same salt dosage of 10 lbs/ft³ (160 g/L), with a relatively high wastewater disposal cost of \$0.05 per gallon (\$13 /m³). Resin prices used are \$250/ft³ and \$325/ft³ (\$8.80/L and \$11.50/L) respectively. Salt cost is \$100/metric ton. The percentage of water treated is 67% with 33% bypassed around the ion exchange to give a nitrate content in the blended water of approximately 5.6 ppm as N. The influent water chemistry used is as follows on the next page.

TABLE 5 Water Chemistry Example

Ca	2 meq/L (40 mg/L)	100 ppm as CaCO ₃
Mg	1 meq/L (12.2 mg/L)	50 ppm as CaCO ₃
Na	2 meq/L (46 mg/L)	100 ppm as CaCO ₃
NO ₃	1 meq/L	50 ppm as CaCO ₃ (62 mg/L as NO ₃ or 14 mg/L as N — see note below)
SO ₄	1 meq/L (48 mg/L)	50 ppm as CaCO ₃
HCO ₃	2 meq/L (122 mg/L)	100 ppm as CaCO ₃
Cl	1 meq/L (35.5 mg/L)	50 ppm as CaCO ₃

As a general note, it is important to have a balanced water chemistry with all cations and anions in balance; if the water chemistry is out of balance by more than 10%, a more accurate analysis should be obtained. Regarding units of measurement, these can be entered in the software in various units and they will be converted to common units that can be summed — such as meq/L or ppm as CaCO₃. When entering a nitrate value, if choosing to enter it as mg/L or ppm, it is very important not to enter the value expressed as N (nitrogen) but as NO₃ (nitrate) as the software is set up only to accept values as nitrate. If the water analysis shows nitrate as mg/L N, it can be easily converted by multiplying the mg/L as N value by 4.429 to convert it to mg/L as NO₃. For example, 12 mg/L as N = 53.1 mg/L as NO₃.

This first example compares two uniform grade resins, a higher capacity Type I SBA, [Purolite A600E/9149](#), and our Type II, [Purolite PFA300E](#). Resin prices used are \$250/ft³ and \$325/ft³ (\$8.80/L and \$11.50/L) respectively. Salt cost is \$100/metric ton. It is assumed that wastewater must be hauled offsite for disposal at a cost of \$13/m³ or \$0.05 per US gallon. Therefore, choosing uniform grade resins, even though they are generally priced higher than standard resins, can reduce rinse water requirements (see Table 4 above) by about 15–25% for co-flow and counter-flow regenerated systems, respectively. Additionally, to save on disposal costs, this example assumes that all of the fast rinse water is recycled to the front end of the treatment plant without issues.

Overall, the example shows that it is more economical to use [Purolite A600E/9149](#) resin — payback time is less than six months of operation. Predicted savings in salt and wastewater disposal costs is about \$40,000 per year using Purolite A600E/9149. The savings would be even higher if comparing a standard Gaussian distribution type resin to a uniform grade resin — refer to Table 1 above for examples of standard and uniform grade resins. Below are excerpts from the PRSM software.

FIGURE 7

Excerpt from PRSM Output File for Example 1

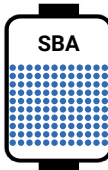
PLANT SPECIFICATIONS		PLANT DESIGN	REGENERANT		
Water Produced (US gal/day)	1,440,000		NaCl		
Design Flowrate (US gal/min)	1,000.0				
Actual Flowrate through plant (US gal/min)	1,000.0				
Vessels Installed	1				
Vessels Active During Service	1				
INLET WATER CHEMISTRY					
Cations		Anions		Other Specifications	
Ca	40.0000 ppm	HCO ₃	100.0000 ppm as CaCO ₃	Temperature	59°F
Mg	12.1550 ppm	Cl	35.5000 ppm	TOC	1.000 ppm
Na	46.0000 ppm	SO ₄	48.0000 ppm		
K	0.0000 ppm	Nitrate as NO ₃	62.0000 ppm		
NH ₄	0.0000 ppm	F	0.0000 ppm		
Ba	0.0000 ppm	Other	0.0000 ppm as CaCO		
Sr	0.0000 ppm	Subtotal	5.0000 meq/L		
Fe	0.0000 ppm	SiO ₂	0.0000 ppm		
Other	0.0000 ppm as CaCO	CO ₂	0.0000 ppm		
Total	5.0000 meq/L	Total	5.0000 meq/L		
TREATED WATER BREAKPOINTS					
Treated Water Specifications			Endpoint		
Total Nitrate Leakage (ppm as NO ₃)			25.00		
Total Nitrate Leakage (ppm as N)			5.65		

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	Option 1	Option 2
	SBA PFA300E	SBA A600E/9149
AVERAGE LEAKAGE		
Average Nitrate Leakage (ppm as NO ₃)	6.58	6.58
Average Nitrate Leakage (ppm as N)	1.49	1.49
Average Nitrate Leakage in Production (ppm as NO ₃)	24.87	24.87
Average Nitrate Leakage in Production (ppm as N)	5.62	5.62
SERVICE BYPASS		
Percent Water Treated	67.00	67.00
Percent Water Bypassed around IX	33.00	33.00
OPERATING SPECIFICATIONS		
Cycle Time (hrs)	16.8	18.5
Net Water per Cycle (US gal/cycle)	675,360	743,700
REGENERANT		
Regenerant Mode	Co-flow	Co-flow
Sodium Chloride Dosage (lb/ft ³)	10.00	10.00
Regenerant Concentration (%)	10.0	10.0
Total Applied (lbs)	2,499.99	2,499.99
Total Applied (eq)	19,384.27	19,384.27
Excess (eq)	17,080.24	16,849.02
Regenerant as % of Theory (%)	841.32	764.59
CAPACITY		
Available Capacity (Kgrain/ft ³)	8.40	9.20
Design Factor	0.85	0.85
Operating Capacity (Kgrain/ft ³)	7.11	7.83
IONIC LOAD		
Active Resin Volume (ft ³)	250	250
Specific Flowrate (US gpm/ft ³)	2.68	2.68
Ionic Load per train (eq)	2,304.03	2,535.25

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	Option 1	Option 2
	SBA PFA300E	SBA A600E/9149
RESIN VESSEL SPECIFICATIONS		
Bed Depth (inches)	47	47
Diameter (inches)	108	108
Flowrate per Vessel (US gal/min)	670.00	670.00
Specific Flowrate (US gpm/ft ³)	2.68	2.68
Cross Sectional area (ft ²)	63.62	63.62
Linear Velocity (US gpm/ft ²)	10.55	10.55
Pressure Drop (psi)	5.72	5.72
Resin Volume (ft ³)	250	250
WASTEWATER		
Backwash Water (US gal/ft ³)	14.96	14.96
Dilution Water (US gal/ft ³)	11.18	11.18
Slow Rinse (US gal/ft ³)	7.48	7.48
Fast Rinse (US gal/ft ³)	22.44	22.44
Backwash Water Volume Recycled (US gal/ft ³)	0.00	0.00
Rinse Volume Recycled (US gal/ft ³)	0.00	0.00
Total Waste Water per Cycle (US gal)	14,015.74	14,015.74
WATER		
Water Treated (kUS gal/year)	352,152	352,152
Waste Water Volume (kUS gal/year)	7,316	6,643
Soft Water used for dilution (kUS gal/year)	1,459	1,325
Soft Water used for slow rinse (kUS gal/year)	976	886
NaCl consumed (Metric Tons/year)	592	538

Option 1

REGENERATION SCHEDULE	
Product	PFA300E
Units	US
Regeneration Direction	Co-flow
Volume of Resin	250 ft ³
Dosage of NaCl	10.00 lb/ft ³
Mass of NaCl	2,499.99 lbs
Total Volume (not including backwash)	10,275.5 US gal
Total Time (not including backwash)	88.2 min.

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RECOMMENDED STEPS				
	Volume (US gal)	Flowrate (US gal/min)	Specific Flowrate (US gpm/ft³)	Time (min.)
Step1: Backwash (Raw Water)	3,740.3			
Step 2: Bed Settle				5.0
Step 3: Brine (10.00% Concentration)	2,795.0	62.3	0.25	44.8
Step 4: Slow Rinse (Softened Water)	1,870.1	62.3		30.0
Step 5: Fast Rinse (Raw Water)	5,610.4	670.0		8.4

Option 2

REGENERATION SCHEDULE	
Product	A600E/9149
Units	US
Regeneration Direction	Co-flow
Volume of Resin	250 ft³
Dosage of NaCl	10.00 lb/ft³
Mass of NaCl	2,499.99 lbs
Total Volume (not including backwash)	10,275.5 US gal
Total Time (not including backwash)	88.2 min.

RECOMMENDED STEPS				
	Volume (US gal)	Flowrate (US gal/min)	Specific Flowrate (US gpm/ft³)	Time (min.)
Step1: Backwash (Raw Water)	3,740.3			
Step 2: Bed Settle				5.0
Step 3: Brine (10.00% Concentration)	2,795.0	62.3	0.25	44.8
Step 4: Slow Rinse (Softened Water)	1,870.1	62.3		30.0
Step 5: Fast Rinse (Raw Water)	5,610.4	670.0		8.4

ANNUAL OPERATING COST & PAYBACK SNAPSHOT		ANNUAL OPERATING COST & PAYBACK SUMMARY		
Option 1	Option 2	Component	Option 1	Option 2
\$434,745 Total Operating Cost	\$394,769 Total Operating Cost	Salt Cost (\$)	59,194	53,751
		Wastewater Cost (\$)	375,551	341,018
		Total Annual Operating Cost (\$)	434,745	394,769
		Annual Savings (\$)		39,977
	\$39,977 Annual Savings	Resin Cost (\$)	62,500	81,250
	5.63 Payback in Months	Premium for Option 2 Resin (\$)		18,750
		Payback in Months (\$)		5.63

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	Option 1	Option 2	
	PFA300E	A600E/9149	
RESIN & OPERATIONAL COSTS			
Resin Unit Cost (\$/ft³)	250.00	325.00	
Total Resin (\$/train)	62,500	81,250	
COST PERFORMANCE			
	Option 1	Option 2	Total Savings
Resin Cost/Train Total (\$)	62,500	81,250	-18,750
Water/Wastewater Cost (\$/yr)	375,551	341,018	34,533
Sodium Chloride Cost (\$/yr)	59,194	53,751	5,443
Annual Operating Costs/Train Subtotal (\$/yr)	434,745	394,769	39,977
WASTE/WASTEWATER COMPARISON			
	Option 1	Option 2	Total Savings
Wastewater as % of Production (%)	1.39	1.26	0.13
Mass NaCl per Volume of Water Softened (lb/kUS gal)	2.479	2.252	0.228
WATER, WASTEWATER AND REGENERANT COSTS			
	Option 1	Option 2	
Unit Cost of Wastewater (\$/kUS gal)	50	50	
Unit Cost of Raw Water (\$/kUS gal)	4	4	
Water/wastewater cost (\$/yr)	375,551	341,018	
Annual Cost for NaCl (\$/Metric Ton)	59,194	53,751	

Example 2: High Sulfate Water/High Disposal Cost —
A520E Nitrate-Selective vs. Type II A300E (Using Metric Units)

This example compares our nitrate selective resin, [Purolite A520E](#) to a Type II resin, [Purolite A300E](#). Both are Gaussian resins with diameters ranging from 300 to 1,200 microns. Flow rate is 250 m³/h (1,101 gpm) using counter-flow regeneration mode at the same salt dosage of 160 g/L (10 lbs/ft³), with a wastewater disposal cost of \$13/m³ (\$0.05/gallon). Resin prices used are \$14/L and \$11.50/L (\$396/ft³ and \$326/ft³), respectively. The percentage of water treated is approximately 67% with 33% bypassed around the ion exchange to give a nitrate content in the blended water of approximately 5 mg/L as N. The influent water chemistry used is as follows:

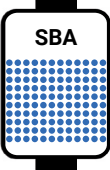
TABLE 6 Water Chemistry Example

Ca	2 meq/L (40 mg/L)	100 ppm as CaCO ₃
Mg	2 meq/L (24.4 mg/L)	100 ppm as CaCO ₃
Na	2 meq/L (46 mg/L)	100 ppm as CaCO ₃
NO ₃	1 meq/L (62 mg/L)	50 ppm as CaCO ₃
SO ₄	2 meq/L (48 mg/L)	100 ppm as CaCO ₃
HCO ₃	2 meq/L (122 mg/L)	100 ppm as CaCO ₃
Cl	1 meq/L (35.5 mg/L)	50 ppm as CaCO ₃

Ratio $\text{SO}_4 / (\text{SO}_4 + \text{NO}_3) = 2 / (2+1) = 0.67$ (or 67%). Since the ratio is greater than 60%, the old rule-of-thumb indicates a nitrate selective resin would be useful. But a quick comparison with our PRSM software will confirm if this is a good choice as shown in the printout from the software on the next page.

FIGURE 8

Excerpt from PRSM Output File for Example 2

PLANT SPECIFICATIONS		PLANT DESIGN	REGENERANT
Water Produced (m ³ /day)	6,000		NaCl
Design Flowrate (m ³ /h)	250.0		
Actual Flowrate through plant (m ³ /h)	250.0		
Vessels Installed	1		
Vessels Active During Service	1		

INLET WATER CHEMISTRY					
Cations		Anions		Other Specifications	
Ca	100.0000 ppm as CaCO ₃	HCO ₃	100.0000 ppm as CaCO ₃	Temperature	15°C
Mg	100.0000 ppm as CaCO ₃	Cl	50.0000 ppm as CaCO ₃	TOC	1.000 ppm
Na	100.0000 ppm as CaCO ₃	SO ₄	100.0000 ppm as CaCO ₃		
K	0.0000 ppm as CaCO ₃	Nitrate as NO ₃	50.0000 ppm as CaCO ₃		
NH ₄	0.0000 ppm as CaCO ₃	F	0.0000 ppm as CaCO ₃		
Ba	0.0000 ppm as CaCO ₃	Other	0.0000 ppm as CaCO		
Sr	0.0000 ppm as CaCO ₃	Subtotal	6.0000 meq/L		
Fe	0.0000 ppm as CaCO ₃	SiO ₂	8.3500 ppm as CaCO ₃		
Other	0.0000 ppm as CaCO	CO ₂	0.0000 ppm as CaCO ₃		
Total	6.0000 meq/L	Total	6.1670 meq/L		

TREATED WATER BREAKPOINTS	
Treated Water Specifications	Endpoint
Total Nitrate Leakage (ppm as NO ₃)	25.00
Total Nitrate Leakage (ppm as N)	5.65

	Option 1	Option 2
	SBA A300E	SBA A520E

AVERAGE LEAKAGE		
Average Nitrate Leakage (ppm as NO ₃)	4.97	2.22
Average Nitrate Leakage (ppm as N)	1.12	0.50
Average Nitrate Leakage in Production (ppm as NO ₃)	23.27	21.95
Average Nitrate Leakage in Production (ppm as N)	5.26	4.96

SERVICE BYPASS		
Percent Water Treated	67.90	67.00
Percent Water Bypassed around IX	32.10	33.00

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	Option 1	Option 2
	SBA A300E	SBA A520E
OPERATING SPECIFICATIONS		
Cycle Time (hrs)	9.5	11.5
Net Water per Cycle (m ³ /cycle)	1,613	1,926
REGENERANT		
Regenerant Mode	Counter-flow	Counter-flow
Sodium Chloride Dosage (g/L)	160.02	160.00
Regenerant Concentration (%)	10.0	10.0
Total Applied (kg)	1,208.19	1,208.00
Total Applied (eq)	20,652.75	20,649.57
Excess (eq)	19,120.72	18,741.45
Regenerant as % of Theory (%)	1,348.07	1,082.19
CAPACITY		
Available Capacity (eq/L)	0.29	0.37
Design Factor	0.70	0.69
Operating Capacity (eq/L)	0.20	0.25
IONIC LOAD		
Active Resin Volume (liters)	7,550	7,550
Specific Flowrate (BV/hour)	22.48	22.19
Ionic Load per train (eq)	1,532.03	1,908.13

	Option 1	Option 2
	SBA A300E	SBA A520E
RESIN VESSEL SPECIFICATIONS		
Bed Depth (mm)	1,319	1,319
Diameter (mm)	2,700	2,700
Flowrate per Vessel (m ³ /h)	169.75	167.50
Specific Flowrate (BV/hour)	22.48	22.19
Cross Sectional area (m ²)	5.73	5.73
Linear Velocity (m/h)	29.65	29.25
Pressure Drop (kPa)	53.53	52.77
Resin Volume (liters)	7,550	7,550

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	Option 1	Option 2
	SBA A300E	SBA A520E
WASTEWATER		
Backwash Water (BV)	0.00	0.00
Dilution Water (BV)	1.49	1.49
Slow Rinse (BV)	3.00	3.00
Fast Rinse (BV)	5.00	5.00
Backwash Water Volume Recycled (BV)	0.00	0.00
Rinse Volume Recycled (BV)	2.50	2.50
Total Waste Water per Cycle (m³)	52.80	52.80
WATER		
Water Treated (m³/year)	1,487,010	1,467,300
Waste Water Volume (m³/year)	48,732	40,230
Soft Water used for dilution (m³/year)	10,405	8,588
Soft Water used for slow rinse (m³/year)	20,906	17,259
NaCl consumed (Metric Tons/year)	1,115	920

Option 1

REGENERATION SCHEDULE	
Product	A300E
Units	Metric
Regeneration Direction	Counter-flow
Volume of Resin	7,550 liters
Dosage of NaCl	160.02 g/L
Mass of NaCl	1,208.19 kg
Total Volume (not including backwash)	71.7 m³
Total Time (not including backwash)	153.1 min.

RECOMMENDED STEPS				
	Volume (m³)	Flowrate (m³/h)	Specific Flowrate (BV/hour)	Time (min.)
Step 1: Backwash (Raw Water)	0.0			
Step 2: Bed Settle				5.0
Step 3: Brine (10.00% Concentration)	11.3	15.1	2.00	44.8
Step 4: Slow Rinse (Softened Water)	22.6	15.1		90.0
Step 5: Fast Rinse (Raw Water)	37.8	169.8		13.3

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Option 2

REGENERATION SCHEDULE	
Product	A520E
Units	Metric
Regeneration Direction	Counter-flow
Volume of Resin	7,550 liters
Dosage of NaCl	160.00 g/l
Mass of NaCl	1,208.00 kg
Total Volume (not including backwash)	71.7 m³
Total Time (not including backwash)	153.3 min.

RECOMMENDED STEPS				
	Volume (m³)	Flowrate (m³/h)	Specific Flowrate (BV/hour)	Time (min.)
Step1: Backwash (Raw Water)	0.0			
Step 2: Bed Settle				5.0
Step 3: Brine (10.00% Concentration)	11.3	15.1	2.00	44.8
Step 4: Slow Rinse (Softened Water)	22.6	15.1		90.0
Step 5: Fast Rinse (Raw Water)	37.8	167.5		13.5

ANNUAL OPERATING COST & PAYBACK SNAPSHOT		ANNUAL OPERATING COST & PAYBACK SUMMARY		
Option 1	Option 2	Component	Option 1	Option 2
\$765,192 Total Operating Cost	\$631,687 Total Operating Cost	Salt Cost (\$)	100,364	82,845
		Wastewater Cost (\$)	664,828	548,842
		Total Annual Operating Cost (\$)	765,192	631,687
		Annual Savings (\$)		133,504
		Resin Cost (\$)	86,825	105,700
		Premium for Option 2 Resin (\$)		18,875
		Payback in Months (\$)		1.70
	\$133,504 Annual Savings			
	1.70 Payback in Months			

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	A300E	A520E	
RESIN & OPERATIONAL COSTS			
Resin Unit Cost (\$/liter)	11.50	14.00	
Total Resin (\$/train)	86,825	105,700	
COST PERFORMANCE			
	Option 1	Option 2	Total Savings
Resin Cost/Train Total (\$)	86,825	105,700	-18,875
Water/Wastewater Cost (\$/yr)	664,828	548,842	115,985
Sodium Chloride Cost (\$/yr)	100,364	82,845	17,519
Annual Operating Costs/Train Subtotal (\$/yr)	765,192	631,687	133,504
WASTE/WASTEWATER COMPARISON			
	Option 1	Option 2	Total Savings
Wastewater as % of Production (%)	2.22	1.84	0.39
Mass NaCl per Volume of Water Softened (kg/m³)	0.509	0.420	0.089
WATER, WASTEWATER AND REGENERANT COSTS			
	Option 1	Option 2	
Unit Cost of Wastewater (\$/m³)	13	13	
Unit Cost of Raw Water (\$/m³)	1	1	
Water/wastewater cost (\$/yr)	664,828	548,842	
Annual Cost for NaCl (\$/Metric Ton)	100,364	82,845	

In this second example, the nitrate selective resin is more economical with a payback of about two months, despite the higher price for the resin. Again, the largest driver is the high cost of disposal of wastewater generated.

In general, PRSM allows a relatively quick comparison of multiple options including co-flow and counter-flow regeneration options using standard, uniform, packed bed and shallow shell grades of resins.

If you would like to know more about our PRSM design software, please visit our website at <https://bit.ly/3nIFZR1>.

Commissioning

Loading

Before the resin is loaded into the ion exchange vessels, it is important to disinfect the vessel internals and pipework using an AWWA approved procedure. All precautions should be taken to avoid contamination of the resin during transportation, storage and handling, whether by oil and grease, dirt or microbes. If microbial contamination occurs, the resin should be cleaned with an approved procedure (e.g. peracetic acid cleaning: <https://bit.ly/3tTdf9h>). It is important not to subject the resin to high concentrations of oxidants for an extended period to avoid damage to the resin but also to avoid the potential of some resins to release nitrosamines at ppt level into the treated water.

When loading resin into the ion exchange vessels, it is important not to damage any of the internals. The vessel should be first filled to 1/3 of its height with clean water before the resin is loaded. The water will act as a buffer, allow more even settling of the resin and minimize the formation of air pockets.

Backwashing

After loading is complete the resin bed should be carefully backwashed at a rate to expand the resin bed by 50–60% of its settled volume. This will help classify the resin beads and get rid of any potential fines or air pockets.

Backwashing curves are provided for each resin on their product data sheet. Backwashing rates are dependent on water temperature. Beware of over zealous backwashing as resin beads can be lost through the upper distributor.

Rinsing

Since the resin is supplied in the chloride form, no initial regeneration is needed. The resin can simply be rinsed at service flowrate before being put online. The resin supplier should be consulted on the volume of rinse needed for compliance with its drinking water certification.

Initial Start-Up Service Cycles

Since the dosage of salt specified for nitrate removal systems is never adequate to completely regenerate the resin, it is important at start-up to **never run the resin beyond the volumetric throughput (gallons per ft³ of resin or bed volumes) specified in the design**. This is particularly important for co-flow regenerated systems. It takes about five to six service/regeneration cycles for the resin to come to equilibrium and to achieve steady-state nitrate leakage. Therefore, overextending the service run during this period will generally result in higher nitrate leakage and a much longer time to achieve steady-state operation. During the startup period, unless the inlet water chemistry has changed versus the design water, the recommended procedure is to operate the plant for five to six cycles at its rated throughput (rather than to a nitrate break) using the dosage of salt specified. After that period, the average nitrate leakage can be computed from samples taken and analyzed throughout the next set of service cycles.

Extended Resin Lay-Up

If the resin, after installation, is to be laid up for an extended period, it is equally important to minimize microbial growth. The resin should first be regenerated in the normal manner and then stored in a brine solution of at least 15% concentration. Once a week, the brine solution should be circulated to further minimize pockets of potential growth. When the vessel is ready to be put back into service, perform a regeneration cycle.

Residuals Handling

The total wastewater volume expected can be computed from the addition of the volumes of backwash, brine and rinse. The composition of the spent brine will be a mixture of sodium salts comprised largely of chloride but also sulfate, nitrate and bicarbonate that was eluted from the resin. This will be diluted by the volume of rinse and backwash water used. Wastewater treatment plants (WWTPs) are becoming increasingly hesitant to accept high chloride waste because of its deleterious impact on the biological process used. Consequently, an increasing number of plants are being forced to find alternative disposal methods, including haulage of the brine offsite to other WWTPs that will accept and blend with standard wastewater. Deep well injection is a possibility, but only for plants that can get a permit from the local jurisdictions.

Additional capital improvements can be made to reduce waste volumes. If the influent water has good TSS control, backwashing can be reduced to once every five to 10 cycles. Backwash water and fast rinse water can be reused for brine makeup water in the next cycle. PRSM can help evaluate the recycling of these wastes.

Treated Water Quality

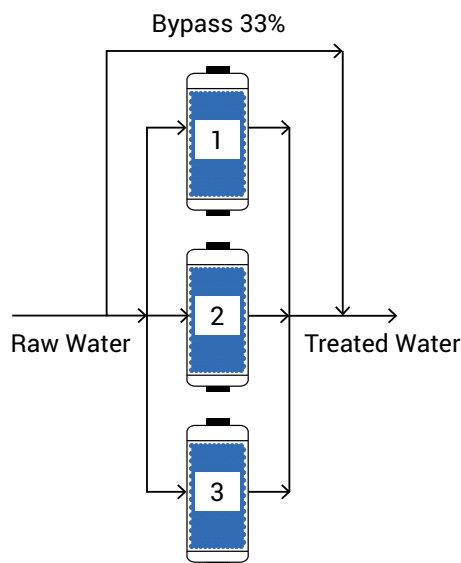
When using chloride brine for regeneration, the chloride content of the treated water at startup is generally higher than the influent level because other anions are being removed in place of chloride. Chloride released would be in equivalent proportion to the concentration of other anions that are removed. Sulfate and alkalinity would initially be reduced to low levels by the resin. This may increase the Chloride to Sulfate Mass Ratio (CSMR) of the treated water to higher levels vs. the influent ratio. Because it is normal practice to bypass a fraction of the raw water (e.g., 50%) around the ion exchange system, the CSMR of the blended water will not be at infinity at start-up as some sulfate will be present in the blended output.

The pH and alkalinity which are generally reduced during the initial part of the service cycle usually recover within a few hours of operation. A bicarbonate wash step at the end of the regeneration phase can boost pH and alkalinity value at the start of the service cycle. Large nitrate plants can mitigate this problem if multiple vessels are operated in parallel in a staggered-start manner. By staggering the start-up and regeneration of individual vessels, it is possible to provide blended water that minimizes changes in pH and chloride levels.

Figure 9 is an example of how a staggered-start operation of three ion exchange vessels along with part of the water bypassed around the ion exchange vessels and then blended with the treated water. This can help reduce changes in the alkalinity (and by extension the pH) of the treated water.

FIGURE 9

**Staggered-Start
Operation with Three
Ion Exchange Vessels in
Parallel with 33% of the
Water Bypassed**



In this example, three ion exchange vessels are operated simultaneously in parallel, but with each vessel starting up equally spaced in time from one another; 33% of the raw water is bypassed around the treatment vessels. If all vessels were started up at the same time and no amount of the water was bypassed around the treatment vessels, the alkalinity would start at close to zero and gradually climb to the same as the influent water after about 120 bed volumes of water have been treated — this is shown by the grey graph in Figure 10. With the staggered-start approach and 33% bypassed water, the alkalinity of blended treated water would essentially stay above 0.8 times the influent value and then rise to the influent value after about 80 bed volumes of water have been treated. The pH would also stay in the alkaline range and would thus mitigate the impact of the reduced pH that would otherwise occur in the treated water.

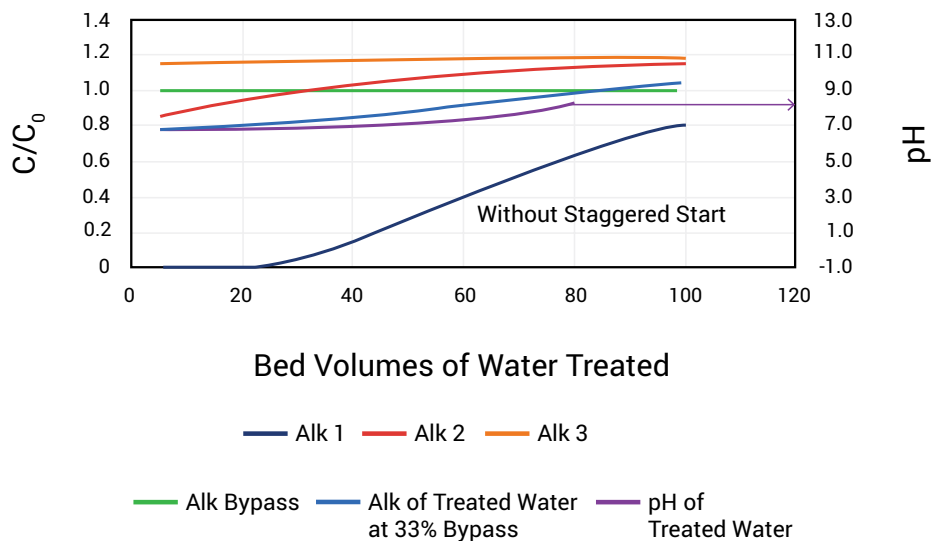
FIGURE 10

Using Three Ion Exchange Vessels in Staggered-Start Mode to Buffer the Alkalinity and pH of the Treated Water

The blue line is the alkalinity in the total treated water using staggered start and 33% bypass.

The grey line is the alkalinity without staggered operation and bypass blending.

Effective Blending to Control Alkalinity and pH Using Three Vessels in Parallel with Staggered Start and 33% Bypass Water



Similar buffered results would be obtained for chloride and sulfate in the treated water. Consult Ecolab for more advice on this topic.

Summary

The need for nitrate removal in drinking water is growing, but so are the regulations governing brine disposal. To be competitive, it is important to choose the right nitrate removal resin and equipment design based on overall operating costs. It is imperative to consider all costs, not just for the resin and the regenerant salt, but importantly as well, the rapidly increasing cost of wastewater disposal.

References

1. Arsenic & Nitrate Removal from Drinking Water by Ion Exchange U.S. EPA
<http://nepis.epa.gov/Adobe/PDF/P100AVF2.pdf>

Appendix A

While our PRSM software can easily handle the entire set of calculations for a new or existing nitrate plant, it is important for water treatment practitioners to get a deeper feel for the calculation routines that are used. We believe the following set of largely manual calculations, if followed logically, can help in this regard. Once, the design logic is understood, it becomes easier to use PRSM to get the best productivity out of it.

Manual Calculations for Vessel Sizing and Regeneration (US Units)

Below is a step-by-step method of calculating vessel diameters, resin volumes and regeneration rates.

The example is for a 1 MGD or 700 gpm (3,800 m³/day or 158 m³/h) plant:

1. Choose a Linear Velocity (LV) at or close to the upper end of the acceptable LV range will tend to reduce the size, cost and number of ion exchange vessels needed.
2. Vessel Diameter Sizing: Initially choose a LV of 12 gpm/ft² (30 m/h).
 - a. Calculate nearest vessel cross-sectional area needed: $700 \text{ gpm} / 12 \text{ gpm/ft}^2 = 58.33 \text{ ft}^2$
 - b. Choose the smallest commercially available standard diameter vessel from Table 7 that meets the cross-sectional area requirement above.

TABLE 7 Choosing a Commercially Available Vessel Diameter

Commercial Vessel Diameter (OD) (ft) (mm)	Approx. Cross-Sectional Area (ft ²) (m ²)
12 (3,600 mm)	113 (10.2 m ²)
11 (3,300 mm)	95 (8.5 m ²)
10 (3,000 mm)	78.5 (7.1 m ²)
9 (2,700 mm)	63.6 (5.7 m ²)
8 (2,400 mm)	50 (4.5 m ²)
7 (2,100 mm)	38.5 (3.5 m ²)
6 (1,800 mm)	28.3 (2.6 m ²)
5 (1,500 mm)	19.6 (1.76 m ²)
4 (1,200 mm)	12.6 (1.1 m ²)

In this case, either a 9-ft or 10-ft diameter vessel will be chosen, depending on availability. Since 10-ft diameter vessels are more readily available, this is chosen for the exercise.

3. Calculate the volume of resin needed:

- a. For co-flow regeneration, a minimum resin bed depth of approximately 3 feet (0.9 m) is recommended. For a 10 ft diameter vessel:

Minimum resin volume needed = cross-sectional area of 78.5 ft² x 3 ft bed depth = 236 ft³ of resin approx.

Since resin deliveries are usually in supersacks of 42 ft³ each, the nearest whole number of supersacks should be chosen: 6 supersacks x 42 ft³ = 252 ft³.

Then, recheck resin bed depth: 252 ft³/78.5 ft² = 3.2 ft — this is acceptable.

- b. For standard counter-flow regeneration, a minimum bed depth of 4 feet is needed. For a 10-ft diameter vessel:

Minimum resin volume needed = cross-sectional area of 78.5 ft² x 4 ft bed depth = 314 ft³ approx.

Since resin deliveries are usually in supersacks of 42 ft³ each, the nearest whole number of supersacks should be chosen: 8 supersacks x 42 ft³ = 336 ft³.

Again, recheck resin bed depth: 336 ft³/78.5 ft² = 4.3 ft — this is acceptable.

Backwash Note

The backwashing step is done as part of each regeneration procedure if the system is designed for co-flow regeneration. For counter-flow regeneration, backwashing may be done infrequently, say once per month, since backwashing has the potential to cause unintentional mixing of the highly regenerated resin at the outlet of the resin bed with the rest of the resin that is less so, leading to potentially higher than normal nitrate leakage during the following cycle. When backwashing is eventually done, the resin bed would usually be double-regenerated before returning to service. During backwashing, the resin bed is generally expanded by 50 to 60% of its original settled volume to remove as much of the suspended solids that may have accumulated on the resin beads during the previous service period. Check Ecolab's resin specification sheet for recommended linear velocity rates that will accomplish the desired degree of bed expansion at the specific temperature of the water available. A typical backwash rate at 50 °F (10 °C) can be 2 gpm/ft² (5 m/h). For a 10 ft (3.048 m) diameter vessel with a cross-sectional area of 78.5 ft², that equates to a flow rate of 157 gpm (35.6 m³/h). Usually, backwashing is done for at least 10 to 15 minutes; if the backwash effluent water is not relatively clear of suspended solids after this period, the backwash can be continued until effluent quality is satisfactory.

Brine Makeup and Application

A saturated brine solution (typically 26%) is usually prepared using sodium chloride salt that meets acceptable quality standards (e.g., B200-53 AWWA). Saturated brine contains approximately 2.6 lbs of salt per gallon (approx. 300 grams per liter). During regeneration, the saturated brine solution is mixed with enough dilution water to create the desired concentration of brine (typically 5–12%) before it is passed through the resin bed. This roughly requires a dilution ratio of 2 to 1 for dilution water vs. saturated brine. At 10% brine concentration, the salt content of each gallon of 10% brine will be approximately 0.9 lbs.

Volume and Flowrate of 10% Brine Solution

In this example, assume that the salt dosage applied is 10 lbs per cubic foot of resin (or 160 g/L). Using a volume of 336 ft³ of resin in co-flow regeneration mode, the total volume of 10% brine needed can be calculated from:

$$336 \text{ ft}^3 \times 10 \text{ lbs/ft}^3 \text{ needed} = 3,360 \text{ lbs.}$$

Therefore, the volume of 10% brine needed is:

$$3,360 \text{ lbs} / 0.9 \text{ lbs/gallon} = 3,733 \text{ gallons}$$

Brine is usually applied at a specific flow rate of 0.25–0.5 gpm/ft³ (2–4 BV/h) — the more contact time the better the efficiency. Ideally, the contact time between the brine and the resin should be a minimum of 30 minutes.

At 0.25 gpm/ft³ and a volume of 3,733 gallons of 10% brine, the brining time will be:

$$3,733 \text{ gallons} / (0.25 \text{ gpm} / \text{ft}^3 \times 336 \text{ ft}^3) = 45 \text{ minutes (approx.)}$$

Following the brine, the resin is usually rinsed to rid it of residual brine. Usually, the resin must be rinsed until the chloride content of the rinse water is about 25 ppm or lower compared to the chloride level in the raw water. At that point, the resin bed can be put into service.

The first phase of rinsing known as the slow rinse step is conducted at the same flowrate used during the brining step. The objective of this is to continue the regeneration process of the resin, by pushing out the brine in a plug-flow fashion and ensuring that the nitrate and other anions are adequately removed from the resin in preparation for the next cycle.

For the slow rinse, 7.5–15 gallons of water per cubic foot of resin is typically used. In the example of 336 ft³ of resin, a total of 5,040 gallons will be needed at 15 gals/ft³. Using the same 0.25 gpm/ft³ specific flowrate used for the brining step, the slow rinse flow rate will be 84 gallons per minute, requiring a total of 60 minutes.

For the fast rinse step, the service flowrate can be used to save time. In this case, the service flow rate is 700 gpm, so the estimated time for the fast rinse, assuming 38 gallons/ft³ (5 BV) will be approximately: 336 ft³ x 38 gals/ft³ / 700 gpm = 18 minutes approx.

The above estimates are summarized in Table 8, on the next page.

TABLE 8 Regeneration Steps

	Design Basis	Flow	Time	Total Waste per Step
Backwash	2 gpm/ft ²	157 gpm	10 min	1,570 gallons
Brining	0.25 gpm/ft ³	84 gpm	45 min	3,733 gallons
Slow Rinse	0.25 gpm/ft ³	84 gpm	60 min	5,040 gallons
Fast Rinse	–	700 gpm	18 min	12,600 gallons
Total			133 min	22,943 gallons

Counter-flow regeneration usually results in more efficient regeneration of the resin bed vs. co-flow regeneration. In the case of a counter-flow regenerated resin bed, the service flow would be in one direction through the bed while the brine and slow rinse will be in the opposite direction. This allows the freshest brine to make contact with the resin beads that are closest to the service outlet end of the vessel — resulting in a deeper cleaning of the resin in that area of the bed and generally lower nitrate leakage during the service phase. The trade-off is a more costly equipment design and a somewhat more complex method of operation.

Table 9, below, outlines the particle size range for the standard, Purofine and Puropack grades in which the resins are available. Standard grade resin is supplied with a wider range of bead diameters (from 300–1,200 µm) compared to Purofine and Puropack grades which are supplied with more uniform diameter beads. Puropack grades are predominantly used in packed bed equipment designs while Purofine grading generally provides a slightly higher operating capacity and better leakage than the standard grade resin with a wider. Please consult your local Ecolab representative for more advice on resin selection.

TABLE 9 Particle Size Gradings Available

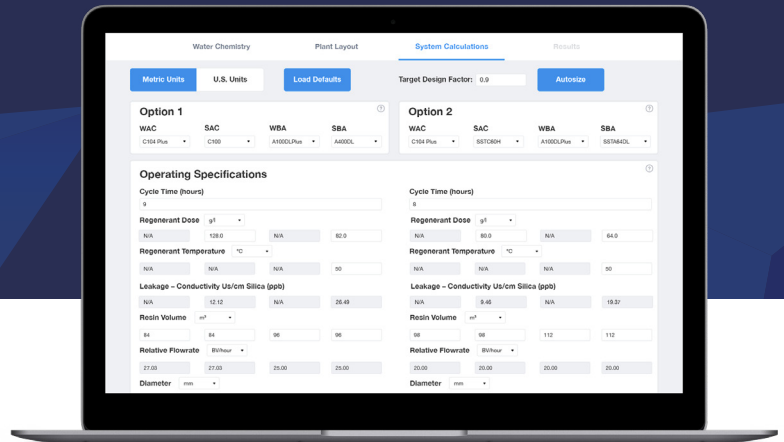
Grading	Mean Diameter, µm	Uniformity Coefficient
Standard Gaussian	300–1,200	1.7 max.
Purofine Uniform	570 ± 50	1.1–1.2 max.
Puropack Uniform Gel	650 ± 50	1.1–1.2 max.
Puropack Uniform Macroporous	750 ± 100	1.2–1.4 max.

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Efficiency Evaluation – Compare operating costs of existing ion exchange plant vs. new design

Schedules – Obtain detailed regenerant schedules for cation and anion resins

Page, Topic and Calculation Help – View detailed notes and suggestions for the optimal design

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