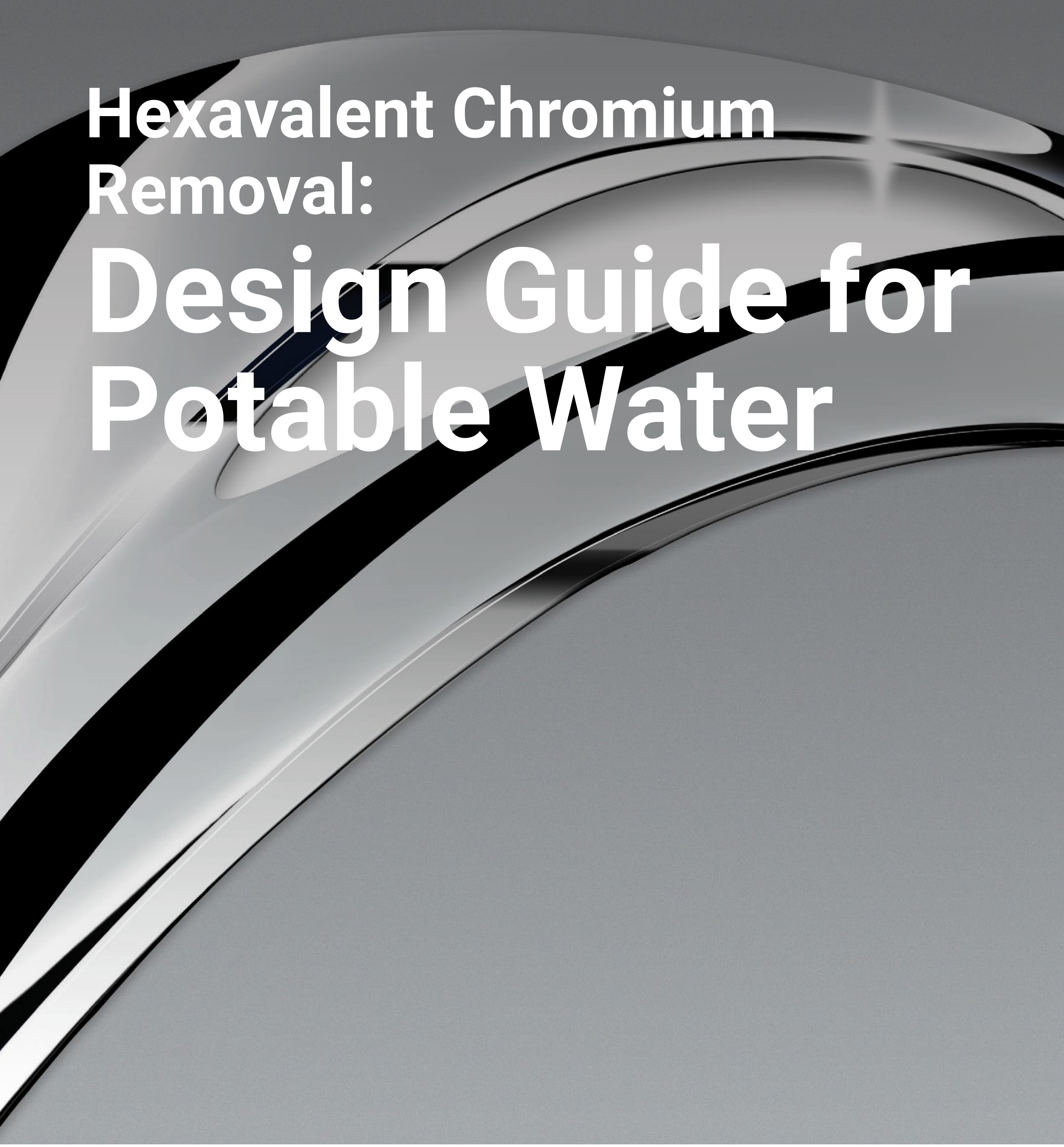
Hexavalent Chromium Removal:

Design Guide for Potable Water



Discover the most cost-effective ion exchange solutions for your site to be in compliance with state and federal maximum contaminant levels (MCLs).

Purolite®

About Purolite

Purolite is a leading manufacturer of ion exchange, catalyst, adsorbent and specialty resins. With global headquarters in the United States, Purolite is the only company that focuses 100% of its resources on the development and production of resin technology.

Responding to our customers' needs, Purolite has the widest variety of products and the industry's largest technical sales force. Globally, we have five strategically located research and development centers and eight application laboratories. Our ISO 9001 certified manufacturing facilities in the United States of America, United Kingdom, Romania and China combined with more than 40 sales offices in 30 countries ensure complete worldwide coverage.

PREMIER PRODUCTS

The quality and consistency of our products is fundamental to our performance. Throughout all Purolite plants, production is carefully controlled to ensure that our products meet the most stringent criteria, regardless of where they are produced.

RELIABLE SERVICE

We are technical experts and problem solvers. Reliable and well trained, we understand the urgency required to keep businesses operating smoothly. Purolite employs the largest technical sales team in the industry.

INNOVATIVE SOLUTIONS

Our continued investment in research and development means we are always perfecting and discovering innovative uses for ion exchange resins and adsorbents. We strive to make the impossible possible.

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Contents

Introduction

Chromium is a heavy metal that occurs throughout the environment. The trivalent form is a required nutrient, while the hexavalent form, also commonly known as Chromium (VI), Cr (VI), Chrome 6 or Cr-6, is a known carcinogen and an emerging health concern for groundwater. Treatment options should be chosen carefully as technologies are sensitive to water conditions.

Key Factors affecting treatment include alkalinity, sulfate, TOC, Cr-6 and uranium levels. Costs associated with equipment, residual disposal and operational preferences can affect the selection of treatment and process.

Purolite offers several industry-leading solutions that work within a variety of site and operational conditions. Regenerable Purolite A600E/9149, Purolite PGW6002E or Purolite S106 can provide cost-effective solutions for reducing or eliminating contamination to meet compliance with state and federal maximum contaminant levels (MCLs).

Advantages of Purolite ion exchange resins for hexavalent chrome removal include:

- Single supplier for the full range of resin options available in the industry.
- Reliable modeling software for ease of design, capacity and operational expectations.
- Customizable brine minimization approach or single-pass approach.
- Multi-contaminant design approach is possible for simultaneous removal with other contaminants.
- Full-service capabilities for resin installation, removal and disposal.

Each treatment site will have its combination of factors that must be carefully evaluated and modeled. As a rule of thumb, WBA resin tends to be favored for water with increasing levels of sulfate and total dissolved solids. On the other hand, high sulfate levels usually mean more frequent regeneration of SBA resins and therefore increasing cost for regenerant and wastewater disposal. Below is a more in-depth discussion of the merits of both types of resins.

With SBA resin, no pH adjustment is normally needed and the resin can be reused multiple times by using a brine solution periodically to elute the chromium from the resin. The SBA design must include proper treatment and disposal of the spent chromium-containing brine. Choosing between WBA and SBA resin technology will depend on:

A. The impact of competing anions (e.g. SO_4, NO_3, HCO_3, Cl) on resin capacity

B. The size of the treatment plant and the availability of operators for daily maintenance

C. The target treatment level for chrome VI

D. Whether acid and caustic for pH control with WBA resin can be accommodated

E. The site options available for handling and disposal of chromium-containing brine

Design Guidelines

Recommended Design Guidelines for Chrome VI Treatment Systems

Pretreatment

Prefilters to prevent total suspended solids (TSS) accumulation in the resin bed is vital to good operation. The longer the resin will be in service, especially with single-use ion exchange resins, the more important proper design and operation of a prefiltration system is to the resin performance. A particle size distribution analysis can help determine the size of incoming solids. If the well produces any sand, a de-sander is also recommended.

Resin performs best when foulants are eliminated. If any of these are present in the water in concentrations high enough to affect resin performance, they need to be adequately removed:

- Iron <.5 ppm
- Manganese >20 ppb
- Oil and Grease: Any concentration is detrimental
- Oxidants: Any concentration is detrimental
- Langelier Saturation Index: Ensure there is no scaling potential
- Microbes: Influent water must be bacteria-free
- TOC > 2 ppm

Weak Base Anion Exchange: Purolite S106

Purolite S106 is a single-use epoxy polyamine weak base anion resin (WBA) that exhibits excellent selectivity and kinetics in the removal of ppb levels of hexavalent chromium.

Single-use "load and dispose" systems do not utilize an on-site regeneration process and are ideal in locations with significant footprint constraints or where accessibility to brine disposal options is limited. After the resin is spent, it can be sent to a landfill for disposal or transferred to a chrome recovery facility. Resin will then be replaced for on-going treatments.

As with all water treatment applications, a detailed raw water analysis is needed for proper resin selection and system design. Water parameters needed include:

- pH
- Total Dissolved Solids (TDS)
- Total Suspended Solids (TSS)
- Alkalinity
- Nitrate
- Sulfate
- Chloride
- Uranium

With WBA resin, it is necessary to reduce the influent water pH using an acid.

Operation of two ion exchange vessels in a lead-lag configuration within a pH range of 5.0 to 6.0 is recommended. Reducing the pH converts most of the chrome-6 from its divalent to its monovalent state — this essentially doubles the loading capacity of the resin for chromium-6 and facilitates single-use operation of the resin to meet targeted MCLs in the treated water

A reduction of over 99% can be achieved when operating at a service flowrate of 20 bed volumes per hour. Resin can treat between 100,000 and 300,000 bed volumes between replacements.

Consideration should be given to the following design and operating factors:

- The pH of the influent water must be reduced to between 5.5 and 6 before the S106.
- The bicarbonate alkalinity of the raw water will determine the acid dosage needed.
- The pH of the treated water must be re-adjusted upward to the influent levels before the water is sent to the distribution system.
- Most drinking water well quality is amenable to WBA treatment with S106

- Any uranium present in the influent water will also be removed by the resin; this can sometimes limit loading capacity and can determine disposal cost for the spent resin.
- S106 resin can generally treat hundreds of thousands of bed volumes of water before it is spent, making it economically feasible in many cases. Please contact a Purolite technical sales representative to help determine throughput estimates.
- S106 contains no formaldehyde and does NOT require preconditioning that other phenol-formaldehyde type WBA resin do for chrome VI.

Residuals Handling

- Adjust pH to less than 6 before ion exchange (IX) vessels using mineral acid or CO_2 gas.
- Readjust pH to feed levels after IX vessels using caustic or by degasification.
- Test for uranium accumulation in spent resin.

TABLE 1 Weak Base Anion Design Parameters

Design Parameter	Value
Resin Depth	3 ft minimum (0.91 m)
Linear Velocity	8 to 12 gpm/ft^2 (20 to 30 m/h)
Specific Flow Rate	1 to 5 gpm/ft^3 (8 to 40 BV/h)
Empty Bed Contact Time	2–3 minutes minimum
Influent pH	5.5–5.9

Vessels are generally designed in a lead/lag configuration
1 bed volume = 1 unit of water/1 unit of resin

WBA Example

In this example, the influent chromium-6 is 15 ppb. The goal is to be less than or equal to 8 ppb. Therefore, partial treatment and blending is most economical. The sulfate level is 120 ppm, so SBA regeneration is not feasible. WBA is the best solution in this case.

A throughput projection can be done by contacting Purolite. We assume an estimated Cr-6 leakage of 1 ppb.

TABLE 2A Raw Groundwater Parameters

Raw Water Parameter	Value
Well Pump Flow Rate	227.1 m^3/h (1,000 gpm)
Treated Flow Rate	113.6 m^3/h (500 gpm)
Bypassed Flow Rate	113.6 m^3/h (500 gpm)
Total Chromium	15.5 ppb
Chrome VI	15 ppb
Alkalinity as $CaCO_3$	120 ppm as $CaCO_3$
Chloride	120 ppm
Sulfate	120 ppm
Nitrate as N	5 ppm as N
Uranium	2 ppm
pH	7.5

TABLE 2B Example Case Design Information

Design Parameter	Value
Total Flow Rate	227.1 m^3/h (1,000 gpm)
Influent Chrome VI	15 ppb
Leakage Chrome VI	1 ppb
Effluent Concentration Goal of Chrome VI (Blended)	8 ppb
Bypass Flow Percent	50%
Bypassed Flow Rate	113.6 m^3/h (500 gpm)
Treated Flow Rate	113.6 m^3/h (500 gpm)
Number of Trains	1
Vessel Diameter	2.4 m (8 ft)
Flow per Vessel	113.6 m^3/h (500 gpm)
Volume per Supersack	42 ft^3
Number of Supersacks per Vessel	5
Media Volume per Vessel	5,947 l (210 ft^3)
Media Volume Total Onsite	11,893 l (420 ft^3)
Vessel Area	4.6 m^2 (50 ft^2)
Bed Depth	1.3 m (4.2 ft)
Linear Velocity	29.1 m/h (11.9 gpm/ft^2)
Specific Flow Rate	23.3 BV/h (2.9 gpm/ft^3)
EBCT Goal: 2.5 to 3 min.	2.4 minutes
Projected Throughput	193,333 BV
Days Between Exchanges	422 days

Design Steps

- Determine treated flow

$$\textbf{Bypass Percentage} = \frac{\textbf{(Effluent Concentration Goal – Leakage Concentration)}}{\textbf{(Influent Concentration – Leakage Concentration)}}$$

$$\textbf{Example: Bypass Percentage} = \frac{\textbf{(8 ppb – 1 ppb)}}{\textbf{(15 ppb – 1 ppb)}} = \textbf{50\%}$$

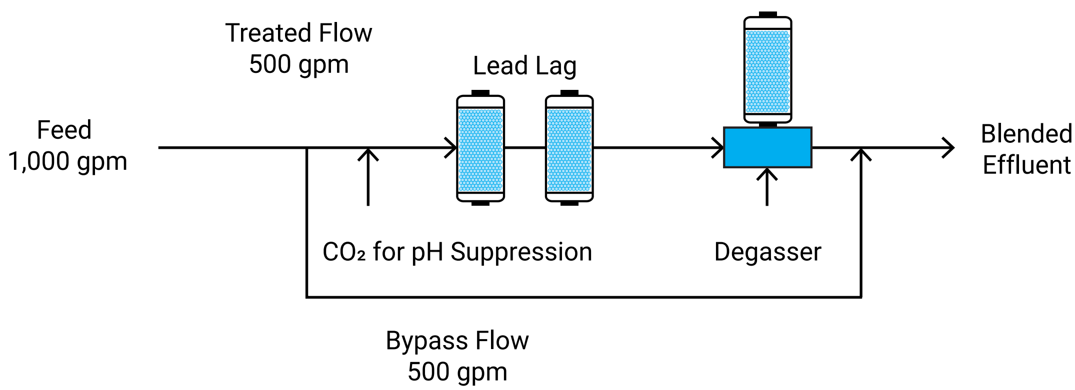
Bypass Flow = Bypass Percentage x Total Flow Rate

Example: Bypass Flow = 50% x 1,000 gpm = 500 gpm

- Determine available equipment diameter.
- Determine number of trains to meet appropriate design conditions.
- Determine volume of resin to achieve the minimum bed depth by varying the number of supersacks. It is much easier to load and unload based on using full supersack volumes (42 cu ft per supersack).

FIGURE 1

WBA Design with S106



Strong Base Anion Exchange Resins

Strong base anion exchange resins are effective over a wider pH range and do not typically require pH adjustment. Water passes through the resin where chrome VI and other anions are exchanged for chloride initially.

Purolite A600E/9149 is a Type I strong base anion (SBA) gel ion exchange resin. Purolite A600E/9149 exchanges chrome VI anions for less strongly held chloride ions on the resin beads and requires periodic regeneration with salt solution (brine) and disposal and/or treatment of the Cr-6 laden brine. Regeneration frequencies of between 5,000 and 25,000 bed volumes can be achieved between regenerations depending on the influent water chemistry.

Purolite PGW6002E is a high capacity Type I SBA resin that works well as a single use resin with lower sulfate levels.

SBA resin is more selective for chrome-6 vs other major anions typically present:

$$CrO_4^{2-} > SO_4^{2-} > NO_3^- > Cl^- > HCO_3^- > F^-$$

Depending on the water chemistry — especially sulfates — SBA resins can be used as either a single-use or a regenerable resin.

The reaction is:

$$CrO_4^{2-} + Resin - Cl_2 \rightarrow \leftarrow Resin - CrO_4^{2} + 2Cl^-$$

Single-Use SBA Resin: Purolite PGW6002E

When sulfates are very low, Purolite PGW6002E, a high capacity SBA resin, can last months to years in the field. Economic evaluation is necessary to determine the throughput and change-out costs as well as the capital savings of a single-use system. The advantages of Purolite PGW6002E are no generation of liquid waste (i.e. no spent brine) and no need for pH adjustment.

Residuals Handling

- Test for uranium accumulation in spent resin

TABLE 3 **Single-Use SBA Resin Design Parameters**

Design Parameter	Value
Resin Depth	3 ft minimum (0.91 m)
Linear Velocity	8 to 12 gpm/ft^2 (20 to 30 m/h)
Specific Flow Rate	1 to 5 gpm/ft^3 (8 to 40 BV/h)
Empty Bed Contact Time	2–3 minutes minimum

Vessels are generally designed in a lead/lag configuration

SBA Single-Use Example with Purolite PGW6002E

In this example, the influent chromium-6 is 15 ppb. The goal is to be less than or equal to 8 ppb. Therefore, partial treatment and blending is most economical. The sulfate level is 5 ppm, so SBA single-use is a good option.

A throughput projection can be done by contacting Purolite. We assume an estimated Cr-6 leakage of 2 ppb.

TABLE 4A Raw Groundwater Parameters

Raw Water Parameter	Value
Well Pump Flow Rate	227.1 m^3/h (1,000 gpm)
Treated Flow Rate	122.6 m^3/h (540 gpm)
Bypassed Flow Rate	104.5 m^3/h (460 gpm)
Total Chromium	15.5 ppb
Chrome VI	15 ppb
Alkalinity as $CaCO_3$	100 ppm as $CaCO_3$
Chloride	30 ppm
Sulfate	5 ppm
Nitrate as N	2 ppm as N
Uranium	2 ppm
pH	7.5

TABLE 4B Example Case Design Information

Design Parameter	Value
Total Flow Rate	227.1 m^3/h (1,000 gpm)
Influent Chrome VI	15 ppb
Leakage Chrome VI	2 ppb
Effluent Concentration Goal (Blended)	8 ppb
Bypass Flow Percent	46%
Bypassed Flow Rate	104.5 m^3/h (460 gpm)
Treated Flow Rate	122.6 m^3/h (540 gpm)
Number of Trains	1
Vessel Diameter	2.4 m (8 ft)
Flow per Vessel	136.3 m^3/h (600 gpm)
Volume per Supersack	1,189 l (42 ft^3)
Number of Supersacks per Vessel	5
Media Volume per Vessel	5,947 l (210 ft^3)
Media Volume Total Onsite	11,893 l (420 ft^3)
Vessel Area	4.6 m^2 (50 ft^2)
Bed Depth	1.3 m (42 ft)
Linear Velocity	26.2 m/h (10.7 gpm/ft^2)
Specific Flow Rate	23.3 BV/h (2.9 gpm/ft^3)
EBCT: Goal 2 to 3 min	2.6 minutes
Projected Throughput	50,000 BV
Days Between Exchanges	90 days

Design Steps

- Determine treated flow

$$\textbf{Bypass Percentage} = \frac{\textbf{(Effluent Concentration Goal – Leakage Concentration)}}{\textbf{(Influent Concentration – Leakage Concentration)}}$$

$$\textbf{Example: Bypass Percentage} = \frac{\textbf{(8 ppb – 2 ppb)}}{\textbf{(15 ppb – 2 ppb)}} = \textbf{46\%}$$

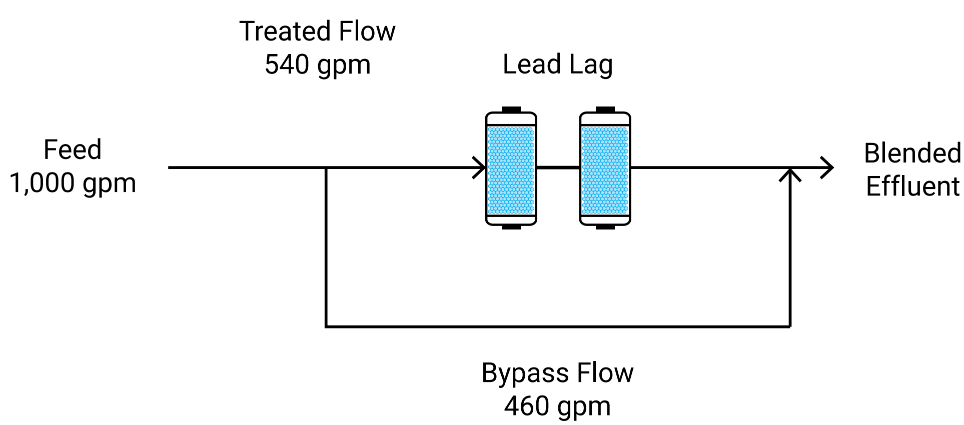
Bypass Flow = Bypass Percentage x Total Flow Rate

Example: Bypass Flow = 46% x 1,000 gpm = 460 gpm

- Determine available equipment diameter.
- Determine number of trains to meet appropriate design conditions.
- Determine volume of resin to achieve the minimum bed depth by varying the number of supersacks. It is much easier to load and unload based on using full supersack volumes.

FIGURE 2

SBA Single-Use Design with PGW6002E



Regenerable SBA Resin with A600E/9149

Using A600E/9149, a regenerable SBA resin is feasible when the concentrations of sulfate and other competing anions are moderate and regeneration is needed every few weeks or longer.

When a vessel of resin has reached its change-out criteria, the vessel is taken out of service in preparation for regeneration. During the regeneration step, several bed volumes of sodium chloride ($NaCl$) brine regenerant are pumped through the resin at a high enough concentration to strip the chrome VI and other anions from the resin and put the resin back in the chloride form. The brine will contain high concentrations of both sodium chloride and chrome VI. The system then goes through a slow rinse to displace the last contaminants followed by a fast rinse, mainly to displace the $NaCl$. The vessel is then ready to be placed back in service.

High chrome VI in the spent brine may result in it being classified as hazardous — a brine analysis will usually be needed.

Brine Disposal Options

In most cases, spent brine cannot be discharged. The impacts on wastewater treatment plant discharges and National Pollutant Discharge Elimination System (NPDES) requirements must be evaluated for each system.

Spent brine will also concentrate other anions in the water. Complete characterization is necessary to ensure uranium concentration does not exceed NPDES requirements.

TABLE 5 SBA Regenerable Design Parameters

Design Parameter	Value
Resin Depth	3 ft minimum (0.91 m)
Linear Velocity	8 to 12 gpm/ft^2 (20 to 30 m/h)
Specific Flow Rate	1 to 5 gpm/ft^3 (8 to 40 BV/h)
Empty Bed Contact Time	2–3 minutes minimum

Systems are generally designed with several vessels in parallel service and one in standby or regeneration mode: i.e. n + 1

Regeneration

Purolite A600E/9149 can be regenerated using a 10-15% brine solution. It is important to allow adequate contact between the resin and the brine solution to optimize performance. For hard to treat water, a combination of 10–15% brine provide the extra cleaning efficiency needed. Standard operating and regenerating conditions for sodium chloride co-flow service are provided in Table 6 below.

TABLE 6 Standard Operating and Regenerating Conditions for Co-Flow Service

Step	Design Basis	Duration
Service	8–16 BV/h 1–2 gpm/ft^3	Dependent on influent organic loading and desired breakpoint.
Backwash	Set for minimum water temperature to give 50% bed expansion. Refer to Figure 2 for details.	1 BV for clean water supplies and 2–3 BVs where suspended solids are higher.
Bed Settle	To allow the bed to reform fully classified.	5 minutes
NaCl Injection	5 BV of 12% brine solution at 2–4 BV/h (0.25 to 0.5 gpm/ft^3).	Typically, 60–90 minutes depending on regeneration level and flow rate.
Displacement Rinse	Flow similar to the brine solution at 2–4 BV/h (0.25–0.5 gpm/ft^3); rinse volume 2 BV or 15 gal/ft^3.	Typically, 30–40 minutes depending on water volume applied and flow rate.
Final Rinse	3–6 BV (22.5 to 45 gal/ft^3) preferably at service flow rate 8–16 BV/h (1–2 gpm/ft^3).	Typically, 10–20 minutes. Less displacement rinse will require more final rinse.

BV = Bed Volumes
BV/h = Bed Volumes per hour

SBA Regenerable Example with A600E/9149

In this example, the influent chromium-6 is 15 ppb. The goal is to be less than or equal to 8 ppb. Therefore, partial treatment and blending is most economical. The sulfate level is 25 ppm, so SBA regenerable is a good option.

A throughput projection can be done by contacting your resin supplier. We assume an estimated Cr-6 leakage of 2 ppb for regenerated resin.

TABLE 7A Raw Groundwater Parameters

Raw Water Parameter	Value
Well Pump Flow Rate	227.1 m^3/h (1,000 gpm)
Treated Flow Rate	122.6 m^3/h (540 gpm)
Bypassed Flow Rate	104.5 m^3/h (460 gpm)
Total Chromium	15.5 ppb
Chrome VI	15 ppb
Alkalinity as $CaCO_3$	120 ppm as $CaCO_3$
Chloride	120 ppm
Sulfate	25 ppm
Nitrate as N	5 ppm as N
Uranium	2 ppm
pH	7.5

TABLE 7B Example of SBA Regenerable

Design Parameter	Value
Total Flow Rate	227.1 m^3/h (1,000 gpm)
Influent Chrome VI	15 ppb
Leakage Chrome VI	2 ppb
Effluent Concentration Goal of Chrome VI (Blended)	8 ppb
Bypass Flow Percent	46%
Bypassed Flow Rate	460 gpm
Treated Flow Rate	540 gpm
Number of Vessels in Service	2
Number of Vessels in Standby	1
Number of Vessels Total	3
Flow per Vessel	270 gpm
Vessel Diameter	1.8 m (6 ft)
Volume per Supersack	1,189.3 l (42 ft^3)
Number of Supersacks per Vessel	3
Media Volume per Vessel	3,568 l (126 ft^3)
Media Volume Total Onsite	10,704 l (378 ft^3)
Vessel Area	2.6 m^2 (28 ft^2)
Bed Depth per Vessel	1.4 m (4.5 ft)
Linear Velocity	26.2 m/h (9.5 gpm/ft^2)
Specific Flow Rate	16.8 BV/h (2.1 gpm/ft^3)
EBCT	3.5 minutes
BV/hour	17
Estimated Throughput	7,000 BV
Bed Life	17 days

TABLE 8 Regeneration: Based on 5 BV NaCl and 12% Brine Solution

Step	Design Basis	Flow	Time	Total Waste per Step
Backwash*	2.4 gpm/ft^2	68 gpm	28 min	1,885 gallons
Brine Step	0.5 gpm/ft^3	63 gpm	75 min	4,725 gallons
Slow Rinse	0.5 gpm/ft^3	63 gpm	40 min	2,520 gallons
Fast Rinse	–	270 gpm	20 min	5,400 gallons
Totals	–	–	163 min	14,530 gallons

* Backwash based on using a typical Type I SBA resin. Influent water temperature 20 °C, 50% backwash expansion occurs at approximately 2.4 gpm/ft^2. Time is based on backwashing 2 bed volumes.

Design Steps

- Determine treated flow

$$\text{Bypass Percentage} = \frac{\text{(Effluent Concentration Goal – Leakage Concentration)}}{\text{(Influent Concentration – Leakage Concentration)}}$$

$$\text{Example: Bypass Percentage} = \frac{\text{(8 ppb – 2 ppb)}}{\text{(15 ppb – 2 ppb)}} = 46\%$$

$$\text{Bypass Flow} = \text{Bypass Percentage} \times \text{Total Flow Rate}$$

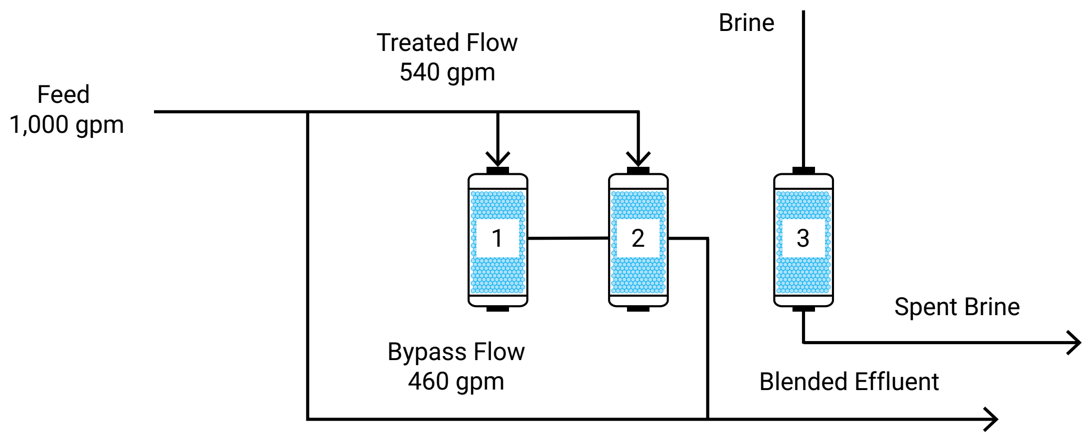
$$\text{Example: Bypass Flow} = 46\% \times 1{,}000 \text{ gpm} = 460 \text{ gpm}$$

- Determine available equipment diameter.
- Determine number of trains to meet appropriate design conditions.
- Determine volume of resin to achieve the minimum bed depth by varying the number of supersacks. It is much easier to load and unload based on using full supersack volumes.
- Design regeneration protocol.

FIGURE 3

Co-Flow Regeneration Example: Vessel 3 is Off-Line While in Regeneration

SBA Regeneration



Notes

Notes

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