

ENGINEERING BULLETIN

Purolite® A400

This bulletin provides engineering data for using Purolite A400 supplied in the chloride (salt-exhausted) form for water demineralization. Capacity and leakage data is presented for co-flow and counter-flow systems.

This Engineering Bulletin presents product details and engineering performance data for Purolite® A400. Information is also provided for anion and cation service operation, variation in performance and co-flow and counter-flow regeneration conditions. For more detailed product information, or to find a product for a specific application, please go to www.purolite.com or contact your closest Purolite regional office as listed on the back cover.

INTRODUCTION

Founded in 1981, 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 the needs of our customers, Purolite has built the largest technical sales force in the industry, the widest variety of products and five strategically located Research and Development groups. Our ISO 9001 certified manufacturing facilities in the U.S.A, Romania and China combined with more than 40 sales offices in 30 countries ensure complete worldwide coverage.



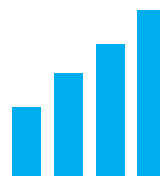
PREMIER PRODUCTS

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 organization in the industry.



INNOVATIVE SOLUTIONS

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

Purolite A400 is an industrial grade, polystyrenic, gel, type I strong base anion exchange resin and is normally supplied in the chloride (salt - exhausted) form. It is also available in the hydroxide (regenerated) form as Purolite A400OH. Its principal application is in water demineralization. Like all strong base anion resins, the resin swells between the exhausted and the regenerated form and this must be taken into account in any design calculations. The data in this engineering bulletin is specific to Purolite A400 supplied in the chloride form.

Strong base type I anion resins have relatively higher temperature resistance than other strong base anion resins when operated in the hydroxide form, and also offer very good silica removal with low silica leakage, even in co-flow regenerated plants. Purolite A400 is therefore widely encountered in anion units working in hot climates or other situations when warm water is encountered, e.g. where the raw water is preheated. Strong base resins of this type are also widely encountered all around the world as the anion component of mixed beds.

This document provides information and engineering data on the removal of anions as part of the demineralization process. On exhaustion, the resin can be regenerated with a dilute solution of sodium hydroxide.

Table 1 – Typical physical and chemical characteristics	
Polymer structure	Polystyrene crosslinked with DVB
Physical form	Amber to pale yellow, clear spherical beads
Functional groups	Type I quaternary ammonium
Ionic form, as shipped	Chloride (Cl ⁻)
Total capacity, Cl ⁻ form	1.3 eq/l (28.4 Kgr/ft ³) min.
Moisture retention, Cl ⁻ form	48 – 54%
Particle size range	300 – 1200 µm 1% max. <300 µm
Uniformity coefficient	1.7 max.
Reversible swelling, Cl ⁻ → OH ⁻	20%
Specific gravity, Cl ⁻ form	Approx. 1.08
Shipping weight, Cl ⁻ form	680 – 715 g/l (42.5 – 44.7 lb/ft ³)
Maximum temperature limit OH ⁻ form: Maximum temperature limit Cl ⁻ form:	60 °C – 140 °F 100 °C – 212 °F

Available grades

Purolite A400 is also available in different grades supplied in the Cl⁻ form, unless otherwise stated. Other ionic forms are also available in most grades and product data sheets with more detailed information on the products listed are available on our Web site, www.purolite.com.

Single bed applications

- **Purolite® A400** is a standard grade resin with a Gaussian particle size distribution in the range of 300-1200 µm. Its principal application is in co-flow and traditional counter-flow regenerated plants, where classification of the bed inside the operating vessel is possible.
- **Purolite® A400C** is a modified grade with a particle size in the range 425 – 1200 µm, used in high flow rate applications to reduce pressure drop across the bed.
- **Purofine® PFA400** is a uniform particle size product with a mean particle size of 570±50 µm and a UC of 1.1 – 1.2, offering improved performance with regard to capacity, leakage, pressure drop and rinse water volumes in co-flow and counter-flow engineering designs.
- **Puopack® PPA400** is another uniform grade product, offering similar advantages, but with a mean particle size of 650±50 µm. This product has been specifically developed for the Puopack system and other packed bed designs that use either up-flow or down-flow service operation. This resin is also widely used in co-flow and other counter-flow engineering designs such as split flow, air and water hold down, etc.
- **Purolite® A400E** is a specially cleaned, food-grade resin for use in food processing.

Dual layer (stratified bed) applications

- **Purolite® A400DL** is a specially designed, coarse grade version of Purolite A400. Its principal application is in layered bed anion exchange units in conjunction with a DL grade Purolite weak base anion resin such as Purolite® A100DL.

Mixed bed applications

Three grades of Purolite A400 are widely used in mixed beds. These are all specifically designed to separate well from the cation components. All three grades are anti-static treated to reduce clumping when first installed.

- **Purolite® A400MB** is a modified, simple mixed bed grade resin designed to give better separation than the standard grade product. It is usually used with gel mixed bed grade cation resins and is most often encountered in combination with Purolite® C100MB, Purolite® C100MBH, Purolite® C100x10MB or Purolite® C100x10MBH.
- **Purolite® A400TL** is a specially graded resin with a relatively fine particle size for use in TRILITE mixed bed systems, with or without use of intermediate inert resin. It is usually found in conjunction with a TL grade cation resin, such as Purolite® C100TL, Purolite® C100TLH, Purolite® C100x10TL, and Purolite® C100x10TLH. Purolite® A400TL can be supplied in the sulfate form for easier conversion to the regenerated hydroxide form.
- **Purofine® PFA400MB** is a uniform particle size product, normally used in mixed bed applications. It is usually used in conjunction with Puopack® PPC100H.

Typical operating data

Service operation

In the demineralization process, the anion column is always located downstream of the cation column, sometimes with a weak base anion unit and/or a degasser tower between the cation and strong base anion, depending on the raw water quality and plant design. The resin has to be downstream of the cation because calcium and magnesium ions must be removed prior to the anion bed. If not, these ions will precipitate when they come in contact with anion resin in the hydroxide form, creating major operating problems and loss of performance.

We suggest you read the Purolite A100 Engineering Bulletin to understand when weak base anion resins are employed prior to strong base anion resins.

When raw water contains a significant amount of alkalinity (bicarbonate), degassing towers can be located after the cation column, prior to the strong base anion bed. Degassers significantly reduce the ionic load onto the anion resin, decreasing the volume of anion resin required and the amount of regenerant used, and significantly cutting operating costs if the alkalinity loading is high. The exchange of the associated cations with H^+ ions taking place within the cation vessel converts all bicarbonate to carbonic acid. In turn, carbonic acid dissociates into carbon dioxide and water in the low pH conditions existing after the cation bed.

A degassing tower consists of a column filled with ceramic or plastic pall rings that get sprayed with decationized water. The water flows down through the packing, while a flow of low-pressure air is blown into the bottom of the tower. The high contact surface between water and air created by the pall rings speeds up the migration of carbon dioxide dissolved in the water to the air, thus reducing the concentration of carbon dioxide in degassed water to or close to the solubility level. The degassed water is then collected in a sump for pumping through the next stage using dedicated pumps.

In service operation, decationized water—or decationized and degassed water—is normally pumped through the anion resin bed, which is retained within a pressure vessel. The vessel has top and bottom distribution / collection systems. These systems are designed to ensure the water passes evenly through the ion exchange bed in service operation. As the water passes through the resin, the anions present (principally sulfate, nitrate, chloride, carbon dioxide, silica and any other dissolved anionic species) are exchanged with hydroxide ions. The pH of the anion treated water increases across the resin bed, from the acid to the slightly alkaline range, and at the same time the conductivity falls significantly. When the plants are working correctly, the conductivity at the exit of the anion column is dictated by the sodium leakage from the cation bed. When the anion resin is exhausted, it is regenerated with sodium hydroxide solution to put the resin back into the regenerated hydroxide form, making it ready for the next service operation. It is important that the internal systems within the unit efficiently distribute and collect both the water during service operation and the regenerant solution, rinses, etc., during regeneration, especially since the regenerant and the slow rinse run at much lower flow rates than the service flow rate.

In service operation, optimum performance is achieved at service flow rates between 8 and 40 BV/h (Bed Volumes per hour) or 1 to 5 gpm/ft³ (US gallons per minute per cubic foot of resin), with linear flow rates (velocities) of 10 to 50 m³/m²/h (m/h) or 4 to 20 gpm/ft² (US gallons per minute per square foot of vessel cross-section), whereas caustic regeneration is carried out at flow rates of between 2 to 6 BV/h or 0.25 to 0.75 gpm/ft³. Internal distribution / collection systems can operate efficiently at both the higher service and lower regenerant flow rates within these limits. Channelling can occur within the resin bed at very low service flow rates, and result in poor plant performance and short capacity between regenerations. This generally happens with the use of long service cycles.

The ratio of height to diameter is important in any ion exchange unit design. While some small industrial demineralization plants operate with very shallow bed depths, bed depths below 610 mm (2 ft.) should be avoided. Bed depths greater than 1,000 mm (3 ft. 3 in.) are recommended. Vessel height and pressure drop are normally the controlling factor on the maximum height of the bed. We recommend that pressure drop across the bed should be maintained at less than 150 kPa (22 psi) for Purolite A400 as this allows for bed

compaction and any solids loading across a classified bed. Bed depths greater than 2,500 mm (8 ft.) are rarely encountered.

Although smaller freeboards are commonly encountered, we recommend a minimum 75% freeboard (space) above the resin bed to allow at least 50% bed expansion during backwash. This is normally adequate for a co-flow regenerated vessel, and assures good hydraulic classification of the resin bed. Fully classified beds have a higher void fraction, which leads to lower pressure drop. This is particularly advantageous when high specific velocities are encountered. As the water has already passed through a cation stage, the water should be free of solids and a backwash strainer can be used. In the event of a higher backwash rate being mistakenly employed, this will ensure no loss of resin. A lower water temperature will also cause increased bed expansion during backwashing and is another reason why a backwash strainer can prevent resin loss if the water temperature falls significantly between summer and winter seasons.

Anion service operation is usually terminated by a number of different means:

- Detection of increased conductivity at the exit of the anion column, due to increased sodium leakage from the cation bed. This can only be reliably used if the capacity of the anion resin bed is greater than that of the cation.
- Detection of increased silica leakage at the exit of the anion column.
- Volumetric throughput, based on the volume of water treated, terminating the service cycle before either the cation or anion columns exhaust.
- A time schedule is also occasionally used, but this is the least precise method of control as it relies on the regeneration being initiated before either column has exhausted.

Regeneration can be manually or automatically initiated via the control system, but plant regenerations are now fully automatic. Depending on the engineering design, regeneration can either start with the cation bed followed by the anion regeneration, or in more sophisticated designs, the two regenerations will be performed almost simultaneously to reduce the time the plant is off line.

Variation in performance

The end of the document includes capacity and leakage data that shows, in general terms, the capacity gained from Purolite A400 is related to the proportion of sulfate and carbon dioxide in the water and to the silica endpoint taken to terminate the service cycle. The data also shows that a higher regenerant temperature improves silica leakage and capacity. This is why some plants elevate the temperature of the sodium hydroxide for regeneration.

Regeneration

Resin regeneration can be performed either co-flow or counter-flow. The regeneration is termed co-flow when the regenerant flows through the resin bed in the same direction that water flows during the service operation, normally downwards or “top to bottom.” When the regenerant flow is in the opposite direction to service flow, then the term used is counter-flow regeneration. Other terms such as co-current and counter-current are also used to describe these two principal regeneration techniques.

For counter-flow regeneration, it is important to note that in the up flow stages (except backwash) the bed must remain static. Packed beds, air hold down, split flow and water hold down are just a few examples of this type of system.

In some counter-flow regenerated systems, the design allows service flow to be upward through the bed and regeneration downwards. In such cases it is therefore important that the bed must remain static throughout the service operation.

Co-flow regeneration

Co-flow regeneration normally consists of 5 steps and takes between 1 and 2 hours to complete, depending on the detailed design. Decationized water is adequate quality for all steps, including regenerant dilution.

The first step of co-flow regeneration is backwash. Backwash water enters the unit through the bottom collection / distribution system, loosens the bed and causes the bed to expand as the water passes up through it. Flow rate should be set for the freeboard available in the unit at the minimum water temperature. Backwash is designed to decompact the resin for better regenerant contact as well as to remove suspended solids that filtered out of the incoming supply and accumulated within the bed. The volume of backwash water will depend on the extent of solids loading. Decationized water should be free of solids and a relatively small amount of backwash water is normally required to loosen the bed. After the backwash a “bed settle” step is required.

Bed settle allows the resin to settle back and reform the static bed prior to regenerant injection. Depending on the size of the bed, free board and backwash rate used, this step can take between 5 and 10 minutes. Anion resins are lighter than cation resins so the bed settle time is usually longer for anion resins.

Table 2 – Typical sodium hydroxide regeneration conditions for co-flow regenerated columns

STEP	DESIGN BASIS	DURATION
Backwash	Set for minimum water temperature to give 50% bed expansion. Refer to Figure 24 for details.	1 FBV on clean water supplies and 2 – 3 FBV where solids are present
Bed settle	To allow the bed to reform fully classified	5 to 10 minutes
NaOH injection	60 – 100 g/l (3.75 – 6.25 lb/ft ³) applied as a 3-6% caustic solution at 2 – 4 BV/h (0.25 to 0.5 gpm/ft ³). Regenerant volume needs to be in excess of resin volume.	Typically 30 – 45 minutes depending on regeneration level and flow rate
Slow rinse	2 – 3 BV (15 to 22.5 gal/ft ³) at approx. regenerant flow rate	Typically 30 – 40 minutes depending on volume of water applied and flow rate
Final rinse	3 – 6 BV (22.5 to 45 gal/ft ³) preferably at service flow rate or alternatively > 15 BV/h (2 gpm/ft ³)	Typically 10 – 20 minutes. The less slow rinse employed the more final rinse required.

(Key: BV = Bed Volume, BV/h = Bed Volume per hour, FBV = Free Board Volume above resin bed)

Regenerant injection at the correct flow rate and caustic concentration are critical. Good contact between the caustic solution and the resin is essential for optimum performance. The sodium hydroxide regeneration level (amount of caustic per litre or cubic foot of resin) will typically be between 60 and 100 g/l (3.75 – 6.25 lb/ft³), although regeneration levels as low as 48 g/l (3.0 lb/ft³) and as high as 200 g/l (12.5 lb/ft³) are sometimes used. Note that all regeneration levels are expressed for the pure chemical (100%) strength. In order to calculate the exact volume of regenerant required per regeneration, the concentration of sodium hydroxide available on site must be known.

Sodium hydroxide should be introduced at flow rates of 2 to 4 BV/h (0.25 to 0.5 gpm/ft³) and at concentrations from 3 to 6%. The contact time between the resin and the regenerant solution should be minimum 30 minutes.

The slow (regenerant displacement) rinse is always carried out at flow rates similar to the caustic injection step. This is to ensure uniform contact time between the resin and the regenerant solution and that the rinse water follows the same route of the regenerant through the resin bed. Since slow rinses are usually more efficient at removing spent regenerant from the resin, using a longer slow rinse can reduce the amount of final rinse required at the end of the regeneration. Normally 2 to 3 BV (15 to 22.5 gal/ft³) of slow rinse are applied.

The final rinse is often carried out at the service flow rate. This also acts as a proving condition prior to returning to service after regeneration. On some occasions, where flow restrictions occur, the plant final rinse is carried out at a rate lower than the service flow rate. Normally 3 to 6 BV (22.5 to 45 gal/ft³) are required depending on the design of the distribution / collection systems and the amount of slow rinsing previously performed.

Counter-flow regeneration

Traditional counter-flow regeneration techniques normally have fewer steps than those described earlier for co-flow regeneration and typically take between 1 and 1½ hours depending on the detailed design. This type of regeneration requires the use of anion-free water to achieve optimal performance for some steps, and so demineralized water is commonly used for sodium hydroxide dilution / injection as well as the slow rinse steps. Only then can the published silica leakage be obtained. The required amount of demineralized water is either produced and set aside during the previous service cycle or, in case of multi stream plants, it can be supplied by one of the other on-line streams.

The backwash step, which is always the first step of a co-flow regeneration, is not normally performed each cycle in a counter-flow regenerated system. However, a means of carrying out periodic full bed backwashes, either inside the service unit or in external dedicated vessels, should always be included in the plant design. Some engineering designs allow for sub-surface backwashes to be carried out each cycle, but such partial backwashes should not be intended as a replacement of periodic full bed backwashes. The resin should always be regenerated with double the normal amount of sodium hydroxide to restore full counter-flow performance after a full bed backwash. These full bed backwashes can be as infrequent as every 30 cycles and are normally determined by the increased pressure drop across the bed.

In counter-flow regeneration, bed depths below 1,000 mm (3 ft. 3 in.) should be avoided. It is preferential for beds to be filled in excess of 1,200 mm (4 ft.).

The regeneration level (amount of sodium hydroxide applied per litre or cubic foot of resin) will be lower than for co-flow regenerated units, typically between 40 and 80 g/l (2.5 – 5 lb/ft³). However, regeneration levels outside of this range are sometimes used. The regenerant should be introduced at flow rates of 2 to 4 BV/h (0.25 to 0.5 gpm/ft³) with concentrations from 3 to 6%. The contact time between the resin and the regenerant solution should be a minimum of 20 minutes.

The slow (regenerant displacement) rinse is always carried out at flow rates similar to the regenerant injection step and in the same direction. This is to ensure a uniform contact time between the resin and the regenerant solution and that the rinse water follows the same route of the regenerant through the resin bed. Since slow rinse is usually more efficient in removing the spent regenerant from the resin than fast rinse, using more slow rinse can reduce the amount of final rinse required. Normally 1 – 2 BV (7.5 to 15 US gal/ft³) of slow rinse are adequate. The final rinse is often carried out at the service flow rate. This also acts as a proving condition prior to returning to service after regeneration. Normally 2 to 4 BV (15 to 30 US gal/ft³) are required, depending on the design of the distribution / collection system and the amount of slow rinsing previously performed.

Table 3 – Typical sodium hydroxide regeneration conditions for counter-flow regenerated columns

STEP	DESIGN BASIS	DURATION
NaOH injection	40 – 80 g/l (2.5 – 5.0 lb/ft ³) applied as a 3 – 6% caustic solution at 2 – 4 BV/h (0.25 to 0.5 gpm/ft ³). Regenerant volume needs to be in excess of resin volume.	Typically 20 – 40 minutes depending on regeneration level and flow rate
Slow rinse	1 – 2 BV (7.5 to 15 gal/ft ³) at approx. regenerant flow rate	Typically 20 – 30 minutes depending on volume of water applied and flow rate
Final rinse	2 – 4 BV (15 to 30 gal/ft ³) preferably at service flow rate or alternatively > 15 BV/h (2 gpm/ft ³)	Typically 10 – 20 minutes; closed loop recycle rinse can be introduced during final rinse

(Key: BV = Bed Volume, BV/h = Bed Volume per hour)

It is increasingly common to employ closed-loop recycle rinses around the cation and anion units in counter-flow regenerated demineralization plants. This offers two advantages: it reduces the amount of waste water produced by the plant and it allows the design to include a proving pre-service rinse prior to placing the line back in service. Anion resins sometimes develop long rinses due to organic fouling and a recycle rinse system can significantly reduce water consumption and avoid overloading of resins overloading. The rinse recycle, on well-designed counter-flow plants, with efficient distribution / collections systems, can sometimes be introduced after the first 50% of the final rinse if water quality allows.

Purolite A400 and other grades are perfectly suitable for traditional counter-flow regeneration systems but, when more sophisticated plant designs are used, other more specialized grades, such as Purofine PFA400 or Puropack PPA400, can enhance the performance further. Consult your local Purolite sales office if you need any guidance.

Performance data

The following graphs and correction factors are designed to help the design engineer estimate the exchange capacity and silica leakage achieved with Purolite A400 under different operating conditions. All the data shown are the result of years of industrial experience and are supplied in good faith. The final performance will depend on the detailed design and operation of the system, the quality of the regenerant chemicals as well as the long term maintenance of the plant. Engineers using a standard plant of simple design may wish to take a design margin (safety factor) with regard to the published data to allow for less than ideal operation.

The data presented in this section are specific to co-flow regenerated designs with bed depths over 1,000 mm (3 ft. 3 in.) and counter-flow regenerated designs with bed depths over 1,200 mm (4 ft. 0 in.). For more shallow bed depths, there may be a requirement to down rate the expected performance depending on the quality of the design.

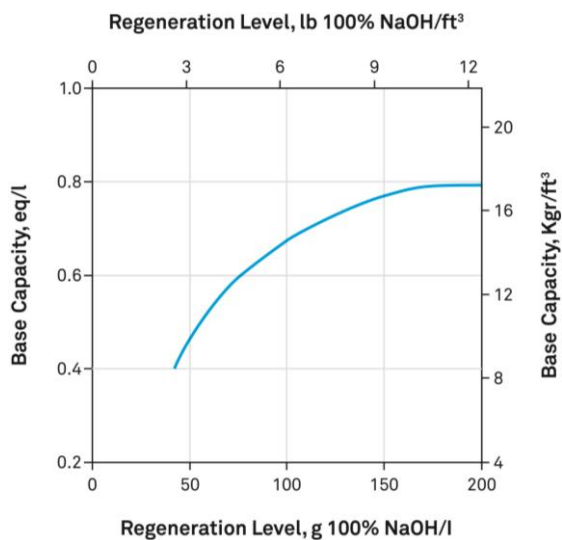
The data supplied are divided in three groups: figures 1 to 11 deal with capacity and leakage for co-flow regeneration, figures 12 to 23 with capacity and leakage for counter-flow regeneration and figures 24 to 25 with hydraulic data (backwash expansion and pressure drop). Within each of the first two groups there is a base capacity and a base leakage curve, both followed by other curves showing correction factors. To calculate the expected capacity or leakage, multiply the base capacity or leakage by the relevant correction factors.

For users interested in performing these engineering calculations electronically, Purolite's PureDesign software is available for download on www.purolite.com at no charge.

The data presented in this bulletin can also be used to estimate the operating performances of resins such as Purolite A400C, Purolite A400E or Purolite A400DL. Refer to dedicated engineering bulletins for products like Purofine PFA400 and Puropack PPA400, which offer enhanced performance under some operating conditions.

Co-flow regeneration

Figure 1 – Base capacity (co-flow regeneration)



Co-flow regeneration, continued

Figure 2 – C1-Capacity correction factor sulfates / total anions

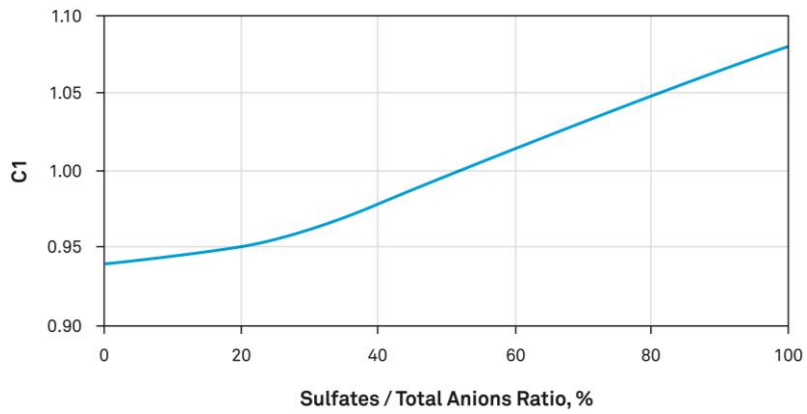
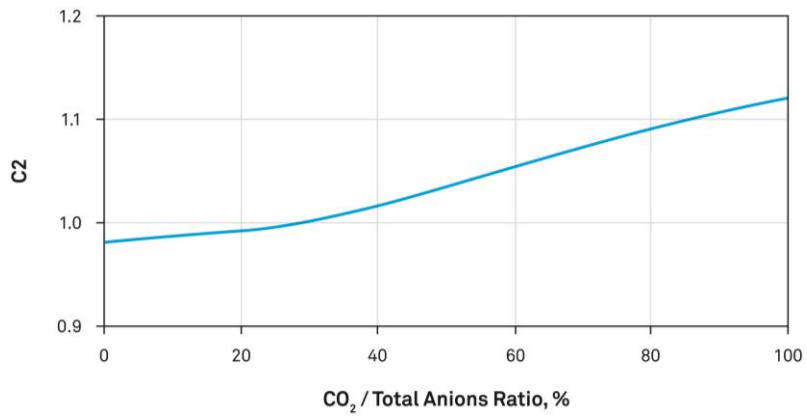


Figure 3 – C2-Capacity correction factor CO₂ / total anions



Co-flow regeneration, continued

Figure 4 – C3 - Capacity correction factor silica endpoint

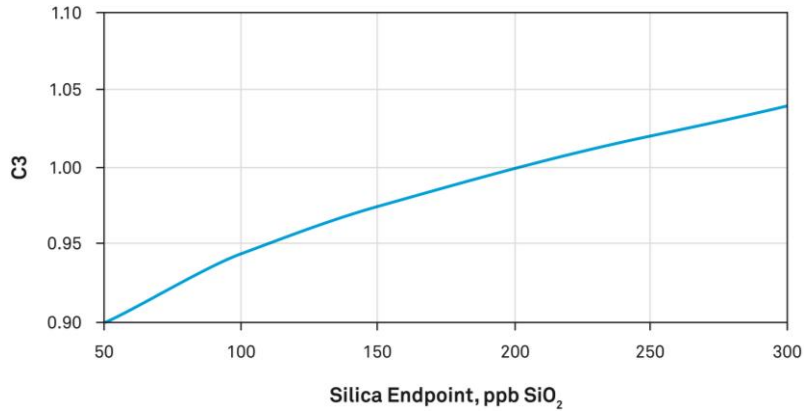
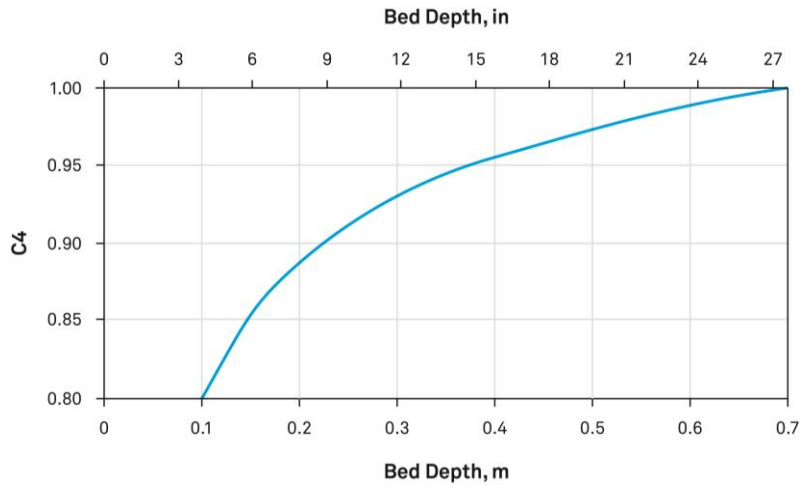


Figure 5 – C4 - Capacity correction factor for bed depth



Co-flow regeneration, continued

Figure 6 – C5-Capacity correction factor for silica and regeneration temperature

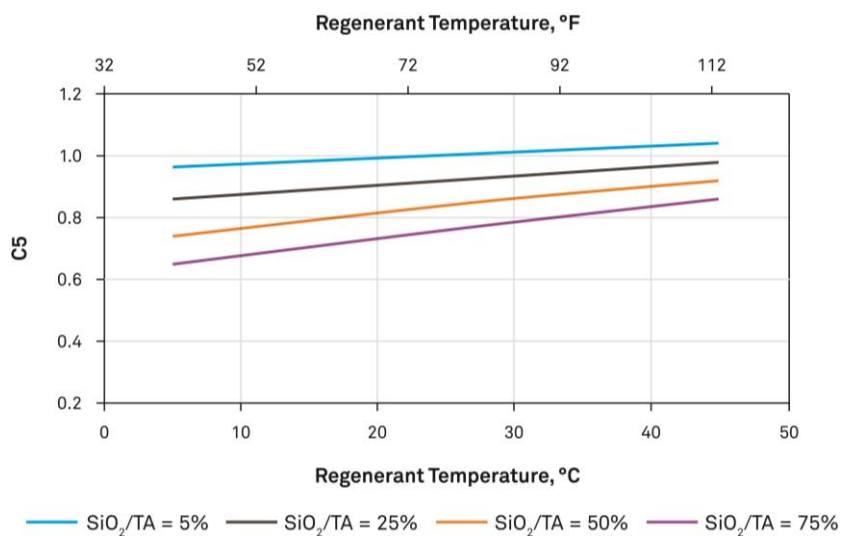
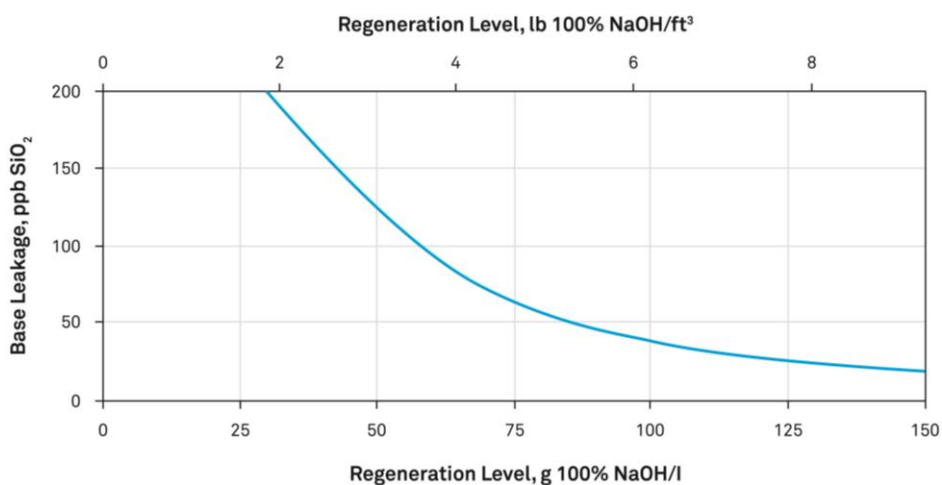


Figure 7 – Basic silica leakage



Co-flow regeneration, continued

Figure 8 – L1-Leakage correction factor SiO_2 / total anions

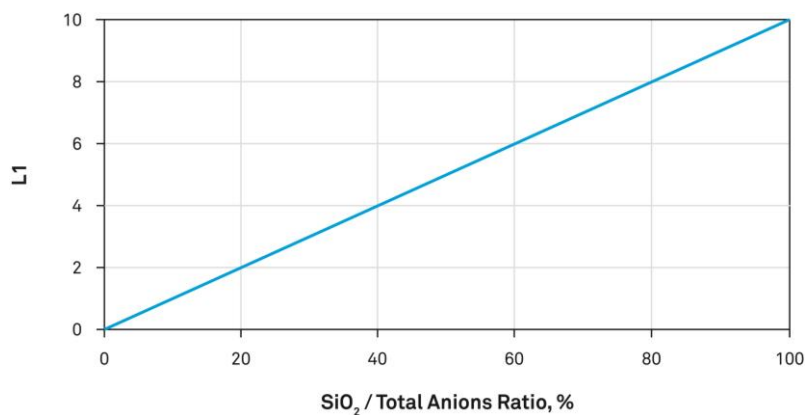
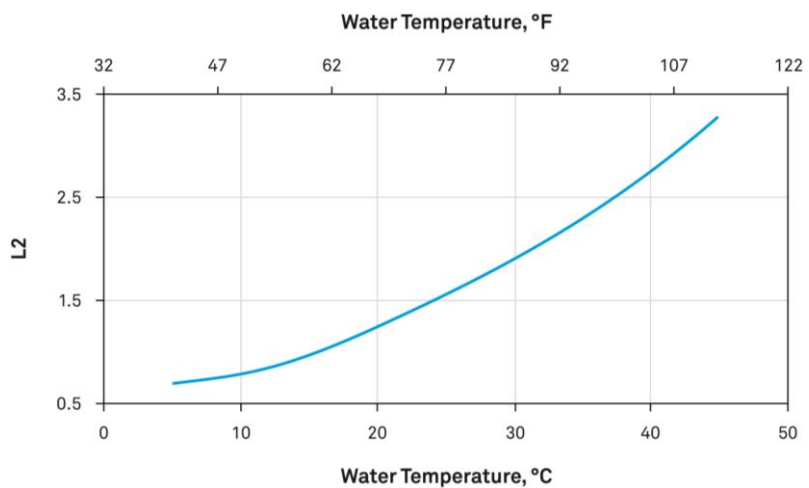


Figure 9 – L2-Leakage correction factor for feed water temperature



Counter-flow regeneration

Figure 10 – L3-Leakage correction factor for regeneration temperature

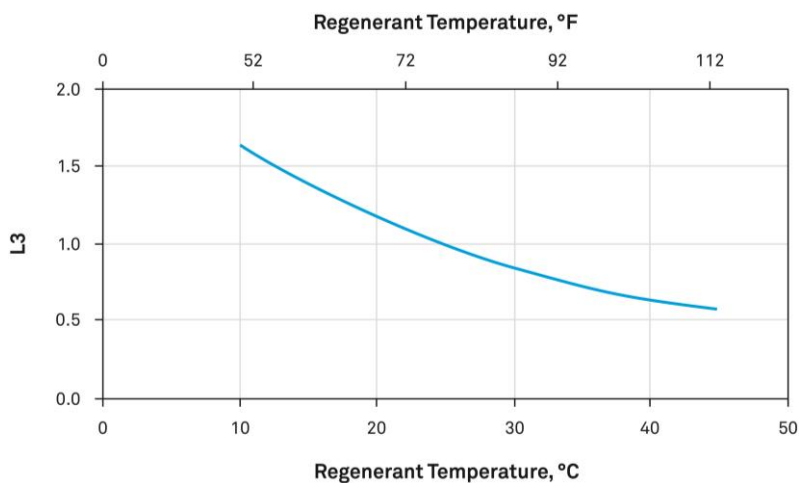
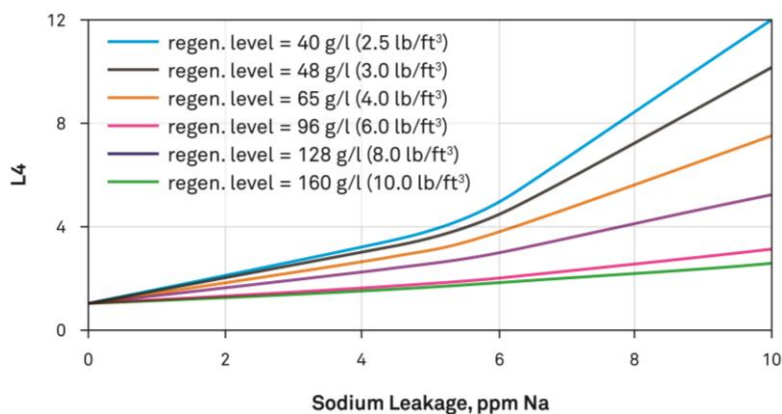


Figure 11 – L4-Leakage correction factor for sodium leakage / regeneration level



Counter-flow regeneration, continued

Figure 12 – Base capacity (counter-flow regeneration)

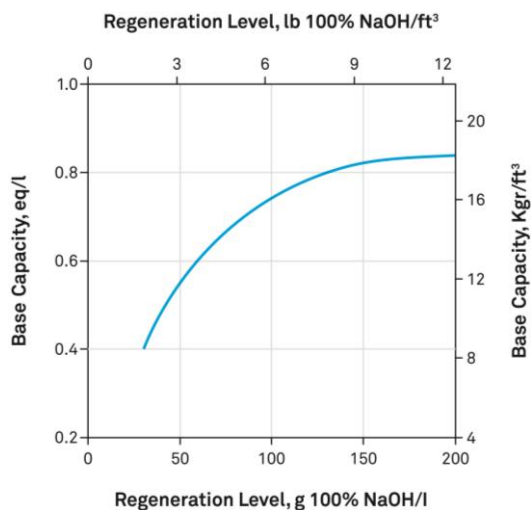


Figure 13 – C1-Capacity correction factor sulfates / total anions

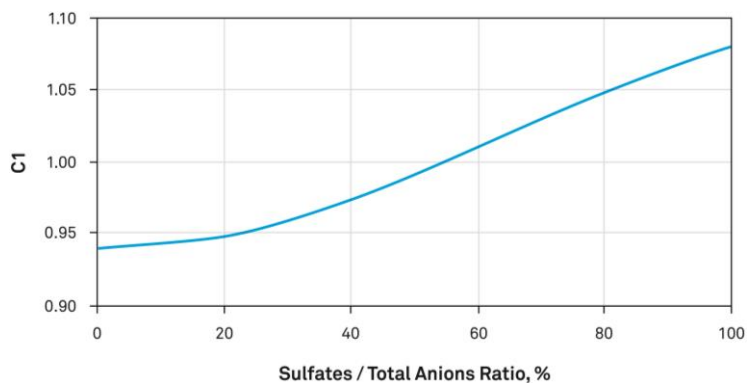
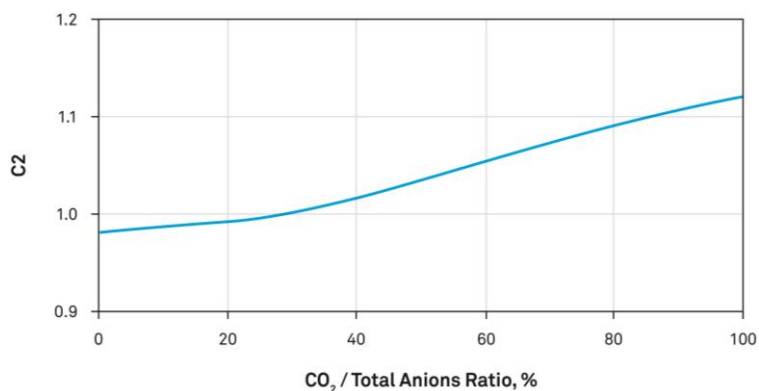


Figure 14 – C2-Capacity correction factor CO₂ / total anions



Counter-flow regeneration, continued

Figure 15 – C3-Capacity correction factor silica endpoint

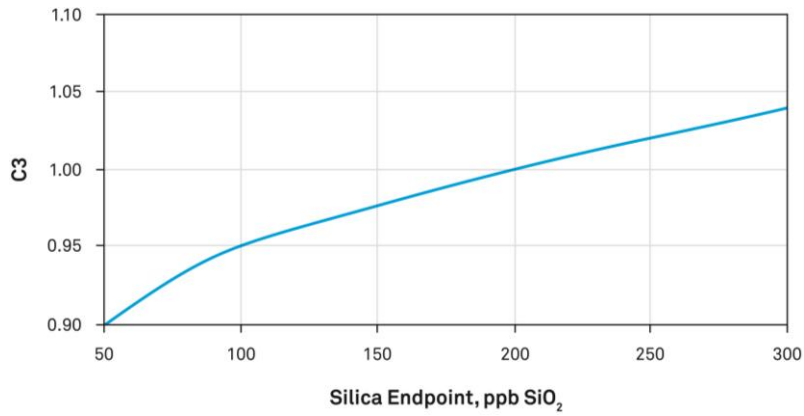
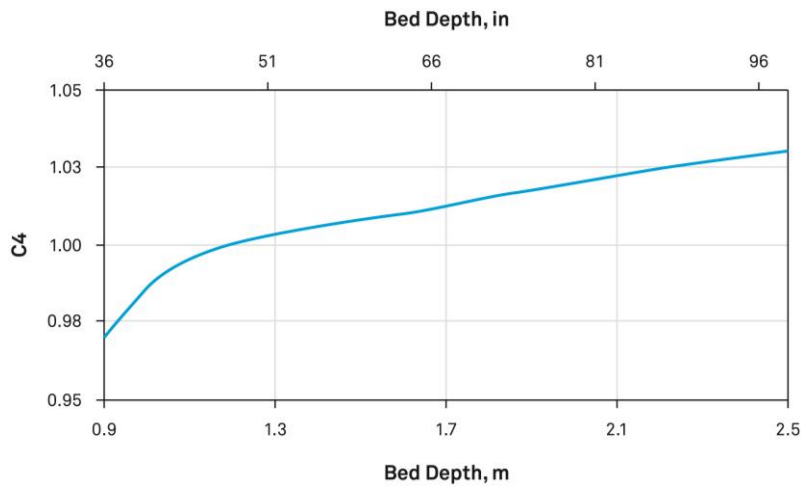


Figure 16 – C4-Capacity correction factor for resin bed depth



Counter-flow regeneration, continued

Figure 17 – C5-Capacity correction factor for silica regeneration temperature

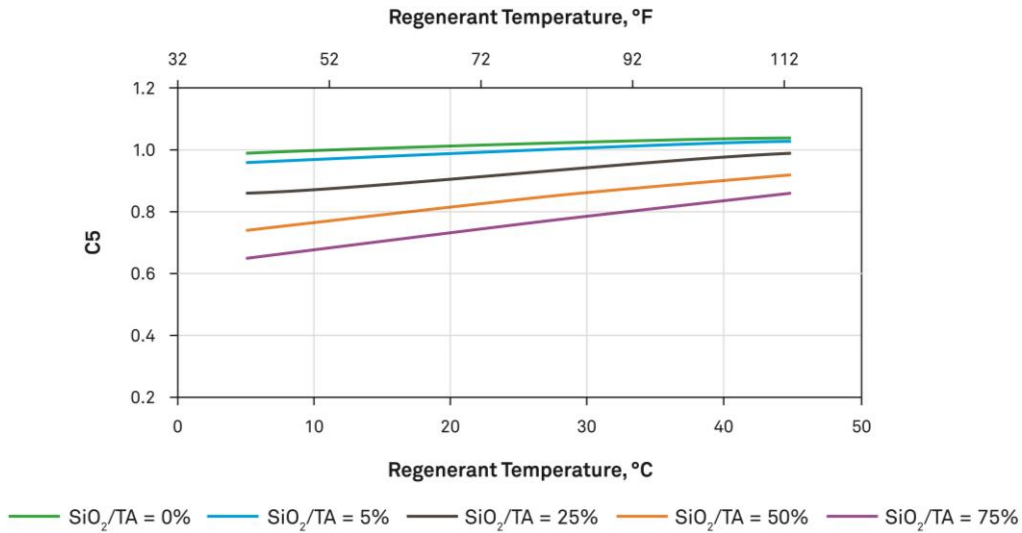
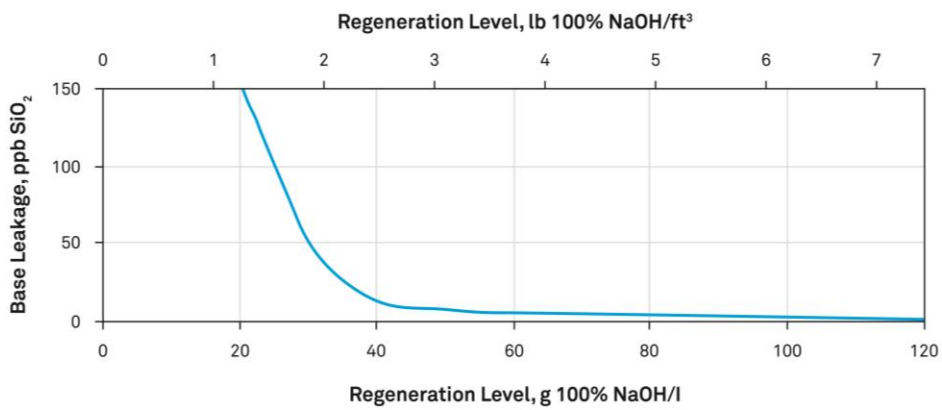


Figure 18 – Base silica leakage



Counter-flow regeneration, continued

Figure 19 – L1-Leakage correction factor SiO_2 / total anions

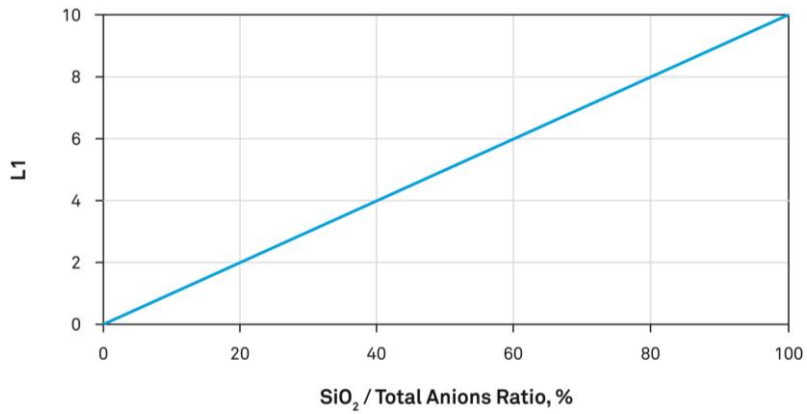
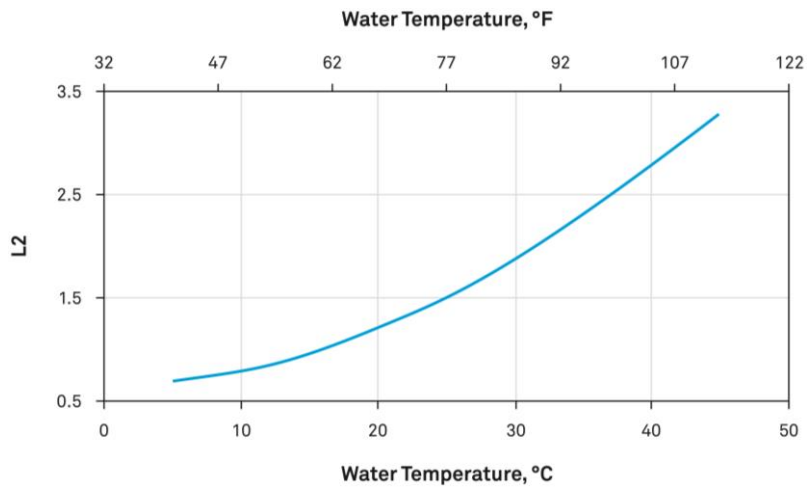


Figure 20 – L2-Leakage correction factor for feed water temperature



Counter-flow regeneration, continued

Figure 21 – L3-Leakage correction factor for regeneration temperature

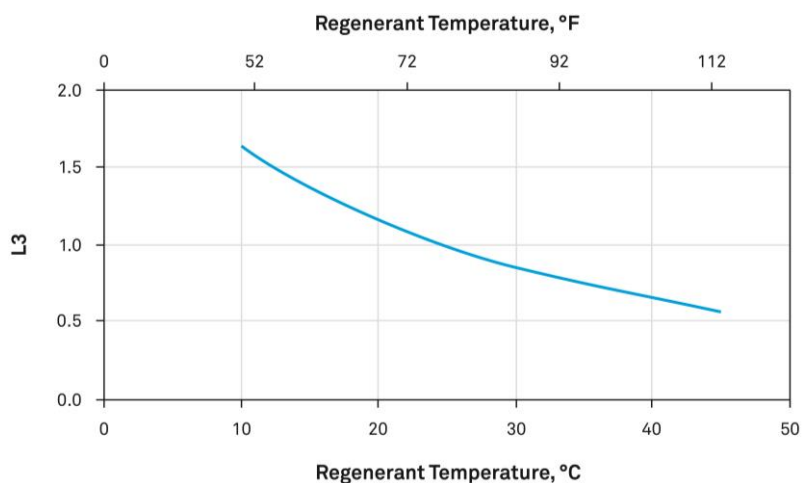
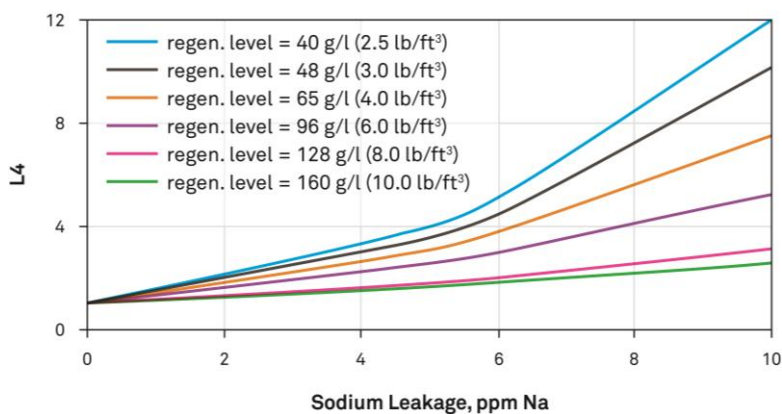
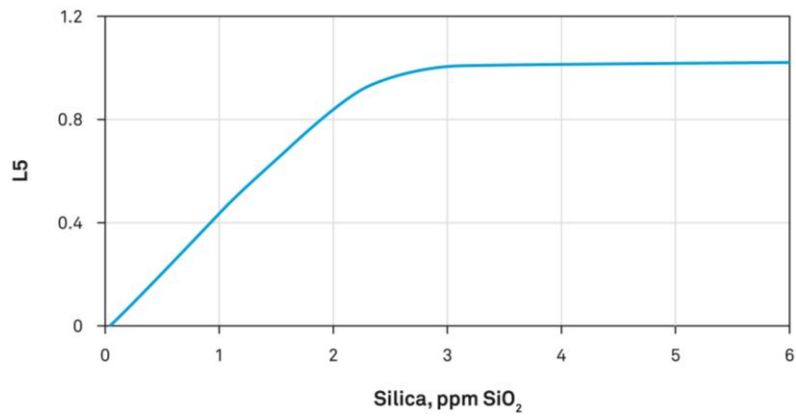


Figure 22 – L4-Leakage correction factor for sodium leakage / regeneration level



Counter-flow regeneration, continued

Figure 23 – L5-Leakage correction factor silica in feed



Hydraulic characteristics

Figure 24 – Backwash expansion

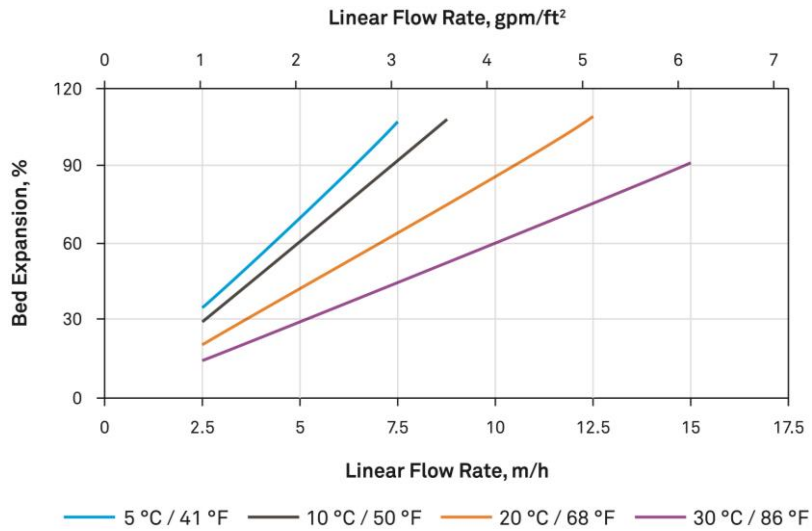
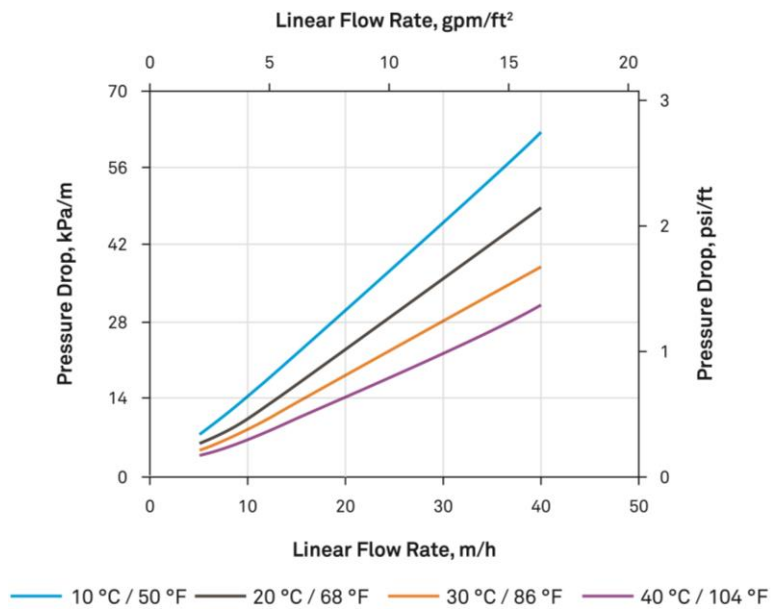


Figure 25 – Pressure drop



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