

A photograph of an industrial facility, likely a condensate purification plant, featuring large white cylindrical tanks and a network of pipes. The scene is set against a clear blue sky. The image is partially obscured by a white diagonal shape on the left and a blue diagonal shape with a white dot pattern on the bottom right.

# Condensate Polishing with Purolite™ Resins

This Application Guide illustrates how operational conditions can impact the performance of ion exchange resins within a condensate purification plant. Examples of different systems and process challenges are examined.

# Condensate Polishing with Purolite Resins

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## Introduction

Condensate polishing is the treatment of condensed steam from turbines operating in the power industry. Once through steam generators (OTSG), high pressure (> 600 psig) drum boilers, some pressurized water reactor (PWR) nuclear steam generators and high heat flux boilers such as oil-fired coastal stations treat condensate with high-flow vessels (up to 50 gpm/ft<sup>2</sup>) and regenerate at significantly lower flows in an external system located near a polishing system. Coal-fired plants and some PWRs have partial condensate purification. The final stage of make-up treatment plants are sized to treat up to 25% of the feedwater flow to the boiler for short periods, i.e., during startup when contaminants in the system are most prevalent. Some PWRs and all boiling water reactors (BWRs) use polishing resins once to prevent the introduction of impurities from the regeneration process.

This Application Guide reviews the service performance of ion exchange resins under polisher operating conditions, focusing on chemical and physical properties. Additionally, several common regeneration systems used for full-flow purification will be reviewed. The goal of polishing resin is to protect the boiler system by producing the required quality and quantity of water at minimum operating cost, no matter what process challenges arise.

## The Need for Condensate Purification

Why is it necessary to treat condensate, which may already be in a high state of purity? There are several reasons. The essential need is maintaining operating efficiency and system life by controlling impurities in the boiler feedwater that contribute to deposition on heat transfer surfaces and support corrosive conditions. The level of impurities allowed will depend on the boiler design and heat flux at heat transfer surfaces. Trace impurities have a concentrating effect on heat transfer surfaces resulting in  $\mu\text{g}/\text{kg}$  (ppb) or lower quantities concentrating to  $\text{mg}/\text{kg}$  (ppm) levels contributing to deposits and under-deposit corrosion.

High-pressure units, supercritical drum, once-through boiler systems and nuclear units require zero solids feedwater. The result of these solids is a risk of corrosion by ions such as sodium, chloride and sulfate and efficiency loss in power generation. If failures occur, the economic penalty is severe.

A unique situation arises with once-through boilers operating under supercritical conditions, i.e., when critical pressure (221 bar or 3,200 psig) and temperature (374 °C or 705 °F) are exceeded, and a single-phase fluid exists rather than two-phase water/steam.

In this case, the impurities in the boiler fluid are present as the fluid enters the turbine. Consequently, there is a subsequent risk of substances depositing within the turbine, including metallic elements like copper and iron, at the temperatures and pressures involved. The solubility of these impurities decreases rapidly as the fluid passes through the high pressure section of the turbine. This can lead to hard and tenacious deposits resulting in scale and build up in the turbine.

These boiler systems require condensate purification plants to remove copper and iron (soluble and insoluble species) to very low concentrations.

There are several potential sources of contaminants in the water/steam circuits of power plants:

- Cooling water from condenser in-leakage from brackish and seawater.
- Make-up water can bring in ions and organic matter.
  - If regeneration is not managed properly, regenerate chemicals could enter the system.
  - The plant may be over-run during the service cycle.
- Chemicals associated with the polisher resin regeneration.
- The conditioning chemicals used to protect the circuit e.g., ammonia, morpholine and hydrazine can serve as sources of contamination if removed by the condensate purification plant.
- Contaminants remaining from outage activity.

Insoluble impurities can be the corrosion products from construction materials within the system. Copper and iron are the predominant species and are usually included in the water quality specification. However, other substances, particularly silica from lagging and adhesive materials, may be insoluble under commissioning conditions.

It follows that condensate purification plants needs to be capable of removing both soluble and insoluble species to very low concentrations. Ion exchange resins can fulfill both requirements, but additional filtration, pre-coat or deep beds, have frequently been used.

## Condensate Composition

The condensate quality entering a polisher typically has very low (< 10 ppb) of total dissolved solids (TDS) and neutralizing amines sufficient enough to maintain a pH range from 8.8–9.6. Ammonia is the most common amine with concentrations of 0.2–2.2 mg/kg (0.2–2.2 ppm)  $\text{NH}_3$ .

Unexpected events such as a condenser leak will contribute salts from cooling water, often composed of sodium and chloride primarily from seawater. Additionally, iron oxides remaining on cationic resins will complex with bisulfate from excess sulfuric acid used during regeneration which can be a source of sulfate that can be present in the mixed bed when placed into service.

Crud will also be present with different levels depending on protective chemistry. Oxygenated treatment will have a crud level of approximately 2 ppb whereas amine or alternate amines will be above 5 ppb.<sup>19</sup>

## Condensate Quality Required

The water quality required from a polisher has driven development in unit operation over the years. The original specification for water quality on supercritical fossil-fueled units was:

- **Conductivity:** 0.1  $\mu\text{S}/\text{cm}$  at 25 °C (77 °F)
- **Sodium:** < 5  $\mu\text{g}/\text{kg}$

With the advent of nuclear stations, this specification was initially used. However, an investigation showed gas side conditions at the boiler tube surfaces in the evaporator sections could give breakaway oxidation. Operating procedures were changed to prevent this, but it introduced an increased risk of corrosion occurring within the waterside of tubes. Minutes trace of acidic sulfates were present in water from a polisher, particularly in the period immediately following regeneration. Calculations were made on the concentration factors likely to arise in the boiler. These were used to project the water quality required from the polisher to protect the system from pitting and corrosion of ferritic steels and stress corrosion of austenitic materials. Accordingly, more stringent water quality was set as follows:

- **Sodium:** 2  $\mu\text{g}/\text{kg}$
- **Chloride:** 2  $\mu\text{g}/\text{kg}$
- **Sulfate:** 2  $\mu\text{g}/\text{kg}$
- **Iron:** 0.8  $\mu\text{g}/\text{kg}$
- **Cation Conductivity:** < 0.08  $\mu\text{S}/\text{cm}$  at 25 °C (77 °F)

The goal is to achieve a molar balance of ions that provides neutral conditions at the heat transfer surfaces. Subsequently, supercritical and early gas-cooled nuclear station polishers adopted a similar standard.

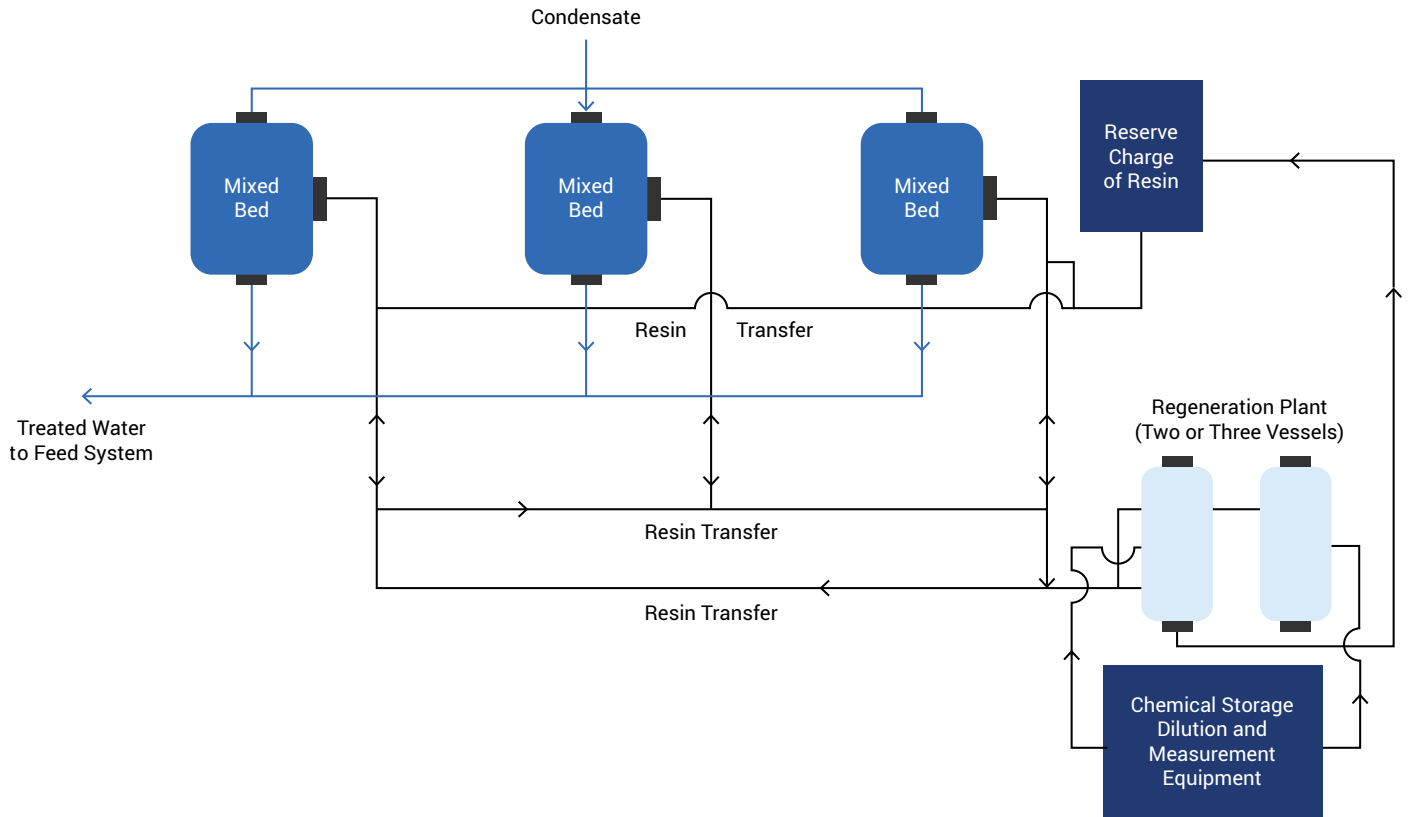
PWR stations encounter secondary system corrosion due to poor-quality water. The steam generator has a significant concentrating factor resulting in impurity concentrations of 100–200 times. As a result, PWR feedwater specifications were stringently tightened, alleviating the corrosive conditions. Water quality specification applied to PWR polisher effluent is as follows:

- **Cation conductivity:** < 0.06  $\mu\text{S}/\text{cm}$  at 25 °C (77 °F)
- **Chloride:** < 0.02  $\mu\text{g}/\text{kg}$
- **Sulfate:** < 0.02  $\mu\text{g}/\text{kg}$
- **Sodium:** < 0.02  $\mu\text{g}/\text{kg}$
- **Silica:** < 2  $\mu\text{g}/\text{kg}$

Cation conductivity measures condensate effluent from a cation exchange cartridge that removes all cation components, specifically amines. If this conductivity increases, anions such as chloride or sulfate passing the cation cartridge as acids ( $\text{HCl}$  and  $\text{H}_2\text{SO}_4$ ) will inflate conductivity resulting in a dependable indicator that the polisher is not performing and requires removal from service. Using cation conductivity on raw condensate will represent a condenser leak.

A polisher must maintain low concentrations of iron and copper in the feedwater of any high-pressure power plant to minimize corrosion and prevent deposits. This quality will depend on the specific plant type employed by the polisher. The total iron quality standard required for feedwater to high-pressure boiler plants is < 0.8  $\mu\text{g}/\text{kg}$ . The combination of filtration and ion exchange typically ensures these limits are achievable.

Progressively, higher quality water is demanded from condensate polishers. The following sections will show how these requirements have affected the design and operation of polishers and the choice of ion exchange resins. Figure 1 shows the layout of a typical condensate purification plant.

**FIGURE 1****Typical Layout for a Condensate Purification Plant with Mixed Beds**

## Conditioning Chemicals

Protecting the feed and boiler circuits of high-pressure power plants is accomplished by using both alkaline amine compounds to address low pH corrosion and hydrazine to remove residual dissolved oxygen. This chemistry composes an “all volatile treatment” or AVT.

AVT aims to control pH between 8.8–9.6, with the actual pH set by the site operating conditions. Usually, a pH range of 8.8–9.2 will protect the system and minimize the transport of metallic impurities from the feed circuit to the boiler. However, raising the pH to 9.4 or above may be necessary if there is a risk of erosion-corrosion. Increasing the pH level can significantly affect the operation of the condensate polishing resins.

Ammonia concentration, for example, must increase by a factor of four to raise the pH from 9.2–9.6. The cation load thus increases by the same factor, increasing regeneration frequency when operating to an amine break.

Alternative volatile amines such as morpholine, ETA (monoethanolamine) and AMP (2-amino-2-methyl propanol) afford better protection than ammonia by providing improved pH conditions in the water phase of the two-phase (steam/water) region of the boiler.<sup>1</sup> ETA became the predominant organic amine used in PWR secondary, resulting in excellent control of iron transport.

The use of alternative amines will affect the performance of condensate polishing resin when compared to operations under ammonia, as higher concentrations are needed to achieve a given pH. The advantage of organic amines is that their volatility is lower than ammonia, thus controlling pH in zones where ammonia will not. Details on operating polishers with alternative organic amines are covered later in the section on [cation resins and treating amine-dosed condensate, page 21](#).

The use of hydrazine generally poses no problems to the polisher as the breakdown products are mainly ammonia (from high-temperature degradation) and nitrogen (from the reaction with oxygen).

Oxygenated treatment (OT) is an alternate treatment for sub, supercritical and OTSG boilers. This treatment requires 100–300 ppb continuous oxygen feed and high-quality feedwater. OT allowed units to operate at lower pH of 8.5–8.8<sup>(19, 20)</sup>, allowing for lower ammonia and no hydrazine. Corrosion and depositions in boilers and steam systems employing OT are significantly lower than in boilers on AVT.

## Factors Affecting the Performance of a Condensate Purification Plant

Condensate polishing plants are designed to treat a quantity of water and achieve the unit operation's quality specifications. The ability of this polisher to meet these requirements will depend on the polishing vessel design and operating conditions that affect the ion exchange process. The performance and life of the ion exchange resins will also be affected.

Consequently, the choice of resin will need to correlate with factors related to power plant design, mainly:

- Flow rate
- Chemical treatment (see above)
- Regeneration systems
- Influent condensate quality to be treated
- Effluent condensate quality required

### Flow Rate

A CPP is designed to treat large quantities of water. For example, a 660MW PWR unit requires approximately 1,500 m<sup>3</sup>/h (6,600 gpm) of treated water. Hence to minimize plant capital cost, the ion exchange beds are operated at a high flow rate relative to a normal makeup demineralization plant. In the case of a mixed bed, these are generally designed to operate at a specific flow rate of 100–150 m/h or 40–60 gpm/ft<sup>2</sup>.

High flow rates result in two effects on polishing resins performance:

- Increased pressure drop, with an increased risk of bead physical breakdown
- Decreased time for the ion exchange reactions to occur

By choosing proper resin types and particle sizes, these individual effects will be optimized; however, minimizing one effect may accentuate adverse effects. Pressure drop is related to flow rate and particle size. Therefore, using larger beads, a lower pressure drop is achieved (the differential pressure is inversely proportional to the square of the particle size. If the particle size is doubled, the differential pressure decreases by a factor of four). However, using large beads proportionately decreases the surface area available for ion exchange resulting in slower kinetics and consequential risk of poor water quality with reduced operating capacity.

Under normal condensate polishing conditions, a high service flow rate alone is unlikely to result in a severe physical breakdown of the cation and anion resins. However, the resins can be weakened by other factors that may lead to a subsequent physical breakdown, such as:

- Osmotic stress that arises during regeneration
- High flow rate compressing with the beads forming surface stress cracks
- Resin transfer from polishing vessel to regeneration facility

High flow rates decrease the time available for ion transfer to the bead as condensate passes through a bed, making ion exchange resin kinetics a critical property.<sup>7-13</sup>

Several chemical and physical factors determine the overall rate of exchange

- Diffusion of ions across the static film of water at the surface of a bead
- Diffusion within a bead
- Particle size of beads (surface area to bead volume)
- Exchange of ions onto the functional groups of a resin
- Types of ions present
- pH conditions within the bed

New or regenerated CPP cation and anion resins in the  $H^+/OH^-$  form will have a high rate of exchange to the functional groups. The overall rate-controlling factor is diffusion across the static film at the surface of a bead. However, performance deterioration of resins may occur due to fouling and/or aging. Anion resins are more susceptible than cation resins as they are likely to receive fouling species such as organic matter from several sources, including organo sulfonate from the cation resin. Moreover, they are chemically less stable than cation types, and some degradation of the strongly basic groupings will inevitably occur. It has been shown<sup>10-14</sup> that those effects result in poorer anion exchange kinetics at the surfaces of the beads, therefore, controlling the overall rate of exchange and contributing to kinetic leakage of sulfate, especially during condenser leaks.

The rate of exchange at high flow rates will vary for the different ions being addressed. Relatively low flow rates as in a make-up water treatment plant, differences in inorganic ion uptake will be rarely observed. However, difficulty can be encountered when removing organic species which impact anion kinetics.

Higher flows, specifically in condensate polishing, the rate of exchange of inorganic ions becomes observable in practice, specifically for sulfate, which can have a slower exchange than chloride. The kinetic rate difference is of little significance when resins are new. However, as deterioration in kinetics progresses due to fouling and aging with time, overall slower removal of these anions evolves.

Several investigations on anion kinetics have been reported in recent years, and additional details relative to the above are available from references.<sup>7-13</sup> The present position can be summarized as follows:

Anion resins work near the limits of their kinetic ability at the high flow rates used in mixed bed operations. The zone of exchange, which is the depth of bed required to produce the desired water quality, is a significant proportion of the total bed depth. It follows that any deterioration in service or kinetic ability will increase the length of the zone, with the following adverse effects being possible:

- Not obtaining the required water quality
- Resin capacity for treating condensate contaminated with cooling water will decrease

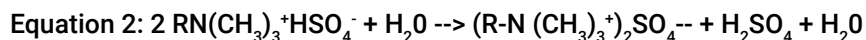
(See also [Mixed Bed Cation Resin in Hydrogen Form, page 27](#)).

## Regeneration Systems

Regeneration of the condensate polishing resins within the service vessels is not practical for high flow systems because of the wide variation between service and regeneration flow rates and the need to prevent contamination of the water and steam circuit with the regeneration chemicals (sulfuric acid and sodium hydroxide). In early CPP, the resins were transferred from the service vessels to a single regenerator vessel, and the cation and anion resins were separated and regenerated in this vessel.

The separation of the cation and anion resins is crucial in the polishing resin regeneration procedure. Cross-contamination of cation and anion resins with the wrong regenerant will lead to quality issues. While the slight contamination of cation resin with sodium is undesirable when operating in the hydrogen form, it is less important compared to anion resin contamination with sulfuric acid. If this occurs, it can become challenging to obtain the required sulfate concentration in the treated water following regeneration.

The following equations illustrate how this arises (sulfuric acid regeneration).



Anion resin contacted by sulfuric acid is converted to the bisulfate form (Equation 1).

Subsequently, when resins are mixed, and the final rinsing begins, bisulfate form resin is converted into sulfate form with the release of sulfuric acid (Equation 2). The bulk of the anion resin must then take up this sulfate. This can be done with new anion resin. Still, any deterioration<sup>2</sup> in the kinetic performance due to fouling or aging will require prolonged rinse periods before satisfactory sulfate concentrations can be obtained. The uptake rate of sulfate ions by anion resin is slow. There is generally insufficient time for sulfate released near the bottom of the unit to be removed to the desired level before condensate leaves the bed. The depth of the polishing zone for anion components will be determined by the total rinse time and the kinetic condition of the anion resin. Short polishing zones exist for new resin, but this increases progressively with any deterioration in anion kinetic performance.

Allowing the regenerated mixed bed to stand for a period before returning to service will reduce rinse time and shorten the polishing zone. However, this may not be possible on a short-cycle designed plant or in the event of a severe condenser leak.

Cation and anion resins need to be of suitable size and density to allow good separation on backwashing and settling.

A range of cation and anion resins combinations may be used, and in general, optimum separation will be achieved with cation resin of 710–1,200  $\mu\text{m}$  and anion resin of 425–850  $\mu\text{m}$ . Alternatively, similar separation can be achieved when using highly uniform Supergel™ resins.

Density differences are enhanced by using a gellular cation resin of high DVB (10%) and a macroporous anion resin, but adequate physical strength is required for these resins.

Typical chemical and physical characteristics of suitable condensate polishing resins are given in Tables 4–7.

In addition to using resins with optimum separation characteristics, plant modifications have also been made to improve the regeneration process to reduce the risk of cross-contamination.

## Separate Cation – Anion Regeneration Units

One of the first improvements to the condensate polishing regeneration unit was to employ separate cation and anion vessels. Provided good separation could be achieved, there was less chance of cross-contamination. Each regeneration unit could be specifically designed to give more freeboard for vigorous backwashing and air scouring. This is particularly important for a naked mixed bed that acts as a filter. Initially, the mixed bed resins were backwashed in the cation regeneration vessel to separate the mixture into the two components.

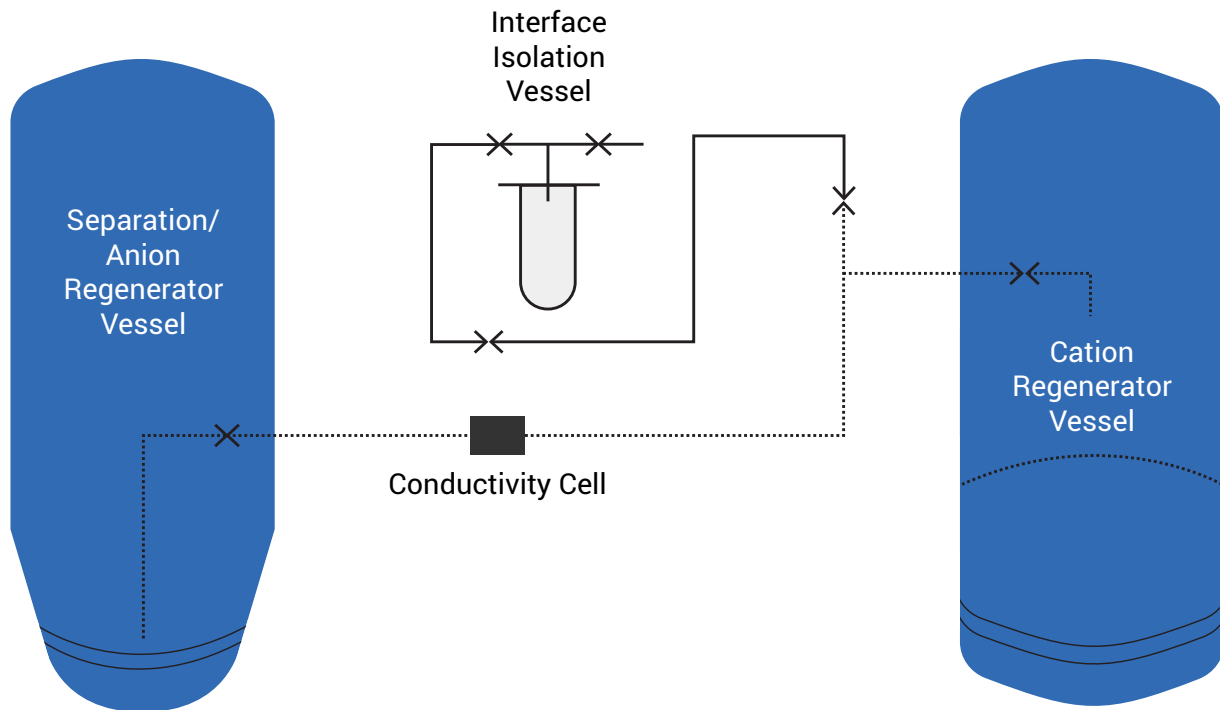
Then, via sluicing nozzles located at the resin interface in the cation regeneration/separation unit, the anion resin was sluiced off the surface of the cation resin into a separate regeneration unit.

### CONESEP®

#### OVIVO<sup>4</sup>

While this system is used worldwide, it is dependent on the interface located at the exact position of the sluicing nozzles. This is not always guaranteed, so hence potential cross-contamination can occur. Further improvements were required.

Now, the mixed polisher resin is transferred from the service vessel to the primary separation vessel, which serves as the anion regeneration vessel. On backwashing, the resins separate, and the lower cation resin layer is hydraulically transferred (Figure 2) to a separate cation regeneration vessel simply by introducing water into the base of the Conesep vessel and forcing resin to flow out through a transfer pipeline. During this transfer, the anion/cation resin interface descends smoothly through the vessel and cone-shaped base to compress the interface and eventually enter the transfer pipeline. While in the transfer pipe, it is sensed by conductivity or optical means, and the transfer terminates. The interface resin is moved to a holding tank until after the regenerated anion is moved to the mix and hold tank, then the interface resin is moved back to the backwash vessel, waiting for the next polisher to be regenerated. The original full-scale installation produced results in cation and anion cross-contamination figures of about 0.3% v/v.<sup>4</sup>

**FIGURE 2****Plant Diagram for the CONESEP® System**

The level of cross-contamination is acceptable for plants aiming to produce water with sodium levels of less than 0.1 ppb when operating in HOH mode.

Variations introduced since the design was first used include adjustments to the all-important base design, the development of alternative interface sensing techniques and the development of a secondary separation stage. This involves a secondary classification, by backwashing, of the anion resin component after its regeneration with sodium hydroxide. This second separation relies on the fact that any cation resin beads in the anion resin are now in the denser sodium form and are more easily separated from the anion resin, which is now in the less dense OH form.

The small amount of cation resin recovered by this procedure is moved to an interface isolation vessel and subsequently added to the next charge to be regenerated.

These improvements benefit to operation in the ammonium or amine cycle when the cation resin in the mixed bed has very low residual sodium content. Separation down to < 0.06% v/v of cation resin in anion resin has been achieved on a full-scale operating plant.<sup>5</sup>

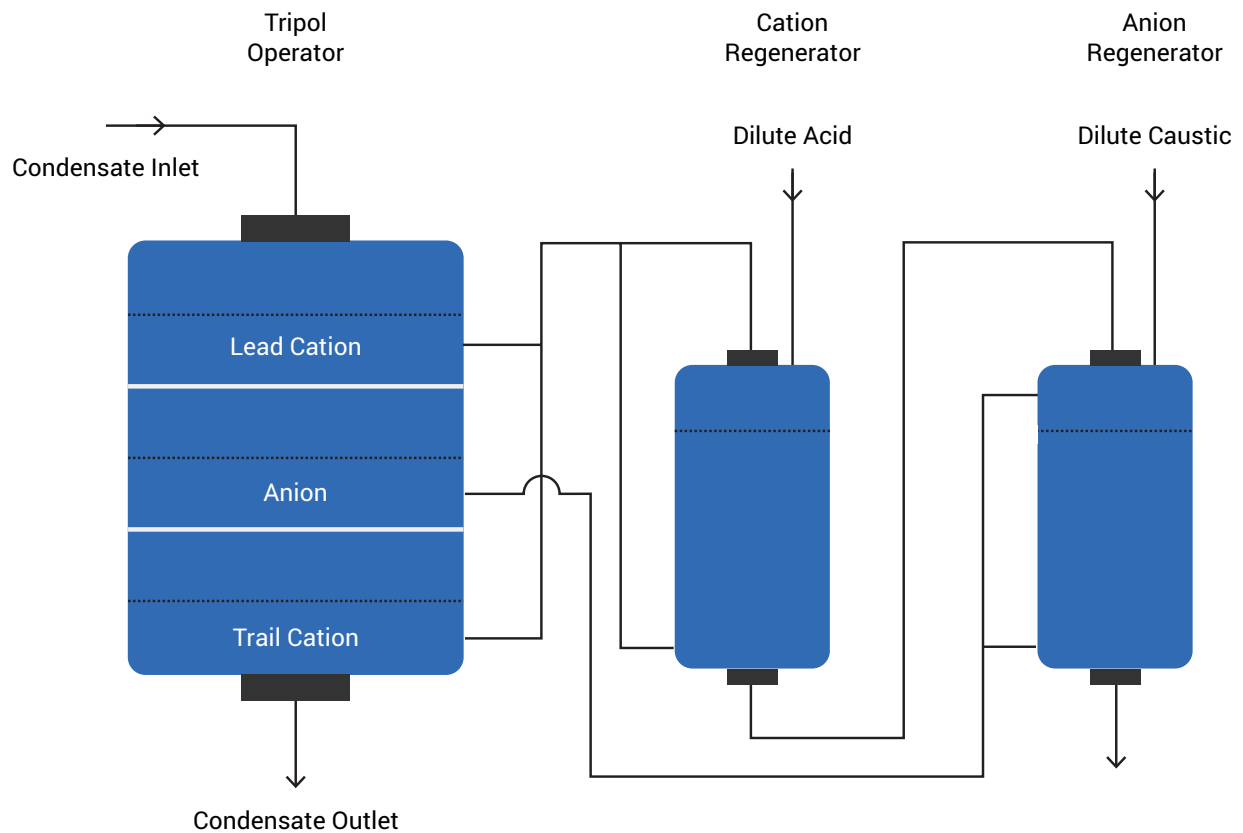
# TRIPOL

## PWT Projects Ltd.

TRIPOL plants are predominately found in Europe and are configured not as a mixed bed but with the resins separated by screens into three layers – cation – anion – cation<sup>6</sup> – as shown in Figure 3. The resins are transferred from the service vessel for regeneration.

**FIGURE 3**

### The Tripol Process



The cation and anion resins are kept apart in the regeneration system, even to the extent of having separate resin movement lines so that cross-contamination or the wrong regenerant on the resin is completely avoided. Resin ratios and volumes can be altered to suit particular operating conditions, but typically, the lead and trail cation are each 350 mm (14 in) deep and the anion 500 mm (20 in) deep. The linear flow rate is typically 200 m/h (80 gpm/ft<sup>2</sup>), and the separated beds technique avoids the compaction that occurs in a deep mixed bed so that the head pressure is about the same as a classic mixed bed condensate polishing plant running at 120 m/h (50 gpm/ft<sup>2</sup>).

The process is not sensitive to resin type or particle size. Both macroporous and gellular cation and anion resins have been used successfully. Under arduous conditions, the usual recommendation is to use a 10% DVB cation resin gel and a high-strength, high-capacity gel anion resin to achieve the best possible capacity.

During the original development of the process, it was observed that single beds of cation and anion resins could exhibit better kinetics than mixed beds. These findings<sup>13</sup> favor the use of larger resin beads in single resin beds to reduce head loss without impacting kinetics.

In the USA, two other processes prevent resin cross-contamination by regenerant chemicals.

## AMMONEX®

### Crane Cochrane

The process was developed specifically for condensate purification plant operation with the cation component in ammonium form. Two regeneration vessels are used. Following transfer from the service vessels, separation is carried out by backwashing. The anion portion is then transferred to the second vessel.

In this vessel, the resin transfer is usually biased towards the anion section to limit the quantity of cation transferred with the anion resin. The anion resin is then regenerated with sodium hydroxide and rinsed. Ammonium hydroxide is then passed through the bed to convert any cation resin present from the sodium to ammonium form. Meanwhile, the main cation section is regenerated with sulfuric acid and rinsed. The cation and anion resins are then mixed. Subsequently, the bed may be ammoniated either externally or during the service cycle.

## SEPREX®

### Ecodyne Graver

This system transfers the resins from the service vessel to the first of two regeneration vessels. The resins are then separated by backwashing with the cation remaining in the separation vessel and the anion portion transferred to a second vessel. After draining water from the anion resin, a 16% sodium hydroxide solution is applied. This enhances the separation by floating the anion resin from any traces of cation resin that have been carried over. The anion resin is then taken from the vessel to the third vessel for rinsing and mixing. The remaining cation resin is rinsed and transferred to the cation regeneration vessel and mixed with the next charge of cation resin to be regenerated.

The main cation bed is regenerated and rinsed in the separation vessel before transferring to the third vessel for mixing with the anion resin, where it is held in standby until needed.

## Mixed Beds

### Cation Resin in Hydrogen Form

Most condensate polishing plants operate with the cation resin in hydrogen form. The end of a service cycle – in the absence of condenser leakage – is a breakthrough of ammonia or amine, whether from a cation preceding a mixed bed or from a mixed bed working alone.

Ionic loading on the cation resin when condensate pH is maintained at elevated levels is high. Therefore, a resin is required that combines a high operating capacity for amine and resistance to osmotic and mechanical attrition.

The operating capacity of the cation will depend on:

- Level of regeneration
- Breakpoint chosen
- Degree of cross-linking of the resin (DVB content)

The operating capacity of cation resin in ammonium form has been reported in the range of 0.7–1.2 eq/L. This range variation is partially due to differing hydraulic conditions in large diameter beds addressing both uniformity and velocity of flow.

In the case of a condenser leak, total loading on the cation resin will increase due to the ingress of sodium. Still, the inherent capacity of the resin is little affected, and the polisher run length to exhaustion can be estimated from the increased cation load.

A standard 8% DVB gel cation resin is recommended for condensate polishing from a capacity consideration. The exception is that it is not sufficiently robust. An optimum choice is the 10% DVB [Supergel SGC650H](#) gel resin, which has high physical strength and a capacity for ammonia in the range of 1.2–1.7 eq/L.

Removal of anions from condensate takes place solely within mixed beds. The exception is where a Tripol plant is installed, and a separate anion section is present.

Estimating the operating capacity of anion resin in condensate polishing is difficult. Several factors such as uniformity of flow, low concentration of anions, and the high quality of product water required, complicate this interpretation.

Deterioration of anion kinetics will play a significant role in the quality of condensate, specifically when dealing with condenser leaks. Hydraulic factors such as non-uniform uptake or channeling of ions could affect polishing beds with high linear velocity and short bed contact time.

Historically, anion resin operating capacity has been estimated at approximately 25% of the total anion volume and used in design calculations to determine a bed's timing to exhaust under a known condenser leak. Obtaining accurate data on anion capacity from plant tests is difficult, but with deteriorating anion resin kinetics, even the 25% figure is challenging. Capacities as low as 10–15% have been obtained under condenser leakage conditions on operating plants.

Regularly changing the anion resin represents the best economic option to optimize anion capacity and protection from leaks.

## Cation Resin in Ammonium Form

Ammonium used to condition the water in feed and boiler systems represents the main load on a cation resin operating in hydrogen form. The higher the pH control level, the greater the load. This is a disadvantage because it causes a frequent need to regenerate the cation bed and/or the mixed bed. Regeneration of the mixed bed has attendant problems concerning maintaining satisfactory sulfate levels.

Operating the cation resin in the ammonium form, ammonia in the feed water is not removed, but the resin can take up cations such as sodium and calcium. However, the difference in selectivity of ammonium and sodium ions is slight, and resin sodium content must be maintained at a very low concentration to obtain a satisfactory low concentration of sodium in the treated water.

Resin with high selectivity for sodium relative to ammonium and an adequate physical property is preferred under these conditions. Data indicates that selectivity differences with increased cross-linking (DVB content) are slight, and the choice can be based on satisfactory physical properties and cost. Purolite's [Supergel SGC650](#) and [Purolite C150TL](#) are typical resins suitable for these conditions.

The sodium capacity of cation resin in ammonium form depends upon the concentration of sodium present in the condensate, usually resulting from a condenser leak. The selectivity coefficient  $K^{Na}/NH_4 = 0.77$  is lower than  $K^{Na}/H = 1.7$ , so the resin will have a lower capacity for sodium when operating in the ammonium form, and the concentration of ammonium ion present results in higher equilibrium leakage of sodium relative to hydrogen exchange. When treating condensate at pH 9.6 and a level of 2 µg/kg sodium is to be obtained in the treated water, the concentration of sodium on cation resin at the bottom of a bed cannot exceed 0.1%. The equilibrium conditions for sodium/ammonium exchange results in a longer exchange zone than for sodium/hydrogen exchange; therefore, the capacity of ammonium form resin for sodium will be much lower. The actual capacity obtained will depend on the sodium concentration in the condensate; the greater the concentration, the greater the capacity.

The pH conditions within a mixed bed operating with the cation in ammonium form will be that of the condensate, i.e., 9.0–9.6. It has been shown that anion exchange rates are slower at these high pH levels relative to hydrogen form cation operation.<sup>7</sup> The zone of exchange is extended, and therefore, a higher kinetic leakage of chloride and sulfate ions and a lower capacity would be predicted for the anion resin relative to when hydrogen form cation resin is used under comparable conditions. Nevertheless, data<sup>15</sup> on the performance of anion resin used in a Tripol plant operating in the ammonium form indicates that under high simulated condenser leak conditions, it obtained a capacity equivalent to 30% of the total volume capacity of a macroporous anion resin. This, in part, may also reflect the better hydraulic conditions for anion exchange in such a plant relative to mixed beds.

## Use of Cation Resins When Treating Alternate Amine-Dosed Condensate

Amines other than ammonia may be used to protect nuclear systems from corrosion. Relatively high concentrations are needed to obtain the required pH conditions. Nuclear Power stations use morpholine in the range of 6–30 mg/kg (6–30 ppm)<sup>1</sup>, or ETA dosed at 6 ppm with 4 ppm ammonia.

Condensate resins used in nuclear applications are primarily for one-time use, as regeneration systems cannot separate and regenerate to a level that will remove undesirable ions from the resins and subsequently release them once placed into service. All BWR deep beds and many PWR are one-time use. However, a few PWR units that require continuous full flow polisher operations have developed a refined process achieving a quality regeneration<sup>18</sup>.

Condensate purification plants treating condensate dosed with alternate amines have reported a risk of macroporous cation resins breakdown<sup>16</sup> with the degree of breakage dependent on the DVB content of the resin. The higher the DVB content, the greater the risk of breakage with subsequent regenerations.

Laboratory results from internal regenerated mixed beds show breakdown arises from osmotic forces encountered during amine form regeneration. This is subsequently enhanced if any cation is in contact with sodium hydroxide from the anion regeneration. Macroporous resins with 20–25% DVB were particularly susceptible to breakdown, whereas 10% DVB gel resin and 12% macroporous resin were virtually unaffected.

Another issue that has produced complications is using ETA and new cations resins, which impacts anion kinetics. When placed into service with ETA, new cation resins result in anions quickly becoming kinetically fouled. Soaking the anion in hot water can reverse this kinetic loss; however, the kinetics begin to fail when placed back into service. The use of older cation when ETA is started in a system will not respond similarly, and the anion kinetics will not degrade. To alleviate this issue, some plants with luxury will replace only anion resin in their condensate system. Others will operate their polishers only when needed.

Studies have been done on the possible source of the kinetic failure with little success.<sup>21</sup>

Consider the following when choosing resin for treating amine-dosed condensate:

- Physical stability
  - Osmotically stable during regeneration
  - Mechanically, during transfer and cleaning (ABRO — Air bump and rinse operation)
- Favorable sodium/amine selectivity
- Sufficient resin separation (density/particle size)
- Favorable operating capacity versus acid requirement for regeneration

## Operating Conditions

### Hydrogen Form Operation

The physical strength and separation characteristics will dictate the choice of hydrogen form resin. Both 10% gel and 12% macroporous cation resins have satisfactory resistance to breakdown. Gel resin, however, has enhanced separation characteristics due to its slightly higher density relative to a macroporous. Additionally, it has a higher operating capacity.

### Morpholine Form Operation

The presence of morpholine in the treated water affects the equilibrium leakage of sodium from the mixed bed. The leakage values depend on the selectivity coefficient  $K_{Na/Morpholine}$  of the cation resin and the sodium content on the resin.

The data in Reference 16 indicates that the cation selectivity coefficient increases with DVB content. Therefore, a resin of the highest possible DVB content should be considered to minimize sodium leakage. A 20% DVB resin would be preferred when operating with morpholine. However, the risk of breakage in an internal regenerated mixed bed is higher and may outweigh its potential advantage over selectivity.

The 12% DVB macroporous cation resin would have adequate osmotic strength, but a lower selectivity coefficient (factor of 20) than the 20% DVB macroporous cation. The 12% DVB macroporous has a selectivity coefficient factor of two higher than a 10% gel cation (with satisfactory osmotic strength). Therefore, there is little outstanding difference between the 10% gel and the 12% macroporous resin in terms of equilibrium leakage of sodium.

Two factors dictate sodium content on the resin:

- Quantity of cation cross-contamination present in the anion resin after separation
- Levels of sodium remaining on the separated cation resin after regeneration

The separation procedures described earlier should ensure a satisfactory level of cation cross-contamination. This assumes an absence of cation resin fines.

If cation breakage occurs, it will increase the difficulty of obtaining the required degree of separation. Physical stability must be a prime consideration when choosing a cation, whether it is a 10% DVB gel or 12% DVB macroporous resin.

This needs to be established for each batch of product supplied for condensate polishing. Individual batches should be tested under simulated operating conditions.

## 2-Amino-2-Methylpropanol Form Operation

Similar conditions and considerations apply to those for morpholine form operation. Still, for 2 amino–2 methyl propanol (AMP) operation, the selectivity coefficient<sup>16</sup> for the 12% DVB macroporous resin is a factor of five higher than the 10% gel resin. A 12% DVB macroporous resin may obtain a lower level of sodium leakage. Still, the selectivity advantage might be partially affected by the greater difficulty in removing sodium from the 12% DVB resin during regeneration than the 10% material.

There is a need to establish water quality in terms of sodium leakage likely to be obtained with these resins under conditions that accurately simulate plant conditions. This data, together with that from the long-term comparative physical stability tests mentioned in Reference 16 should allow the correct type of cation resin to be chosen for operating under AMP form conditions.

## Monoethanolamine

This alternate amine (ETA) has become the preferred secondary treatment for the PWR market due to its superior control in reducing corrosion byproduct movement. Although corrosion control is significant, some issues are less favorable. When using ETA on regenerated deep bed resins, there is a need to achieve significantly low cross-contamination of cation in the anion as ETA is more selective than Na on the cation resin resulting in excursions above the action level primarily at startup and near exhaustion. Additionally, there have been documented reports<sup>22</sup> that organic sulfate from the cation results in kinetic degradation on the anion and is notable when service operation is over 130 °F. Deep bed service has been modified to startup and forced outage only, remaining in standby during normal service.

## Filtration

Insoluble corrosion products such as iron and copper may contaminate the water-steam circuit of a power plant. This usually occurs during commissioning when iron concentrations as high as 2,000 µg/kg can be experienced. Subsequently, high levels of debris are likely at start-ups after the system is disturbed, and concentrations of 100–200 µg/kg may arise. Total concentrations during normal load operation will usually be < 5 µg/kg.

Prior to polishing vessels, older plants employed a variety of physical filters. In subsequent designs, the ion exchange vessel also acts as a filter. The main filtration stage occurs when a cation bed precedes the mixed bed. In some cases, pre-coat filters are provided to operate before or after the mixed bed unit.

A deep bed exchange unit acts as an efficient filter removing 70–90% of debris. Inlet concentration and particle size will impact the removal efficiency.

There is no evidence that the type of resin used in deep bed polishing, whether gel or macroporous, affects filtration efficiency. The debris can be satisfactorily removed from the bed by air scouring and backwashing.

## Use of Powdered Ion Exchange Resins

Pre-coat filter demineralizers have been adapted for use with powdered ion exchange resin. A thin film of mixed powdered cation and anion resins is formed onto the outside of a hollow cylindrical element. Various element designs are available, but they are usually comprised of filter material wound onto a perforated stainless-steel form or sintered metal element. The liquid being treated flows into the element, passing through the ion exchange resin material and out to service.

Powdered resins are like those used in deep bed ion exchange, except the resin particles are ground to a smaller size, typically 10–150 microns. Mixing cation and anion resins form a varying flocculant size depending on the ratio of cation to anion resin used. The precoat is formed by slowly passing the mixed resin flocculant onto the element using recirculating water from a precoat mix tank until the flock forms a uniform layer. The unit is then put into service and operated until either a specified differential pressure of 25 psig (1.7 bar) is reached or ion exchange capacity is exhausted, resulting in a conductivity increase. The dry weight of mixed resins used to form the precoat filter is equivalent to 0.1–0.3 lb/ft<sup>2</sup> (1 kg/m<sup>2</sup>) of element surface, and the usual service flow is up to 4 gpm/ft<sup>2</sup> (.016 m<sup>3</sup>/min). Service flow per filter demineralizer will be 25,000–50,000 gpm (100–200 m<sup>3</sup>/min). Thus, a precoat demineralization will have as much as 12,500 ft<sup>2</sup> element surface area. The precoat has a low resistance to flow. Therefore, a typical differential pressure for a freshly precoated unit will be 1.5–3 psig (0.1–0.2 bar).

When the endpoint is reached, spent resin is removed by backwashing with a reverse flow of water to displace and flush used precoat and crud to a waste handling system. The unit is then ready for fresh precoat.

Powdered cation resin is supplied in hydrogen or ammonium forms. Powdered anion resin is supplied in hydroxyl form. [Purolite Microlite® powdered resins](#) are supplied pre-mixed in blends of only resin when systems are ionically limited or a blend of resin and fiber when a degree of crud filtering is required. Product with only resin is mixed with cation in the appropriate ionic form (H or NH<sub>4</sub>) and in various cation to anion ratios from ionically equivalent to cationic rich, addressing amines and problematic corrosion products. The premixed products have a distinct advantage in the preparation of consistent pre-coats.

Filter demineralizers with powdered resin have been used widely within condensate purification systems in Europe and the USA. In the USA, they are used in conjunction with deep beds and as standalone demineralizers. However, their use alone is confined to stations employing freshwater cooling. Freshwater condenser leaks have significantly lower ionic concentrations than saltwater, and generally, the precoat will address the contamination. This highlights the limited ion exchange capacity relative to conventional deep beds. When both filter and deep bed demineralizers are installed, the main application of the filter demineralization is as a polishing treatment after a deep bed or as a crud filter situated before the deep bed. When used as a prefilter, only fiber or a high fiber ratio product is used.

When installed after a deep bed, the primary role of the units is to provide an additional ion exchange facility in the event of a premature breakthrough of the mixed beds and remove any residual soluble impurities present after the mixed bed stage. This could arise following the regeneration of a mixed bed where sulfate concentrations in the treated water can be higher than in the middle of a service cycle. Under these conditions, the filter demineralizer will maintain sulfate concentrations in the treated water at < 0.2 µg/L SO<sub>4</sub> throughout the service cycle of a mixed bed.

Filtration is often the primary function of a powdered resin system, especially when the units are installed to precede the deep beds. This is useful during plant commissioning and outage startup when high levels of debris may be present.

Powdered resins have excellent filtration properties. Even with high inlet debris levels, the quality of the treated water can normally be maintained at < 5 µg/L of total suspended solids. When debris levels are high, there will be a cost advantage in using cheaper filter media such as cellulose fiber. Such material can be used alone or combined with powdered ion exchange resin. Purolite's [Microlite FC+](#) is suitable for this application.

## Considerations for Condensation Purification

Three of the most frequently debated topics concerning condensate purification are:

- Whether to use mixed beds alone or with a preceding cation unit
- Whether to operate cation resin in ammonium, amine or hydrogen form
- The type of resin that should be used

It is helpful to consider these points from an ion exchange viewpoint.

### Deep Beds vs. Cation Units

An additional cation unit will usually be considered only when the cation resins are operated in hydrogen form. Under this condition, the cation-deep bed system is preferred for the following reasons:

- Higher quality water is produced
- Higher capacity can be obtained from the anion component of the mixed bed
- Greater ability of the system to cope with changes in the pH of condensate
- Greater flexibility in the cation/anion ratio used in the deep bed
  - Reducing the number of deep bed regenerations can reduce the potential mass of sulfate introduced into the system
  - Protection to the deep bed resins from the additional filtration facility

A Tripol plant is, in effect operating with a preceding cation unit with some of the above advantages being realized.

# Hydrogen Form vs. Ammonium or Amine Form Cation Resin in a Mixed Bed

The following looks at the relative advantages of the different ionic forms.

## Hydrogen Form

- Lower kinetic leakage of anions
- Higher capacity under condenser leak conditions
- Resin separation improved over ammonium form where superior regeneration facilities (Conesep, Ammonex or Seprex) are invariably required
- Meet more stringent water quality parameters (0.3 µg/kg sodium, chloride and 0.5 µg/kg sulfate)

## Ammonium Form

- The number of regenerations of the deep bed will be greatly reduced; hence the risk of sulfate ingress into condensate will be lower
- There is an obvious saving of both the condensate conditioning chemicals and the resin regenerants

## Amine Form

The benefits are the same as the ammonium form. However, there is also a more significant cost saving in the conditioning agent as a higher amine concentration is used to achieve a given pH relative to ammonia.

# Resins for Condensate Purification Plants

Ideal resin qualities for CPP:

- Low organic leachables content
- Good cation: anion separation characteristics
- High operating capacities
- High anion kinetics reaction
- Uniformity of physical size
  - Low resistance to flow (pressure loss)
- High thermal and oxidative stability
- Resistance to osmotic shock and attrition
- Resistant to fouling

A variety of condensate polishing resins have been used over the years with varying degrees of success as dictated by the plant operating conditions.

These resins have ranged from low DVB gel resins to high DVB cation gel and macroporous and mixed in combinations of cation to anion in mixed beds combinations:

- Gel/Gel
- Gel/Macroporous
- Macroporous/Gel
- Macroporous/Macroporous

Ecolab produces high-strength gel resins augmenting the advantage for separation and operating capacity. The higher strength gel cation resin is available as the Supergel (SGC) product and has resistance to physical and chemical breakdown. Supergel anion resin (SGA) is also available.

## Appendix

The following tables and graphs provide information relating to the performance of ion exchange resins designed for condensate polishing applications.

Table 1 shows the Purolite Resins recommended for various operations.

**TABLE 1** Purolite Resins for Condensate Polishing

Unit or System	Operation	Recommended Purolite Resins
<b>Cation Unit</b>	–	Purolite C150C or Supergel SGC650
<b>Mixed Bed (Including Conesep, Ammonex and Seprex)</b>	H:OH Operation NH <sub>4</sub> :OH Operation Amine:OH Operation	Purolite C150TL or Supergel SGC650
<b>Cation Anion</b>	H:OH Operation NH <sub>4</sub> :OH Operation Amine: OH Operation	Purolite A500TLPlus or Supergel SGA550
<b>Tripol</b>	H:OH Operation NH <sub>4</sub> : OH Operation Amine: OH Operation	Supergel SGC650
<b>Cation Anion</b>	H:OH Operation NH <sub>4</sub> :OH Operation Amine: OH Operation	Supergel SGA550
<b>Pre-Coat Filters</b>	H:OH Operation NH <sub>4</sub> :OH Operation	Microlite PrCH Microlite PrCN
<b>Cation Anion Filter Fiber</b>	H:OH Operation NH <sub>4</sub> :OH Operation	Microlite PrAOH
	H:OH Operation NH <sub>4</sub> :OH Operation	Microlite FC+

**TABLE 2 Premixed Pre-coat Products for Condensate Filter Demineralization**

Product Name	Ionic Form	Ratios (Dry Weight) C/A (Cation/Anion)
MB1/1H	H <sup>+</sup> /OH <sup>-</sup>	1/1
MB1/1N	NH <sub>4</sub> <sup>+</sup> /OH <sup>-</sup>	1/1
MB2/1H	H <sup>+</sup> /OH <sup>-</sup>	2/1
MB2/1N	NH <sub>4</sub> <sup>+</sup> /OH <sup>-</sup>	2/1
MB3/1H	H <sup>+</sup> /OH <sup>-</sup>	3/1
MB3/2H	H <sup>+</sup> /OH <sup>-</sup>	3/2
MB3/2N	NH <sub>4</sub> <sup>+</sup> /OH <sup>-</sup>	3/2

Product Name	Ionic Form	Ratios (Dry Weight) F/R (Fiber/Resin) C/A (Cation/Anion)
CG4H	H <sup>+</sup> /OH <sup>-</sup>	1/1 1/1
CG4N	NH <sub>4</sub> <sup>+</sup> /OH <sup>-</sup>	1/1 1/1
CG6N	NH <sub>4</sub> <sup>+</sup> /OH <sup>-</sup>	2/1 2/1
CG12H	H <sup>+</sup> /OH <sup>-</sup>	1/2 4/5
CG12N	NH <sub>4</sub> <sup>+</sup> /OH <sup>-</sup>	1/2 4/5
CG19H	H <sup>+</sup> /OH <sup>-</sup>	1/9 4/5
CG19N	NH <sub>4</sub> <sup>+</sup> /OH <sup>-</sup>	1:9 4:5

Condensate polishing resins have rigorous physical demands which require relevant tests to measure mechanical and osmotic tolerance.

Methods defined by Ball, Harries and Pickering<sup>17</sup> in “The Physical Strength of Ion Exchange Resins” were one of the most rigorous and practical for evaluating resin behavior in plant operations. Equipment described in this document is installed at Ecolab laboratories, and the methodology is incorporated in Ecolab's quality control procedures, in line with the original procedure of the Central Electricity Generating Board of the UK. A simplified diagram of the apparatus is shown in Figure 4.

Essentially, "categorized" resin samples are subjected to cycling with either acid (cation resin) or alkali (anion resin) with an alternative treatment with sodium chloride. After each chemical cycle, the resin is hydraulically pumped against a top screen in the attrition tube and allowed to drain down to be ready for the following chemical cycle.

Percent resin breakdown is assessed after several cycles depending on the specific resin being tested.

Table 3 shows the breakdown percentage criteria that Ecolab follows manufacturing of various products.

**TABLE 3** Osmotic Shock Resistance of Purolite Resins

Product Type	Standard Gel		Supergel		Macroporous	
Product Name	C100x10	A 400	SGC650	SGA550	C150	A500
<b>Number of Cycles</b>	25	25	100	100	500	500
<b>% Breakdown*</b>	< 10	< 20	< 10	< 10	< 5	< 5

\* As defined in test method by reduction in mean diameter.

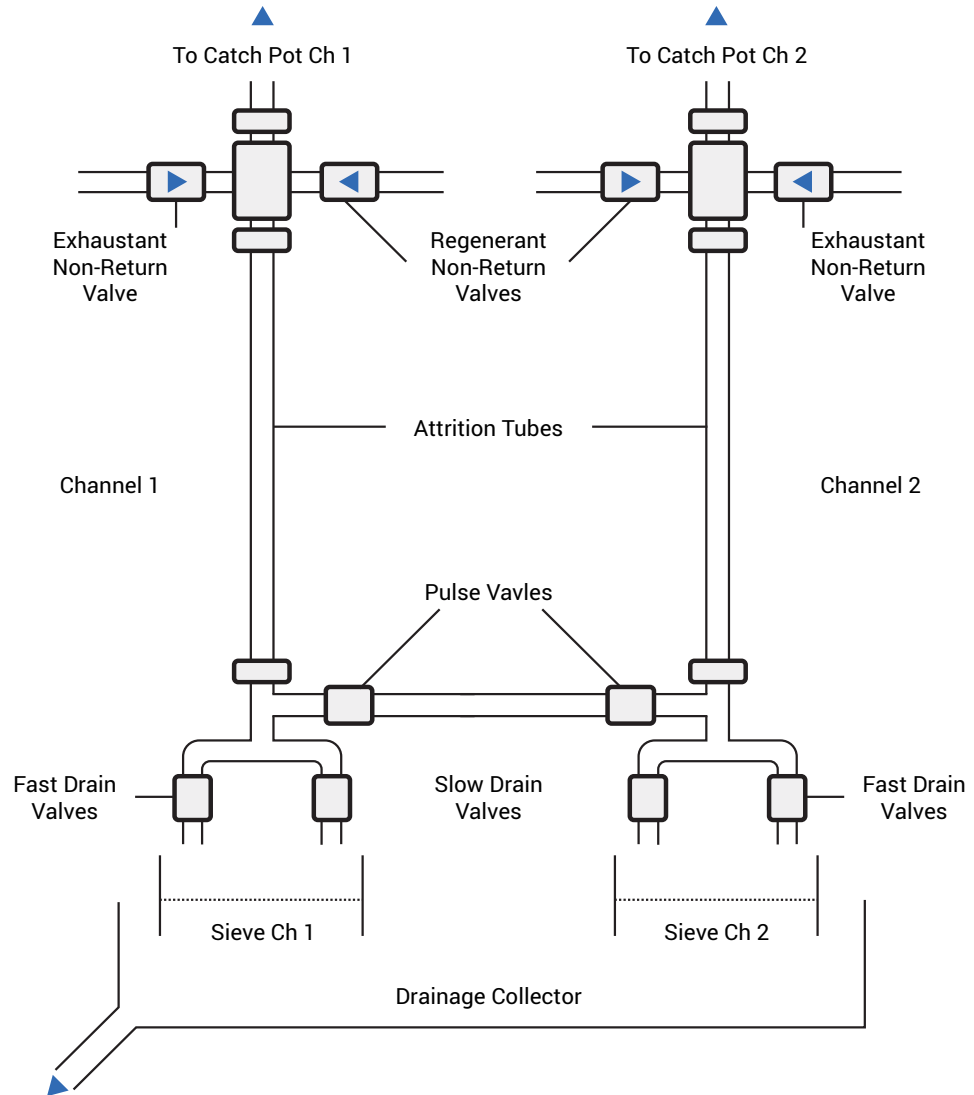
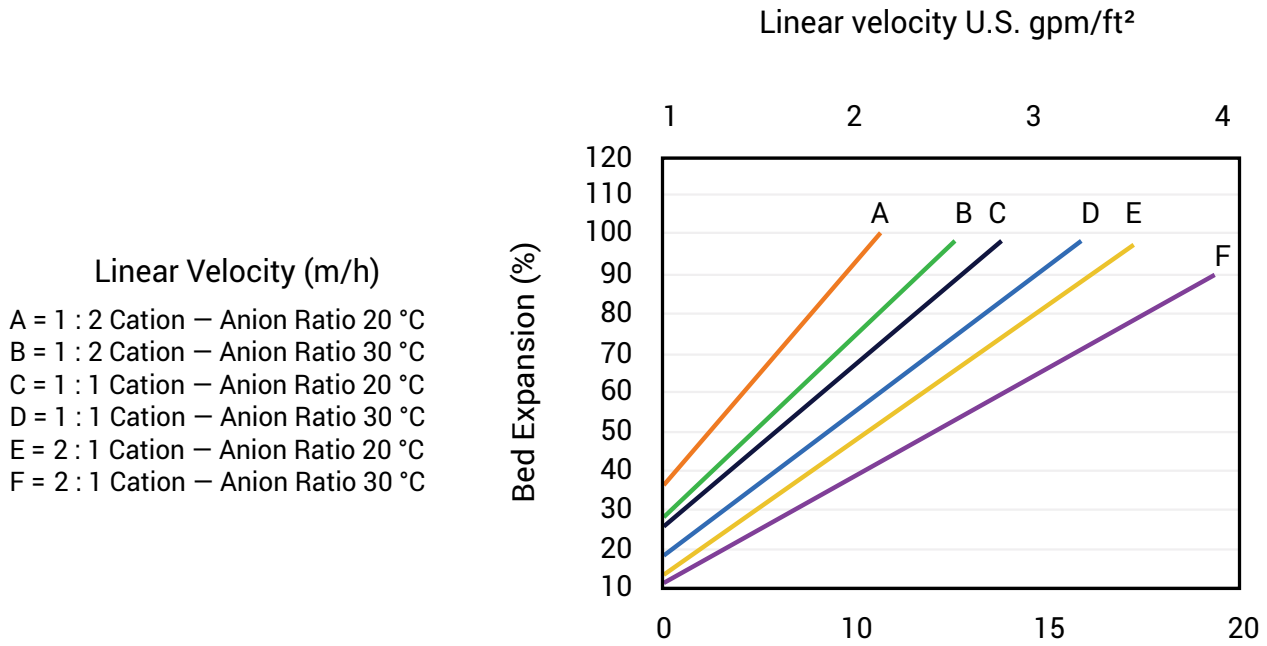
**FIGURE 4****O.S.A. Test Apparatus**

Figure 5 indicates backwash and separation characteristics for a macroporous TL grade combination. Good separation of the resins requires 100% bed expansion. Below 80% expansion, resin separation will likely be poor. Gel mixed bed resins require a 5–10% increased flow rate for bed expansion and proper separation.

**FIGURE 5**

**Backwash: Trilite™  
(TL) Grade Resins**



**FIGURE 6**

**SuperGel  
SGC650:  
Backwash  
Expansion of  
Resin Bed**

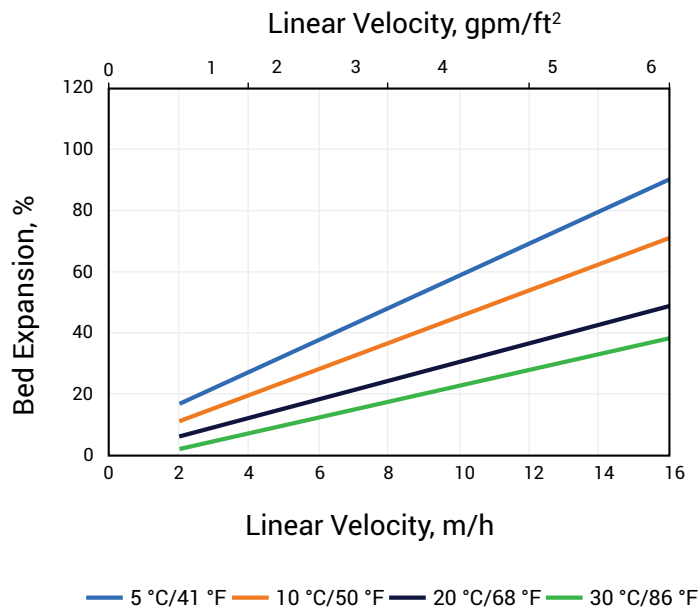
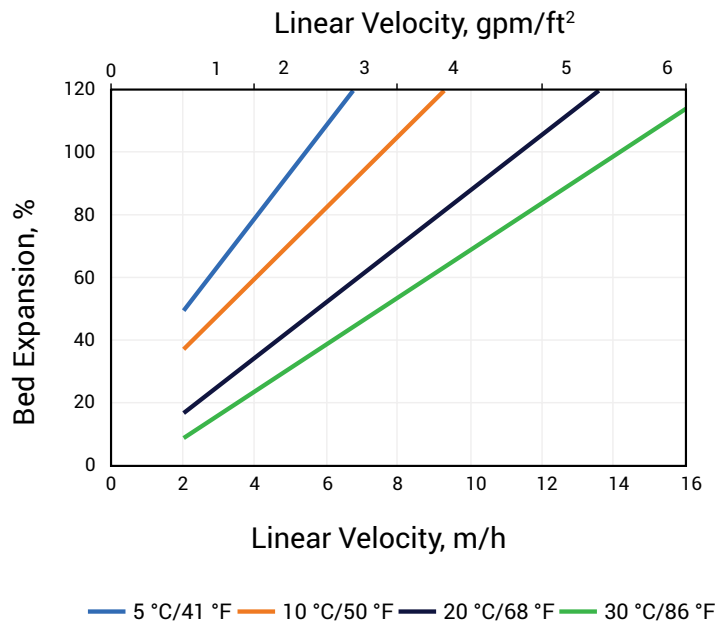


Figure 5 indicates hydraulic pressure drop across Purolite Trilite (TL) grade resins at condensate polishing plant linear flow rates when resin is clean. During plant operation, suspended material filtered by the resin bed contributes to compaction and increased pressure gain. A margin of > 50% is recommended in plant design to minimize pressure issues. The exact pressure drop across the ion exchange bed depends on condensate temperature, crud loading and cycle length (bed compaction).

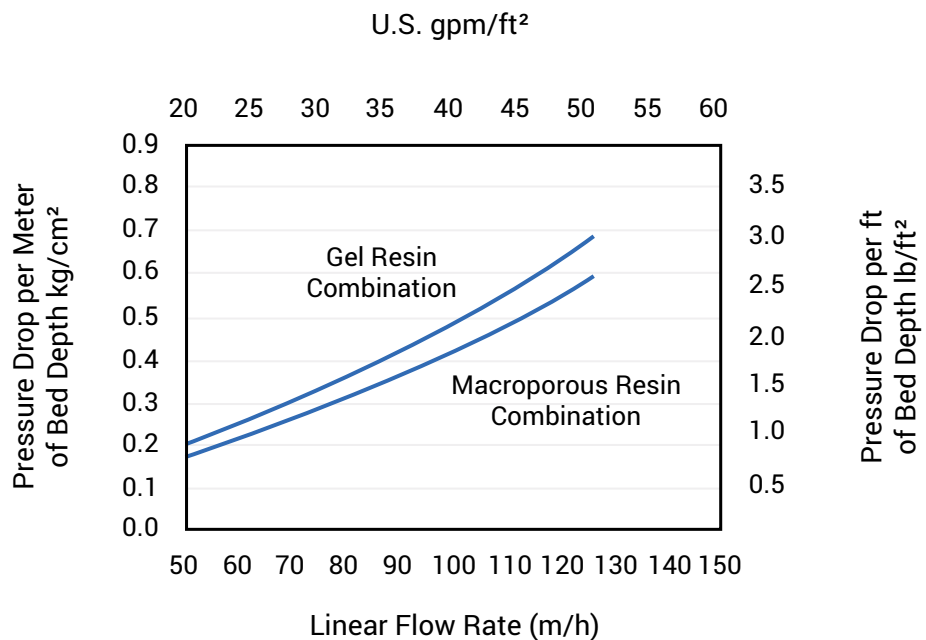
**FIGURE 7**

**SuperGel  
SGA550:  
Backwash  
Expansion of  
Resin Bed**



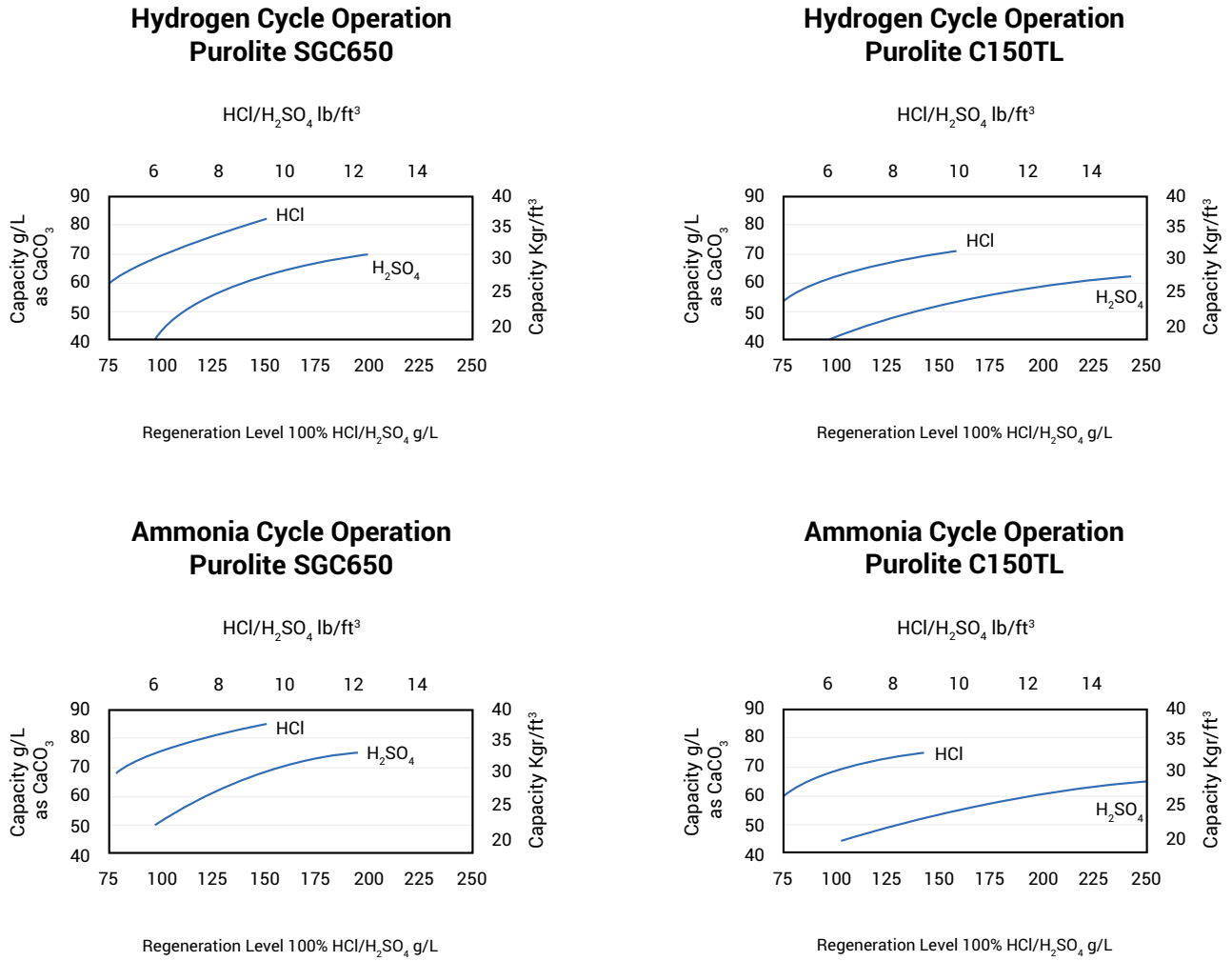
**FIGURE 8**

**Pressure Drop Curve for  
SGC and SGA Resins  
and Macroporous  
TL-Grade Resins**



**FIGURE 9**

**Cation Resin Capacities**



The estimated capacities are based on artificially dosed condensates in relation to acid levels.

The following tables provide properties for Ecolab condensate purification resins.

**TABLE 4** Supergel SGC650H Typical Chemical and Physical Characteristics

Characteristic	Description/Value
Polymer Structure	Gel polystyrene crosslinked with divinylbenzene
Appearance	Spherical beads
Functional Group	Sulfonic acid
Ionic Form	H <sup>+</sup> form
Total Capacity (min.)	2.0 eq/L (43.7 Kgr/ft <sup>3</sup> )(H <sup>+</sup> form)
Moisture Retention	46–50% (H <sup>+</sup> form)
Mean Diameter	670 +/- 50 µm
Uniformity Coefficient	1.1–1.2
Reversible Swelling, NH <sup>+</sup> → H <sup>+</sup> (max.)	10%
Specific Gravity	1.21
Shipping Weight (approx.)	770–790 g/L (48.1–49.4 lb/ft <sup>3</sup> )
Temperature Limit	120 °C (248 °F)

**TABLE 5** Purolite C150TLH Typical Chemical and Physical Characteristics

Characteristic	Description/Value
Polymer Structure	Macroporous polystyrene crosslinked with divinylbenzene
Appearance	Spherical beads
Functional Group	Sulfonic acid
Ionic Form	H <sup>+</sup> form
Total Capacity (min.)	1.8 eq/L (39.3 Kgr/ft <sup>3</sup> ) (Na <sup>+</sup> form)
Moisture Retention	54–59% (H <sup>+</sup> form)
Particle Size Range	710–1200 μm
< 710 μm (max.)	1%
Uniformity Coefficient (max.)	1.3
Reversible Swelling, NH <sup>+</sup> → H <sup>+</sup> (max.)	7%
Specific Gravity	1.18
Shipping Weight (approx.)	740–765 g/L (46.2–47.8 lb/ft <sup>3</sup> )
Temperature Limit	120 °C (248 °F) (H <sup>+</sup> form)
Temperature Limit	140 °C (284.0 °F) (Na <sup>+</sup> form)

**TABLE 6** Supergel SGA550S04 Typical Chemical and Physical Characteristics

Characteristic	Description/Value
Polymer Structure	Gel polystyrene crosslinked with divinylbenzene
Appearance	Spherical beads
Functional Group	Type I Quaternary Ammonium
Ionic Form	SO <sub>4</sub> <sup>2-</sup>
Total Capacity (min.)	1.4 eq/L (30.6 Kgr/ft <sup>3</sup> ) (Cl <sup>-</sup> form)
Moisture Retention	43–48%
Mean Diameter	560 +/- 50 µm
Uniformity Coefficient	1.1–1.2
Reversible Swelling, Cl <sup>-</sup> → OH <sup>-</sup> (max.)	24%
Specific Gravity	1.09
Shipping Weight (approx.)	670–710 g/L (41.9–44.4 lb/ft <sup>3</sup> )
Temperature	100 °C (212 °F) (Cl <sup>-</sup> form)
Temperature	60 °C (140 °F) (OH <sup>-</sup> form)

Notes: Also available in hydroxide OH<sup>-</sup> form as SGA550OH. Optionally products can be supplied with antistatic treatment as SGA550MBSO4 and SGA550MBOH.

**TABLE 7 Purolite A500TLSO4Plus Typical Chemical and Physical Characteristics**

Characteristic	Description/Value
Polymer Structure	Macroporous polystyrene crosslinked with divinylbenzene
Appearance	Spherical beads
Functional Group	Type I Quaternary Ammonium
Ionic Form	SO <sub>4</sub> <sup>2-</sup>
Total Capacity (min.)	1.1 eq/L (24.0 Kgr/ft <sup>3</sup> ) (Cl <sup>-</sup> form)
Moisture Retention	54–65% (Cl <sup>-</sup> form)
Particle Size Range	425–850 μm
< 425 μm (max.)	1%
Uniformity Coefficient (max.)	1.35
Reversible Swelling, Cl <sup>-</sup> → OH <sup>-</sup> (max.)	20%
Specific Gravity	1.09
Shipping Weight (approx.)	665–695 g/L (41.6–43.4 lb/ft <sup>3</sup> )
Temperature Limit	65 °C (149 °F) (OH <sup>-</sup> Form)
Temperature Limit	100 °C (212.0 °F) Cl <sup>-</sup> form)

Notes: Also available in hydroxide OH<sup>-</sup> form as A500TLOHPlus. Both A500TLSO4Plus and A500TLOHPlus are supplied with antistatic treatment. Products without antistatic treatment can be supplied on request.

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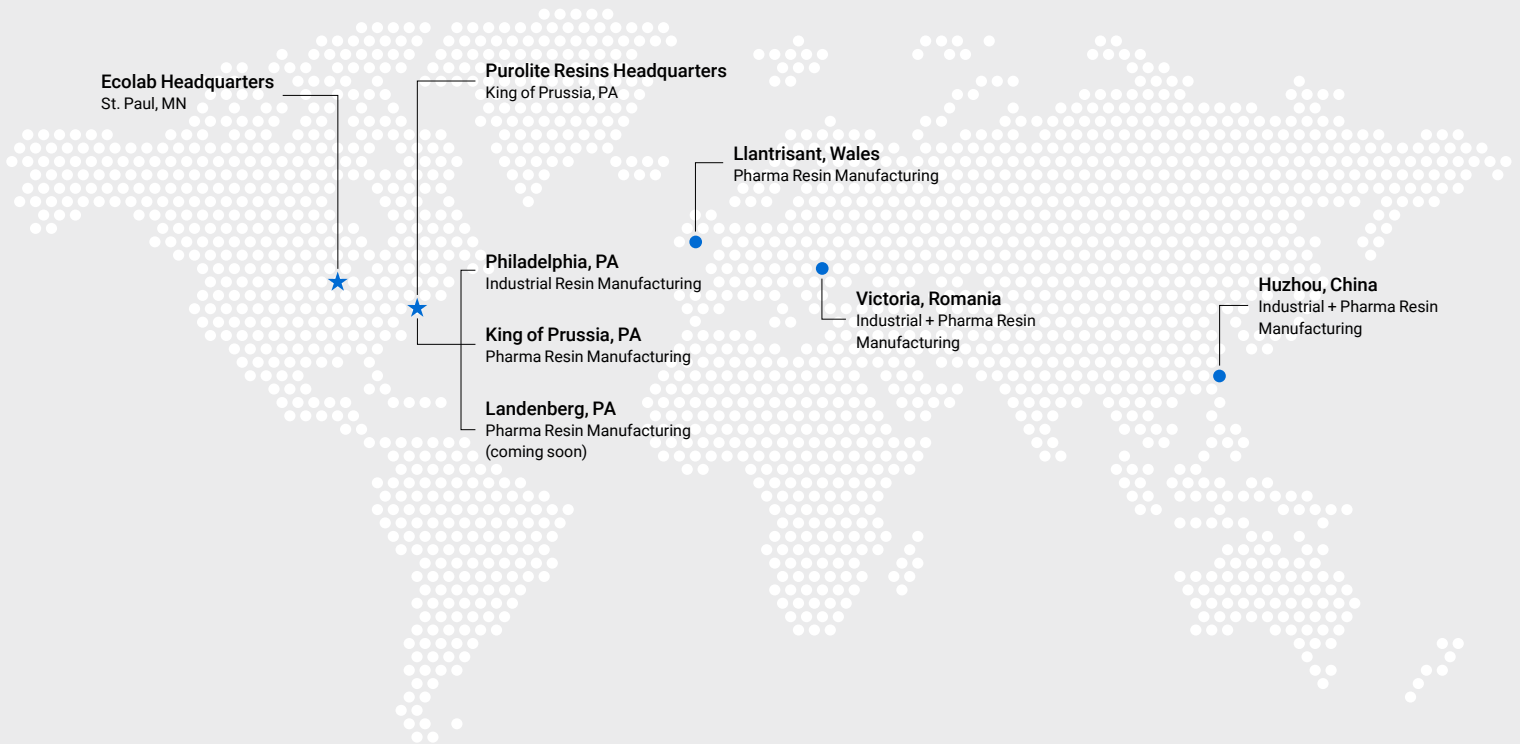
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