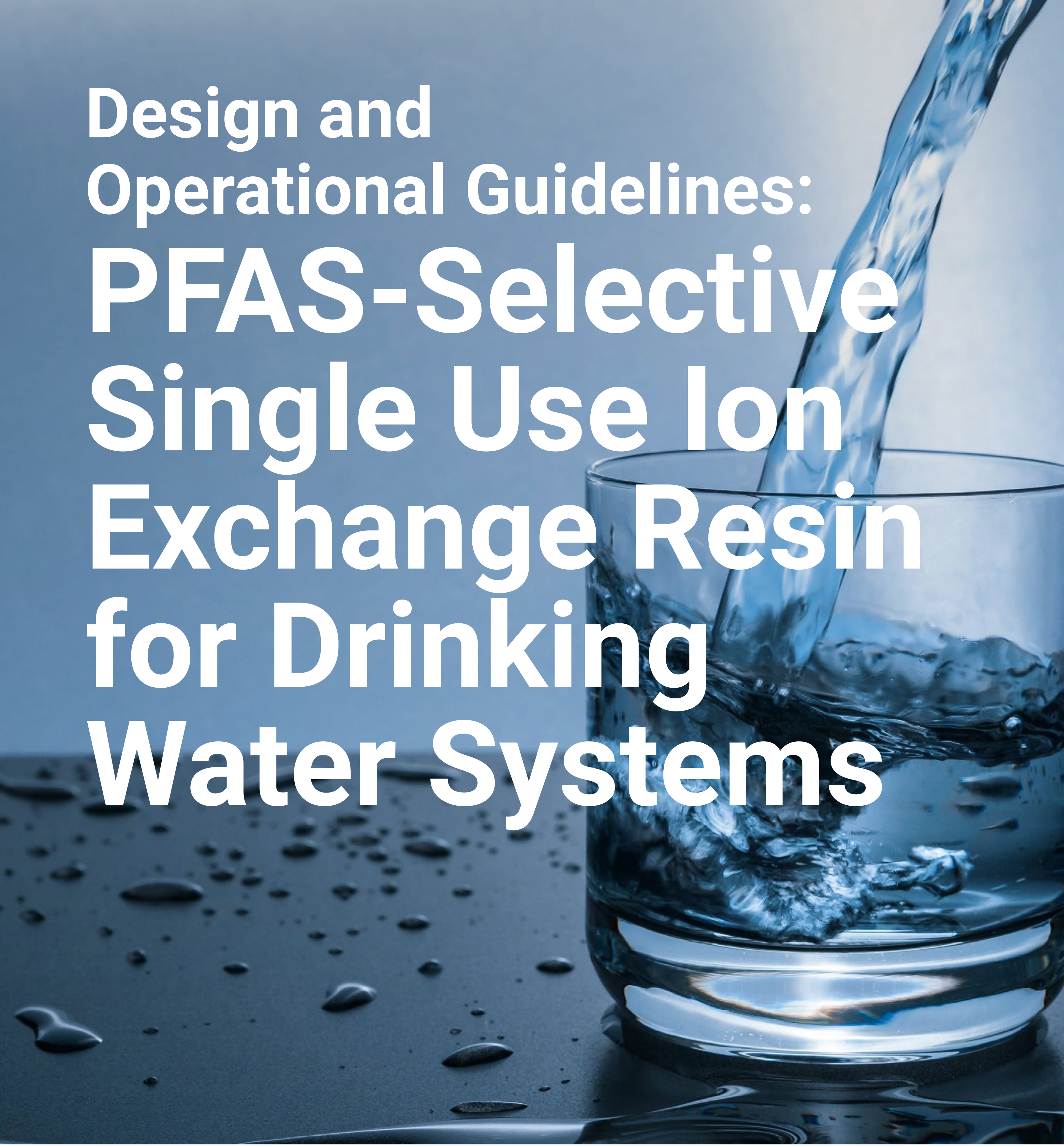
Design and Operational Guidelines: PFAS-Selective Single Use Ion Exchange Resin for Drinking Water Systems



Design and operation guidelines for water systems using Purofine® PFA694E PFAS selective single use ion exchange resin for removing per- and polyfluoroalkyl substances (PFAS) from drinking water.

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About Purolite

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

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

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The quality and consistency of our products are 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.

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

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

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Introduction

Purofine PFA694E can reduce PFAS to non-detect or single digit part per trillion (ng/L) levels for long periods of times due to their inherent high selectivity for PFAS. However, proper treatment system design and operation are crucial to such success. While common anion exchange resins can remove PFAS to some extent, they are not recommended due to their lower selectivity and tendency to produce higher PFAS leakages. Adherence to guidelines and suggested minimum requirements provided below for Purofine PFA694E will allow operators to achieve effective and cost-efficient results.

PFA694E provides:

- High selectivity for both short and long chain PFAS removal
- Small footprints for treatment including the reduction of ancillary equipment
- Long bed life as the resin loads PFAS for months to years depending on water chemistry
- Elimination of liability for the generator when spent PFAS resin is incinerated properly. The resin and the PFAS are both destroyed ending the PFAS "forever chemical" cycle in the environment.

Purofine PFA694E, the premier PFAS-selective single-use ion exchange resin, can be an excellent choice for removing per- and polyfluoroalkyl substances (PFAS) from drinking water.

Pretreatment

TSS

Ion exchange resin can act as an absolute filter. Total suspended solids (TSS) removal is key to preventing blockage and subsequent channeling within the resin bed. TSS is likely the greatest cause of failure of single-use ion exchange resin. Proper design and operation of the prefiltration system to the resin is critical to success. This is because Purofine PFA694E typically operates for months to years before the resin is changed out and because backwashing of the resin during the service period is not allowed.

Backwashing can potentially mix PFAS-loaded resin from the top of the resin bed with less-used resin at the bottom of the bed and cause premature breakthrough of PFAS.

A particle size distribution analysis can be helpful in determining the size of incoming solids. If the well produces any sand, a de-sander is recommended. For all water:

- **Recommendation:** Use a 5-micron bag or cartridge filter before the resin. If high levels of suspended solids are expected that can quickly clog the 5-micron filter, consider installing a series of larger filters ahead of the 5-micron filter (for example, 25-micron followed by 10-micron followed by 5-micron). Base this on particle size distribution analysis.

Oil and Grease

Resin will be readily fouled by oil and grease — remove these completely before the water makes contact with the resin. Organo-clay media alone or in combination with oil- adsorbing bag filters are good choices. Get help from manufacturers of these device to select the right ones for your specific need.

Dissolved Iron and Manganese

As a rule of thumb, these metals can precipitate on downstream media (e.g. resin, granular activated carbon (GAC) or membranes) especially when the iron concentration is above 0.5 ppm and manganese is above 20 ppb. Piloting may be necessary to determine the degree to which these minerals fall out of solution. Pretreatment may be needed for these metals.

- **Recommendation:** Use precipitative greensand or catalytic type media like Purolite MZ10 Plus to remove iron and manganese before the water contacts the resin.

These media are often used in conjunction with an oxidant like permanganate or chlorine. Oxidants will destroy the resin and must be removed before the water contacts the resin. *Remove all traces* of oxidants before the resin with either sodium bisulfite, sodium thiosulfate or GAC per manufacturer's instructions.

Oxidants

Prolonged contact of the resin with oxidants such as chlorine, chloramine, hypochlorite, permanganate and ozone will destroy the resin and also increase the potential for nitrosamine formation in the effluent water.

- **Recommendation:** *Remove all traces* of oxidants before the resin with either sodium bisulfite, sodium thiosulfate or GAC per manufacturer's instructions.

Scaling

When the Langelier Saturation index (LSI) of the water is positive, calcium carbonate scaling can occur. A slightly positive LSI (e.g. +0.2 to +0.5) can form a beneficial thin film of calcium carbonate on the distribution pipework that can protect against corrosion. If an air stripper is used to remove carbon dioxide (CO_2) from the water, the pH of the effluent water will generally increase; this can sometimes turn the LSI from a negative to a positive value. If the LSI becomes too positive (e.g. +1 to +2), excessive scaling can occur — scale precipitation on resin beads and vessel internals will degrade overall system performance.

- **Recommendation:** Determine the LSI based of the water. If the LSI is too positive or can become positive after a pretreatment step, consider feeding an acid to prevent scaling.

Microbes

Bacteria are sometimes found in groundwater and in equipment in contact with the water — this makes it difficult to achieve negative BAC-T counts in the water exiting the resin vessel. Careful investigation should be done to determine the source — besides the well, other sources of bacterial contamination can include dead legs in the piping or improper application of gasket lubricant. If the well is determined to be the source:

- **Recommendation:** Disinfect the inlet well water with a UV disinfection unit. Solids filtration can be used to filter out biomass after a UV. Alternatively, use an oxidant and refer to the oxidants section above.

TOC

Total organic carbon (TOC) can foul and negatively impact resin performance — the extent of fouling depends on the molecular weight distribution of the TOC and its anionic characteristics. TOC in groundwater usually ranges from 1 to 2 ppm or less. At higher levels, the throughput of Purofine PFA694E will be negatively affected (but less so than GAC used for PFAS removal).

- **Recommendation:** Use GAC or a brine regenerable organic-scavenger resin like Purolite A502P, Purolite A860, or Purolite Tanex™ resins before the Purofine PFA694E to significantly improve the throughput of the resin when TOC exceeds 2 ppm.

VOC

Volatile organic carbon (VOC) generally will not affect Purofine PFA694E throughput. If removal of VOC is needed, GAC can be used with an EBCT of approximately 5 minutes (check with your GAC provider for guidance).

- **Recommendation:** If PFAS and VOC co-exist in the water, use GAC treatment for VOC removal before the Purofine PFA694E. If TOC is also present, the GAC can help protect the resin against potential TOC fouling. Because shorter contact times are used for Purofine PFA694E as compared to GAC, smaller or fewer vessels can be used, in most cases, versus using GAC alone to remove both VOC and PFAS.

Resin Vessel Design

Below are the critical elements for vessel design to treat PFAS using Purofine PFA694E resin:

- **Bed Depth:** 3 ft (0.91m) minimum up to 12 gpm/ft^2 (30m/h); 3.7 ft (1.1m) minimum above 12 gpm/ft^2 (30m/h) design flows
- **Linear Velocity:** Design goal = 6 to 18 gpm/ft^2 (15 to 45 m/h)
- **Specific Flowrate:** Design goal = 1 to 5 gpm/ft^3 (8 to 40 BV/h)
- **Empty Bed Contact Time (EBCT):** Design goal = 1.5 to 2.5 minutes contact time for the lead resin bed

The kinetics of Purofine PFA694E are very fast compared to GAC, with GAC typically requiring 8 to 13 minutes in the lead vessel (check with your GAC provider for guidance). Resin vessels must be properly designed to handle the faster hydraulics indicated above. Whether designing a new resin system or retrofitting another media vessel for resin use, pay attention to the following:

- Size new piping or evaluate existing piping for accommodating the maximum flowrate.
- Ensure that influent distributors to the resin vessels are properly designed to distribute the water flow evenly over the cross-section of the vessels — this achieves plug flow or uniform distribution of the water through the resin bed and avoids channeling and premature breakthrough of PFAS.
- Ensure that slot size of the effluent distributors can retain the resin. In general, a slot size of 60 U.S. mesh (~0.01 inch or 250 micron) is adequate to accommodate Gaussian and uniformly sized resin beads (typical bead diameters range from 300 to 1200 microns (16 to 50 U.S. mesh).
- Ensure vessels are lined with an NSF approved coating and that all other components are NSF-compliant.
- Recommend that sample ports be installed at 25, 50 and 75 percent of the resin depth. Such sample ports allow monitoring of the PFAS loading profile and are especially important for troubleshooting of the system.

Preferably, vessel design should also include both a side manway and a top manway. These make it easier to inspect the vessel and resin bed.

Vessel Configuration

Although PFAS treatment goals are achievable with a single vessel, a lead-lag pair of vessels is recommended for several reasons:

- Operational costs will be lower with lead-lag design because the lead vessel will be allowed to operate for a significantly longer period while the lag is still at non-detect. Longer run time allows for more efficient use of resin.
- Because sampling results may take weeks to arrive, a lag bed provides the best assurance that PFAS levels in the discharge water are below treatment goals.

Post-Vessel Design

Inline installation of a "witch's hat" type strainer or basket strainer on the vessel effluent can help catch escaped resin beads in case there is a screen failure in the outlet distributors.

Installation of check valves after the treatment system will ensure water does not flow backwards into the vessel and disrupt the mass transfer zone of the resin bed.

Operational Considerations

Startup

Before loading, disinfect all vessels and piping as per "AWWA C653-13 Disinfection of Water Treatment Plants." Rinse equipment to remove all chlorine residuals to avoid destruction of the resin beads.

A food-grade wash out must be done on slurry trucks and hoses before resin is loaded in them.

Rinse the Purofine PFA694E as per the NSF/ANSI-61 guidelines using at least 20 bed volumes of water (150 gallons per cubic foot of resin) before sending drinking water to the distribution system. Offsite resin rinsing can often be done by service providers before installation. In such cases, minimal onsite rinsing is needed.

Fill vessels partially with water (e.g. 1/3 of volume) to provide a "water cushion" as the resin is slurried into the vessel. This helps to level the resin bed as it is loaded.

Slurry load the Purofine PFA694E to prevent bacterial contamination.

During startup of a new resin bed, nitrosamine sampling is sometimes recommended by regulators. Nitrosamines are not in the resin but can be formed when nitrosamine precursors make contact with chlorine or other oxidants. Rinsing the resin is generally enough to eliminate this issue.

BAC-T sampling is also recommended before sending water to distribution.

When starting up a Purofine PFA694E system, whether on the first load, or in a start/stop scenario, ramp up the flow slowly either by using a variable flow drive (VFD) on the well pump or a control valve that slowly diverts flow from waste to treatment. Water hammer, or instantaneous water flow changes, can cause resin movement and disruptions in the bed. As a rule of thumb, the ramp-up time should be about five minutes from start to full flow.

PFA694EBF for Minimal Water Chemistry Changes

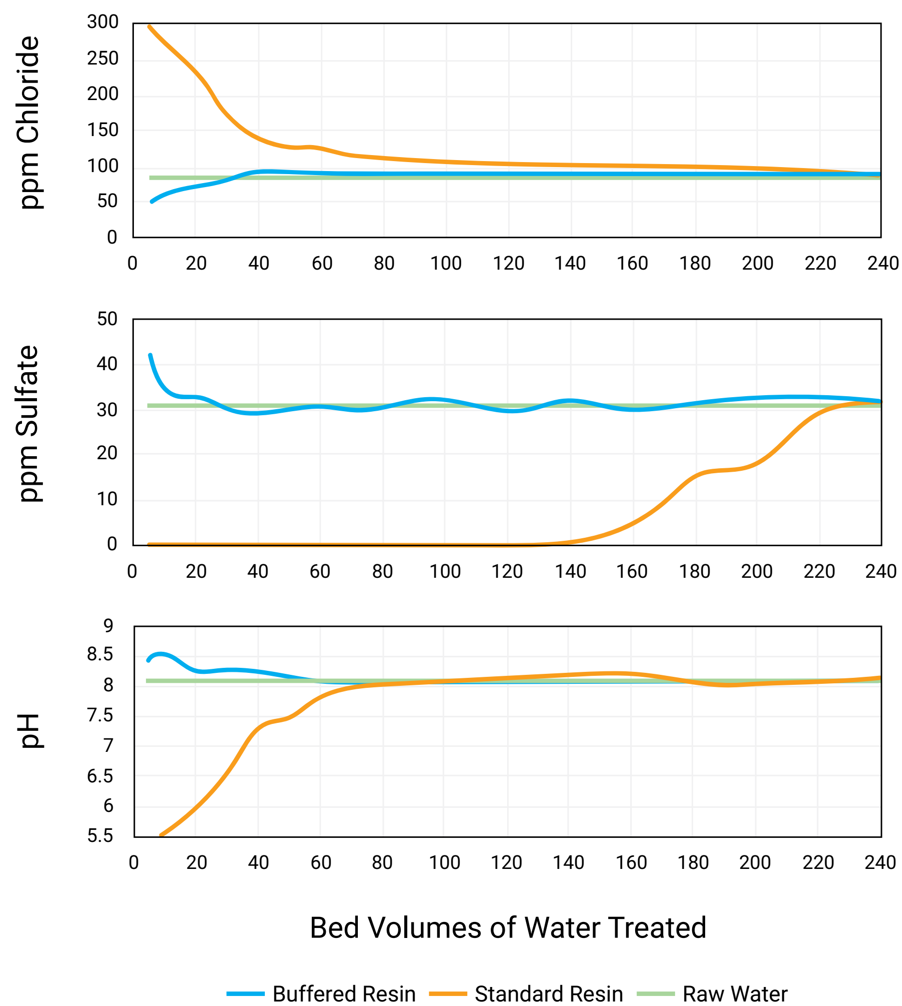
One major drawback of anion exchange resin systems at startup is that they simultaneously remove alkalinity, sulfate and other anions in exchange for chloride. Buffered resin can reduce the effects of water chemistry changes at startup by:

- Prevent effluent chloride from approaching or exceeding local discharge standards
- Prevent high chloride to sulfate mass ratio (CMSR) which can create lead leaching potential in piping systems
- Stabilize effluent pH and meet local discharge standard

In certain situations, the buffered form (such as Purolite PFA694EBF) can create significant savings on operations and waste rinse water.

FIGURE 1

Typical Elution Profile of PFA694EBF at Startup Compared to Non-Buffered Version



Sampling

PFAS sampling protocols can be provided by your analytical laboratory — be sure to check with them before starting any sampling regime.

Purofine PFA694E throughput is determined largely by the competing anions present in the influent water.

Influent Water Testing

Sample monthly for all anions to monitor if there are significant changes in water chemistry (e.g. 5 percent or greater). Check at least for the following in the influent water:

- PFAS
- Sulfate
- Nitrate
- Alkalinity
- Chloride
- Total Organic Carbon
- Total Dissolved Solids

Midpoint and Effluent Sampling

- Sample weekly for PFAS to ensure proper treatment.
- The midpoint sample point is defined as the effluent of the lead bed. This data point provides the "trigger point" information as to when a resin exchange is required. This trigger point will be set by the relevant regulating agency.
- Sample the discharge point of the treatment train to ensure the treatment goal is being achieved.

Monitoring

Once the vessels are properly configured in a lead-lag arrangement, no changes are required to the valving until the resin is ready to be exchanged. Rounds and readings are recommended three times a week.

Monitor the following critical parameters:

- Flow rates
- Meter readings
- Pressure levels in and out of each vessel to determine pressure drop — or readings from a differential pressure (dP) cell
- Other operational items to check routinely include:
    - Proper valve positioning. Some water purveyors install locks to ensure valving is not changed.
    - Air-relief valves can sometimes leak. Throttling them open and closed can dislodge a particle that causes leakage.

Resin Exchanges

Before refilling of fresh resin into a vessel that previously contained spent resin, it is critical to remove all spent resin and to visually inspect and confirm that no spent resin is left behind as this will compromise the operating capacity during the next service cycle. Visual inspection of the vessel and internal distribution systems must be done to confirm equipment integrity as well as to confirm that no resin beads or pieces of beads are wedged in the distribution slots — any such defects must be corrected before the vessel is returned to service. It should be noted that reduction of contaminants at parts per trillion levels to non-detect levels, requires a lot of precision to ensure success. It is highly recommended that detailed photographs of the inspected sections of the vessel be taken and stored as verification that this has been properly done for each vessel.

Before return to service, the vessel and its associated plumbing and valves should be sanitized for use in drinking water treatment using a customer-approved procedure.

After completion of above task, a fresh charge of resin can then be loaded into the empty vessel using a customer-approved procedure, taking all precautions to prevent contamination of the resin from direct handling and/or exposure to contaminants that will foul and impair its operating efficiency (e.g. oil, grease, sweat, soil).

The vessel with the fresh resin is then placed in the lag (or polishing) position while the former lag vessel is placed into the lead position (not physically but) by opening and closing of appropriate valves. After settling of the fresh charge of resin, the resin bed is rinsed to drain using our recommended procedure.

Starting and Stopping a System

As mentioned previously, water hammer should be avoided to prevent resin movement. Flow should be ramped down when stopping and ramped up when re-starting.

If a system needs to sit idle, generally there are no issues with turning a well on and off over the course of a day. Warmer weather conditions are more conducive to bacteria growth. Consider these guidelines for preventing bacterial growth:

- If a vessel is idle more than 24 hours, at least two bed volumes of water should be rinsed through the vessel every day or two.
- If a vessel is idle for longer periods or where periodic rinsing is not feasible, the water should be completely drained from the vessel. When the vessel is ready to be started up, rinse the resin at full flow for 24 hours — this should be enough to flush out any bacteria. Pull BAC-T samples to confirm.

Conditions to Avoid!

If properly run and maintained, resin beds enjoy long and hassle-free life. In order to prevent upsets, ensure these factors are addressed:

- Oxidants like chlorine will destroy the resin as well as cause nitrosamines to form. Influent water should therefore be oxidant-free.
- Water hammer should be avoided. Ramp-up and ramp-down procedures should be in place.
- Entrained air in the influent water may cause bubble formation and subsequent resin movement.
- Any solids need to be removed before the resin as discussed in the pretreatment section. Solids can include suspended solids, precipitated solids (iron, for example) or biological growth.
- Interfering contaminants in the influent water include fuels, solvents, oils and surfactants. Each of these have the potential to negatively impact resin performance by breaking down the resin or blinding off its active sites.
- Resin loss, although obvious, can be detrimental to the performance of a bed.
  - Ensure the manifold valves are configured properly before starting up.
  - Excessive backwashing can displace resin. Backwashing is not recommended.
  - Broken effluent screens can cause resin loss. Secondary resin retention screens — basket strainers or witch's hats — are recommended.

- Backwashing of the resin is not recommended after startup (and not required before startup). If a system is backwashed, either intentionally or through a leaking valve, the mass transfer zone of contamination is mixed and can lead to premature breakthrough.

Troubleshooting

Keeping good records is the first step to understanding where a problem originates. Follow the sampling and monitoring guidelines above.

Premature Breakthrough

Diagnosing system operating problems before they lead to premature breakthrough is critical in achieving good results. An adequate monitoring and sampling protocol should be set up and followed. Operators should pay attention to any sudden changes in influent water characteristics or operation of upstream pretreatment equipment, to any fouling or loss of resin or to any of the above mentioned parameters.

Solids buildup in the vessel:

- If dirt accumulates in the vessel, the influent water will find the path of least resistance. As this path is established, the water will push dirt-encrusted resin out of the way. This results in vessels channeling of the resin and early breakthrough.
- Visual inspection is the easiest way to verify solids buildup. Samples of resin can also be pulled from various spots in the vessel and tested for dirt accumulation.
- Pressure drop (dP) across the lead vessel is another indication of dirt accumulation. If dP is seen to increase excessively, a vessel inspection may be recommended. Watch especially if pressures also go up and then suddenly reduce. That could indicate the resin bed has shifted.
- In some cases, if there is significant life remaining in the resin bed, the dirt layer on top can be removed, the bed can be leveled and the resin can be put back into use. This should be done with the help of a service provider to ensure proper equipment and sterilization procedures are used. The vessel should be tested for BAC-T before being put back into service.
- Prefilters should be inspected for tears or improper installation. Prefilters should be changed regularly — usually when the dP across the prefilter is 10 pounds per square inch.
- If prefilters are not compromised, it is possible the particles in the water are smaller than the micron rating of the filter. A particle size analysis of the influent water can be done to understand the filtration level required.

- Solids build up can also come from dissolved metals like iron and manganese in the influent water. These metals can come out of solution, precipitate and foul the resin. Again, this can be diagnosed by sampling the resin bed and performing a resin analysis.
- Solids buildup can also occur if bacterial growth is occurring. Investigation of systems upstream from the resin bed should be analyzed to determine the source of the bacteria. See pretreatment recommendations.

Resin Movement

- A resin bed should be level to ensure plug flow through the vessel.
- Solids buildup, as discussed above, is the primary cause of resin movement.
- Water hammer can cause resin movement. Ensure ramp-up and ramp-down procedures are followed.
- Entrained air or excessive dissolved air in the influent water will cause resin movement. When the water hits the resin bed, there is a pressure drop causing air to come out of solution. As bubbles form on the resin bead, they can float to the top of the bed causing disruption of the mass transfer zone.
- If influent water distribution is either not designed effectively, or is somehow damaged, influent water pressure can move resin around.
- Excessive backpressure can cause water to flow backwards — especially in startup and shut down modes — causing the bed to get mixed and disturbing the mass transfer zone.
- Check valves should be installed after the treatment vessels to ensure water cannot flow backwards.
- Backwashing of the vessel will cause disruption of the mass transfer zone and lead to premature breakthrough.

Water Chemistry Changes

Anion concentrations will affect the performance of the resin. Spikes in any of the influent anions will deplete resin capacity causing less throughput than originally expected.

Resin Fouling

In addition to dirt and dissolved metals, resin can be fouled by organics in the water. Oil, grease, or surfactant will all blind the active surface of the resin bead. Solvents, fuels, or surfactants can impair the bead structure and cause performance issues. Resin sampling and analysis can diagnose these problems.

Resin Loss

When resin is not in the vessel, it cannot remove the PFAS. Visual inspection should indicate if resin loss has occurred. Please note, resin will shrink as it exchanges chloride ions for other anions in the water. Expect up to 30% shrinkage of the bed from when it's first installed. Causes of resin loss include improper valving, broken screens or excessive backwashing.

Channeling

Channeling can occur as a result of too low a flow. Design flow should be between 6 to 18 gpm/ft^2. Between 2 to 6 gpm/ft^2, channeling may be a risk. Lower than 2 gpm/ft^2 will cause channeling issues which can lead to premature breakthrough.

Insufficient Removal of Spent Resin

If not all of the resin is completely removed in a resin exchange, the residual resin can cause early breakthrough.

High Pressure Drop

- High dP across a vessel can most often be explained by dirt accumulation. See "Solids buildup in vessel" section above.
- High dP across a vessel can also be explained by excessive resin fines clogging the effluent screens. Ensure screens are cleaned out during change outs.
- High dP across a basket strainer or witch's hat can indicate a broken screen at the bottom of a vessel, or excessive resin fines in the resin bed. Removing the strainer and inspecting the contents of the strainer should help indicate what happened.

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Americas
Purolite Corporation
2201 Renaissance Blvd.
King of Prussia, PA 19406
T +1 800 343 1500
T +1 610 668 9090
F +1 800 260 1065
americas@purolite.com

EMEA
Purolite Ltd.
Unit D
Llantrisant Business Park
Llantrisant, Wales, UK
CF72 8LF
T +44 1443 229334
F +44 1443 227073
emea@purolite.com

FSU
Purolite Ltd.
Office 6-1
36 Lyusinovskaya Str.
Moscow, Russia
115093
T +7 495 363 5056
F +7 495 564 8121
fsu@purolite.com

Asia Pacific
Purolite China Co. Ltd.
Room 707, C Section
Huanglong Century Plaza
No.3 Hangda Road
Hangzhou, Zhejiang, China 310007
T +86 571 876 31382
F +86 571 876 31385
asiapacific@purolite.com

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We're ready to solve your process challenges. For further information on Purolite products and services, visit www.purolite.com or contact your nearest Technical Sales Office.

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