Per- and Polyfluoroalkyl Substances (PFAS)

Treatment

What are PFAS?

Per- and polyfluoroalkyl substances (PFAS) are a large group of environmentally persistent, man-made chemicals used in industrial and commercial household uses including firefighting activities, stain repellents, and non-stick cookware. Currently there are over 600 PFAS compounds that the EPA has approved for sale or import into the United States. Due to their widespread use, PFAS are being found at low ambient levels in the environment. Two PFAS that are most often found in finished drinking water are legacy compounds that are no longer manufactured but are still being found in the environment, including perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS). Research has shown that PFAS will increase cholesterol and there are limited findings to other health effects, such as cancer.

Regulatory Activity to Protect Drinking Water

Initial regulatory action to manage PFAS began under the Toxic Substances Control Act. By 2002 the EPA was actively phasing out PFOS and placing additional barriers on PFAS entering commerce, but by that time an estimated 100,000 tons of PFAS had already been produced and PFAS were entering the environment and appearing in human blood samples. In 2009 EPA developed provisional health advisories for PFOA and PFOS to help address risk management when soils and ground water were contaminated. That year, PFOS and PFOA appeared on the Safe Drinking Water Act Contaminant Candidate List.

In May 2016, EPA released lifetime drinking water health advisory levels of 70 nanograms per liter (ng/L) for PFOA and PFOS (individually or combined) for exposure from drinking water. EPA set the advisory level at a concentration believed to be protective against all health effects in humans, including developmental risks, based on concentrations below which there were no observed effects in animal studies. When EPA released its PFAS Action Plan in February 2019, EPA's Administrator indicated the Agency would propose a decision to draft primary drinking water standards by the end of the year. Additionally, in April 2019 the EPA Draft Interim Recommendations for Addressing Groundwater Contaminated with PFOA and PFOS for comment. The draft recommendations include a screening level of 40 ng/L and a preliminary remediation goal of 70 ng/L.

Currently there are no enforceable federal drinking water limits for PFAS. Some states are taking steps to address PFAS contamination and setting their own PFAS drinking water standards. See the Additional Resources section of this Fact Sheet for resources summarizing state and international actions.

Treatment Technologies and Selection

Research to-date demonstrates limited PFAS removal by conventional drinking water and wastewater treatment processes. At present, there are three treatment technologies recognized as providing demonstrated PFAS removal from contaminated water: activated carbon, anion exchange, and high-pressure membrane filtration. Removal efficiency depends on the properties of the influent being treated but each of these treatment methods have demonstrated removal efficiencies of up to 95%. Selecting among these technologies requires understanding and integrating:

- Treatment objectives
- Source water characteristics
- Treatment scenario (e.g., facility size, retrofit limitations, existing unit processes, etc.)
- Secondary impacts (e.g., operational feasibility, waste stream disposal, etc.)
- Timeframe for implementation
- Fiscal constraints for capital and operating expenses

Bench and Pilot Testing

There is a growing body of experience and peer-reviewed literature on removal of PFAS from water, that can be used to select design options. All of the available technologies represent significant increases in capital and operating expenses over conventional treatment. Consequently, bench- and pilot-testing is an important step in assessing the efficacy of treatment options and to identify potential unknown impacts of the system prior to a large capital investment.

Technologies

Activated carbon technologies include both granular activated carbon (GAC) and powdered activated carbon (PAC). GAC and PAC rely on the adsorptive properties of activated carbon media, where contaminants are adsorbed into the pores and onto the surface of the media. PAC is typically utilized in scenarios where contaminant removal must be implemented quickly. PAC is, typically added in the rapid mix tanks of a water treatment plant or a separate contactor, to allow a contact period for adsorption during existing unit processes. GAC contactors can be utilized for long-term PFAS removal. The principle design factor for GAC reactor contactors is the empty bed contact time (EBCT), which is the volume of the empty contactor bed divided by the flow rate of the system. Typical GAC EBCT for PFAS treatment ranges from 10 to 20 minutes.

EPA indicates that GAC filtration can remove 99% of PFOA and PFOS. For other PFAS, the removal rates vary from 77 to 99%, with the highest removal rates for sulfonates and longer chain compounds. A critical consideration for activated carbon treatment of PFAS is the competition of total organic carbon (TOC) and/or other non-targeted constituents. Since the process is effective at removal for a wide spectrum of contaminants, the presence of non-targeted contaminants can drastically decrease PFAS removals. The type of GAC is also a consideration since material and pore structure impacts specific contaminant removal efficacy.

Once GAC media is exhausted and breakthrough of PFAS is observed, the media will need to be regenerated to renew adsorptive capabilities. EPA is currently engaged in research to better understand if PFAS are destroyed or transformed during regeneration and which, if any, are released back to the environment.

Anion exchange (typically called ion exchange [IX]) is when negatively charged ions are exchanged with negatively charged ions on the resin surface – typically chloride. Like GAC treatment, the IX process must be designed based on EBCT. The typical IX EBCT for PFAS treatment ranges from 2 to 5 minutes. As the IX media removes PFAS, the media's negative ions will eventually be exhausted and will need to be regenerated or replaced after safe disposal of exhausted media.

Less data are available demonstrating IX treatment for PFAS, but observed removal rates vary from 77 up to 97% for PFOA and from 90 up to 99% for PFOS from the influent. For other PFAS, removal rates vary from 57 up to 99% removal from the influent. Importantly, there are data suggesting that IX is more effective removing short-chain PFAS than GAC. With shorter ECBT, IX vessels are also typically shorter and have a smaller footprint than GAC vessels, which may make installation easier. IX regeneration produces a waste brine that contains high concentrations of PFAS must be disposed.

Membrane filtration treatment of PFAS can be accomplished using either nanofiltration and/or reverse osmosis (RO) membranes. In the process of membrane filtration involves passing pressurizing influent in contact with membranes with small pores. The semi-permeable membrane is only permeable to water molecules, so PFAS will be restricted and concentrated in the reject stream. The treatment flow rate of the process is limited by the pressure, typically high, and level of dissolved solids. In contrast to GAC/PAC and IX, membrane filtration has demonstrated PFOA and PFOS removals of greater than 99%. Removal of other PFAS varied from 84 up to 99% removal but was typically above 98%.

The waste stream that is generated by membranes is a significant constraint. It contains concentrated PFAS and potentially other contaminants for which there are regulatory controls. The capital and operating costs for membranes are also higher than GAC and IX. The waste stream can be large, potentially 20% of influent volume, which is not only lost but it must be further treated and/or disposed of to prevent further PFAS contamination.

Other Potential Treatment Technologies

Researchers have been working to identify, develop, and test other potential treatment technologies to address PFAS contamination in drinking water and wastewater.

Advanced oxidation is one of these technologies receiving a significant amount of research. Advanced oxidation transforms PFAS using hydroxyl radicals. Approaches include ultraviolet radiation with hydrogen peroxide, or ozone and peroxide, or heat-activated persulfate. Demonstrated efficacy varies from 0 up to 90% degradation of PFOA. Advanced oxidation processes do not remove PFAS but rather transform the PFAS molecule.

Electrocoagulation is another emerging technique, in this instance an electrical current is applied to a solution along with a chemical coagulant to facilitate removal of contaminants, such as PFAS. Initial research results have shown removal of up to 90%.

Additional Considerations

Design parameters that can play a vital role in the performance of a PFAS treatment facility include:

- *Background Water Quality Matrix* – Based on available performance data, many types of contaminants can inhibit treatment of PFAS. For example, TOC can hinder the performance of (RO) membranes and can significantly increase the cost to operate and maintain the facility; iron and manganese can foul GAC and IX filters and cause short-circuiting. The presence of co-contaminants may outcompete PFAS removal or may hinder the capacity of activated carbon or IX treatment systems; matrix effects should be examined and considered during treatment selection and/or design.

- *Profile of PFAS Contamination* – In some studies, multiple types of PFAS have been shown to occur together at contaminated sites. The characteristics of PFAS vary based on the types of functional group, number of carbons, and the presence of carbon-fluorine bonds. Given the varying characteristics of PFAS, the selection of treatment technologies must consider the specific PFAS present to optimize performance. This is an especially pertinent consideration for the GAC and IX processes. Pilot-testing is encouraged to ensure effective process selection.

- *Waste Stream Disposal Options* – Current, widely-accepted treatment options produce waste streams concentrated with PFAS. For instance, GAC or IX media used for PFAS treatment must be regenerated or safely disposed of after exhaustion. Also, the RO process purifies water and creates a concentrated brine of contaminants. This brine must be disposed of in a way that avoids causing further contamination off-site. Disposal of the concentrated waste stream should be considered to avoid potential liabilities and/or unintended added operation and maintenance costs.

Additional Resources

EPA's Drinking Water Treatability Database For PFAS:
https://iaspub.epa.gov/tdb/pages/contaminant/contaminantOverview.do?contaminantId=11020

ITRC's Remediation Technologies and Methods for Per- and polyfluoroalkyl Substances (PFAS) Fact Sheet:
https://pfas-1.itrcweb.org/wp-content/uploads/2018/03/pfas_fact_sheet_remediation_3_15_18.pdf

Water Research Foundation Report #4322 – Treatment Mitigation Strategies for Poly- and Perfluorinated Chemicals:
www.waterrf.org/Pages/Projects.aspx?PID=4322

Water Research Foundation Report #4344 – Removal of Perfluroalkyl Substances by PAC Adsorption and Anion Exchange:
http://www.waterrf.org/Pages/Projects.aspx?PID=4344

Treatment Method	Potential Removal[1]	Costs	Considerations	
			Pros	Cons
Activated Carbon	PFOA: 40-99% PFOS: 18-98% PFBA: 99% PFBS: 98% PFHxA: 95% PFHxS: 90% PFHpA: 90% PFHpS: 82% PFNA: 93%	$$	• Widely used for PFAS removal, high removal rates possible • Powder activated carbon is useful for responding to spills	• Lower removal rates for perfluoroalkyl acids and short-chain PFAS • Possibility of competitive adsorption with other compounds present, such as TOC • Low rate of adsorption in GAC may result in long mass transfer zones and adjustment of associated operating requirements • Requires thermal regeneration of GAC; regenerated GAC may not be as effective as virgin GAC • Creates waste residuals to dispose of exhausted carbon and potential opportunity for pollution
Anion Exchange	PFOA: 77-97% PFOS: 90-99% PFBA: 97% PFBS: 98% PFHxA: 97% PFHxS: 99% PFHpA: 94% PFHpS: 99% PFNA: 98%	$$	• Sorption rates depend on the resin and porosity • Can partially remove PFOA, PFNA, and PFOS • Resin can be specialized for specific PFAS and allows IX to have a higher capacity than activated carbon	• Costs are similar to activated carbon but depend greatly on resin and treatment system • Rate of exchange will depend on many factors, including influent PFAS concentration, design of the IX, solution ionic strength and bead material • Surface water supplies may need clarification/filtration before treatment • Range of efficacy for long and short-chain PFAS
Membrane Filtration	PFOA: 47-99% PFOS: 93-99% PFBA: 99.9% PFBS: 99.8% PFHxA: 99.2% PFHxS: 99% PFHpA: 99% PFHpS: 99% PFNA: 99%	$$$	• Excellent, broad spectrum removal of PFAS • Reasonable for groundwater systems	• Reject water must be treated before discharging • High capital expense with high energy demands • Susceptible to fouling and may require pre-treatment • Reverse osmosis is preferable to nanofiltration due to better removal efficiency but higher operating costs

1. Potential removal rates are based on reported data from the EPA's Drinking Water Treatability Database for PFAS.