

# MEMBRANE APPLICATIONS

## for Removal of PFAS and “Forever Chemicals”

### OVERVIEW

Perhaps one of the most challenging chemical groups of our era is per- and polyfluoroalkyl substances, collectively referred to as PFAS. This anthropogenic (originating in human activity) group of chemicals refers to highly fluorinated aliphatic synthetic chemicals, which have been demonstrated to be harmful in both the environment and humans. These chemicals are very persistent and can accumulate in the human body for many years, causing a variety of non-cancerous and cancerous health effects (EPA 2017). The United States Environmental Protection Agency (EPA) has set PFAS effects on water quality as a national research priority (EPA 2020).

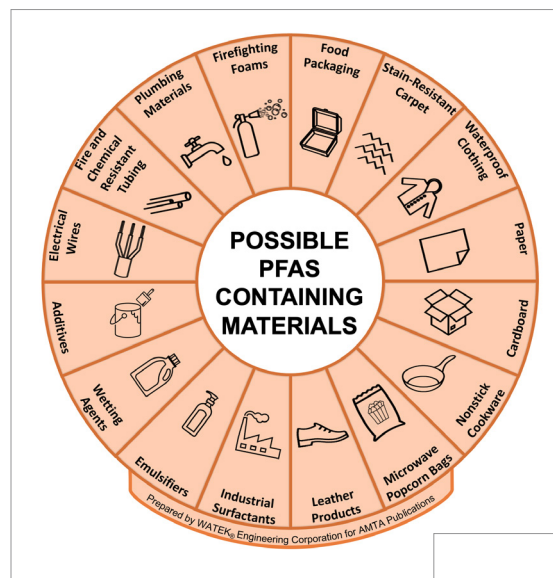
This AMTA Fact Sheet provides useful PFAS resources for membrane practitioners, including: Background Information; Summary of Upcoming and Pending Regulations; Removal of PFAS in Drinking Water Treatment; Pilot and Full Scale PFAS Removal Efficiencies; and Summary and the Future of Membranes in Addressing PFAS/PFOS Contaminants.

### BACKGROUND INFORMATION

The PFAS family of fluorinated synthetic organic compounds are informally referred to as “forever chemicals” because of their resistance to breaking down in the environment.

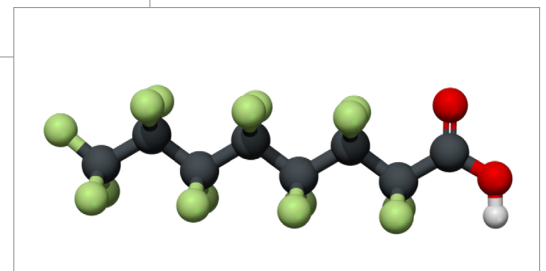
Perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) are the two specific PFAS that have been produced in the largest quantities in the US (EPA 2017). An important characteristic of these chemicals, that has resulted in their versatility, is their ability to repel both oil and water, conferring hydrophobic, hydrophilic, and lipophilic properties. This

has resulted in their use in a large number of industrial and consumer-based products dating back to the 1940s, including food packaging, stain-resistant carpet, waterproof clothing, paper, cardboard, nonstick cookware, microwave popcorn bags, leather products, industrial surfactants, emulsifiers, wetting agents, additives, electrical wires, fire and chemical resistant tubing, plumbing materials, and several kinds of firefighting foams (EPA 2017). While PFOS and PFOA are the most studied of the PFAS group, other replacement chemicals have emerged, including PFBS for PFOS and GenX for PFOA. Refer to **Figure 1** for a sample of materials potentially containing PFAS.



**Figure 1:** Sample of Materials Potentially Containing PFAS

**Figure 2:** Example of PFAS Chain (wikimedia.org)



In addition, the most recalcitrant PFAS—perfluoroalkyl acids (PFAAs)—can be formed via microbially-facilitated environmental degradation of precursor compounds (EPA 2017). Due to their strong chemical bonds, they are highly stable and persistent in the environment (WRF 2016).

These chemicals have been extensively released to the soil, air, and water. They have been detected in solid waste, landfills and surrounding environmental media (i.e., soil, groundwater), leachates, landfill gas, wastewater effluents, biosolids, and drinking water supplies. There is clear evidence of their bioaccumulation and bioconcentration in fish and other wildlife, as well as humans (AWWA 2019, EPA 2017). Direct associations between their presence and non-cancerous and cancerous health impacts, including serious effects on the reproductive, developmental, and immune systems, have been reported (EPA 2017).

## SUMMARY OF UPCOMING AND PENDING REGULATIONS

Due to the high potency and long-lasting potential health impacts, the EPA has issued Lifetime Health Advisories at 70 nanogram per liter (ng/L) for short term exposure to PFOA and PFOS in drinking water, either individually or combined. EPA announced in February 2019 that the agency was embarking on a large-scale program for water sampling, monitoring, remediation, and health effect studies, serving as a foundation for the potential development of a federal maximum contaminant level (MCL). In February 2020, the EPA announced a preliminary regulatory determination, the first step in proposing a regulation for eight contaminants in the fourth Contaminant Candidate List (CCL4), which includes PFOA and PFOS. In addition to the federal action, several states—including California, Michigan, Massachusetts, Vermont, New Jersey, and Rhode Island, among many others—have issued primary standards, response thresholds, or guidance benchmarks for PFAS in drinking water at levels lower than the federal Health Advisory. For example, Massachusetts established a limit of 20 ng/L for the sum of six specific PFAS; Vermont set an MCL at 20 ng/L for PFOA + PFOS; Rhode Island set a limit of 10 ng/L for the sum of six PFAS; and California established Notification Levels of 5.1 and 6.5 ng/L for PFOA and PFOS, respectively. Many states have ongoing efforts for developing or revising guidance and regulations on various PFAS, causing the diffuse regulatory landscape to rapidly evolve.

Perfluorobutanesulfonic acid (PFBS), a replacement for PFOS, has been in military firefighting foam, carpeting, and food packaging, but independent scientists say it may not be much safer than the toxin it replaced. It has been linked with thyroid, kidney, and reproductive problems at very low levels of exposure. While the new assessment is a science document—not a regulatory one—it is expected to impact state and federal regulations.

## REMOVAL OF PFAS IN DRINKING WATER TREATMENT

Unfortunately, data collected from full-scale drinking water facilities indicate that

conventional water treatment processes do not remove PFAS from drinking water supplies. A detailed survey of 15 full-scale drinking water treatment plants, including two potable reuse facilities, determined that conventional treatment methods (including coagulation, flocculation, sedimentation, granular media filtration, ozonation, and/or chlorination) do not lower concentrations of PFAS (Dickenson 2016). Chlorination, ozonation, and advanced oxidation processes are all ineffective for PFAS removal. Granular activated carbon (GAC) will remove PFAS, but may need periodic reactivation or replacement. Likewise, anion exchange (AIX) is effective for PFAS removal but may require periodic regeneration or change-out of spent resin. Nanofiltration (NF) and reverse osmosis (RO) membrane processes will achieve high rejections for most PFAS species; however, their use may create challenges with disposal of the concentrate, which will contain elevated levels of the compounds. Therefore, concentrate management has to be carefully planned. Although NF/RO processes remove long-chain compounds, such as PFOA and PFOS, more efficiently than their short-chain counterparts, both technologies have been demonstrated to be highly effective for the majority of the PFAS family of contaminants, with removals often exceeding 99%.

## PILOT AND FULL SCALE PFAS REMOVAL EFFICIENCIES

Many pilot studies demonstrating PFAS removal with NF/RO membranes have been and continue to be conducted, and full-scale systems are currently under construction. The EPA Treatability Database rates membrane removal by RO as “quite effective,” the highest rating given any process. Pilot results in 2018 from a large, municipal surface water trial in Alabama confirmed this fact. In this trial, a three-month test was conducted

to determine the optimum treatment for PFBS, a short-chain, 4-carbon PFAS of concern. The municipality was already reducing other PFAS in the feed with GAC; however, it is known that GAC is less effective for the short-chain PFAS compounds. Working with the GAC supplier, it was determined that the on-site contactors would have to be substantially expanded to provide at least 40 minutes of contact time for the 11 MGD flow to remove a substantial percentage of PFBS. Thus, both a conventional RO system and a high-recovery, proprietary Closed-Circuit Reverse Osmosis (CCRO) system operating at 90% recovery were piloted.

Final disposal of the PFBS residual stream was a concern, as the RO concentrate would contain high levels of the rejected PFAS. Although current Alabama laws do not regulate the discharge of PFAS, the municipality chose a strategy to repurpose existing activated carbon contactors rather than discharging the PFAS to the environment. Removal results for the CCRO pilot are summarized in **TABLE 1**.

PFAS removal was estimated by comparing incoming PFAS concentrations with those of the concentrate stream. With a 90% RO recovery, the concentrate would be expected to have PFAS levels ten times higher than the feed if all the PFAS were rejected. Variability in data caused by averaging and sampling lag times resulted in some removals calculated above 100%, with others slightly lower; however, the

**TABLE 1. Removal Efficiencies in Pilot Study**

COMPOUND	FEED (NG/L)	PERMEATE (NG/L)	CONCENTRATE (NG/L)	% REMOVAL
PFOA	13	<2	130	100%
PFOS	25	<2	200	>92%
PFBS	7.6	<2	96	100%
PFHxA	7.3	<2	68	>93%
PFHxS	3.0	<2	33	100%
PFHpA	3.6	<2	37	100%

overall removal for the sum of PFAS remained close to 100%. Similar removals have been demonstrated at other pilots, including an extended pilot in North Carolina, where a 41 MGD RO facility is being built (**Figure 3**) for removal of PFAS and other trace organic compounds. Similarly, full-scale wastewater RO facilities used for potable reuse in California have demonstrated complete removal of PFAS from their supplies.

**Figure 3:** PFAS Removal Facility Under Construction in Brunswick County, NC



**FOR MORE INFORMATION:**  
**American Membrane Technology Association (AMTA)**  
 PO Box 14918  
 Tallahassee, FL 32317  
**Phone:** (772) 469-6797  
**Email:** [custsrv@amtaorg.com](mailto:custsrv@amtaorg.com)  
[www.amtaorg.com](http://www.amtaorg.com)



@AmericanMembraneTechnologyAssociation



@amtaorg

## SUMMARY AND THE FUTURE OF MEMBRANES IN ADDRESSING PFAS/PFOS CONTAMINANTS

Considering the widespread presence of PFAS, their persistence, and their toxicity, EPA has indicated their plans for taking concrete actions to address them as one of their highest priorities. In fact, on September 17, 2019, EPA announced allocation of \$6 million to fund research for identification of both short-term solutions and long-term strategies for managing PFAS. This includes the need for cleaning PFAS contaminated sites as well as providing clean, safe, drinking water to impacted members of the public. Along these lines, many water plants are now voluntarily collecting samples to determine PFAS levels in their source water. With an increasing number of utilities finding potentially unsafe levels of PFAS in their supplies, cost effective treatment solutions are needed. For many of these utilities, membranes will provide those solutions, producing safe, reliable drinking water from their existing supplies.

## REFERENCES

- Appleman, Timothy D., Eric R.V. Dickenson, Christopher Bellona, Christopher P. Higgins; 2013; Nanofiltration and granular activated carbon treatment of perfluoroalkyl acids; Journal of Hazardous Materials; 260 (2013) 740
- Appleman, Timothy D., Christopher P. Higgins, Oscar Quinones, Brett J. Vanderford, Chad Kolstad, Janie C. Zeigler-Holady, Eric R.V. Dickenson; 2014; Treatment of poly- and perfluoroalkyl substances in U.S. full-scale water treatment systems; Water Research; 51 (2014) 246-255
- Arevalo, Jorge M., Jonathan Treadway, Trent Jackson; 2019; Pilot Testing Reverse Osmosis to Remove PFOS and Other Emerging Contaminants from a Surface Water Supply; AMTA/AWWA Membrane Technology Conference.
- AWWA, "The PFAS Problem: How Regulators are Responding and What it Means for Drinking Water", October 2019 Volume 111, Number 10
- Dickenson, Eric R.V. and Christopher Higgins; 2016; Treatment Mitigation Strategies for Poly- and Perfluoroalkyl Substances; Treatment Mitigation Strategies for Poly- and Perfluoroalkyl Substances; Water Research Foundation. Web Report #4322.
- EPA – Research Grants – National Priorities: Per- and Polyfluoroalkyl Substances, October 2020
- EPA – Technical Fact Sheet – Perfluorooctane Sulfonate (PFOS) and Perfluorooctanoic Acid (PFOA), November 2017
- Kissa, E. Fluorinated Surfactants and Repellents, Taylor & Francis Inc, 2001
- Lipp, P., Sacher, F., and Baldauf, G.; 2010; Removal of organic micro-pollutants during drinking water treatment by nanofiltration and reverse osmosis; Desalination and Water Treatment; 13: 226-237
- Prevedouros, K.; I. T. Cousins, R. C. Buck and S. H. Korzeniowski, Sources, Fate and Transport of Perfluorocarboxylates, Environ. Sci. Technol., 2006, 40, 32–44
- Quinones, O. and S.A. Snyder; 2009; Occurrence of Perfluoroalkyl Carboxylates and Sulfonates in Drinking Water Utilities and Related Waters from the United States; Environmental Science & Technology; 43 (24): 9089-9095
- Steinle-Darling, E., and Reinhard, M.; 2008; Nanofiltration for Trace Organic Contaminant Removal: Structure, Solution, and Membrane Fouling Effects on the Rejection of Perfluorochemicals; Environ. Sci. Technol.; 42: 5292
- Steinle-Darling, E., Litwiller, E., and Reinhard, M.; 2010; Effects of Sorption on the Rejection of Trace Organic Contaminants During Nanofiltration; Environ. Sci. Technol.; 44, 2592
- Thompson, J., Eaglesham, G., Reungoat, J., Poussade, Y., Bartkowiak, M., Lawrence, M. and Mueller, J.F.; 2011; Removal of PFOS, PFOA and other perfluoroalkyl acids at water reclamation plants in South East Queensland Australia; Chemosphere; 82:9-17
- USEPA. Drinking Water Treatment Database. <https://iaspub.epa.gov/tdb/pages/general/home.do>
- Water Research Foundation, Treatment Mitigation Strategies for Poly- and Perfluoroalkyl Substances, Project Number #4322, February 2016