



Combined Reverse Osmosis/Adsorbent Technology for PFAS Reduction in Drinking Water

OVERVIEW

DuPont engaged the National Sanitation Foundation (NSF) to test the efficacy of combining reverse osmosis (RO) with ion exchange (IEX) commercially available products to demonstrate the capability of these two technologies together to achieve removal levels of per- and polyfluoroalkyl substances (PFAS) from water sources containing various levels to below detectable limits. This paper describes the details of the study, which can inform those stakeholders, including but not limited to, cities, municipalities, manufacturers, academic institutions, and other academic or industry groups looking to implement effective solutions to remove PFAS from affected water streams.

PFAS Introduction

The family of synthetic compounds known as per- and polyfluoroalkyl substances (PFAS) have been in use in various applications since the 1940's.¹ These compounds have been used in multiple industries including textile coverings for oil and water repellency, cookware coating, formulation of firefighting foams, and in materials used in the automotive and electronics industries. More recently, detection of PFAS in groundwater sources and the issuance of a health advisory level by the U.S. Environmental Protection Agency for PFAS has spurred development of treatment technologies for PFAS containing waters.^{2,3}

PFAS TREATMENT TECHNOLOGY

Reduction of PFAS in groundwater and drinking water has been approached with multiple traditional water treating technologies. In the water treatment industry, Granular Activated Carbon (GAC) and Anion Ion Exchange (IEX) are widely acknowledged as fully demonstrated treatment technologies with the ability to treat PFAS containing waters to non-detect levels or to concentrations below advisory levels.⁴ Reverse Osmosis (RO) is a well-established drinking water purification technology and has been demonstrated to effectively reject a wide array PFAS compounds to produce a high purity permeate stream. A common criticism of RO application to any trace contaminant treatment is that the process generates a liquid concentrate or rejection stream that is more highly concentrated in the contaminant of concern, which would likely be returned to the source of the water or introduced to another location if left untreated or uncollected. By combining RO with an IEX step, PFAS can be removed from affected water deeming the post-treated stream compatible for discharge or reuse.

In cases where RO is already installed, it may be desirable to reduce or eliminate the PFAS components of the concentrate stream. Installation of GAC or IEX modules to the reject stream should allow RO users to achieve a total PFAS reduction while maintaining a high quality permeate water source via RO. This could be applicable to streams as large as municipal plants that utilize RO to treat well water or surface water for distribution to residential customers or to small scale point-of-use systems where under sink RO concentrate could be treated.



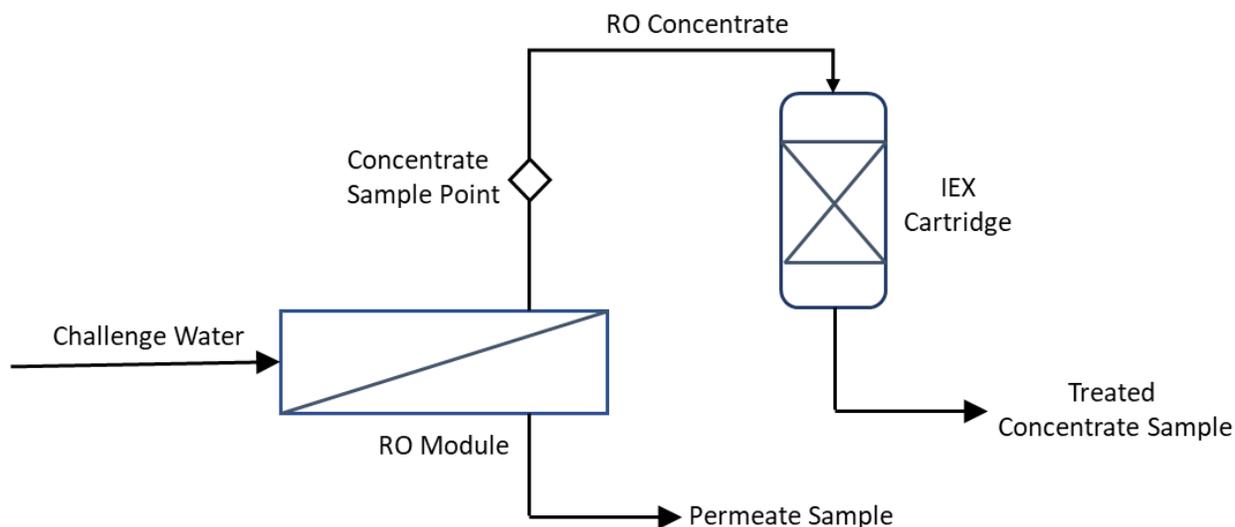
TREATMENT MODULES

A commercially available small-scale RO system, typically used for home applications, was purchased and the RO vessel of the module was fitted with a FILMTEC™ 1812 sized element. The specific element used in the test was the AQUALAST™ 1812-HR element, a residential RO element with high salt rejection properties. The pretreatment components of the module were removed so that test water would encounter the RO membrane at entry. The commercially available system was equipped with a permeate polisher that was also removed from service, allowing permeate to flow directly to a RO storage tank.

The concentrate stream was directed to a housing containing IEX resin contained in a refillable cartridge sized for the housing. The cartridge employed in the study was obtained from an online vendor and allowed a media compartment of 2.5" in diameter and 9.75" in media depth. This equaled a fill volume of approximately 48 cubic inches or 0.78 liters.

The specific IEX resin applied in this study was AMBERLITE™ PSR2 Plus Resin, a strong base anion resin. Originally developed as a perchlorate selective resin, the PSR2 Plus is a gel type resin with a uniform particle size with hydrophobic active sites that also lend selectivity to the PFAS family of compounds. All filtration components in the study are certified as NSF/ANSI 61 compliant.⁵ It should also be noted that two threaded connections on the filter housing were sealed with a silicone material, Dow Corning 732 multi-purpose sealant, as an alternative to PTFE thread seal tape. This sealant is 100% silicone and is also NSF/ANSI 61 compliant.

Figure 1. Treatment train schematic with sample points indicated:



TEST METHODS

The RO module was subjected to NSF/ANSI 58 standard test methodology, with sampling techniques and frequency dictated by the standard.⁶ The challenge water, in addition to the typical total dissolved solids (TDS) requirements of the standard, included perfluorooctanoic acid (PFOA) with a targeted concentration of 500 parts per trillion (ppt) and perfluorooctane sulfonic acid (PFOS) with a targeted concentration of 1000 ppt. In addition to permeate water testing to quantify total PFOA and PFOS rejection, the inlet and outlet streams to the IEX housing were sampled at the same time intervals to ensure testing integrity and data consistency. As the RO module was subject to automatic shutdowns due to storage tank filling, it was



possible for the unit to be idle when sampling was due. Additional protocols were implemented to ensure that the system would be running prior to sampling of media treated concentrate. Specifically, if starting at idle, the system was setup to run for 30 minutes prior to collection of the treated concentrate. The RO concentrate, after sample line flushing, was always collected immediately following the collection of the media treated sample. All liquid samples were submitted for analysis by EPA Method 537.1.⁷

All testing was performed at NSF International in Ann Arbor, Michigan. The testing phase and sampling were conducted exclusively by NSF personnel. All analytical work was performed by the internal lab at NSF International in Ann Arbor, Michigan. Limits of detection for PFOA and PFOS were both reported as 20 nanograms per liter (ng/L) by the lab.

RESULTS

Table 1. RO and IEX System Test Results

Time (hrs)	Influent Water (ng/L)		RO Permeate (ng/L)		RO Concentrate (ng/L)		IEX Treated (ng/L)	
	PFOA	PFOS	PFOA	PFOS	PFOA	PFOS	PFOA	PFOS
4	540	1200	ND	ND	650	1300	ND	ND
12	510	1200	ND	ND	590	1500	ND	ND
24	530	1200	ND	ND	650	1400	ND	ND
30	370	860	ND	ND	510	1200	ND	ND
36	370	940	ND	ND	460	1200	ND	ND
48	420	1000	ND	ND	520	1300	ND	ND
54	370	780	ND	ND	470	1100	ND	ND
60	350	880	ND	ND	470	1100	ND	ND
72	370	910	ND	ND	440	1200	ND	ND
78	390	1000	ND	ND	470	1300	ND	ND
84	330	770	ND	ND	480	1200	ND	ND
144	380	680	ND	ND	490	1200	ND	ND
148	400	870	ND	ND	479	1200	ND	ND

DISCUSSION

The first key takeaway from the testing is that RO membranes are effective at rejecting PFOA and PFOS from an inlet stream of water to produce a permeate stream that is non-detect for both analytes. While this is not necessarily a surprising result given the general properties of RO filtration, confirmation while subjected to a standard test condition is a necessary step in considering RO for PFAS removal. Building the database of specific RO element performance at various inlet concentrations also indicates expected performance when treating PFAS containing waters.

Second, the IEX cartridge containing AMBERLITE PSR2 Plus resin was effective at treating the RO concentrate to a non-detect level for both PFAS. As outlined in Table 1, all samples for the IEX treated stream were non-detect for PFOA and PFOS at each sampling point, with total PFAS concentrations approaching 2000 ng/L in some test periods.



FUTURE WORK AND SCALABILITY

The system demonstrated in this test paired two technologies and showed the potential utility of using multiple technologies in a single treatment system for PFAS reduction in water. The demonstration should also be considered further validation of the individual technologies, as decoupling the treatment units is also an appropriate handling of the data. As a standalone technology, RO filtration is capable of reducing levels of PFOA and PFOS to non-detect in the permeate or product stream. It is expected that higher flow rates across a single element of larger size would yield similar results, however an area for future validation is the investigation of PFAS rejection across multiple elements and where multiple stages of RO filtration are installed. Similarly, direct treatment of water by IEX is further validated for the reduction of PFOA and PFOS and is easily scaled for similar quality water as IEX is already a high recovery technology and increases in vessel size would accommodate higher volumetric flow rates while keeping other treatment parameters constant (i.e. bed volumes per hour, gpm/ft²).

A clear area for further evaluation of the specific technology components is treatment of other PFAS. The challenge water outlined in the NSF/ANSI 58 standard calls only for rejection of PFOA and PFOS, the PFAS most commonly regulated or subject to health advisory levels. However, it is uncommon for a PFAS containing water source to have only these two components. Membrane rejection data for shorter chain components can provide additional guidance for technology selection, and the ability of an adsorbent to treat other PFAS also guides feasibility for treating concentrate streams. Another application that warrants investigation is treatment of an RO concentrate stream with GAC, which is another fully demonstrated treatment technology. With appropriate sizing, a concentrate stream should be treatable to non-detect levels of PFAS using GAC as an adsorbent.

Finally, membrane and adsorbent performance should also be evaluated with alternative source waters. The challenge water used in this evaluation most similarly resembles municipal drinking water or well water, but changing the source to surface water or brackish water will potentially impact performance and ultimately, technology selection.

In summary, RO membranes have effectively reduced PFOA and PFOS levels to non-detect in drinking water using a commercially available small-scale system. The permeate stream tested clear of detectable PFAS in all samples during the evaluation. Treatment of the concentrate stream with anion ion exchange resin also produced a stream of water with non-detect levels of PFAS, allowing for removal and isolation of the two compounds from a water source.

CONCLUSIONS

In conclusion, this test demonstrates the following:

- RO is an effective technology to remove PFOA and PFOS by size exclusion mechanism of this technology.
- IEX is an effective technology to remove PFOA and PFOS by absorption onto the media for trace contaminant removal of water ecosystem.
- The combination of RO with an IEX media in this example provides two streams: (1) a permeate stream suitable for use as potable water meeting drinking water standards for PFOA/PFOS; and (2) a treated concentrate whose utility will depend on the level of other contaminants in the source water, but which meets standards for PFOA/PFOS, eliminating the return of such components back to the environment.



- Such technologies could be considered for point-of-use/point-of-entry for small scale water needs.
- Further work to scale these combined technologies for municipal operations would be required to define flows and system sizing based upon overall feed water conditions.

REFERENCES

1. Kempisty, D.M., Xing, Y., & Racz, L. (Eds.). (2018). *Perfluoroalkyl Substances in the Environment: Theory, Practice, and Innovation*. Boca Raton, FL: CRC Press.
2. U.S. Environmental Protection Agency. (2016). *Drinking Water Health Advisory for Perfluorooctane Sulfonate (PFOS)*. Office of Water (4304T). Health and Ecological Criteria Division, Washington, DC 20460. *EPA Document Number: 822-R-16-004*.
3. U.S. Environmental Protection Agency. (2016). *Drinking Water Health Advisory for Perfluorooctanoic Acid (PFOA)*. Office of Water (4304T). Health and Ecological Criteria Division, Washington, DC 20460. *EPA Document Number: 822-R-16-005*.
4. Interstate Technology & Regulatory Council. (15 March 2018). *Remediation Technologies and Methods for Per- and Polyfluoroalkyl Substances (PFAS)* [Fact sheet]. Retrieved from <https://pfas-1.itrcweb.org/fact-sheets/>.
5. NSF International. (2018). *NSF/ANSI/CAN 61 – 2018: Drinking Water System Components – Health Effects*. Ann Arbor, MI.
6. NSF International. (2019). *NSF/ANSI 58 – 2018: Reverse Osmosis Drinking Water Treatment Systems*. Ann Arbor, MI.
7. Shoemaker, J. AND Dan Tettenhorst. *Method 537.1: Determination of Selected Per- and Polyfluorinated Alkyl Substances in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS)*. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, DC, 2018.

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