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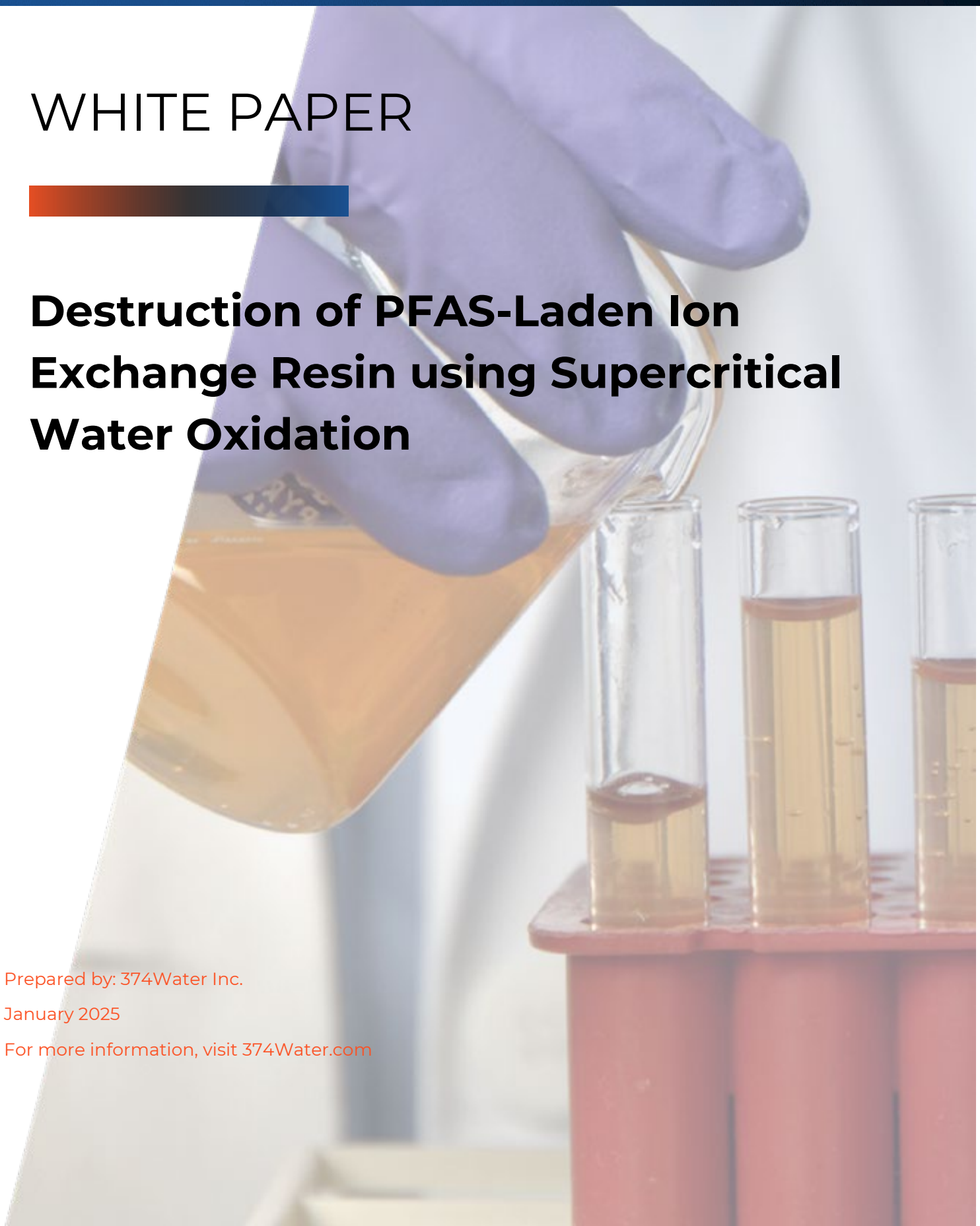
WHITE PAPER

Destruction of PFAS-Laden Ion Exchange Resin using Supercritical Water Oxidation



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Introduction

Ion exchange (IX) resins are used widely across various industries due to their proven performance in removing nuisance contaminants that impact product quality and safe effluent discharge. IX is a leading purification and separation process because the resins are generally stable and long-lasting through multiple regeneration cycles. However, IX resin regeneration is not infinite. Once the resin is spent (i.e. saturated), effective disposal methods must be used to prevent the release of concentrated hazardous contaminants to the environment. Of particular concern is the disposal of spent anion IX (AIX) resin laden with per- and polyfluoroalkyl substances (PFAS). The current status quo of landfilling or incinerating PFAS-laden spent AIX resin can lead to the leaching of PFAS into soil and groundwater systems and/or release of PFAS into the air.

As with most countries, the U.S. GAC (granular activated carbon) and ion exchange (IX) resin markets are crucial for the drinking water and industrial wastewater treatment industry. GAC is widely used for removing organic pollutants, while IX resins are employed in specific industrial and municipal applications to target ions like heavy metals and nutrients. These combined markets are valued in the billions, driven by a growing demand for clean water solutions.

Spent media management, including spent GAC and IX resins, represents a $1.3 billion annual market in the U.S. alone. Traditional regeneration or disposal processes often generate secondary waste, logistical challenges, and environmental concerns. Supercritical water oxidation (SCWO) addresses these issues by destroying organic pollutants in spent media, recovering valuable resources such as carbon and nutrients, and producing clean water. This approach exemplifies the circular economy by transforming waste into reusable resources while reinforcing the water-energy nexus.

This white paper highlights results from treating PFAS laden AIX in bench and commercial scale field trials using 374Water's supercritical water oxidation (SCWO) system (AirSCWO). Appropriate pre-treatment methods were developed to process the resins into a pumpable slurry with enough caloric input for autothermal operation at steady state. SCWO treatment of the slurries was tested at 374Water's US based Biosafety Level 1 lab using their bench scale AirSCWO system and at Duke University using 374Water's highly mobile pilot AirSCWO system.

Background on Treating PFAS using Anion Exchange Resins

What is Anion Exchange Resin and why is it used to remove PFAS?

Anion exchange (AIX) resins are specifically engineered resins used to treat PFAS in groundwater, surface water, process water, AFFF impacted waters, and leachate. PFAS is separated from the solution because it gets "caught" on the resin which has an affinity for the charged sites on the PFAS molecules (Figure 1, Figure 2). In general, AIX can remove both long-chain and short-chain PFAS although additional research is needed to elucidate how PFAS functional groups and structures impact short vs long-chain PFAS removal efficiency.

While single use absorbents are currently used to remove PFAS from water, most absorbents used for PFAS removal are broad and will co-concentrate competing contaminants such as organics, sulfates, and nitrates. The co-competition effectively reduces the effective treatment volume of the absorbents. In comparison, AIX resins have shown significant improvement in capacity and time to breakthrough/change-out as compared to other PFAS absorbents (Woodward, 2017). These factors make AIX a leading choice amongst an evolving market of PFAS water absorbing materials. AIX's capability to remove a broad range of PFAS underscores the need to pair AIX treatment with an appropriate disposal and treatment/destruction technology. One that exceeds the current status quo and can mineralize a broad range of short and long chain PFAS molecules more effectively than current disposal standards.

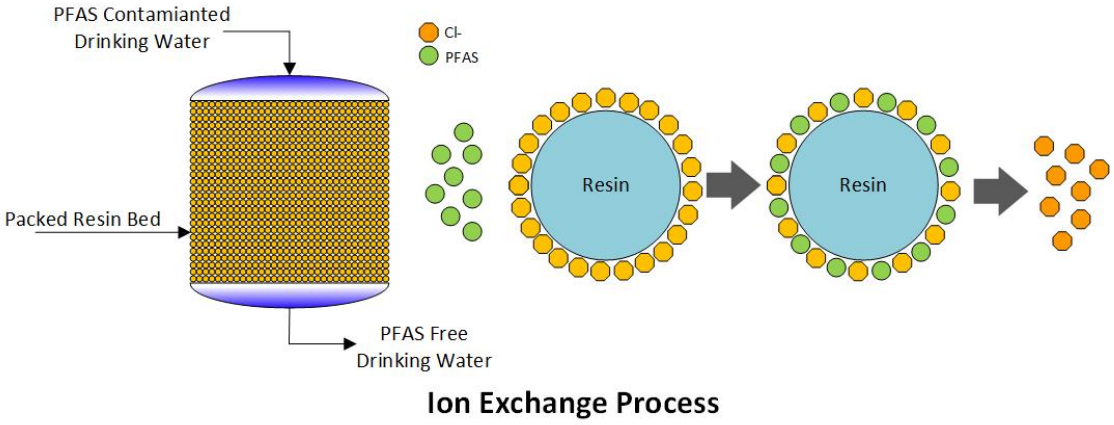

Figure 1: Conceptual diagram of using an anion exchange resin to separate PFAS from drinking water. (Credit: Adapted from Lanlang Corp).

Figure 2: Example of commercial fiberglass vessels filled with ion exchange resin for groundwater treatment (Credit: Water Innovations Inc).

AirSCWO Technology for PFAS Destruction

AirSCWO harnesses the power of supercritical water to destroy organic waste streams resulting in clean water, mineral effluent, clean vent gas and recoverable heat energy. SCWO is an advanced oxidation process that involves breaking down hazardous and non-hazardous organic compounds at elevated temperatures and pressures (>374°C, >221 bar). The process is unique as compared to many alternative PFAS treatment technologies in that PFAS and their precursors are broken down into inert fluoride salts without producing harmful PFAS by-products in the vent gas, water, or mineral outputs (Figure 3).

Figure 3: Conceptual diagram of the inputs and outputs of AirSCWO when treating PFOA-laden waste (credit: 374Water).

AirSCWO indiscriminately eliminates a broad range of recalcitrant organic wastes in addition to PFAS, such as microplastics and antibiotics with high efficiency. Notable results from treating PFAS laden AIX resins using AirSCWO include:

- **Broad, highly efficient PFAS elimination**: Total PFAS from AIX resins was eliminated by >99.9% using targeted PFAS analysis methods. Comprehensive destruction was achieved regardless of chain length (short- or long-chain) or class (sulfonate- or carboxyl-terminated).
- **High throughput**: Operation at temperatures and pressures above the critical point of water facilitate rapid and complete destruction of even the most stable PFAS compounds (Savage, 1999), with a typical reactor residence time of <15 seconds.
- **Environmental Safety**: Converts hazardous compounds into benign byproducts like water, CO_2, and minerals while reducing solids volume requiring handling by >80%.

System Trials

Lab-Scale AirSCWO Performance

Initial lab-scale testing of the AirSCWO system focused on destroying PFAS laden AIX in controlled conditions. At the lab-scale, AirSCWO destroyed PFAS-laden AIX used for groundwater treatment with the following benefits:

- **Near completed PFAS elimination**: Third party validated destruction of >99.99% total PFAS within 20 seconds, as measured by targeted analysis.
- **Data to scale**: The success on the lab scale system, which is designed to mimic the commercial scale unit, validated the progression to test the waste on a larger unit at similar conditions.

AirSCWO 1: 1 Wet Tonne Per Day System Performance

The AirSCWO 1 (AS-1) was initially developed to provide essential data on operational efficiency and scalability for real-world AIX resin waste management scenarios. The AirSCWO 1 has proven to be a highly mobile commercial-scale waste destruction unit. Key results on this system include:

- **Verified PFAS elimination performance**: Results of PFAS elimination on the AS-1 matched lab-scale results, achieving an overall >99.99% PFAS destruction efficiency (Table 1).
- **Operational Feasibility**: Demonstrated consistent performance, proving effective destruction of waste as part of a demonstration contract for the US Environmental Protection Agency and US DoD.

Table: Results from running PFAS-laden spent AIX through 374Water's AirSCWO system.

	Spent IX Feedstock	Effluent	Effluent control	Corrected effluent	Rate-based removal	Rate-based (corrected) removal
	ng/kg	**ng/L, ppt**	**ng/L, ppt**	**ng/L, ppt**	**%**	**%**
Total PFCA	260,218.52	1.04	1.02	0.02	99.97%	100.00%
Total PFSA	1,092,234.96	70.83	98.674	7.256	99.52%	100.00%
Precursors	33,256.92	5.13	ND	1.39	98.85%	99.70%
Short chain	84,383.95	0.97	0	0.97	99.91%	99.90%
Total	**1,385,892.83**	**77**	**104.664**	**8.666**	**99.59%**	**99.95%**

Note: Short chain precursors are those with C<6.

AirSCWO 6: 6 Wet Ton Per Day System

The AirSCWO 6 (AS-6) model was designed for continuous throughput of larger quantities of waste, particularly for mid-sized municipal use, federal agencies and industrial applications with high volumes of waste. Key results on this system include:

- **Industrial-Scale Performance**: Demonstrated reliable, continuous operation at full capacity, efficiently processing high volumes of ion exchange (IX) resins.
- **Environmental Compliance**: Currently under evaluation, with pending data expected to confirm compliance with stringent project-specific regulatory and environmental performance standards.

Conclusion

AirSCWO presents a revolutionary approach to PFAS destruction, offering unmatched efficiency and safety for treating spent PFAS-laden AIX resin. On both the lab-scale and commercial scale, the AirSCWO system consistently achieved >99.9% total PFAS elimination of saturated AIX resins in a matter of seconds. The AirSCWO technology is positioned to meet the growing spent media market (estimated at $1.3 billion USD as of 2024), at a level that exceeds the performance requirements for PFAS treatment. AirSCWO provides an essential tool for managing the treatment of commercially available PFAS concentration technologies such as AIX resin.

References

Schaefer, Charles E., et al. “Assessing rapid small-scale column tests for treatment of perfluoroalkyl acids by anion exchange resin.” *Industrial & Engineering Chemistry Research*, vol. 58, no. 22, 16 May 2019, pp. 9701–9706, https://doi.org/10.1021/acs.iecr.9b00858.

Water Innovations Inc. “HFX – High Flow Ion Exchange.” *Deionization and Recycling | Ion Exchange Water Recycling |Metal Scavenging*, waterinnovations.net/high-flow-ion-exchange-systems/. Accessed 15 Jan. 2025.

Woodard, Steve, et al. “Ion Exchange resin for PFAS removal and pilot test comparison to GAC.” *Remediation Journal*, vol. 27, no. 3, June 2017, pp. 19–27, https://doi.org/10.1002/rem.21515.

Zaggia, Alessandro, et al. “Use of strong anion exchange resins for the removal of perfluoroalkylated substances from contaminated drinking water in batch and continuous pilot plants.” *Water Research*, vol. 91, Mar. 2016, pp. 137–146, https://doi.org/10.1016/j.watres.2015.12.039.