Facing the Challenge of Per- and Poly-fluoroalkyl Substances (PFAS): Does Ion Exchange Process Offer a Solution for in-home Water Treatment?

Fatemeh Asadi Zeidabadi, Ehsan Banayan Esfahani, and Madjid Mohseni
Chemical and Biological Engineering Department, University of British Columbia, Vancouver, BC, V6T 1Z3, Canada

WQRF Water Quality Research Foundation

UBC SWIRL SUSTAINABLE WATER AND INNOVATION RESEARCH LAB

Abstract: PFAS – today's world issue

With near-ubiquitous per- and poly-fluoroalkyl substances (PFAS) contamination due to decades of fluoropolymer usage, a diverse suite of PFAS have migrated into the water sources around the world, endangering drinking water (DW) for millions of people.

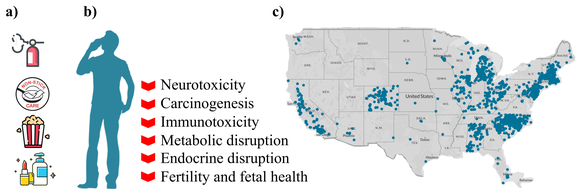

Fig. 1 PFAS a) Applications, b) Adverse health impacts c) US contaminated DW sites [1].

PFOA, a well-known PFAS, has drawn substantial attention due to its frequent detection in the environment. It has been added in the Candidate List of Substances of Very High Concern. Given the undesired impact of PFOA, its applications have been replaced by fluorinated alternatives such as PFBA, GenX, and 6:2 FTCA. However, the occurrence of these alternatives has been also reported in treated drinking waters [2].

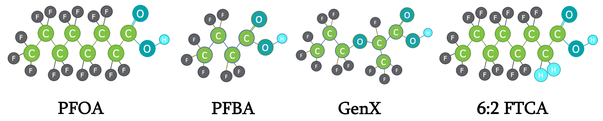

Fig. 2 Chemical structures of PFOA and its common alternatives

Ion Exchange (IX) process stands out as a promising technique for removing diverse PFAS structures from contaminated waters, particularly excelling in eliminating emerging short-chain PFAS that may resist carbon-based adsorption methods. Its rapid PFAS sorption kinetics make it well-suited for in-home water treatment filters, aligning with their typical conditions [3,4]. This study shows the effective removal of PFAS ~80-100% (dependent on PFAS/resin types) and optimum average PFAS regeneration recoveries of ~35-70% (dependent on PFAS/resin/regenerant types).

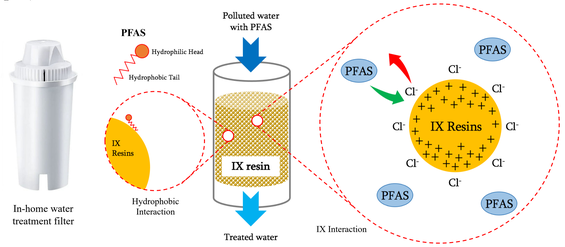

Fig. 3 In-home water treatment filter and mechanisms of ion-exchange (IX) process

Methodology: PFAS Adsorption and Regeneration Recoveries

PFAS Adsorption on IX Resins

Adsorption of a mixture of 4 types of PFAS (PFOA and its alternatives) on 4 types of IX resins

5 g fresh resin

500 ml solution of 100 ppm of each PFAS

In jar tester for 48 h

Strongly basic, Polyacrylic, Macroporous, Quaternary Ammonium

Strongly basic, Polystyrene, Gel, Quaternary amine PFAS Specific

Resin A | Resin B | 4 types of IX resin | Resin C | Resin D

Strongly basic, Polyacrylic, Quaternary ammonium

Polystyrene, Complex Amino PFAS Specific

PFAS Regeneration Recoveries

Desorption of PFAS from pre-loaded IX resins using 5 types of salts in the range of 0.1-8% w/v

0.1 g loaded resin

40 ml solution of each condition

In shaker for 3 h at 150 rpm

Results: PFAS Adsorption on IX Resins

- PFAS-specific resins (C and D) exhibited slower adsorption kinetics compared to non-PFAS specific resins (A and B).
- Adsorption of PFAS on resins A and B reached a saturation point, while the PFAS-specific resins achieved >99.9% removal efficiency without reaching saturation, highlighting their superior capacity for PFAS uptake.
- It is evident that long-chain PFOA exhibits a faster adsorption rate compared to shorter chain (PFBA and GenX) and fluorotelomer PFAS (6:2 FTCA).
- This shows the practical application of IX resins for effective removal of various structures of PFAS with fast kinetic and high capacity.

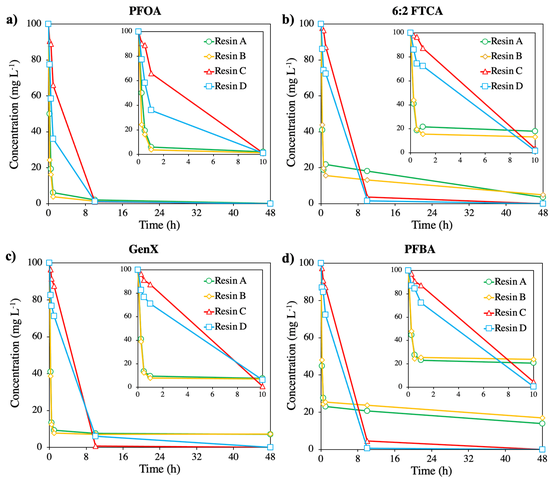

Fig. 4 Adsorption of PFOA and its alternatives on different types of IX resins.

Results: PFAS Regeneration Recoveries

- Regenerable non-PFAS specific resins (A and B) surpass single-use PFAS specific resins (C and D) in recovery.
- 1% salt dosage excels 0.1% and 8% dosages, with average PFAS regeneration recoveries of 22.3%, 29.3%, and 27.5%, respectively.
- Regeneration recoveries of salts follows: NaCl > Na_2SO_4 > $NaHCO_3$ > $(NH_4)_2SO_4$ > NaOH.
- PFAS regeneration efficiencies follow the order of PFBA > GenX ≈ 6:2 FTCA > PFOA, conversing the adsorption kinetic order with IX resins.
- Addition of organic solvent (e.g., methanol) enhanced regeneration recoveries, specially for long-chain PFAS and PFAS-specific resins.

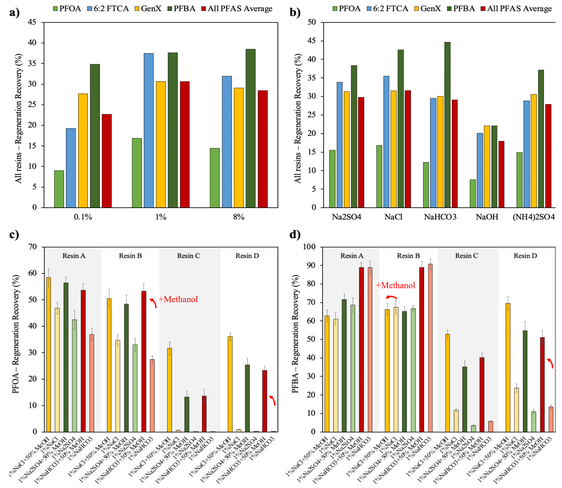

Fig. 5 PFAS Regeneration by salt dosage (a), type (b), and methanol impact (c & d).

Conclusions and Recommendations

Conclusions:

- PFAS-specific resins, while having slower adsorption kinetics, possess substantial capacities for effectively removing various PFAS structures. Despite known as single-use resins, we regenerated them to significant extents, varying based on the type of PFAS and the resins employed.
- Longer-chain PFAS are more readily adsorbed, yet their regeneration is slower. Conversely, shorter chains pose challenges in capture but exhibit easier regeneration.
- The introduction of an organic solvent, such as methanol, notably improved regeneration recoveries, particularly for long-chain PFAS and PFAS-specific resins.

Recommendations:

- This study highlights the viability of IX resins for in-home water treatment filters (aka point-of-use (POU) and point-of-entry (POE)). With their superior kinetic performance and higher PFAS removal capacity, especially for short-chain variants, as opposed to carbon-based adsorbents, coupled with the added benefit of regeneration, IX resins emerge as a recommended choice for POU/POE applications.
- Adsorption and regeneration recoveries of a wider range of PFAS along with the management of PFAS-rich regenerant (e.g., destruction through electrochemical techniques) should be the focus of further research which are active areas of investigation in our laboratory.

Acknowledgement

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References

[1] EWG, 2022, ewg.org/interactive-maps/pfas_contamination/map

[2] Domingo, J. L., & Nadal, M. (2019). Human exposure to per- and polyfluoroalkyl substances (PFAS) through drinking water: A review of the recent scientific literature. Environmental research, 177, 108648.

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[4] Zeidabadi, F. A., Esfahani, E. B., & Mohseni, M. (2023). Effects of Water Matrix on Per-and Poly-fluoroalkyl Substances (PFAS) Treatment: Physical-separation and Degradation Processes–A review. Journal of Hazardous Materials Advances, 100322.