Removal & Destruction of PFAS in Water

<u>CDM Smith</u>

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SERDP
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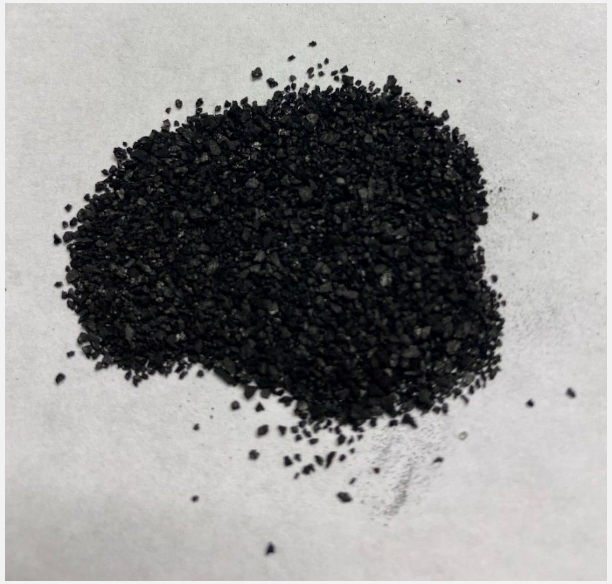
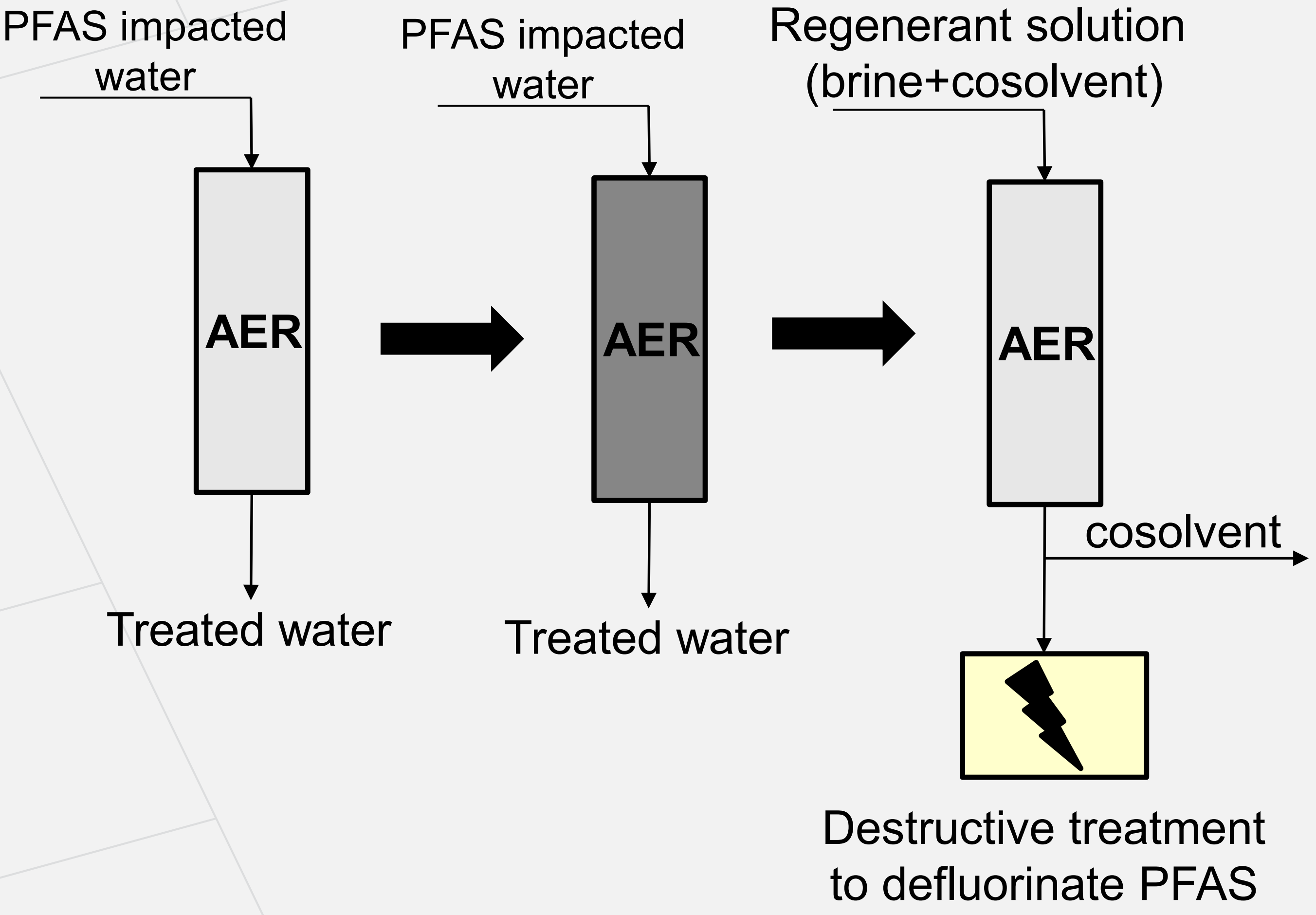
PFAS Treatment in Water

- Focus on drinking water for full-scale treatment
- Granular activate carbon (GAC) and anion exchange resin (AER) most common approaches
  - *NF/RO*
  - *Emerging technologies (novel sorbents, foam fractionation)*
- Treatment effectiveness using GAC/AER often not well understood
  - *Longevity among various GAC/AER products*
  - *Impacts of water geochemistry or pre-treatment*
  - *Various classes of PFAS*
- Need for scalable bench-scale testing in relatively short timeframes
- Spent GAC/AER
  - *Treatment of AER regeneration residuals*



Electrochemical Treatment of Regeneration Brines



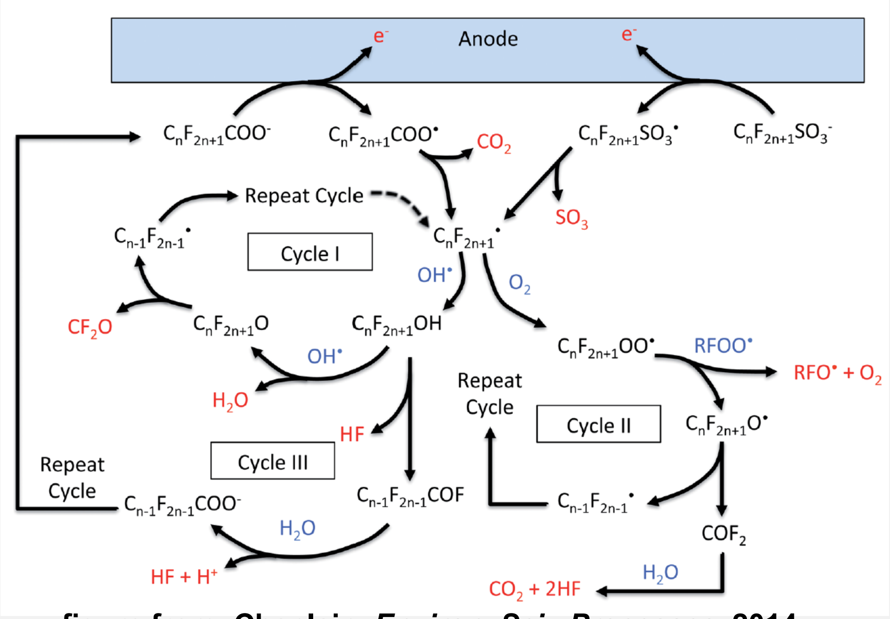


figure from: Chaplain, *Environ. Sci.: Processes*, 2014

Contents lists available at ScienceDirect

Chemical Engineering Journal Advances

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ELSEVIER

Treatment of perfluoroalkyl acids in concentrated wastes from regeneration of spent ion exchange resin by electrochemical oxidation using Magnéli phase Ti_4O_7 anode

Lu Wang[a], Michael Nickelsen[b], Sheau-Yun (Dora) Chiang[c], Steven Woodard[b], Yaye Wang[a], Shangtao Liang[d], Rebecca Mora[d], Raymond Fontanez[a], Hunter Anderson[e], Qingguo Huang[a,*]

Rapid Small Scale Column Tests (RSSCTs) for Evaluating PFAS Removal using GAC/AER

- By reducing the particle size, column testing can be performed using a much shorter residence time than required for a full-scale system, thus obtaining rapid results

- Smaller particle sizes allow for smaller column diameters, and ultimately less water needed for the study

- Our approach: GAC/AER particle size reduction of 3 to 4X
  - *limit any potential laboratory artifacts*
  - *proper evaluation of possible permeability losses*

- Scaling Requirements

to neglect dispersion: $200 < ReSc < 200{,}000$

constant diffusivity: $\frac{EBCT_G}{EBCT_U} = \left(\frac{d_G}{d_U}\right)^2$

is this appropriate for PFAS?

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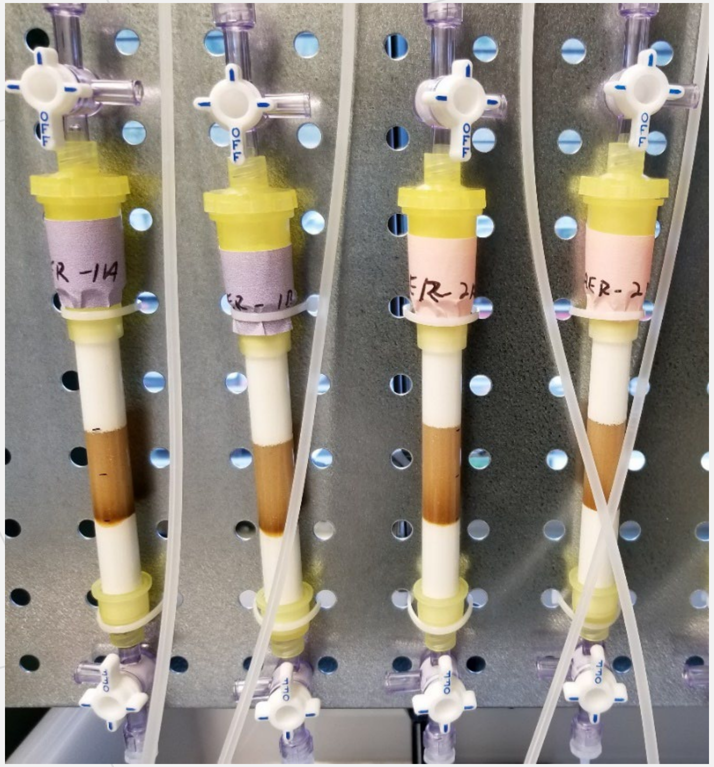
RSSCT Testing to Assess Scaling



1 cm diam. columns for GROUND
(2.5 cm for UNGROUND)

- 1 GAC & 2 AERs
- Low (<1 mg/L) and high (2.5 mg/L) TOC natural waters
- Comparison of GROUND to UNGROUND particles
- GROUND particle size ~0.2 mm
- Evaluate PFAS elution (perfluoroalkyl acids)

RSSCT Experiments

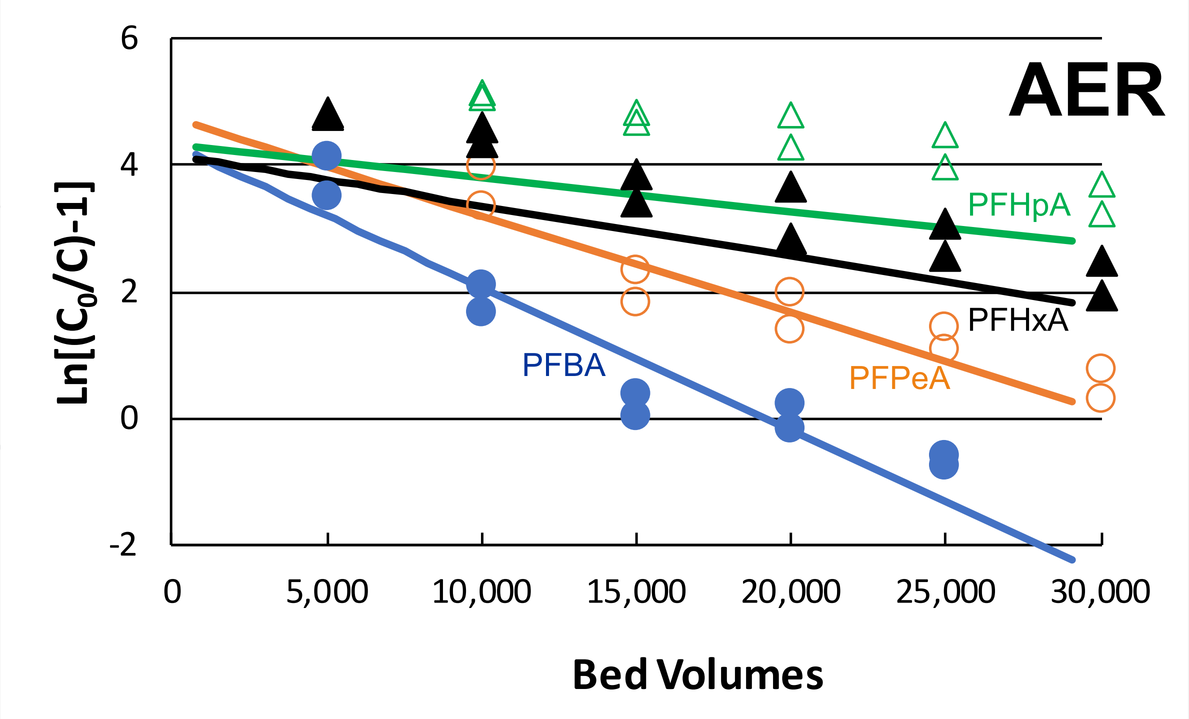
Column Operation

	EBCT (empty bed contact time)
GAC – UNGROUND	10 min
GAC – GROUND	0.8 min
AER – UNGROUND	3 min
AER – GROUND	0.2 min

Application of Thomas Model to Evaluate PFAS as a Function of Bed Volumes (BV)

$$ln\left[\frac{C_0}{C}-1\right]=\left(\frac{kmq_0}{Q}\right)-[EBCT]kC_0BV$$

RSSCT Results: Scaling (UNGROUND used to predict GROUND)



I&EC research
Industrial & Engineering Chemistry Research
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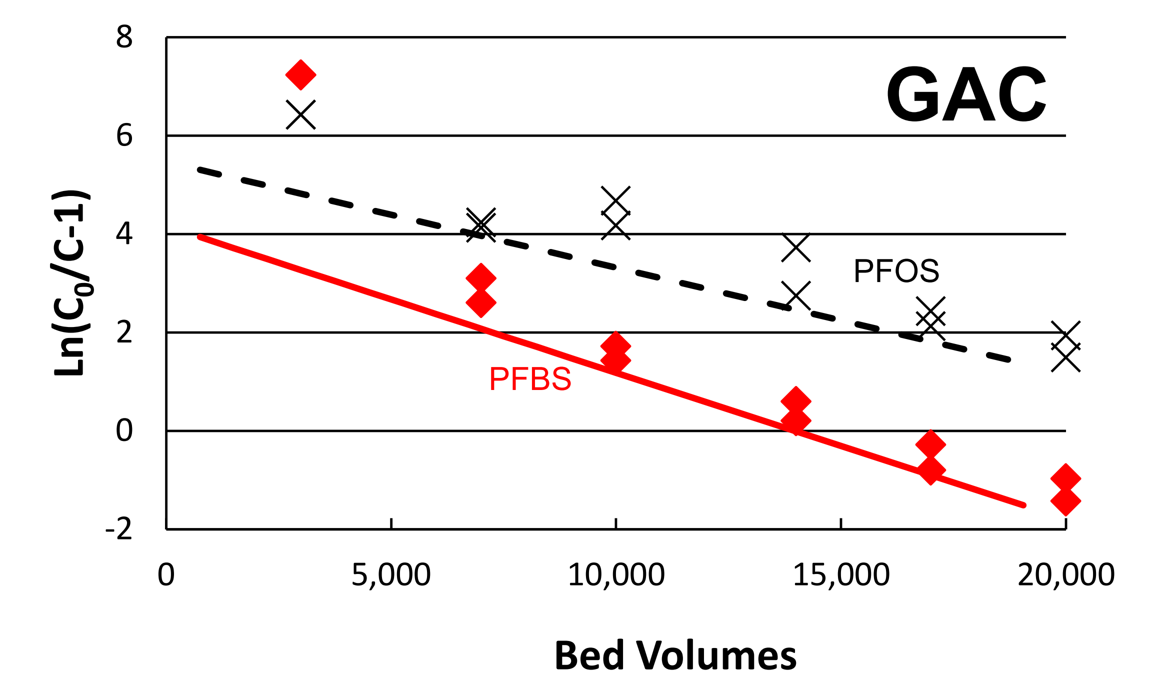
Article

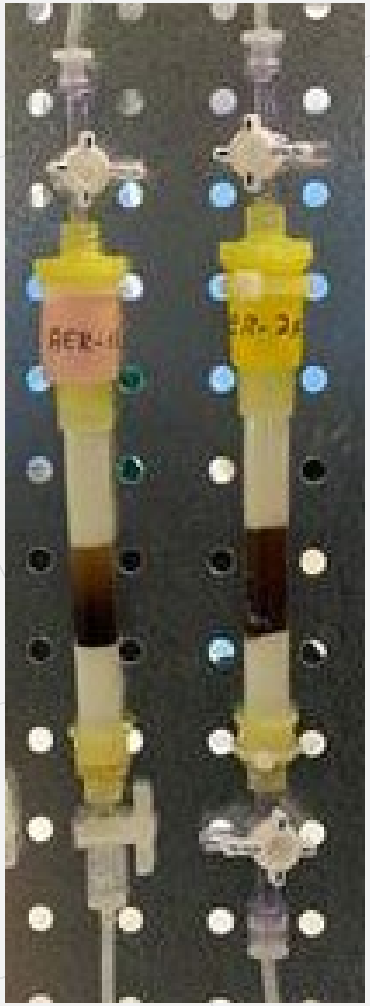
Application of Rapid Small-Scale Column Tests for Treatment of Perfluoroalkyl Acids Using Anion-Exchange Resins and Granular Activated Carbon in Groundwater with Elevated Organic Carbon

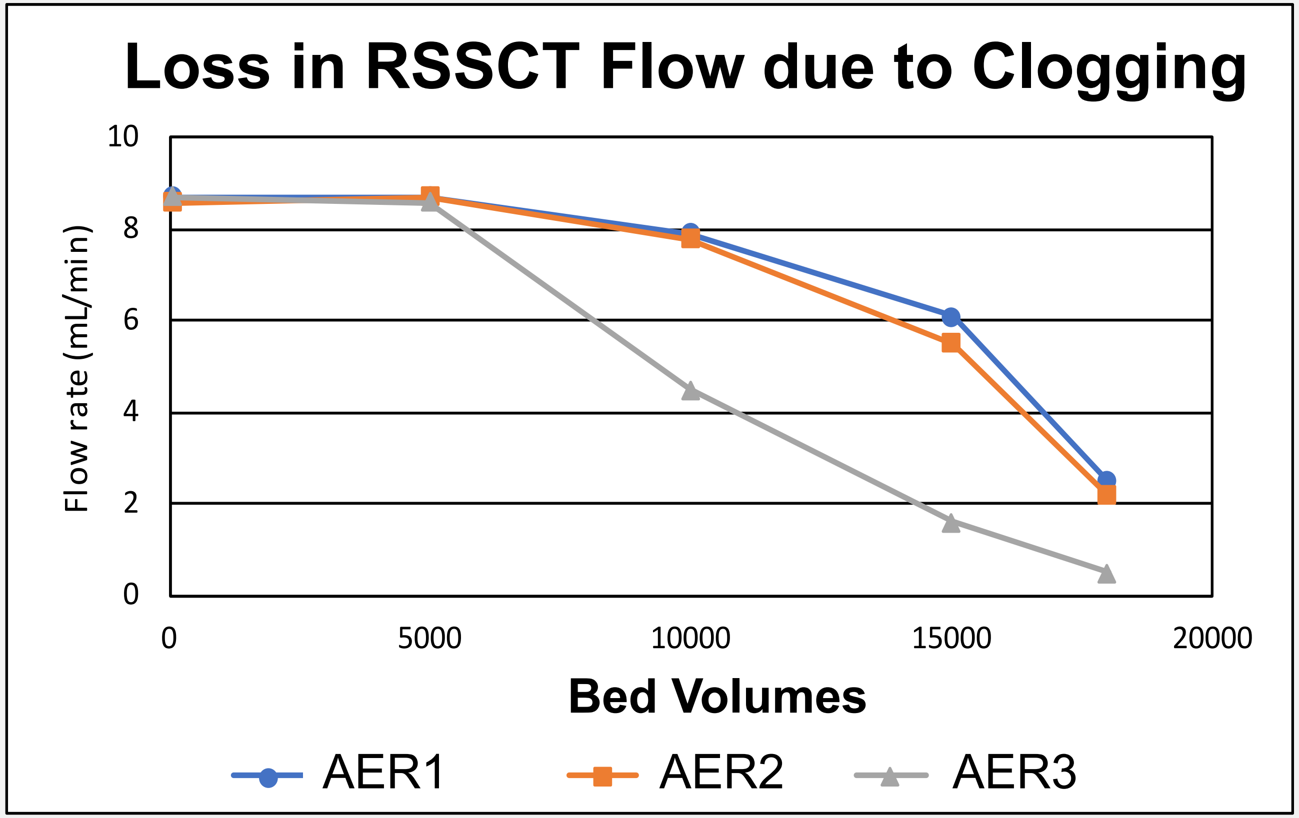
Charles E. Schaefer,* Dung Nguyen, Veronika M. Culina, Jennifer Guelfo, and Naveen Kumar

- Constant diffusivity model confirmed for both GAC and AER, and for high and low TOC waters
- Need to scale q_0 as $(r_U/r_G)^{0.5}$

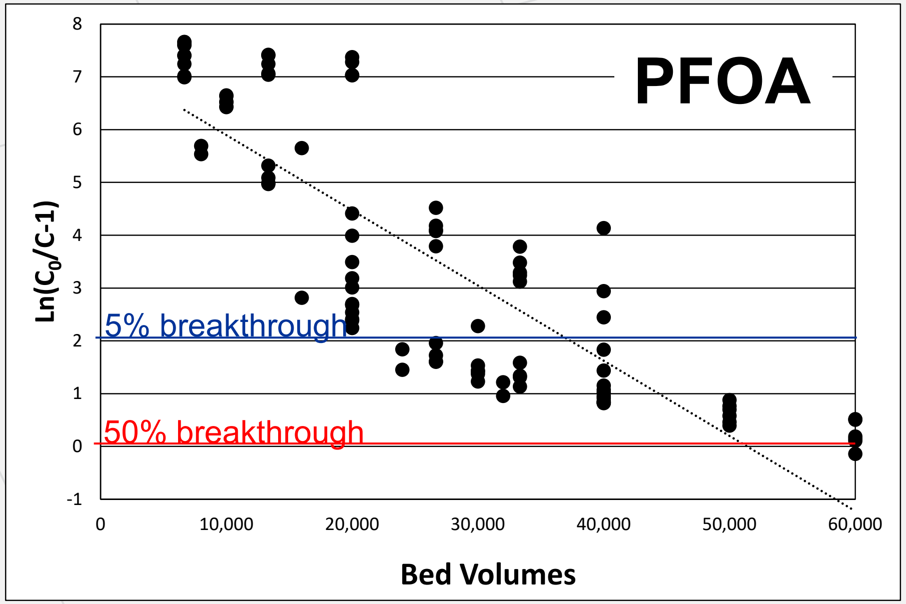


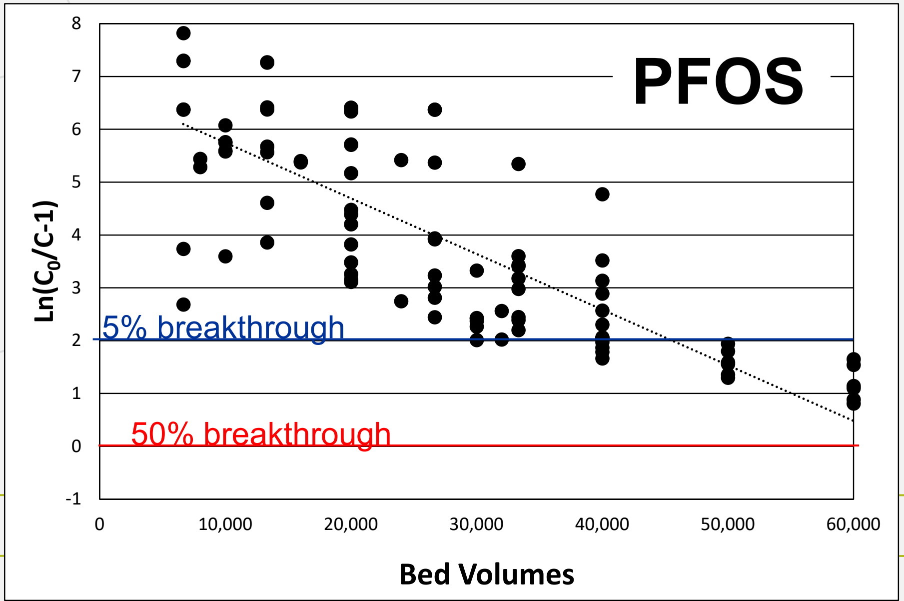
Permeability Loss in AERs Occasionally Observed





Summary of Testing Results: 10 GAC Studies
Low TOC Waters

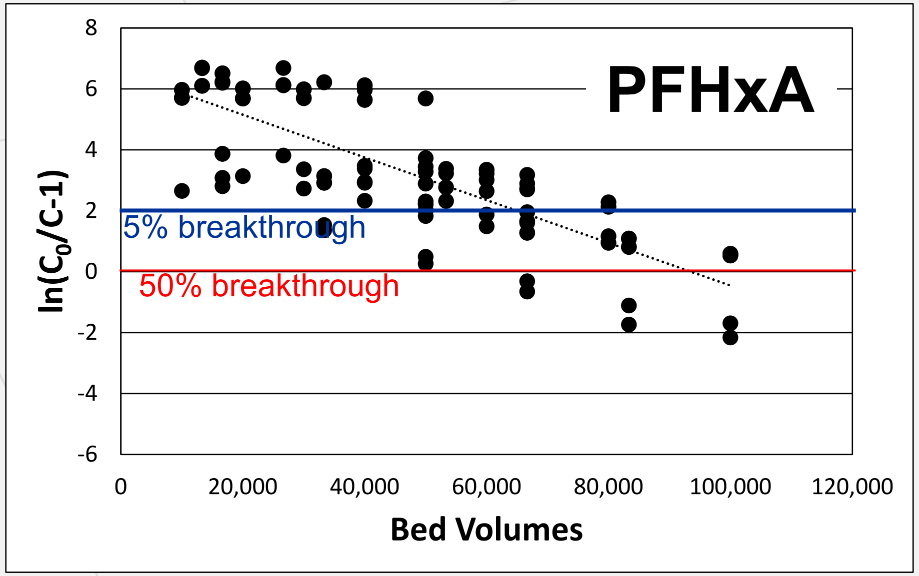


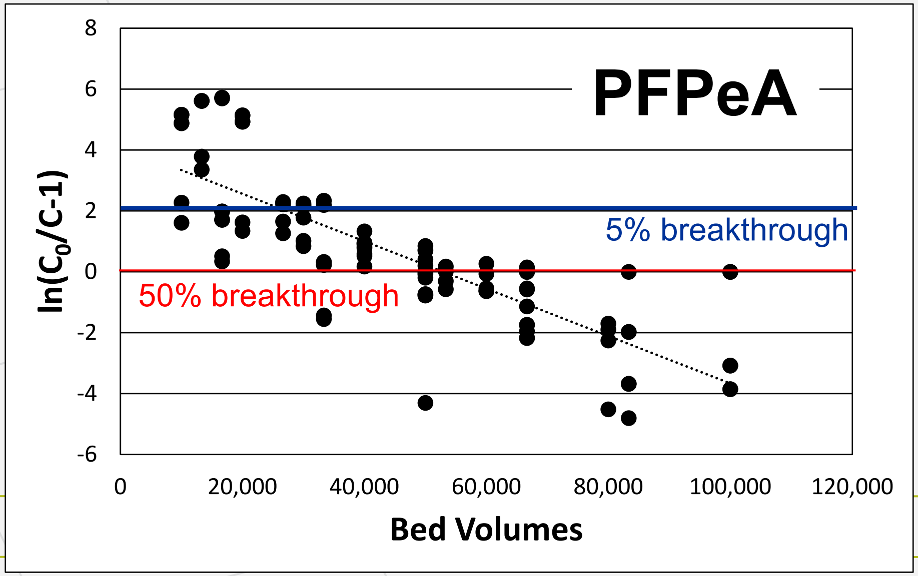


- Coal-based GAC
- Results generally consistent wit the Thomas model

$$ln\left[\frac{C_0}{C} - 1\right] = \left(\frac{kmq_0}{Q}\right) - [EBCT]kC_0BV$$

Summary of Testing Results: 10 AER Studies
Low TOC Waters





- PFAS selective AER
- Results generally consistent wit the Thomas model

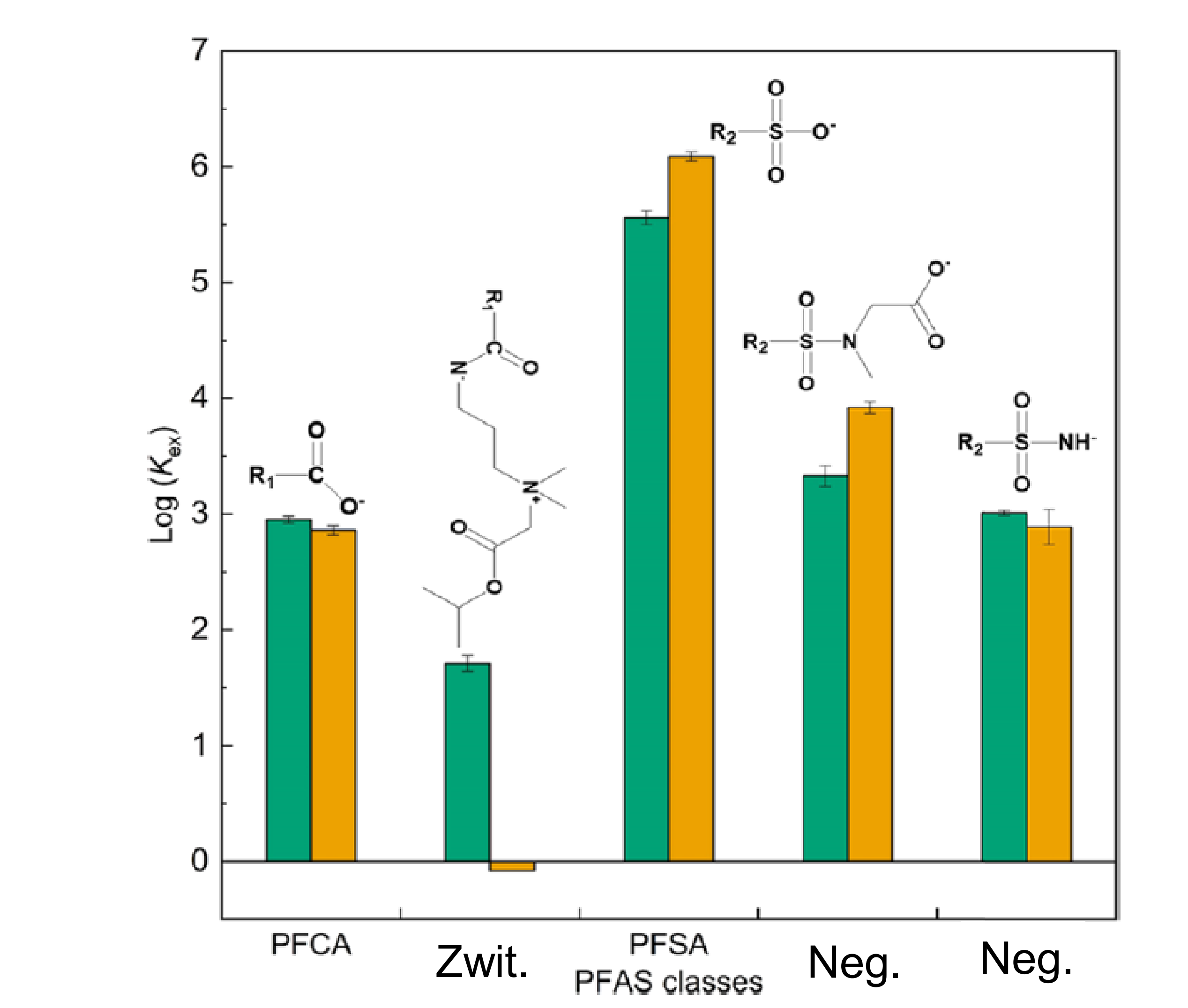
$$ln\left[\frac{C_0}{C} - 1\right] = \left(\frac{kmq_0}{Q}\right) - [EBCT]kC_0BV$$

- Tighter range compared to GAC

Secondary Water Impacts

GAC	Bed Volumes	pH (SU)	Total Arsenic (µg/L)
GAC1	50	8.6	4
	500	7.7	<1
GAC2	50	7.9	<1
	500	7.8	<1

Polyfluorinated Compounds on AERs



Environmental Science & Technology
pubs.acs.org/est
Article

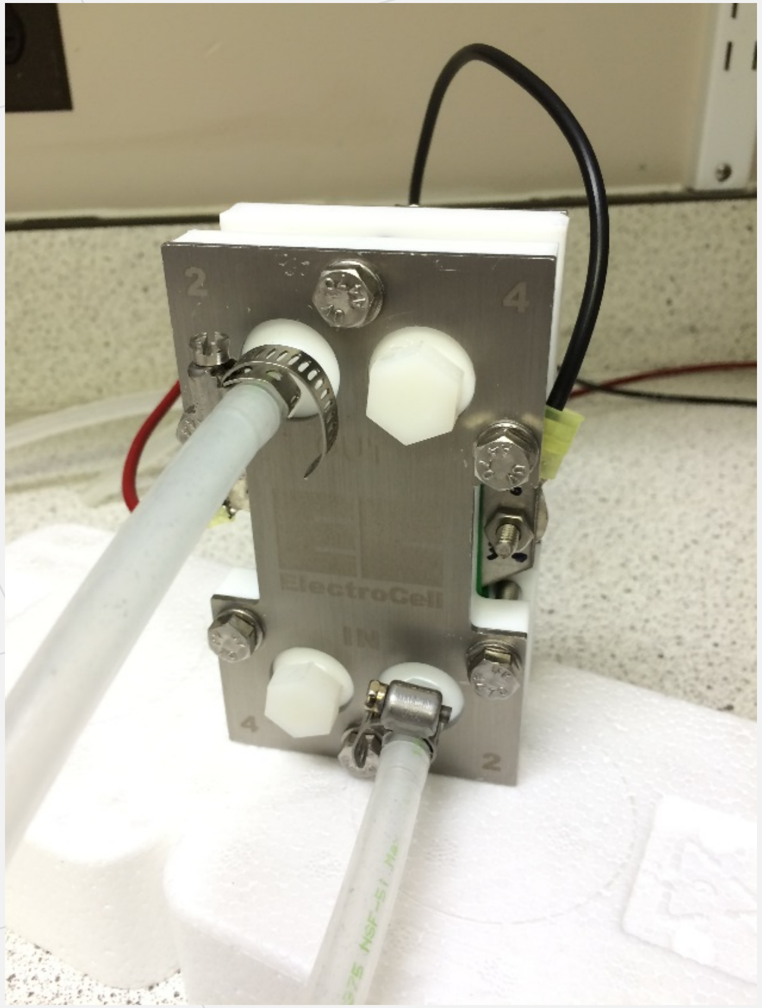
Removal of Per- and Polyfluoroalkyl Substances (PFASs) in Aqueous Film-Forming Foam (AFFF) Using Ion-Exchange and Nonionic Resins

Yida Fang, Anderson Ellis, Youn Jeong Choi, Treavor H. Boyer, Christopher P. Higgins, Charles E. Schaefer, and Timothy J. Strathmann*

Other Considerations

- Product cost (resin more expensive than GAC)
- Residence time/vessel size
- Pressure drop

Electrochemical Treatment of Regeneration Solutions (brine+cosolvent+PFAS)



Bench-scale system (10 cm^2)

Boron-doped diamond anodes

Pros

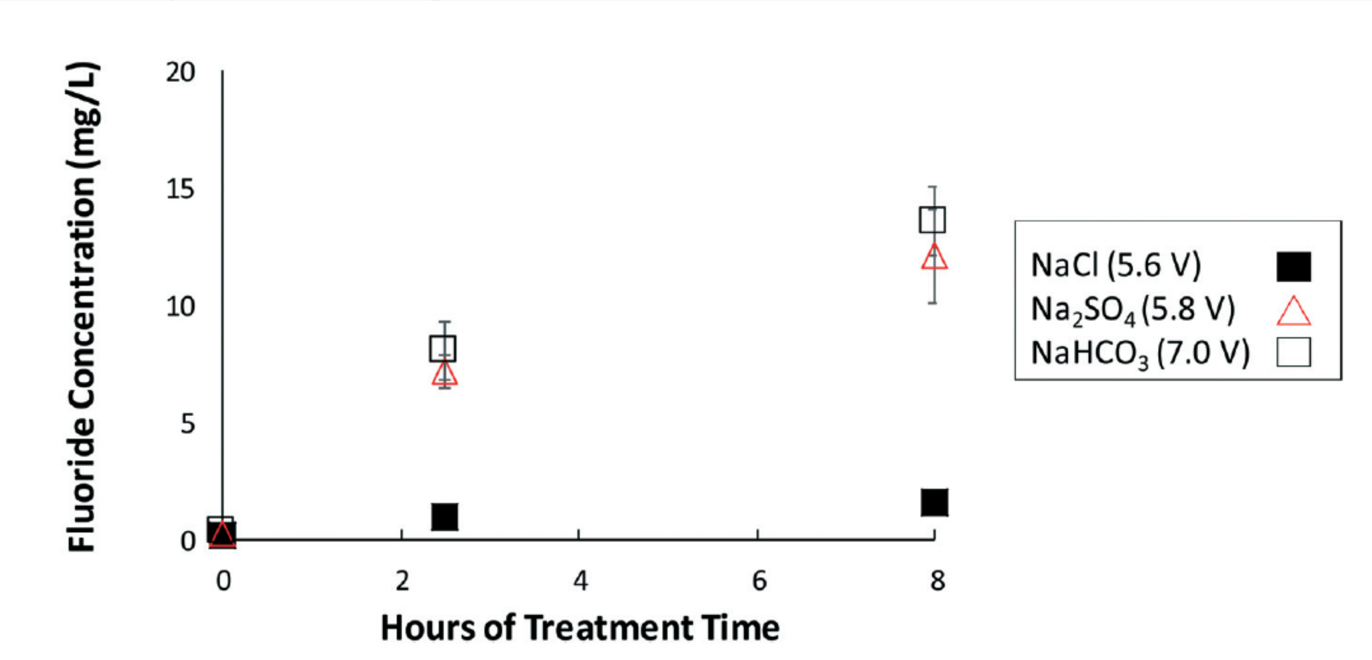
- High oxygen overpotential
- Commercially available (>1 m^2 systems)
- Sturdy and stable
- Effective in difficult matrices
- Effective for both short and long-chained PFAS

Cons

- Relatively high electrode cost
- Cathodic scaling can occur (calcium)
- Perchlorate formation if chloride present

Electrochemical Treatment of PFAS-Impacted Brines

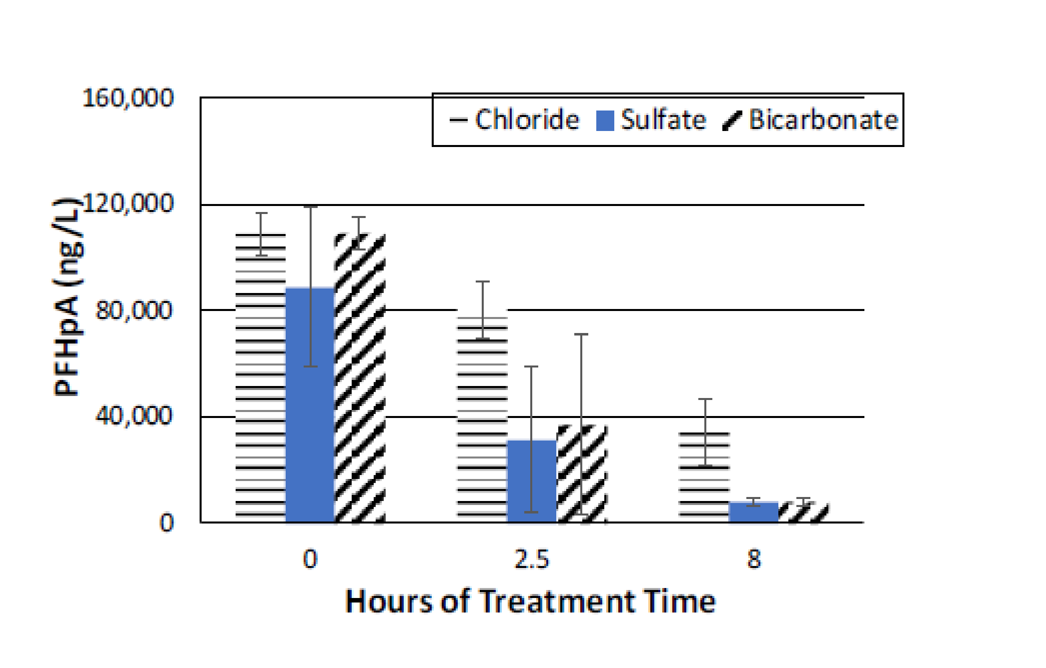
Diluted AFFF used for Electrochemical Testing



- Assume cosolvent removed prior to treatment
- Development of regeneration approaches that do not require cosolvent

<u>With sulfate or bicarbonate salts</u>:

- 81% defluorination
- 140 w-h/L per log removal of total PFAS
- No perchlorate!



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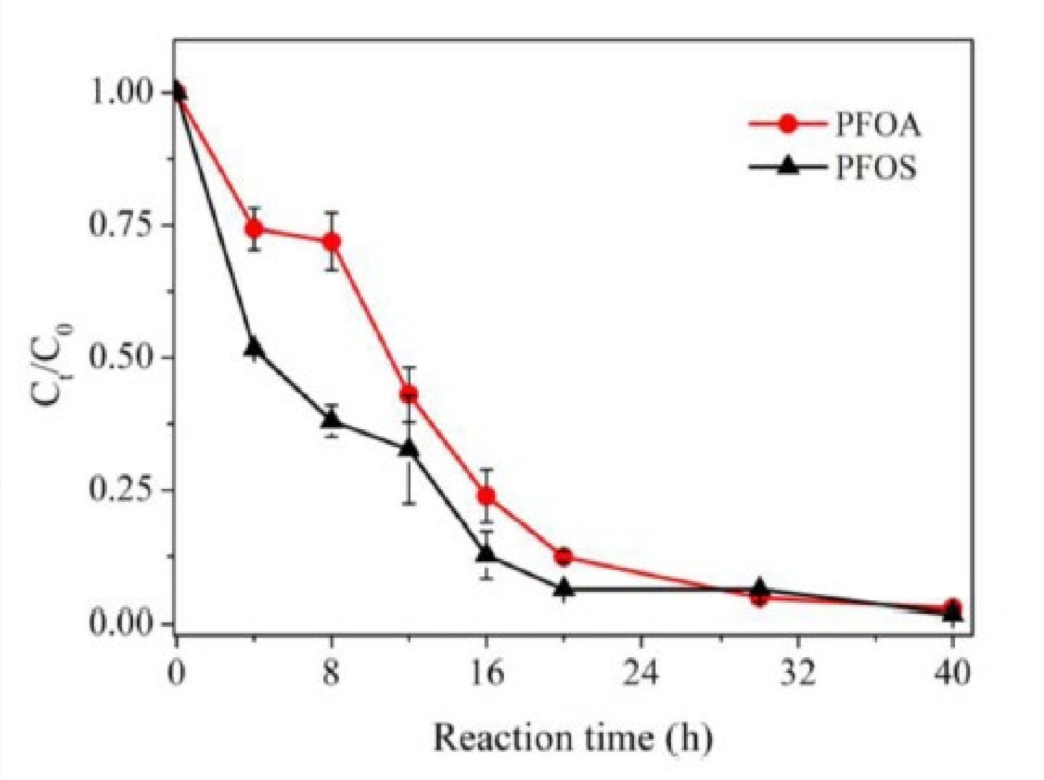
Electrochemical Treatment of AER Regeneration Fluid using Ti_4O_7 Anodes



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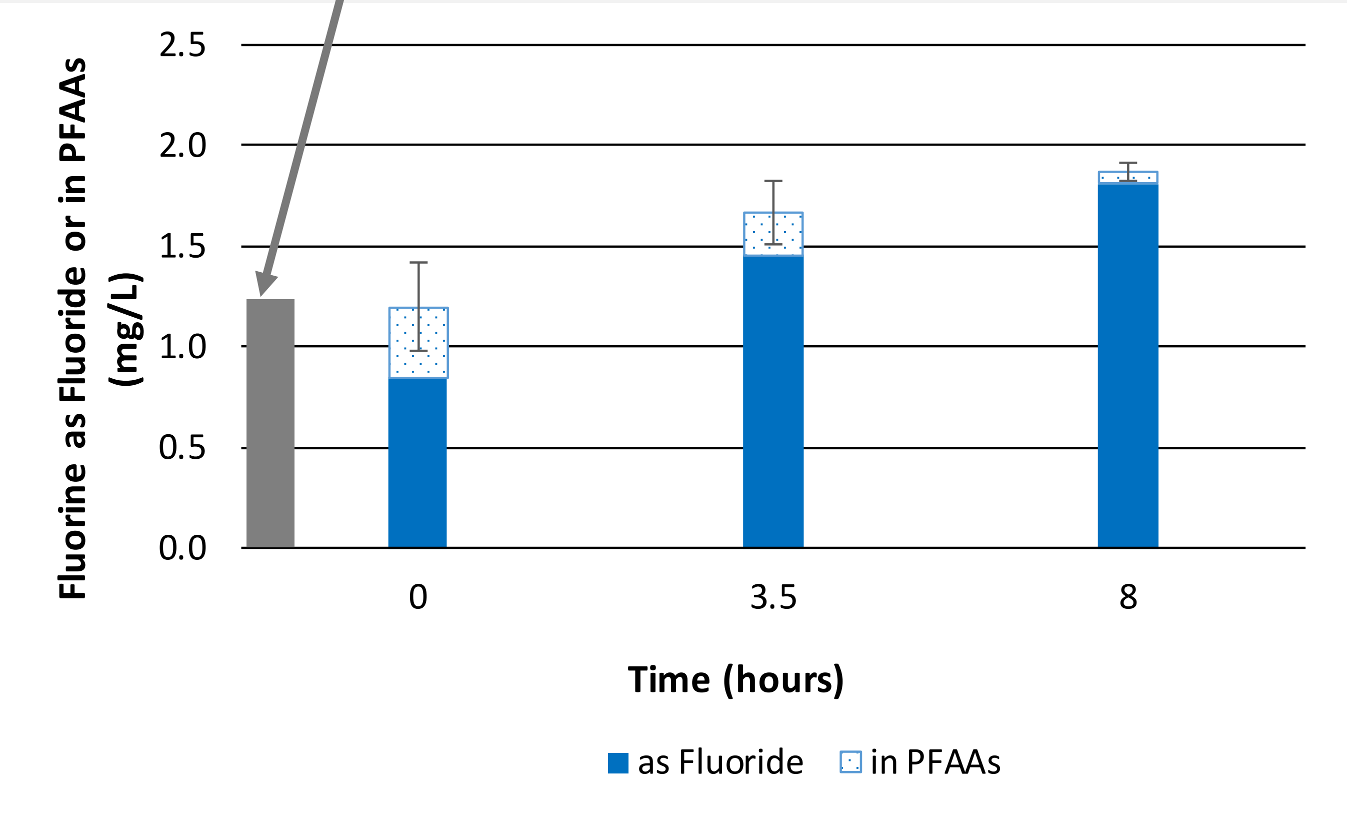
- 5% defluorination measured
- About 5-time higher energy requirement than observed in typical water systems
- <u>Real regeneration fluid</u>!

Fluorine Mass Balance during Electrochemical Treatment of AFFF-Impacted Groundwater

Total fluorine [TOP Assay + fluoride]



TOP analysis and standard PFAS analysis Did not capture ~65% of organic fluorine present

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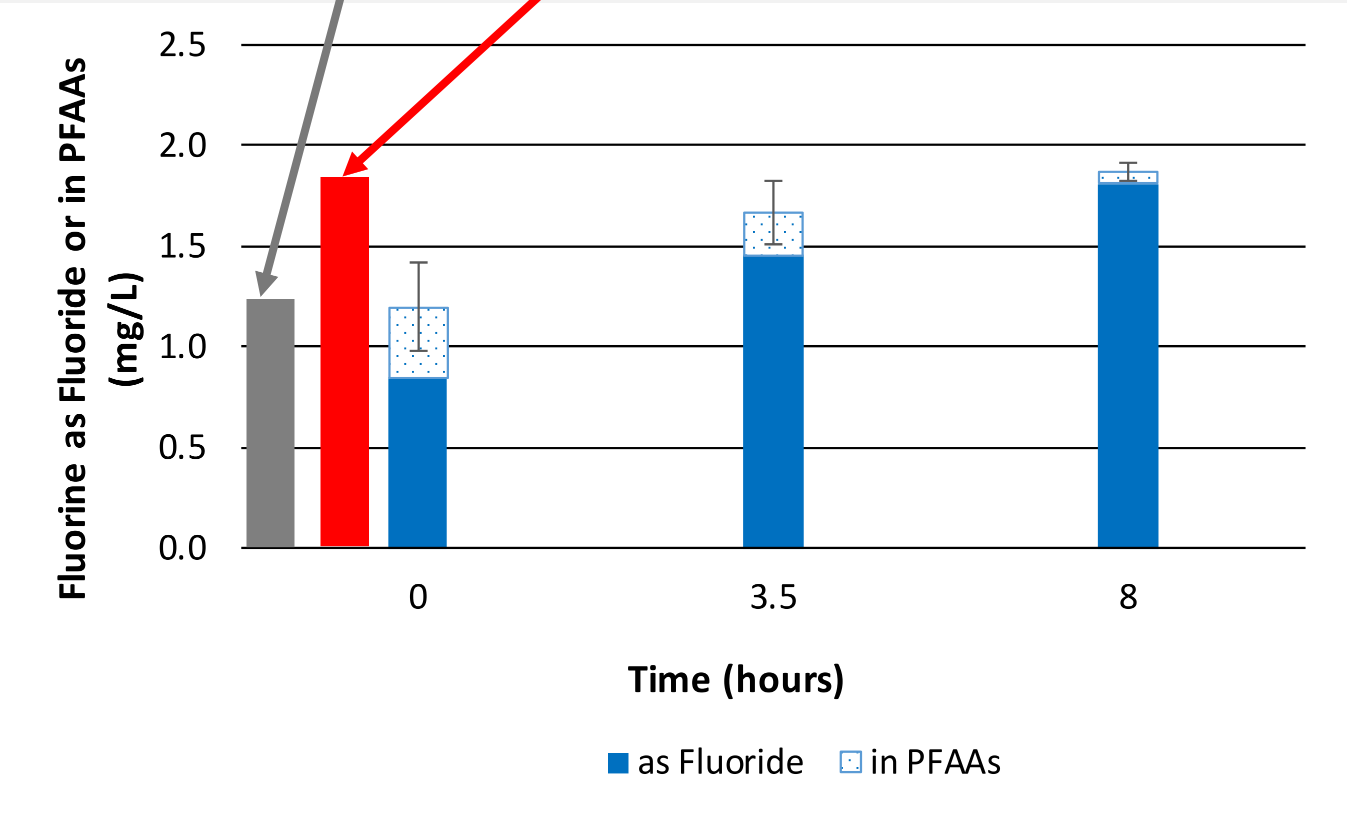
Fluorine Mass Balance during Electrochemical Treatment of AFFF-Impacted Groundwater

Total fluorine [TOP Assay + fluoride]

Total fluorine (fluoride + TOF) in raw water [Combustion IC]



TOP analysis and standard PFAS analysis Did not capture ~65% of organic fluorine present

Conclusions

- Water geochemistry, co-contaminants, and treatment residuals can have a substantial impact on PFAS treatment using GAC or AER
- Bench scale RSSCTs provide value in assessing treatment
- AER regeneration fluid can be treated electrochemically
  - *Energy demand*
  - *F mass balance*

Questions?

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