



# Comprehensive PFAS Treatment: Separate/Concentrate/Destroy

May 3, 2023, 4:00 p.m.



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# Comprehensive PFAS Treatment: Separate / Concentrate / Destroy

Moderator: Rhonda Hampton, P.E., ECT2

Speakers:

- Hunter Anderson, Ph.D, PFAS Subject Matter Specialist, AFCEC/CZTE
- David Kempisty, Ph.D, P.E., Director, Emerging Contaminants, ECT2/Montrose
- Brian Pinkard, Ph.D, P.E., CTO, Aquagga, Inc.



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# SPEAKER



## Hunter's Fun Facts

- From the Oklahoma plains...  
decedent of homesteaders  
from the land runs
- Survived two tornadoes!



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# SPEAKER



## Dave's Fun Facts

- Knows the majority of the 1984 Detroit Tigers' lineup only because he continues to wait & hope for their next championship season.
- Edited two books – on PFAS!
- Has completed a marathon and has gotten married ... on the same day.



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# SPEAKER



## Brian's Fun Facts

- Seattle Mariners fan for many disappointing years
- First time visiting Texas
- Hobbies: rock climbing, skiing, backpacking, running... anything active & outside





# ***Challenges for the DoD***

***Dr. Hunter Anderson***  
***AFCEC/CZTE***



# Challenges for the DoD



## ➤ How “dirty” is “dirty”

- Thousands of AFFF-impacted source areas: when is remediation required?
- Novel retention mechanisms
- Background contamination from decades of atmospheric deposition

## ➤ How “clean” is “clean”

- What are realistic performance objectives for treatment systems
- Legal discharge requirements are highly variable
- Long- vs short-chain treatment efficiencies

## ➤ Desire for destructive technologies

- What premium are we willing to pay for destruction?
- Mobile (on-site) vs regional (hub and spoke) capabilities





# Separate – Concentrate - Destroy



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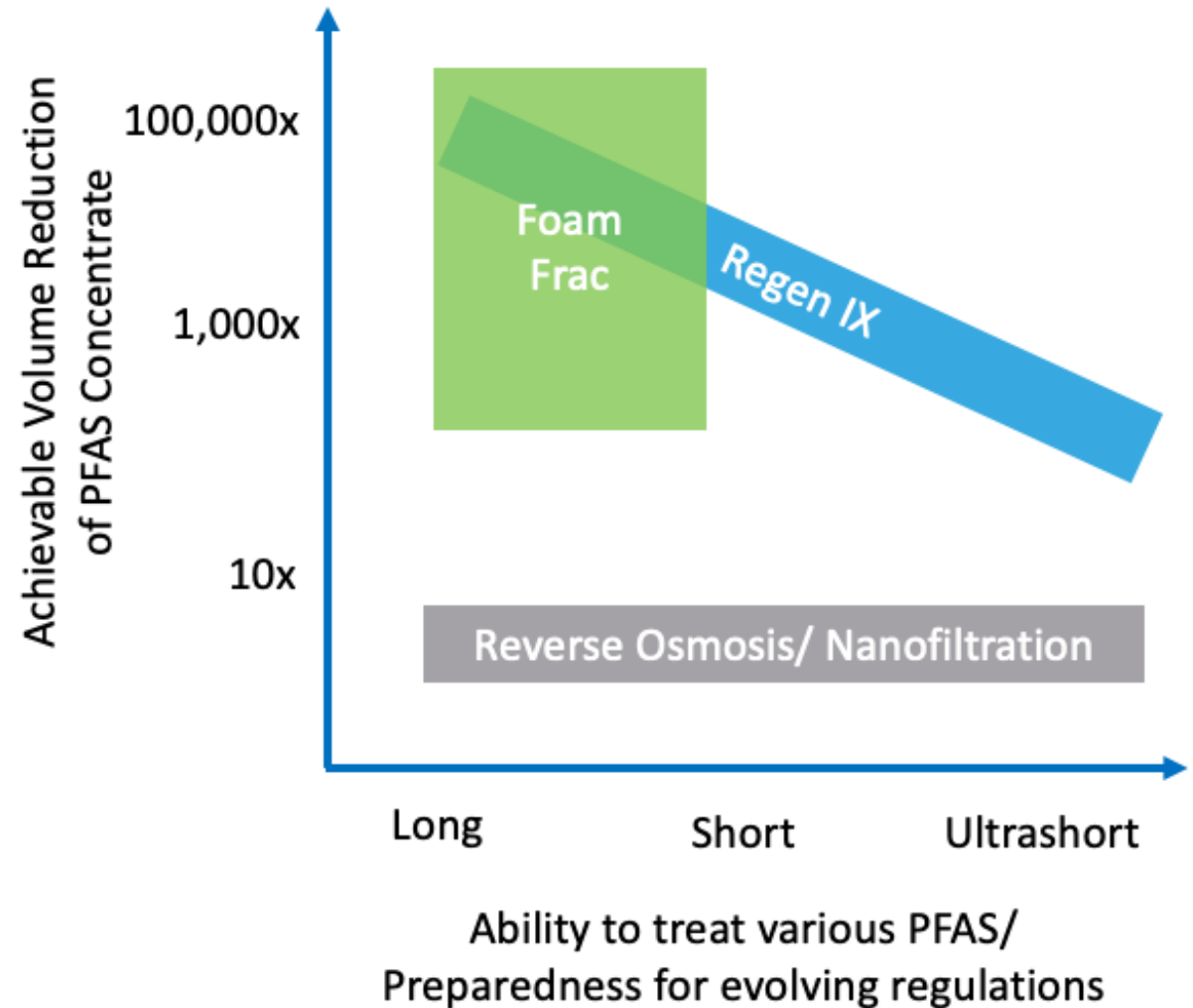


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# Separate and Concentrate: Preparedness for Destruction

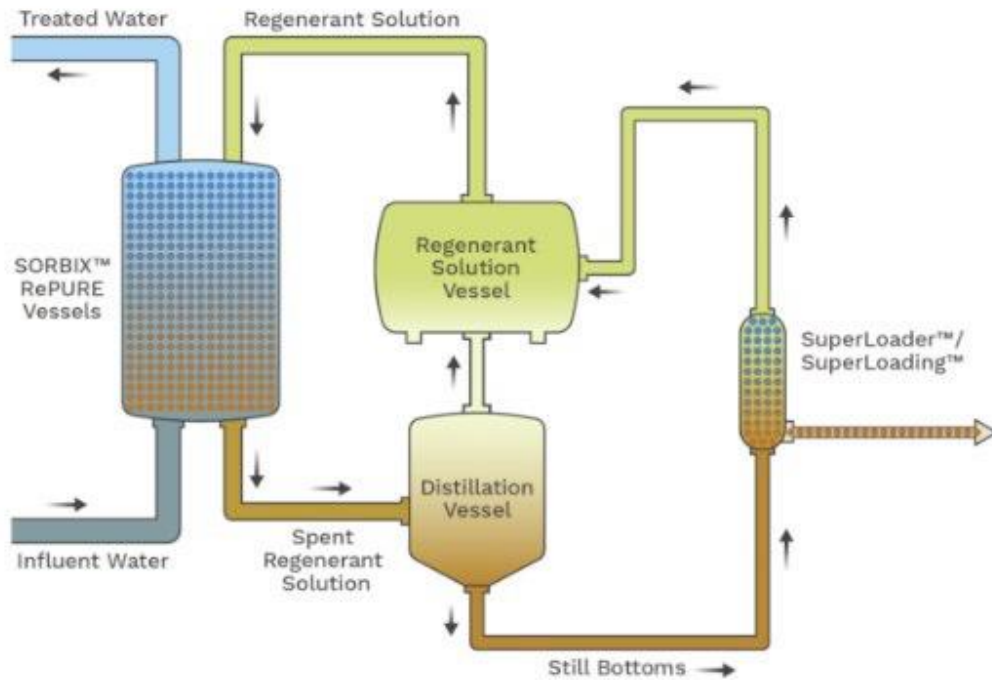
Tomorrow's destructive technologies require a volume reduction and concentration step

- FF and RIEX
- Membranes



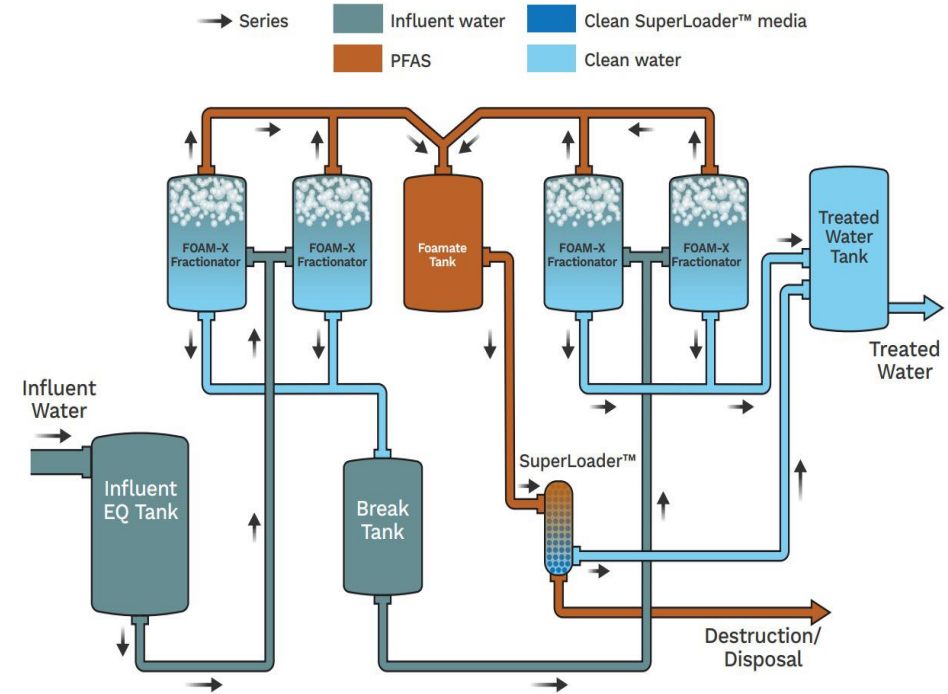
# Separate and Concentrate – Two Technologies

## Regenerable Ion Exchange Resin



- Effective
- Future Proof
- Waste Minimization
- Future Proof
- Hub and Spoke

## Foam Fractionation



- Simple
- Low cost
- Avoided Pre-treatment
- Additives
- Short Chain Challenges
- Off-ramp to destruction



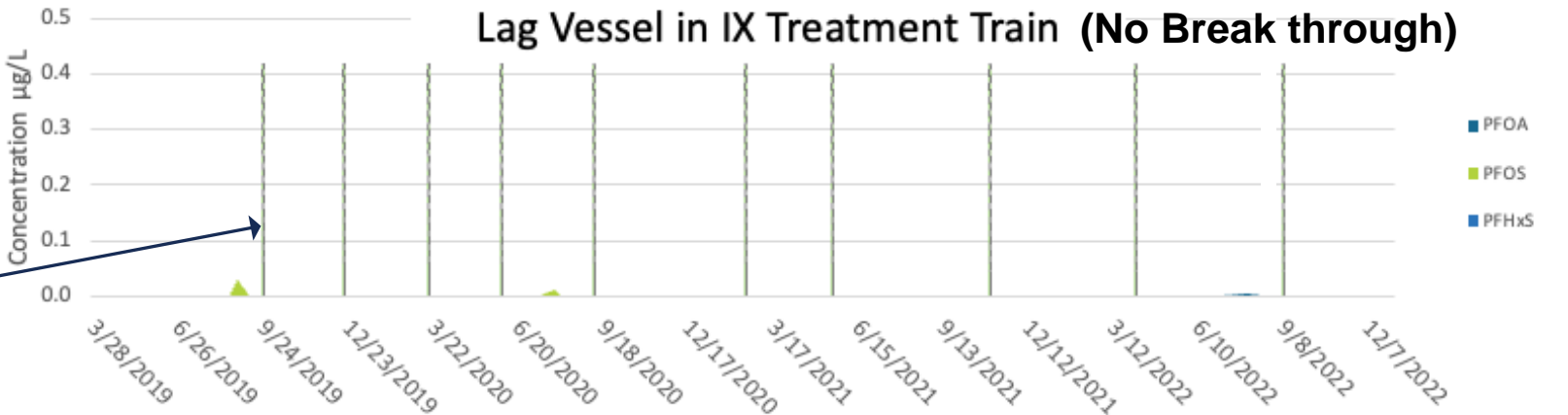
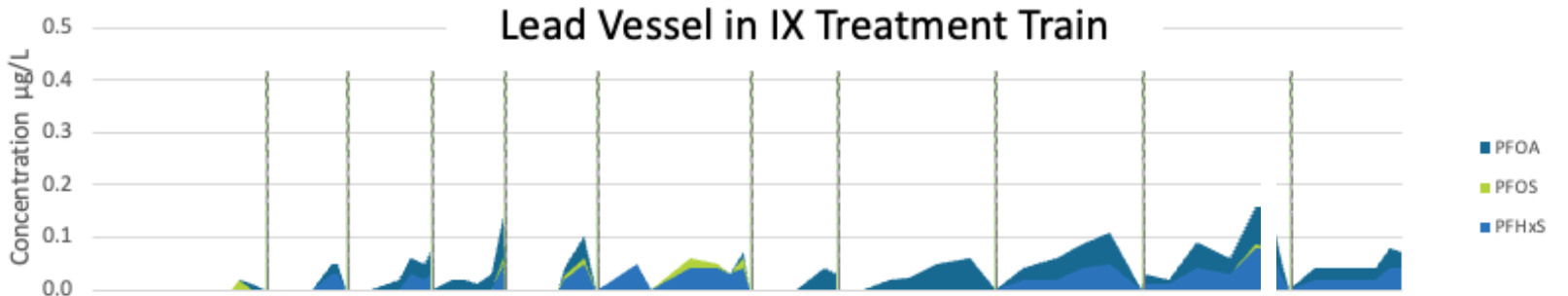
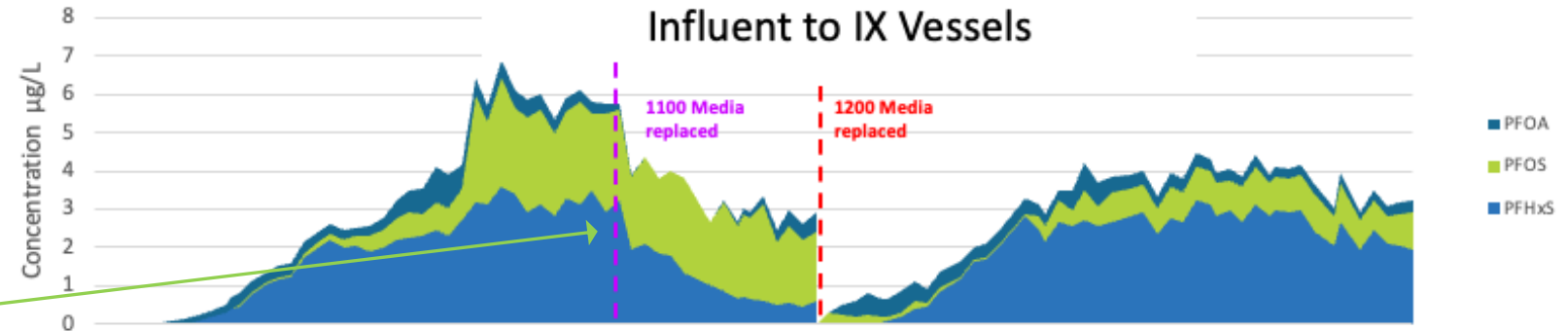
# Separate & Concentrate – Data Regenerable IX Resin

Dashed lines indicate pre-treatment media replaced

***Across 4+ years of regeneration cycles, the IX resin continues to achieve PFAS treatment objectives***

***No IX Resin Disposed in Landfills***

\* Actual site performance



Vertical lines indicate resin regeneration in lead vessel

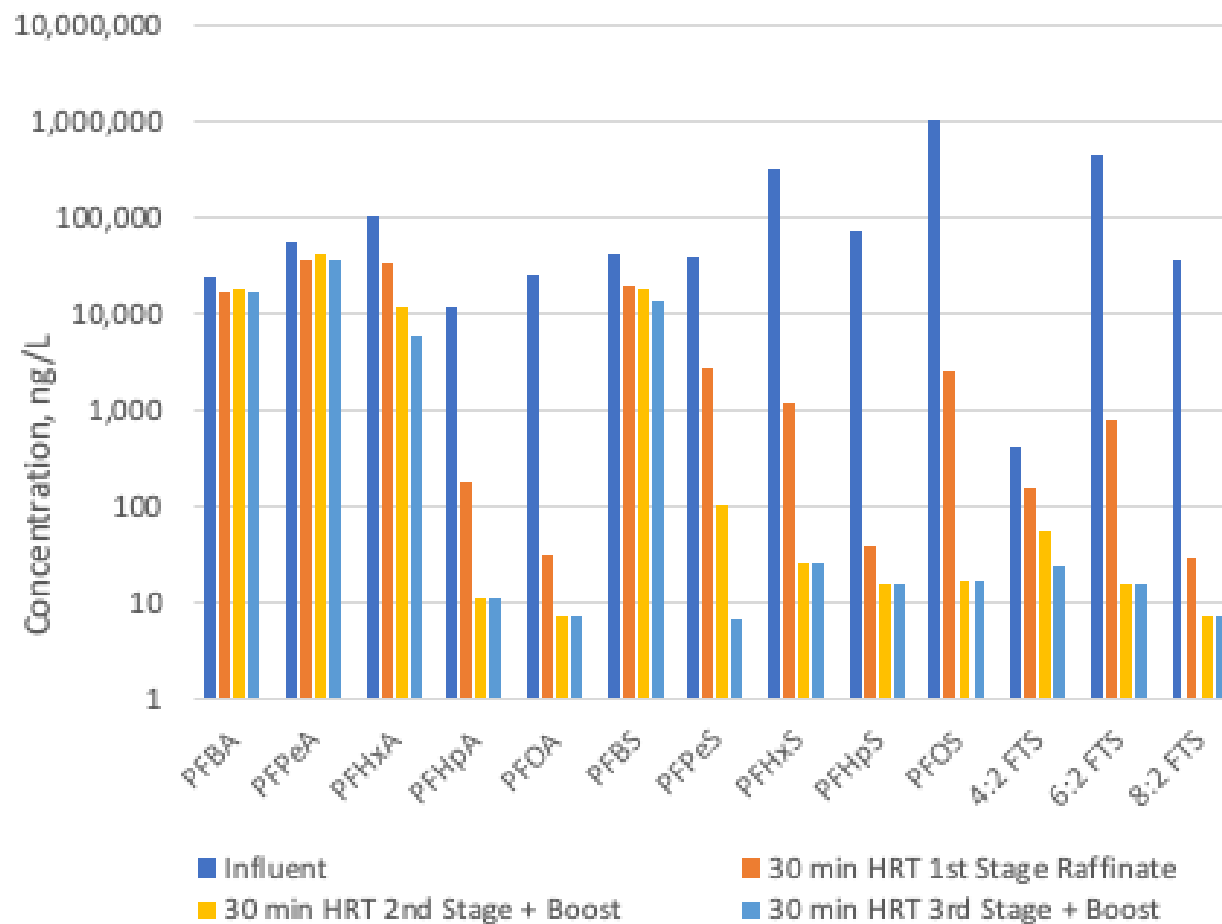
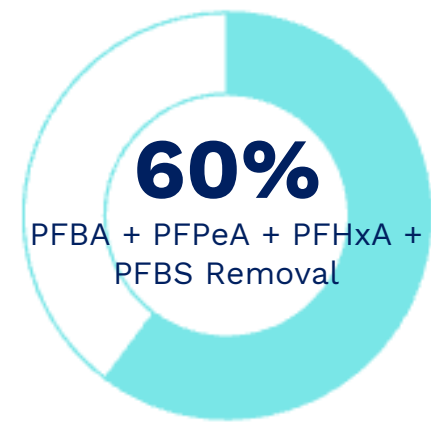




# Separate & Concentrate – Data

## Foam Fractionation

FF Results Only  
2 Stage; 30 min HRT

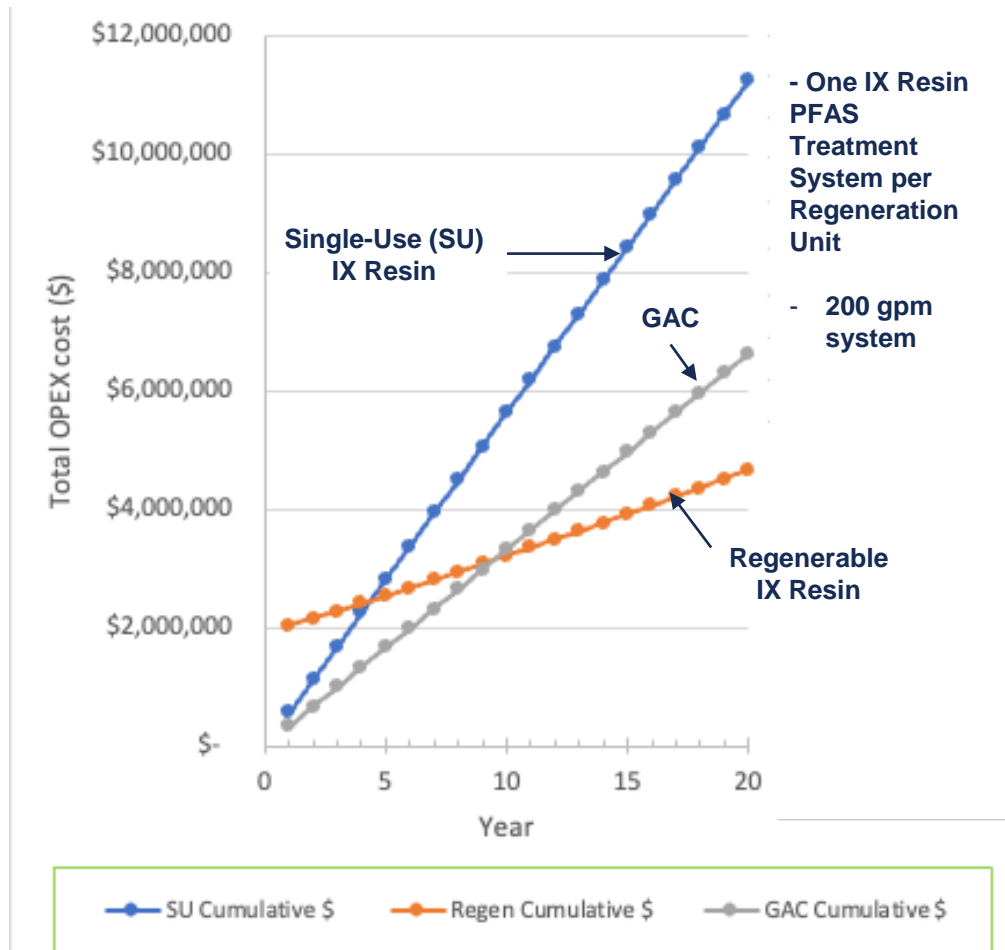


HRT: Resonance time

- FF effectively removed mg/L concentrations to ng/L
- One FF Stage removed PFOS/PFOA ~ 3 OOM
- 97%+ total PFAS removed
- 60 min single stage HRT saw small improvement vs 30 min HRT
- 3rd FF stage only saw slight improvement
- Foamate for destruction: 58 mg/L TOT PFAS



# Separate & Concentrate – Economics Regeneration of IX Resin

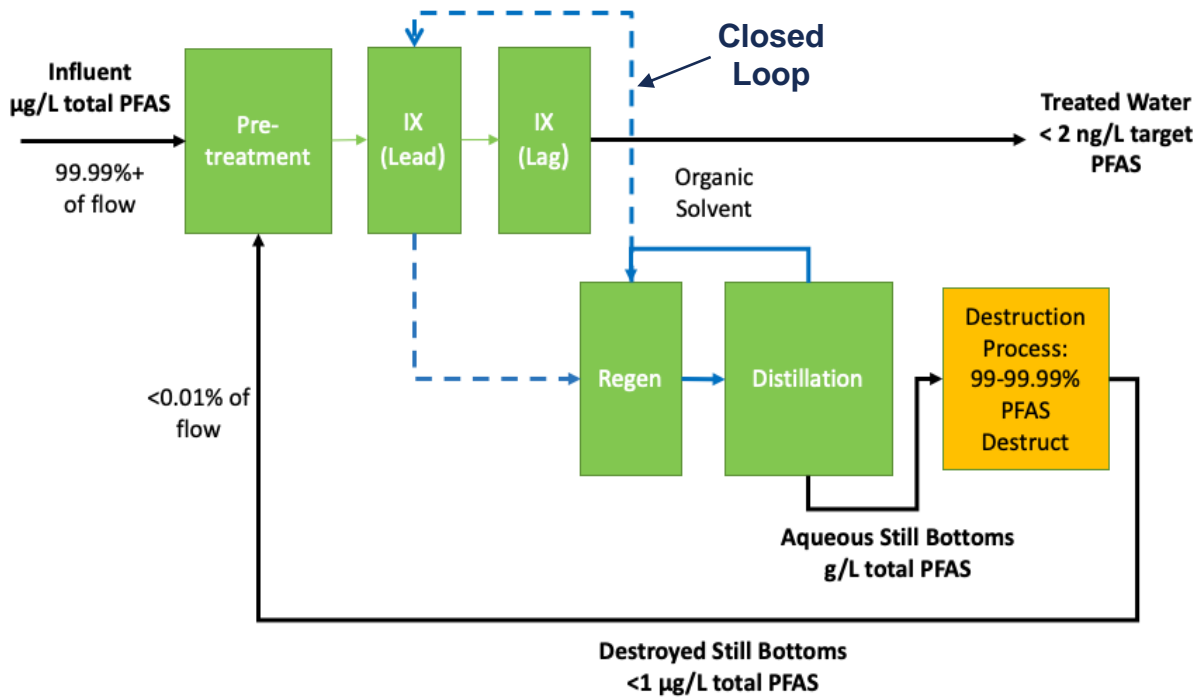


## Optimized Return on Investment: (by # of IX systems per Regeneration plant)

- 1 system per regen plant: ROI ~ 4 years
- 2 systems per regen plant: ROI ~ 2 years
- 3 systems per regen plant: ROI ~ 1.5 years

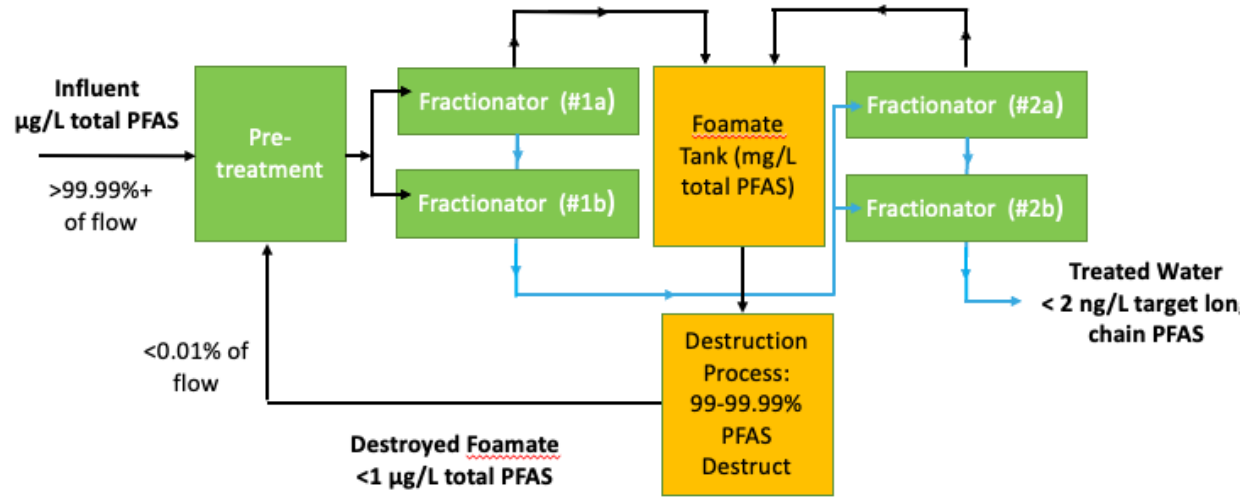
Regeneration of IX Resin provides concentration of PFAS 500,000:1 for destruction... and is also cost-effective long term vs. other options and is future-proof

# Separate, Concentrate, Destroy – Closed Loop Processes



## Regeneration of IX Resin

*Two Complete Closed-loop PFAS Treatment Schematics to Concentrate PFAS*



## Foam Fractionation



# Hydrothermal Alkaline Treatment (HALT) for PFAS Destruction



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# Hydrothermal Alkaline Treatment

- PFAS Destruction technology
- Rapid treatment time (minutes)
- Leverages liquid water at high temperature, high pressure, high pH
- Effective for **complete mineralization of all PFAS**
- Commercial units currently being fabricated and available for field demonstrations

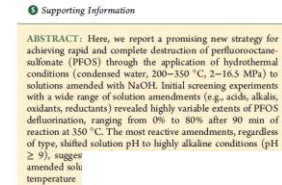


## Rapid Destruction and Defluorination of Perfluorooctanesulfonate by Alkaline Hydrothermal Reaction

Boran Wu,<sup>1,2,4</sup> Shilai Hao,<sup>1</sup> Younjoeng Choi,<sup>1</sup> Chi and Timothy J. Strathmann<sup>3\*</sup>

<sup>1</sup>Department of Civil and Environmental Engineering, Colorado State University, Fort Collins, Colorado 80523, USA  
<sup>2</sup>State Key Laboratory of Pollution Control and Resource Reuse, University, Shanghai 200092, China  
<sup>3</sup>National Engineering Laboratory for Industrial Wastewater Treatment, China University of Science and Technology, Shanghai 200237, China  
<sup>4</sup>Geosyntec Consultants, Oakland, California 94607, United States

**ABSTRACT:** Here, we report a promising new strategy for achieving rapid and complete destruction of perfluorooctanesulfonate (PFOS) through the application of hydrothermal conditions (condensed water, 200–350 °C, 2–16.5 MPa) to solutions amended with NaOH. Initial screening experiments with a wide range of solution amendments (e.g., acids, alkalis, oxidants, reductants) revealed highly variable extents of PFOS defluorination, ranging from 0% to 80% after 90 min of reaction at 350 °C. The most reactive amendments, regardless of type, shifted solution pH to highly alkaline conditions (pH ≥ 9), suggest amended alkali temperature

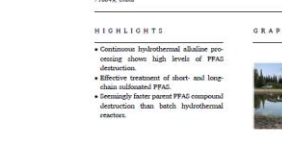


Chemosphere 314 (2023) 127601  
Elsevier  
journal homepage: www.elsevier.com/locate/chemosphere

## Destruction of PFAS in AFFF-impacted fire training pit water, with a continuous hydrothermal alkaline treatment reactor

Brian R. Pinkard<sup>a,b,\*</sup>, Conrad Austin<sup>b</sup>, Anmol L. Purohit<sup>b</sup>, Jianna Li<sup>b,c</sup>, Igor V. Novoselov<sup>b</sup>

<sup>a</sup>Parsons Inc., Tacoma, WA, 98402, USA  
<sup>b</sup>University of Washington, Mechanical Engineering Department, Seattle, WA, 98195, USA  
<sup>c</sup>Key Laboratory of Thermal-Pneumatic Engineering of MOE, School of Energy and Power Engineering, Xi'an Jiaotong University, 28 Xianjing West Road, Xi'an 710049, China



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## Application of Hydrothermal Alkaline Treatment for Destruction of Per- and Polyfluoroalkyl Substances in Aqueous Film-Forming Foam

Shilai Hao, Youn-Jeong Choi, Boran Wu, Christopher P. Higgins and Timothy J. Strathmann<sup>\*</sup>

**ABSTRACT:** Hydrothermal alkaline treatment (HALT) can effectively degrade per- and polyfluoroalkyl substances (PFASs) present in aqueous film-forming foam (AFFF). However, information is lacking regarding the treatment of PFASs in actual groundwater and soil from AFFF-impacted sites, especially for complex soil matrices. Given the lack of studies on direct soil treatment for PFAS destruction, we herein applied HALT to two groundwater samples and three soil samples from AFFF-impacted sites and characterized the destruction of PFASs using high-



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## Application of Hydrothermal Alkaline Treatment to Spent Granular Activated Carbon: Destruction of Adsorbed PFASs and Adsorbent Regeneration

Ori Soker, Shilai Hao, Brian G. Trewyn, Christopher P. Higgins, and Timothy J. Strathmann<sup>\*</sup>

**ABSTRACT:** Granular activated carbon (GAC) adsorption is the most common technology applied to treat water contaminated with per- and polyfluoroalkyl substances (PFASs), but rapid exhaustion of the media necessitates frequent replacement and costly off-site thermal regeneration. Here, we extend the application of hydrothermal alkaline treatment (HALT), which uses strong alkali and near-critical temperatures and pressures (e.g., 350 °C, 16.5 MPa, and 1 M NaOH) to degrade and mineralize PFASs, to the regeneration of spent GAC. Mass balance experiments wherein a known mass of perfluorooctanesulfonate (PFOS) was adsorbed onto GAC prior to treatment showed that HALT achieved >99% destruction of PFOS and 96 ± 4% defluorination with no observed fluoro-organic intermediates [167 g L<sup>-1</sup> GAC, 350 °C, 1 M NaOH,



## Application of Hydrothermal Alkaline Treatment for Destruction of Per- and Polyfluoroalkyl Substances in Contaminated Groundwater and Soil

Shilai Hao, Youn Jeong Choi, Rula A. Deeb, Timothy J. Strathmann,<sup>\*</sup> and Christopher P. Higgins<sup>\*</sup>

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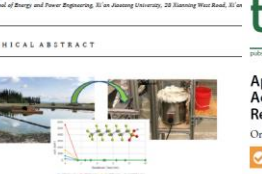


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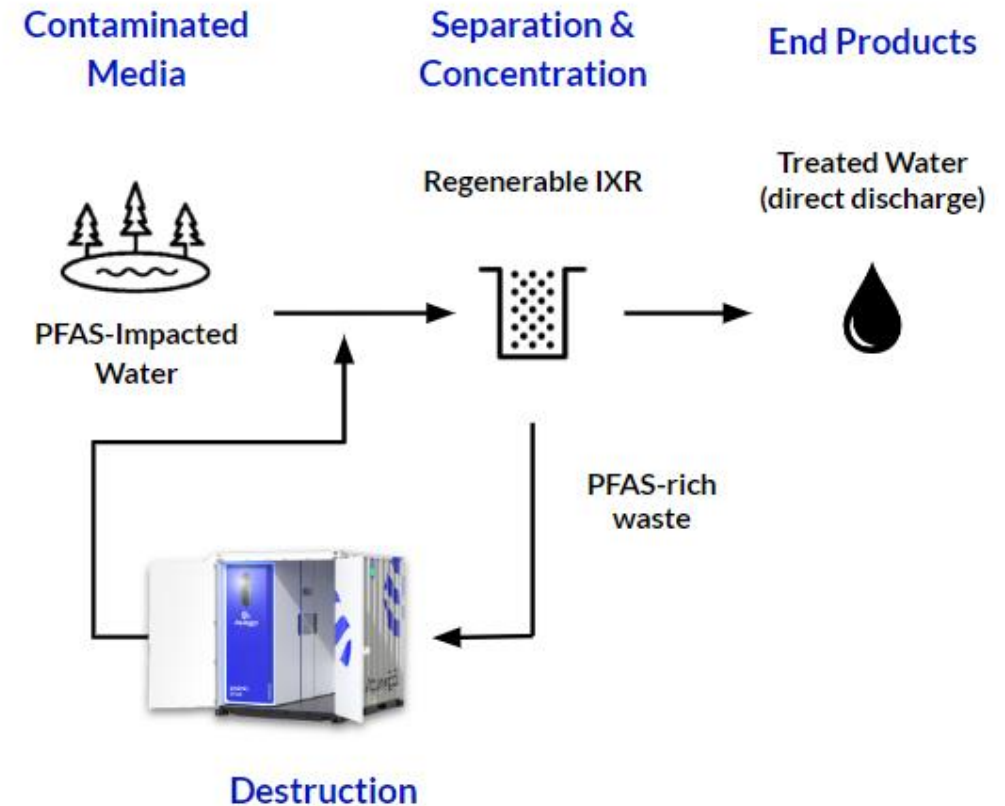


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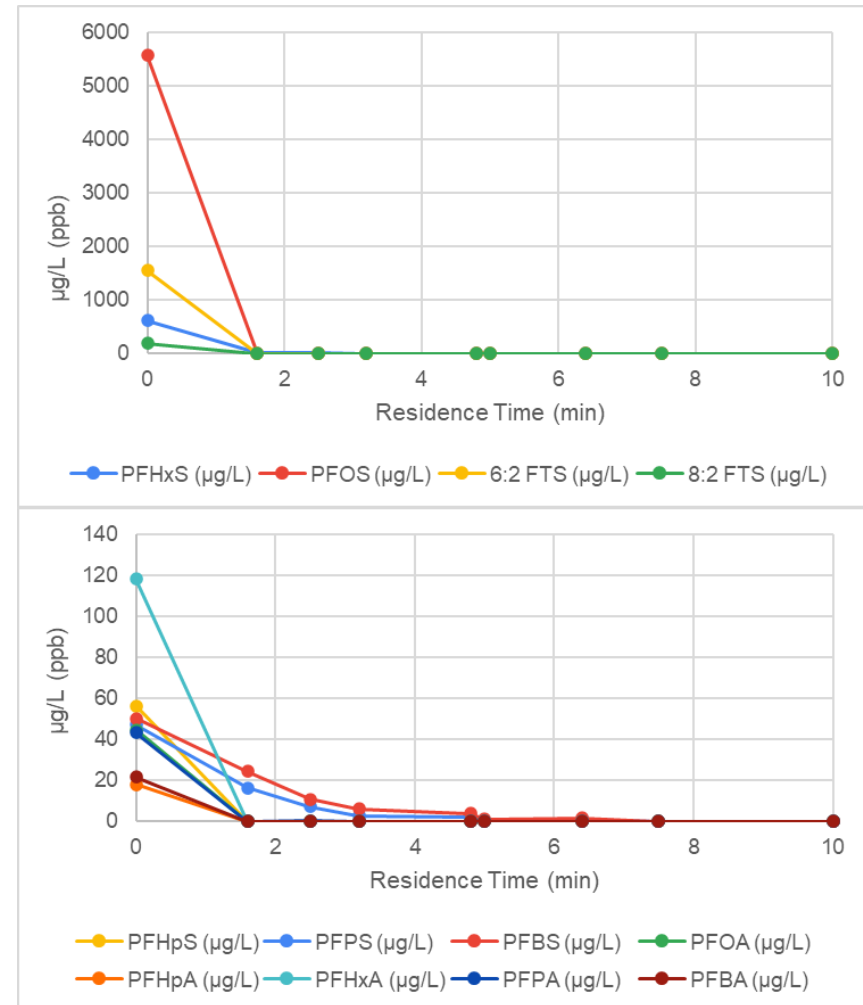
# Integrating PFAS Destruction Technology

- Example: Regenerable IXR with HALT
  - Use IXR to remove PFAS from contaminated liquid and produce concentrated liquid waste stream
  - Use HALT to reduce PFAS levels in concentrate by ~99.99%
  - Blend HALT effluent into IXR influent to capture residual PFAS
  - Keep PFAS in the loop
- Same strategy for foam fractionation with HALT



# HALT of Fire Training Pit Water

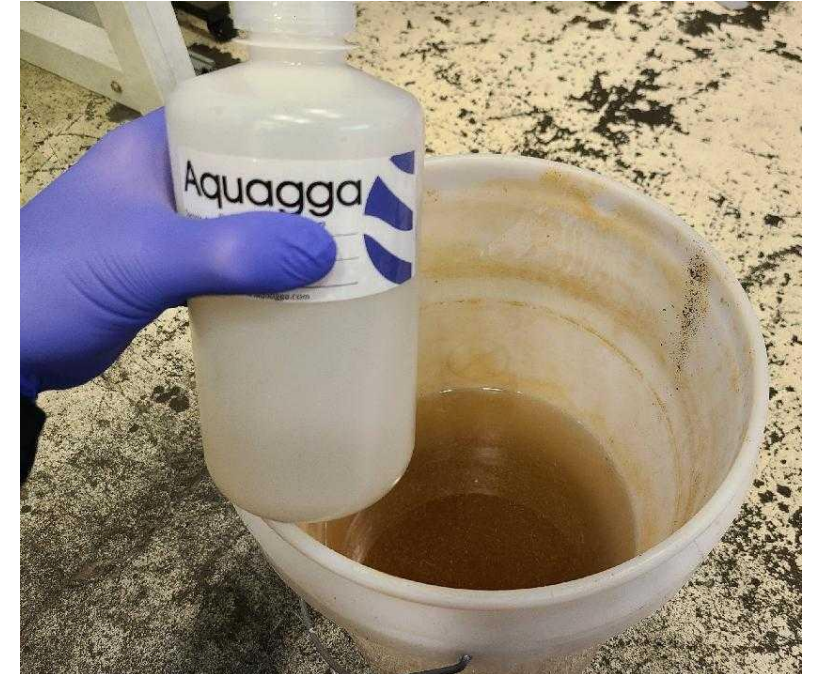
- >99.9% total PFAS reduction within 10 minutes of processing through continuous HALT system
  - PFOS reduction by >99.99%
  - PFHxS reduction by 99.77%
  - PFBS reduction by 99.67%
  - PFOA reduction by 99.997%
  - PFHxA reduction by 99.97%
  - PFBA reduction by 99.94%
- System performance characterized as function of residence time
- Pinkard et al., 2023. *Chemosphere* 314





# HALT of Foam Fractionate (Vendor 1)

Analyte	Foamate (ppb)	HALT Effluent (ppb)	Destruction %
<b>PFOS</b>	<b>2,119</b>	<b>5.08</b>	<b>99.76%</b>
PFHpS	66.5	0.0342	99.95%
PFHxS	751	0.261	99.97%
PFPeS	81.8	0.0861	99.89%
PFBS	48	0.291	99.39%
<b>PFOA</b>	<b>59.6</b>	<b>0.200</b>	<b>99.66%</b>
PFHpA	64.2	ND	>99.99%
PFHxA	145	0.0105	99.99%
PFPeA	37.8	0.0144	99.96%
PFBA	14.6	0.0392	99.73%
6:2 FTS	999	ND	>99.999%
<b>Total PFAS</b>	<b>4,386</b>	<b>6.016</b>	<b>99.86%</b>





# HALT of Foam Fractionate (Vendor 2)

Analyte	Foamate (ppb)	HALT Effluent (ppb)	Destruction %
<b>PFOS</b>	<b>36,400</b>	<b>10.9</b>	<b>99.97%</b>
PFHpS	522	0.199	99.96%
PFHxS	6,260	3.34	99.95%
PFPeS	1,160	1.09	99.91%
PFBS	552	1.58	99.71%
<b>PFOA</b>	<b>484</b>	<b>0.047</b>	<b>99.99%</b>
PFHpA	334	ND	>99.993%
PFHxA	2,540	ND	>99.999%
PFPeA	196	ND	>99.98%
6:2 FTS	8,800	ND	>99.999%
<b>Total PFAS</b>	<b>58,280</b>	<b>17.16</b>	<b>99.97%</b>



# PFAS Destruction Technology Comparison

	Hydrothermal Alkaline Treatment	Supercritical Water Oxidation	Electrochemical Oxidation	UV-Sulfite
Advantages	Ability to handle salts, moderate T & P	Can valorize fuel value to heat process	Low temperature, low pressure process	Low temperature, low pressure process
Disadvantages	Chemical usage	Cannot handle high TDS levels	Perchlorate formation, electrode fouling	Visible light must pass through matrix
PFAS Destruction Performance	Ability to mineralize <b>all PFAS</b>	Ability to mineralize <b>all PFAS</b>	Good with long-chains, poor with short-chains	Good with carboxylic acids, poor with sulfonic acids
Energy Consumption	Moderate	High	High	Moderate
Ability to Treat IXR Still Bottoms?	Yes - demonstrated	No, challenges with high TDS	No, challenges with perchlorate formation & short-chain PFAS	Currently in testing
Ability to Treat Foam Fractionate?	Yes - demonstrated	Currently in testing	No, challenges with electrode fouling	No, challenges with matrix complexity



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# Q&A

- Hunter Anderson, richard.anderson.55@us.af.mil
- David Kempisty, dakempisty@ect2.com
- Brian Pinkard, brian@aquagga.com







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