Battelle

2019 Bioremediation Symposium | April 15-18 | Baltimore, Maryland

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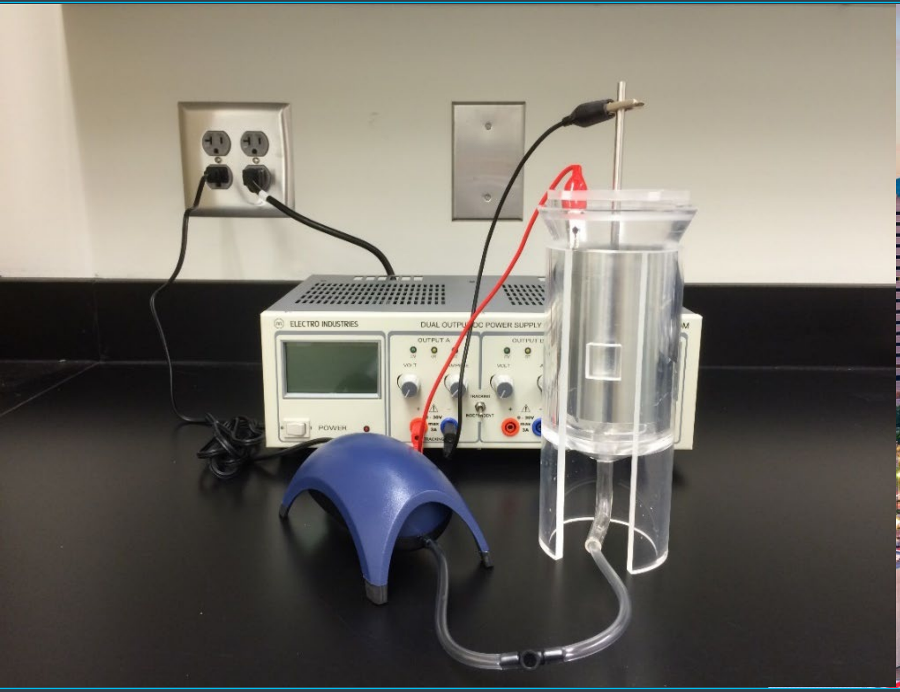


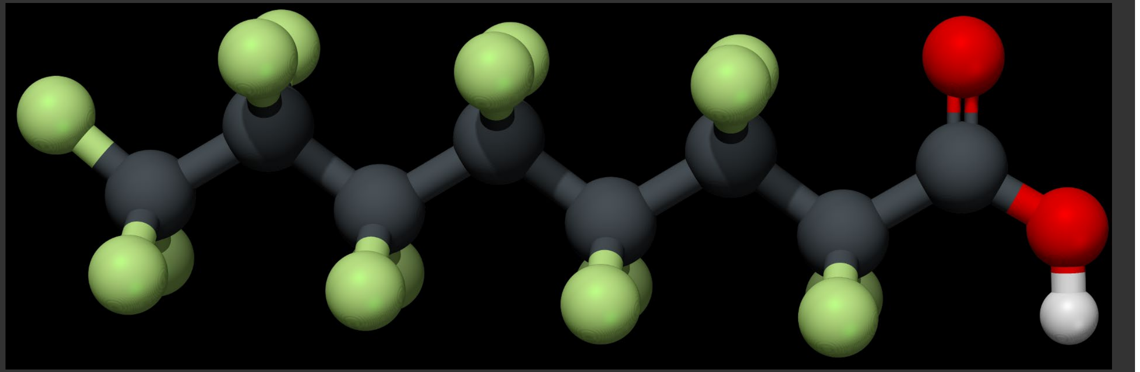
Electro-coagulation Treatment of Perfluoroalkyl Substances in Groundwater and Liquid Waste

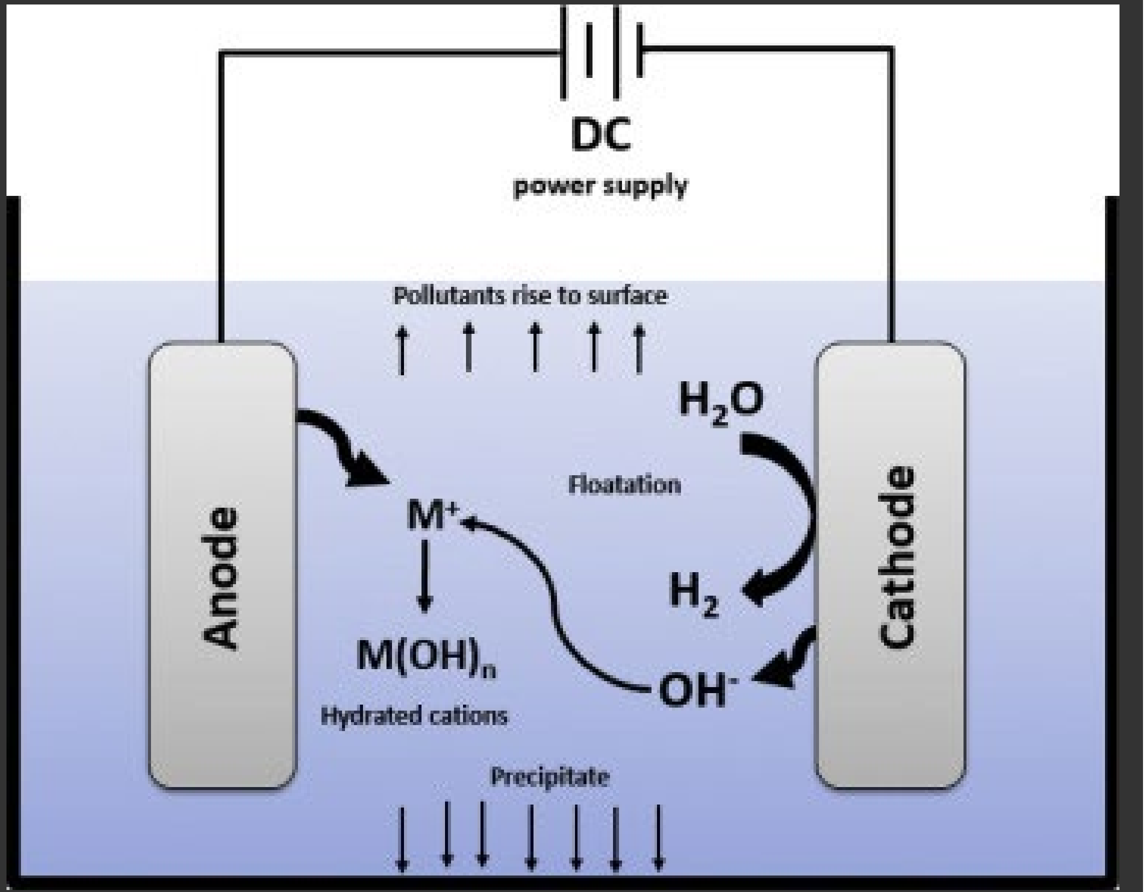
Shangtao Liang, Ph.D; Jack Huang, Ph.D; Hui Lin, Ph.D; Jing Zhou, Ph.D, PE

April, 17, 2019

Outline

- Background
- Bench-scale testing
- Future work
- Q&A

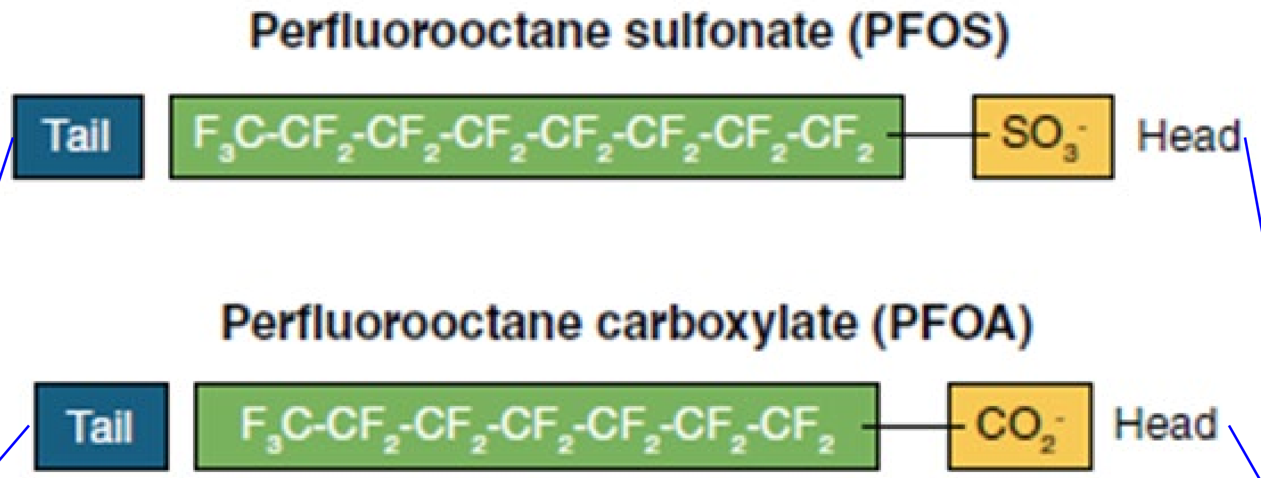




01

Background

PFAS Properties



C-F tail

- Hydrophobic and lipophobic
- Surfactant properties
- Thermal and chemical stability

Functional group properties

- PFAAs are in the anionic state, thus negatively charged in the environment
- Electrostatic interactions
- Polar and hydrophilic

PFAS Treatment Challenges

Van der Waals and
weak ionic forces

Electrostatic forces
Hydrophilic
functional group

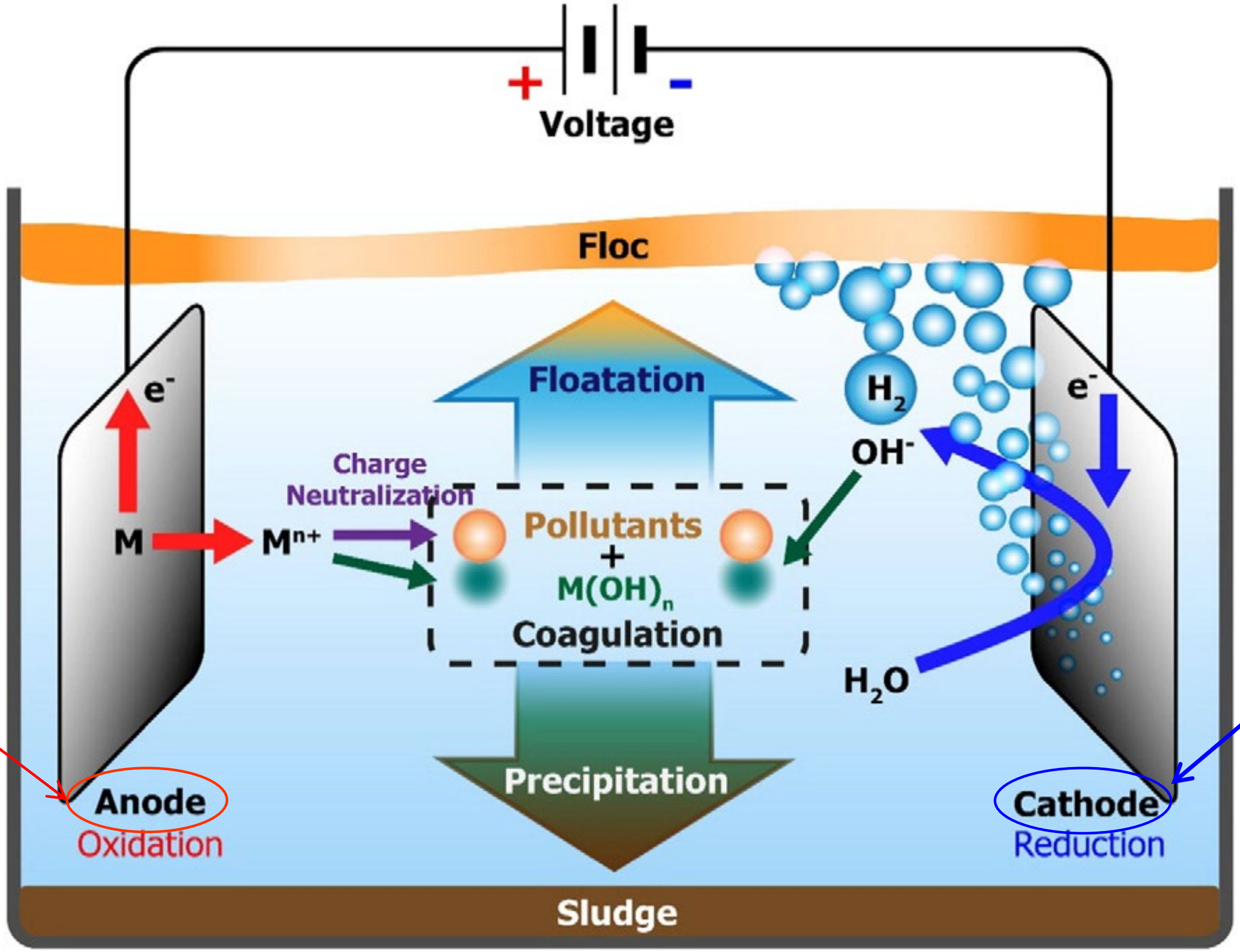
- Total organic carbon competes with PFAS on GAC. DOC <3mg/L or lower

  Resin is a better choice when TOC is high, but TOC reduces bed life
- Suspended solids will coat resin beads and inhibit mass transfer
- Iron and manganese can be oxidized and cause the same problem as SS, <0.05 mg/L Fe and Mn is recommended
- Oil and grease will coat the beds and inhibit mass transfer. Should not be present.
- Accumulated biomass will short bed life similar to SS.

Electro-coagulation (EC) - Mechanism

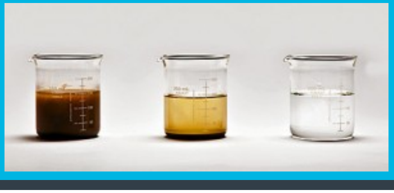
Electro-coagulation is a combined process of <u>coagulation, flotation, and electrochemistry</u>

- Sacrificial anode
- Fe, Al, Zn material
- Requires replacement



- Non-sacrificial anode
- SS, Fe, Al, Zn material

Electro-coagulation (EC) - Applications



Contaminants

- Heavy metals
- Oil and grease
- COD
- BOD
- TSS
- Turbidity
- Dye
- Color
- Sulfide
- TPH
- ……
- PFAS??

Applications

- Water containing heavy metals
- Industrial wastewater
- Wastewater containing PFAS??

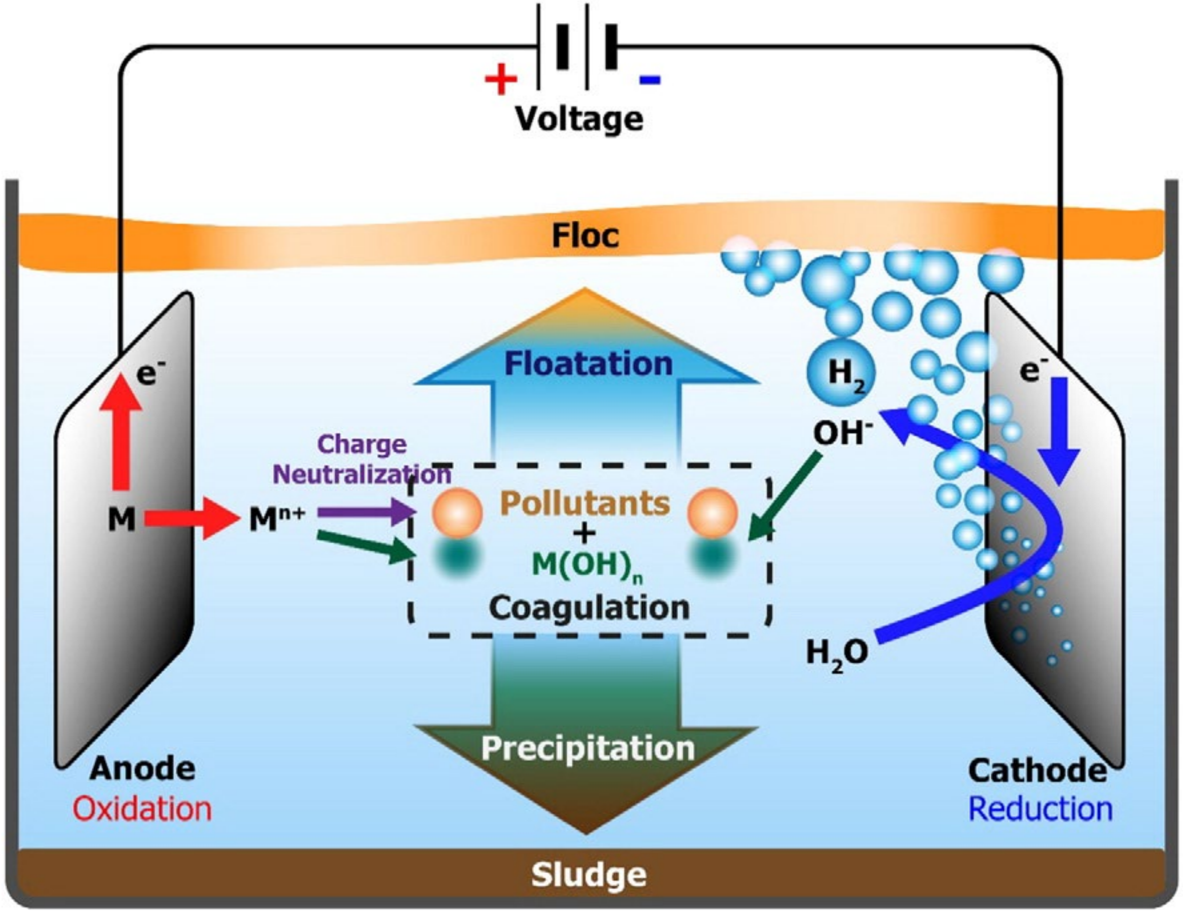
Advantages

- No chemical addition, reduces change of secondary pollution
- Removes mixed contaminants
- Produces less sludge than chemical coagulation
- Simple equipment
- Complete automation is possible

Disadvantage

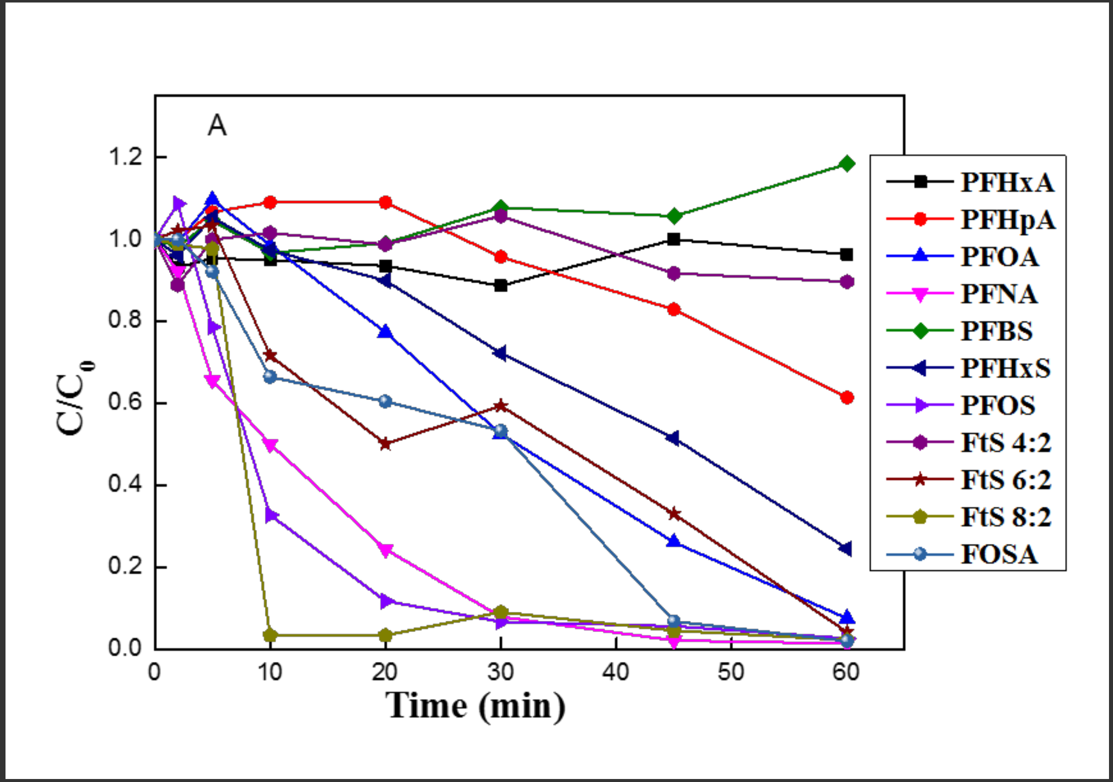
- Regular replacement of anode
- Cathode passivation
- Energy consumption can be high for low strength water
- Sludge management
- Requires post-treatment before discharge

Potential PFAS Fate during EC



<u>Possible PFAS fate</u>

1. Foam fractionation and flotation
2. Binding to coagulants and precipitate out
3. Electrochemical oxidation/reduction of some PFAS compounds

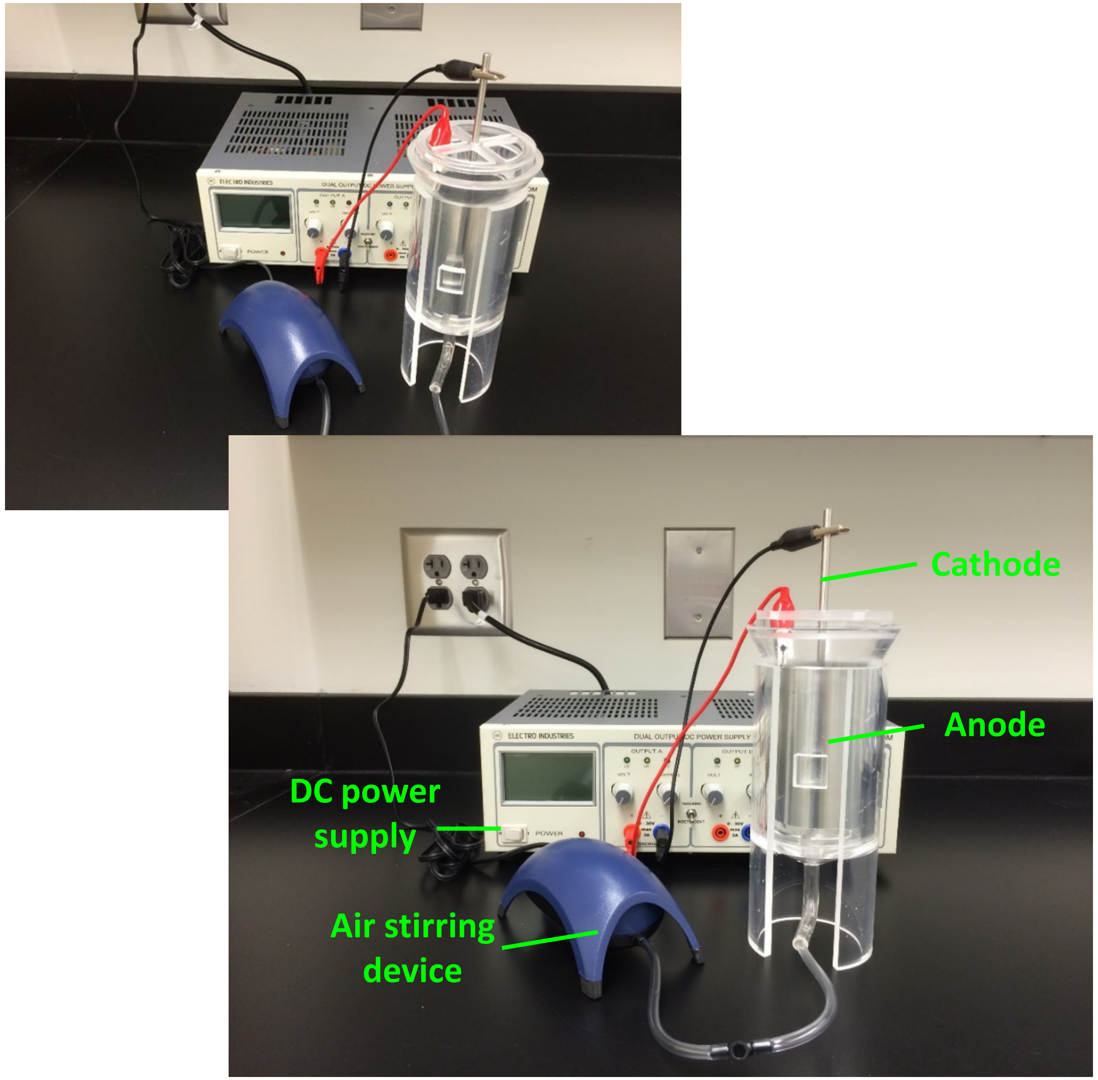


02

Bench-scale Testing

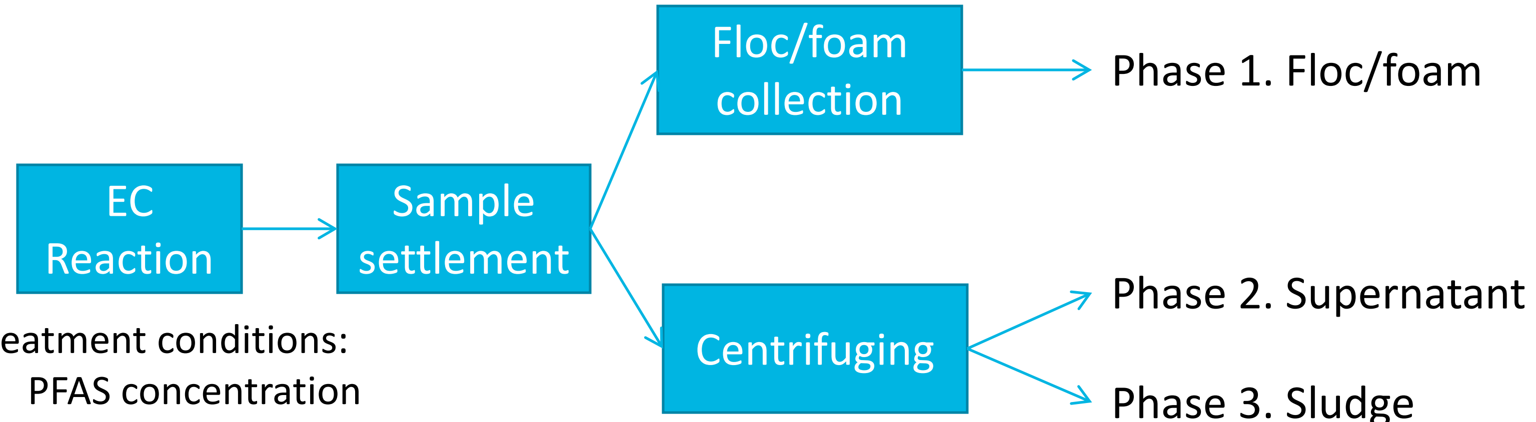
(Data courtesy of the University of Georgia)

Experiment setup



Specifications	
Reactor	In-house constructed bench reactor
Anode	High purity (>99.9%) metal sheets
Cathode	Stainless steel
Reaction volume	300mL
Electrolyte	20 mM Na_2SO_4
Initial pH	3-5
Stirring method	Air stirring

Sampling and Analytical Methods



EC Reaction

Sample settlement

Floc/foam collection

Centrifuging

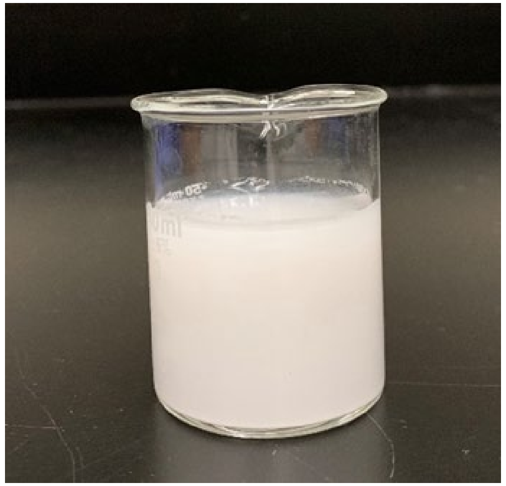
Phase 1. Floc/foam

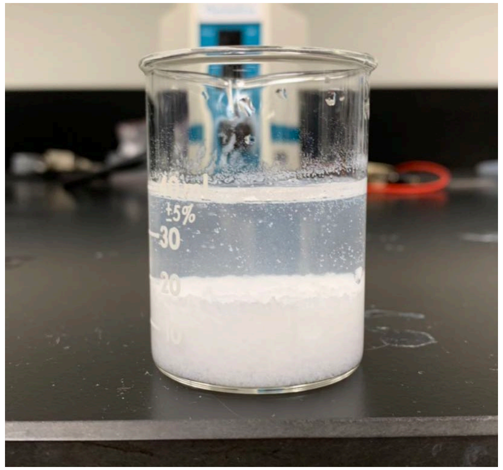
Phase 2. Supernatant

Phase 3. Sludge

Treatment conditions:

- PFAS concentration
- Current density
- Reaction time





Phase 1. Floc/foam

Phase 2. Supernatant

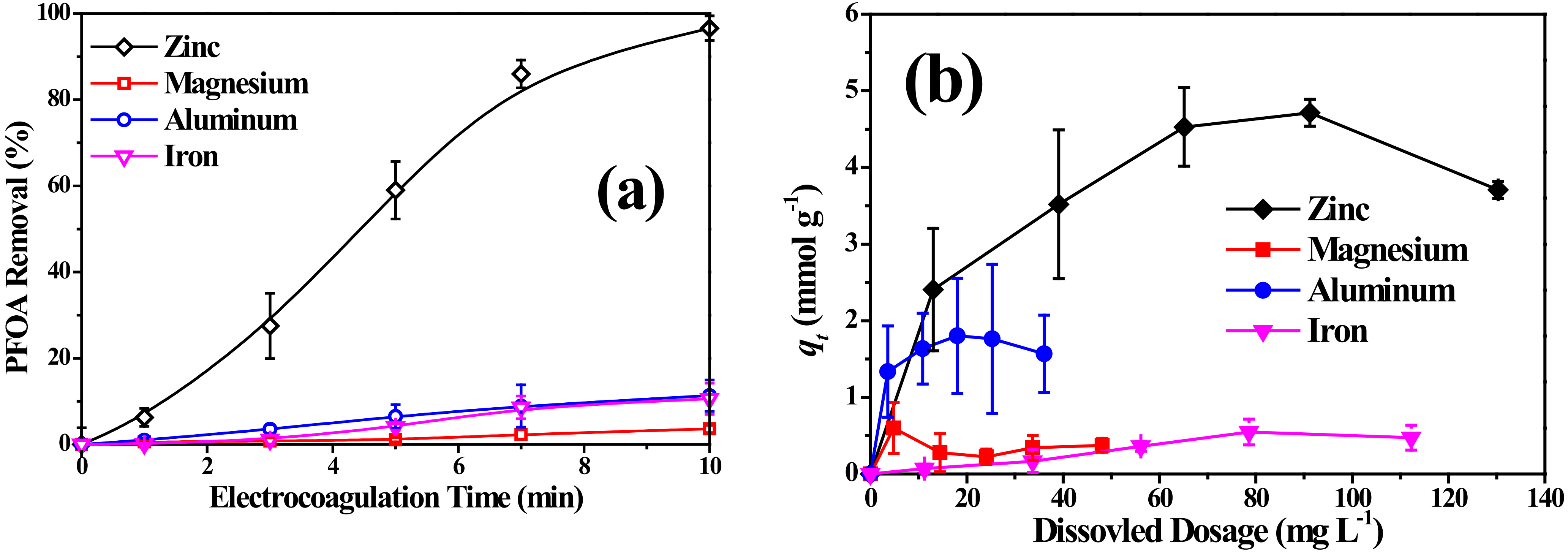
Phase 3. Sludge

Sample preparation

PFAS quantification

DoD QSM Version 5.1.1 Table B-15

Electrode Material Selection

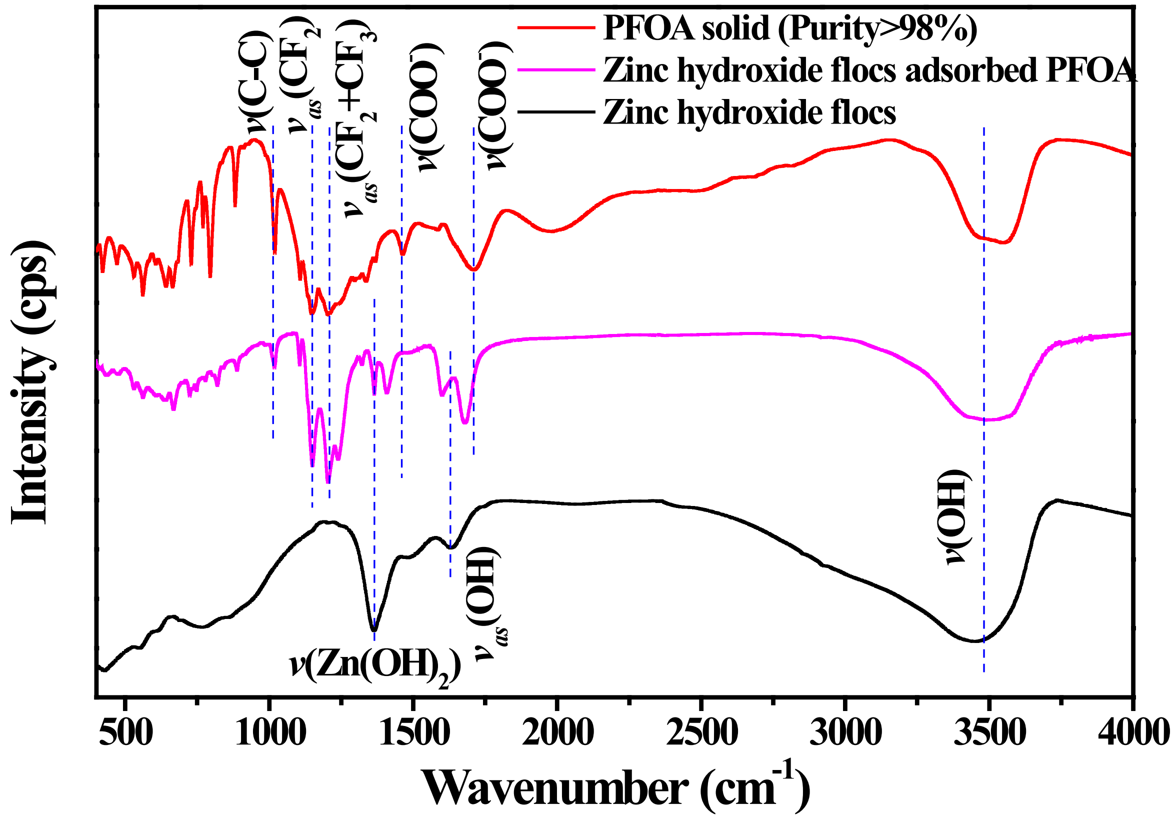


Treatment conditions:

- C_0 = 0.5 mM PFOA
- Current: 0.1 A
- Electrolyte: 10 mM NaCl
- Initial pH: 5

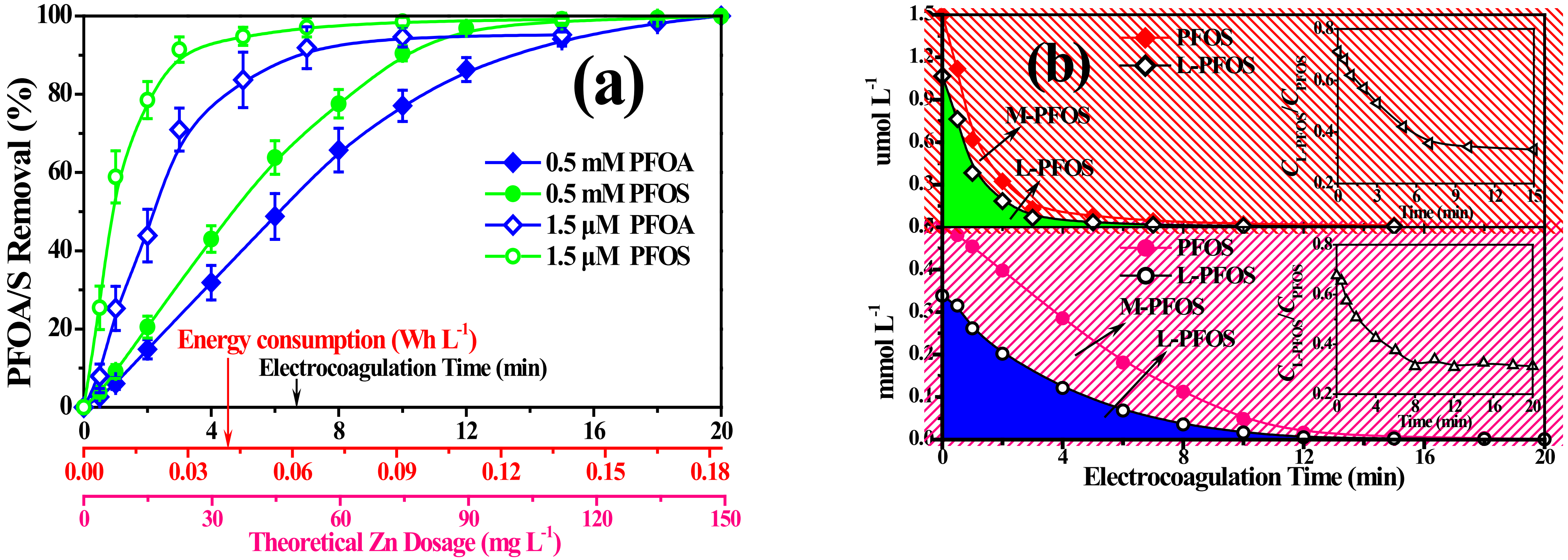
Lin, Hui, et al. "Efficient sorption and removal of perfluoroalkyl acids (PFAAs) from aqueous solution by metal hydroxides generated in situ by electrocoagulation." *Environmental science & technology* 49.17 (2015): 10562-10569.

PFOA Adsorption on Zinc Floc



Fourier transform infrared spectrum (FTIR) spectra of solid PFOA and zinc hydroxide flocs before and after PFOA sorption.

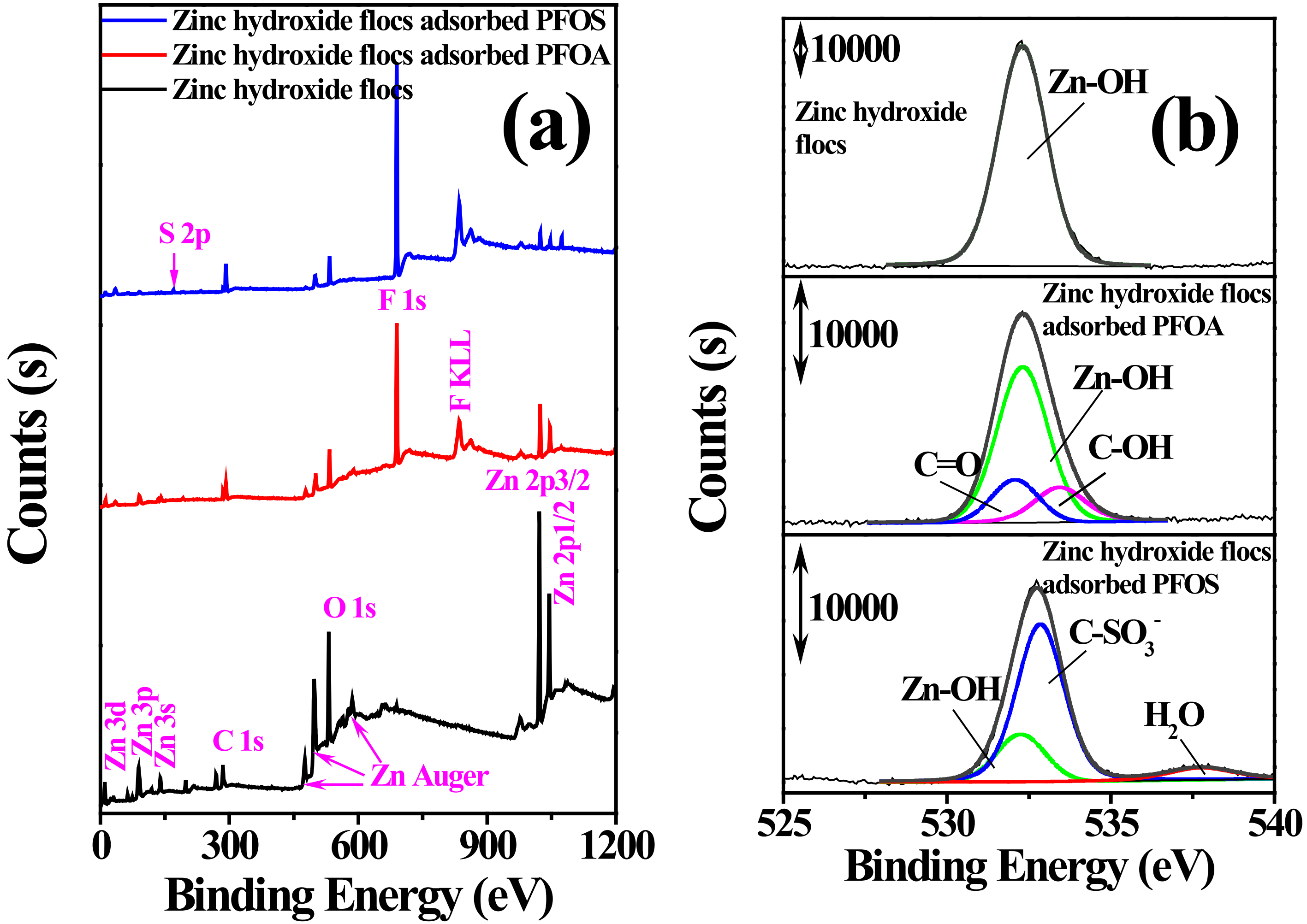
Energy Consumption and Linear vs. Branched PFOS



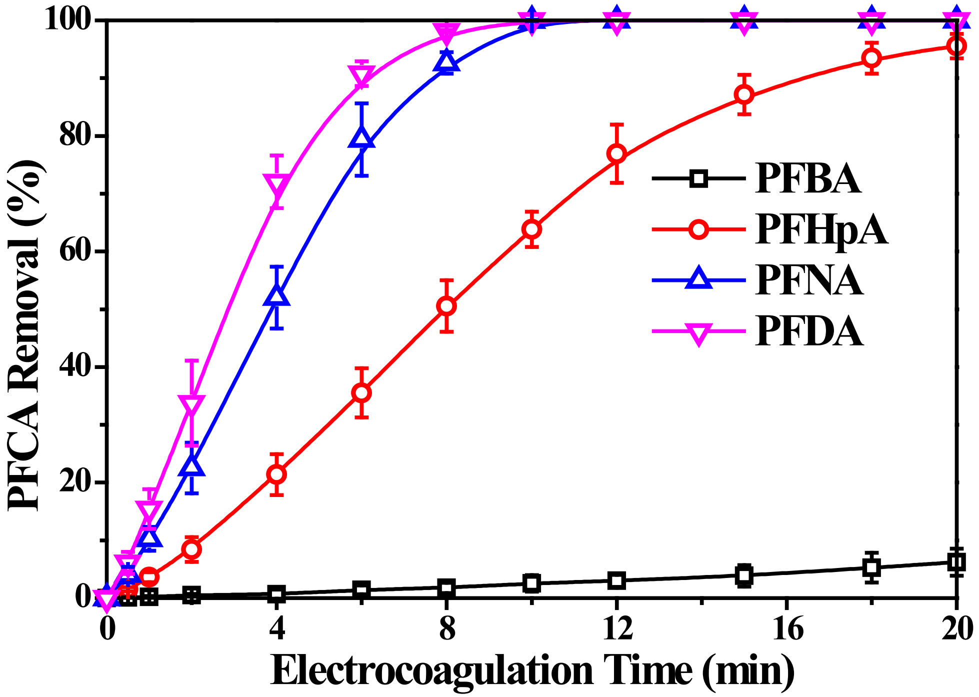
Comparison with other Sorbents

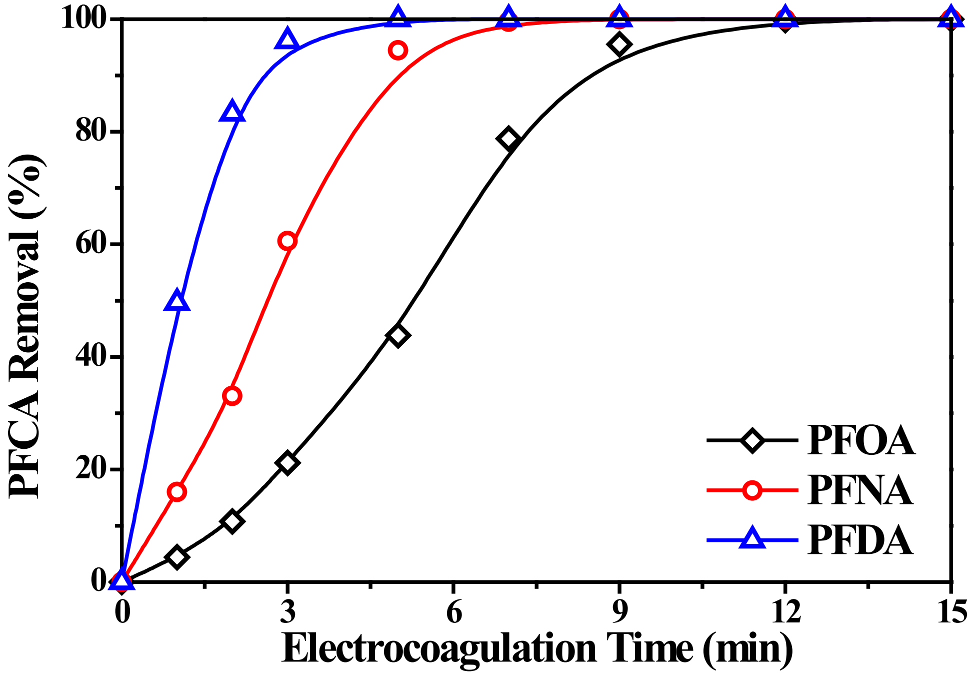
adsorbents			adsorbates	C_0 (mM)[a]	q_m (mmol g^{-1})[b]	t_{equi} (h)[c]	k_2 (g $mmol^{-1}$ h^{-1})[d]	Refs.
Species	Particle size	BET (m^2 g^{-1})						
PAC	< 0.1 mm	812	PFOA	0.048~0.6	0.67	4	13.9	3
GAC	0.9~1.0 mm	712		0.048~0.6	0.39	168	0.07	
AI400	0.3~1.2 mm	---			2.92	168	0.02	
PAC	< 0.1 mm	812	PFOS	0.04~0.5	1.04	4	5.45	
GAC	0.9~1.0 mm	712		0.04~0.5	0.37	168	0.07	
AI400	0.3~1.2 mm	---		0.04~0.5	0.42	168	0.12	
CNTs	---	97.2~547.2	PFOS	0.002~1	0.3~0.4	2	8.08~9.13	4
Chitosan-based MIP[f]	---	---	PFOS	0.04~0.5	2.91	32	0.29	5
Aminated rice husk	0.5~0.6 mm	---	PFOA	0~0.5	2.49	5	1.23	6
			PFOS	0~0.5	2.65	9	0.22	
EC with Zn anode	---	48.7	PFOA	0.05~0.8	5.74[e]	< 0.17	32.67	This work
			PFOS	0.05~0.8	7.69[e]	<0. 17	32.62	

XPS Spectra of Zinc Hydroxide Flocs



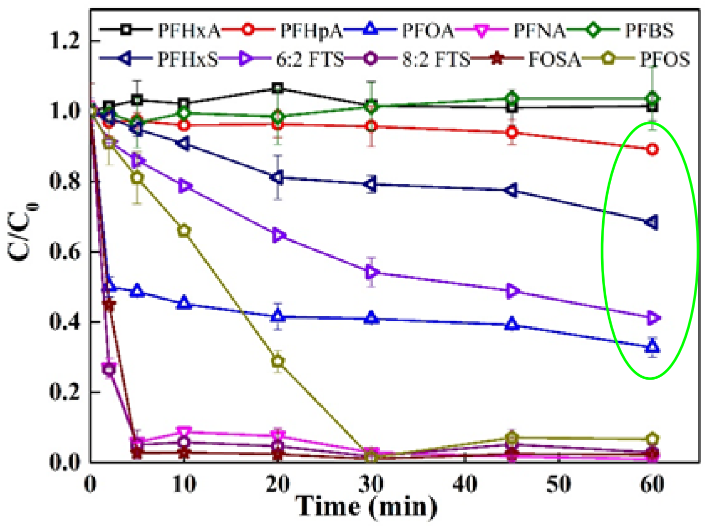
EC Treatment – Other PFAS Compounds



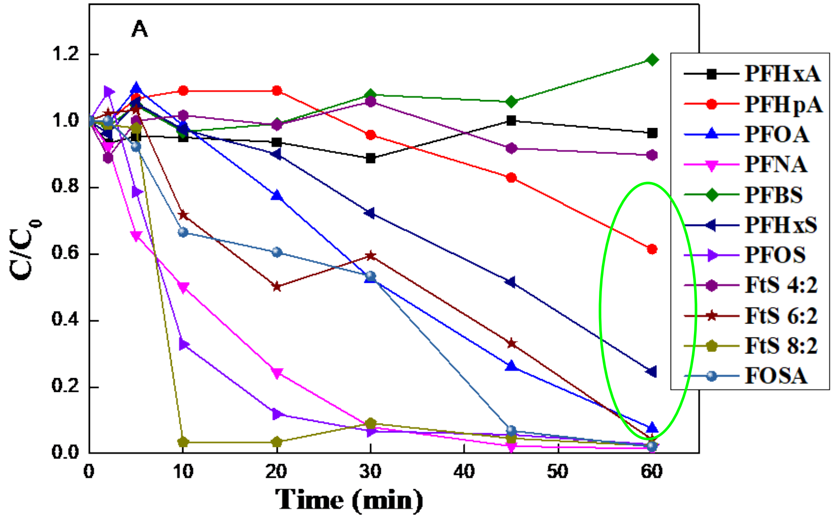


EC Treatment – Concentration Impacts

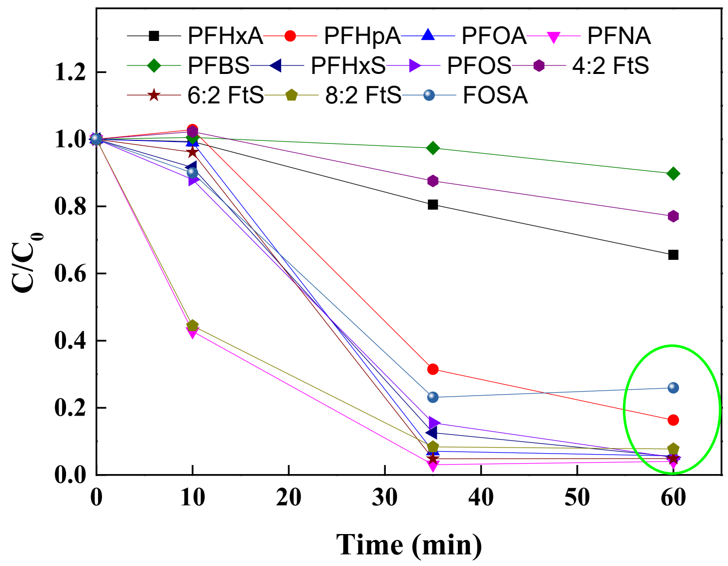
C_0 = 1 µM



C_0 = 0.5 µM



C_0 = 0.01 µM



UGA on-going testing data

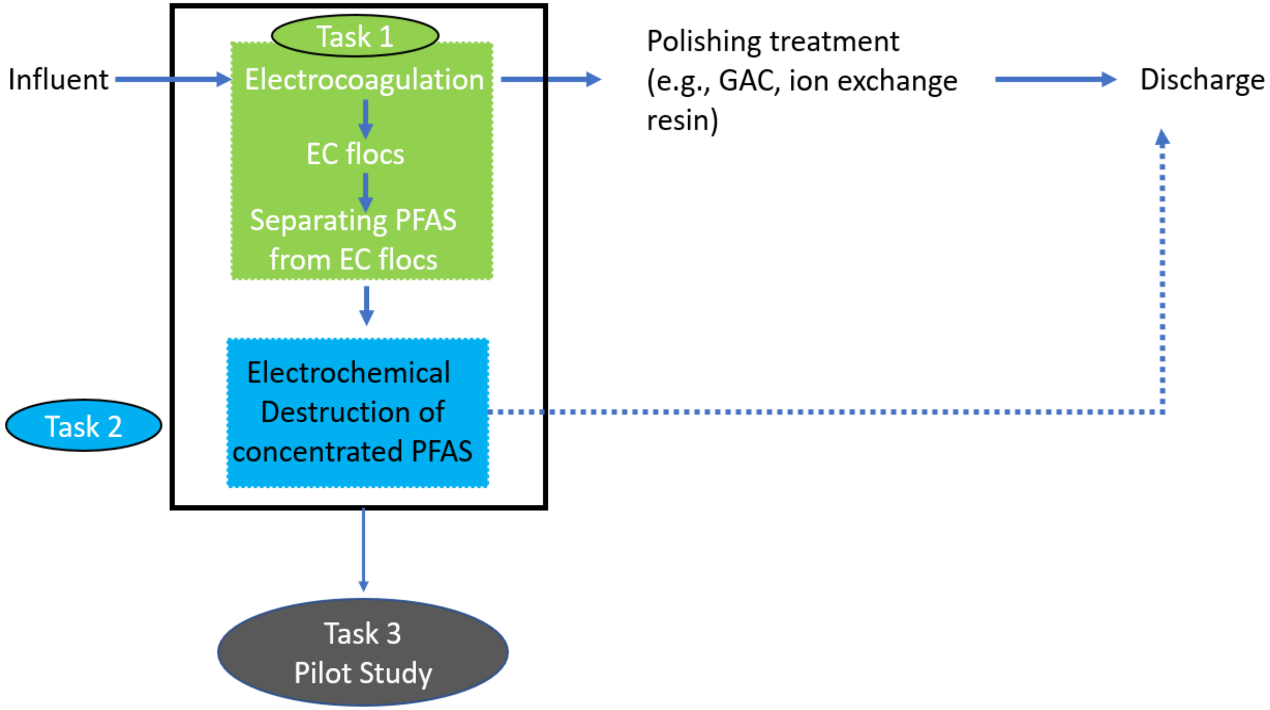
03

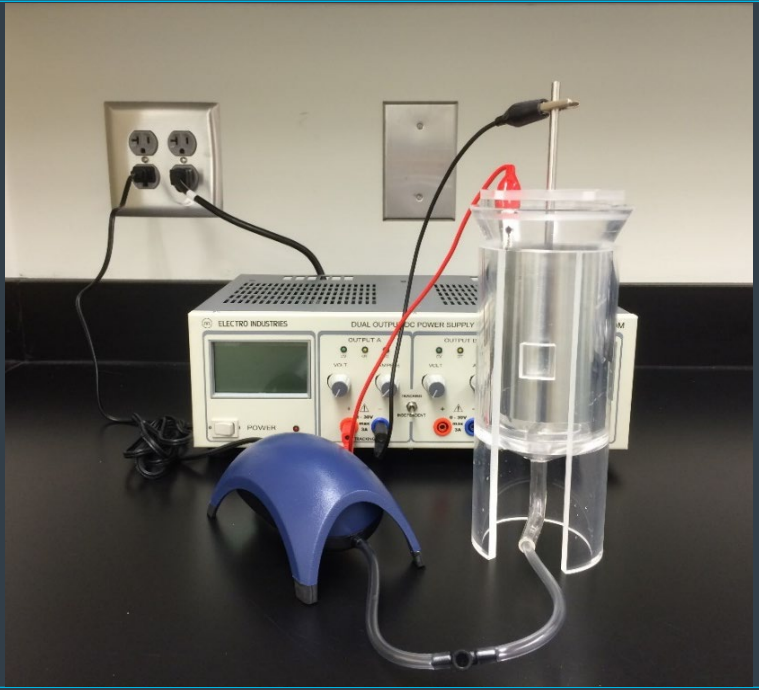
Future study

SERDP 1278

ER18-1278: An Electrocoagulation and Electrooxidation Treatment Train to Degrade Perfluoroalkyl Substances and Other Persistent Organic Contaminants in Ground Water

(Team member: Dora Chiang, Ph.D, PE (PI); Jack Huang, Ph.D (Co-PI); Jing Zhou, Ph.D, PE (Co-PI); Shangtao Liang, Ph.D)





Thank You!

Shangtao Liang, Ph.D.

T 919-961-4750
E shangtao.liang@aecom.com