AN INNOVATIVE PLASMA TECHNOLOGY FOR TREATMENT OF PFAS-IMPACTED WATER AT TWO FIRE TRAINING AREAS

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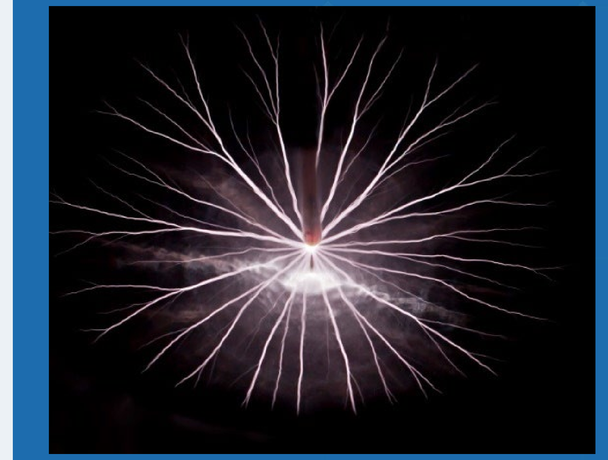

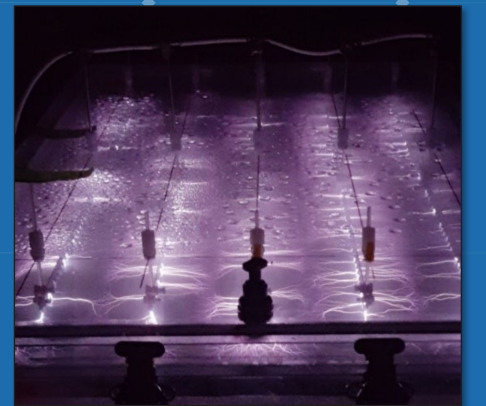

National Defense Center for Energy and Environment

PROBLEM STATEMENT

Aqueous film-forming foams (AFFF) have been widely used as a fire-suppressant for fire-fighting efforts and training activities at hundreds of Department of Defense (DoD) installations nationwide. Ongoing assessment of former fire/crash sites has identified concentrations of PFOA, PFOS, and other PFAS in groundwater well above established health advisory levels. Based on their recalcitrant and often dilute nature, PFAS can be very challenging to remediate in groundwater environments and require technologies capable of breaking the stable C-F bond of the molecules and handling large volumes of water.

TECHNICAL OBJECTIVES

NDCEE funded this project to demonstrate operation of a mobile plasma treatment system for the treatment of various sources of PFAS-impacted at fire training areas.

TREATMENT SYSTEM

DMAX Plasma Mobile Treatment Trailer:

> Flow-through reactor system (up to 10 gpm),

> Dual-reactor design (120-gallons each),

> Surfactant addition for enhanced removal of short-chain compounds.

PROJECT TEAM

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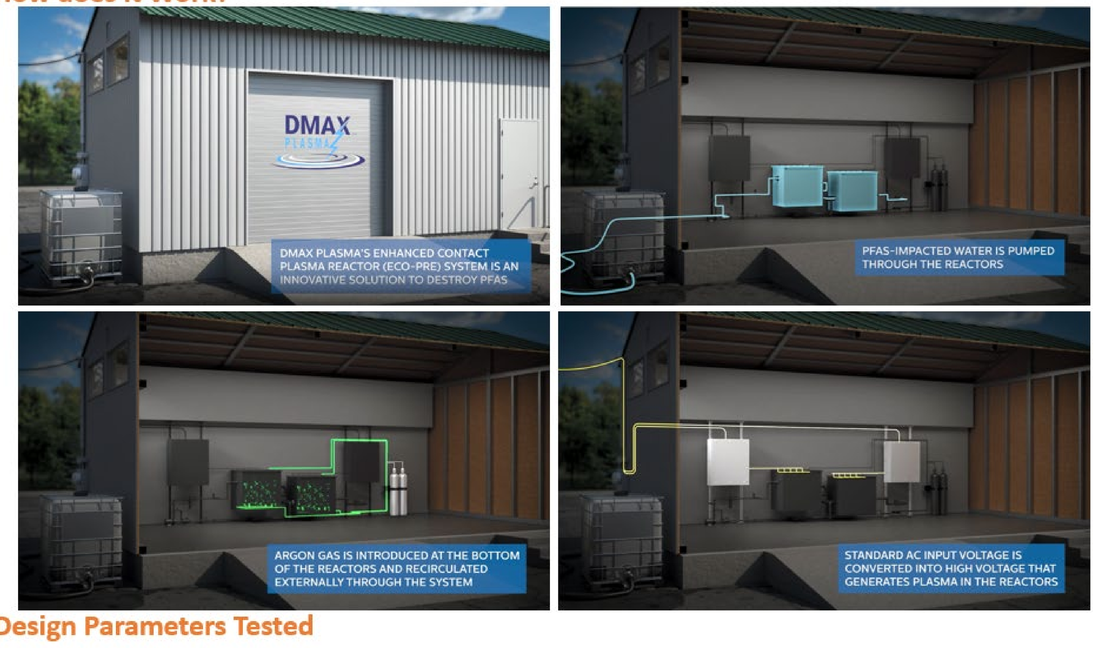
TECHNOLOGY

How does it Work?

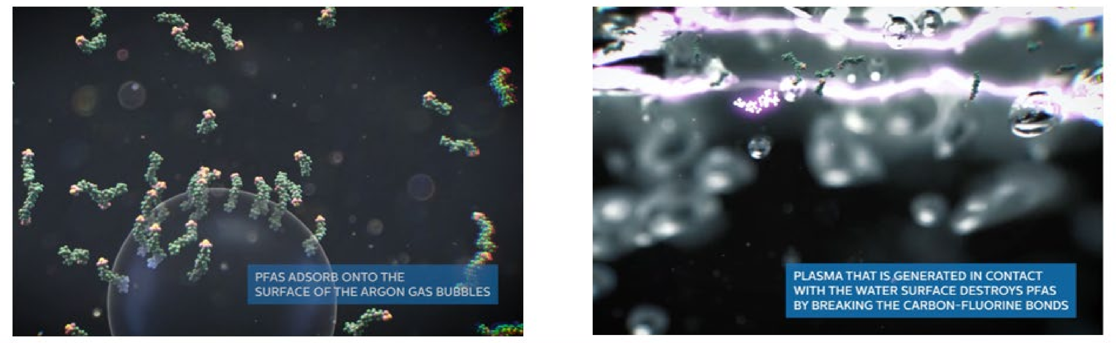


Design Parameters Tested

> Reactor Contact Time: Flow rates of 2-10 gallons per minute (190 – 230 gallons per hour), reactors in series with recirculation or single-pass treatment

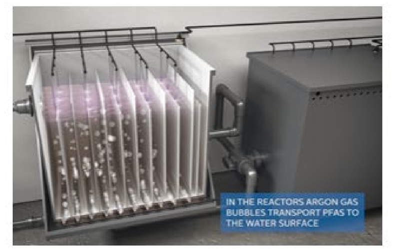
> Surfactant Dose: CTAB and a proprietary surfactant were added at varying concentrations

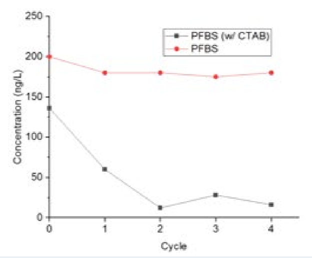
Reaction Zone

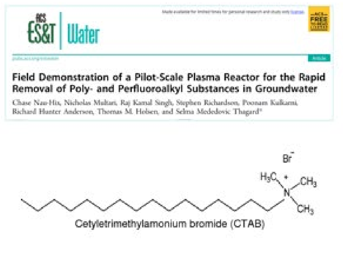


Surfactant Addition

Cationic surfactants electrostatically and hydrophobically interact/associate with short-chained PFAS and transport them to the plasma-liquid interface.







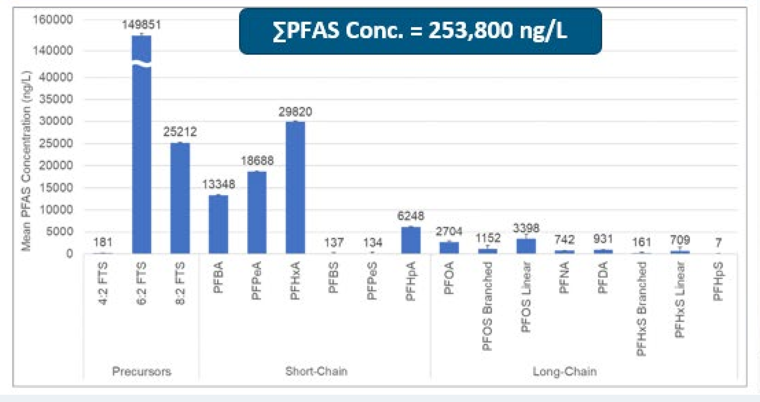
In the CTAB addition experiments (0.9 GPM for 4 cycles) the CTAB concentration was adjusted to 0.04 mM before each cycle.

FIELD DEMONSTRATION

Tyndall Air Force Base (Florida, 2021)

Source Water: surface water from a stormwater collection pond

- Stormwater from an active Fire Training Area with historical AFFF use is collected for disposal
- Source water predominantly precursors and short-chain PFAS compounds

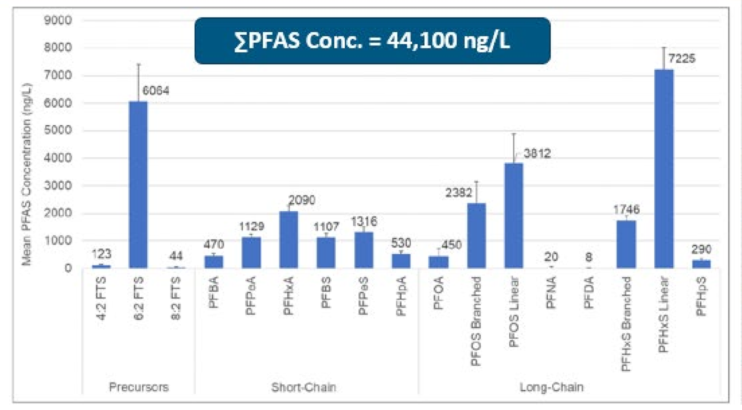


Semi-Batch

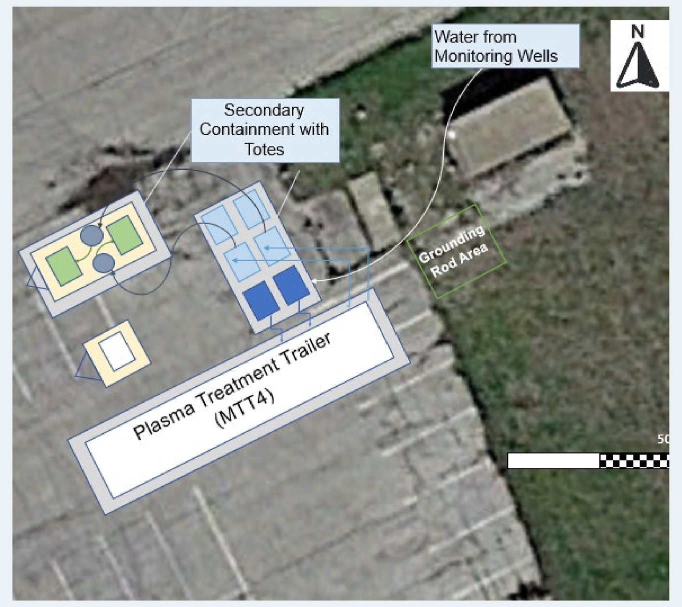
Fort Leavenworth Army Garrison (Kansas, 2022)

Source Water: shallow groundwater

- Historical use of AFFF at the Former Fire Station resulted in groundwater contamination
- Source water predominantly precursors and long-chain PFAS; some short-chain PFAS



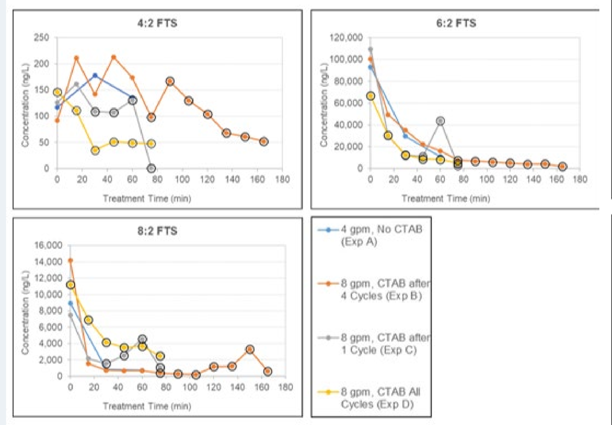
Flow-Through



TREATMENT

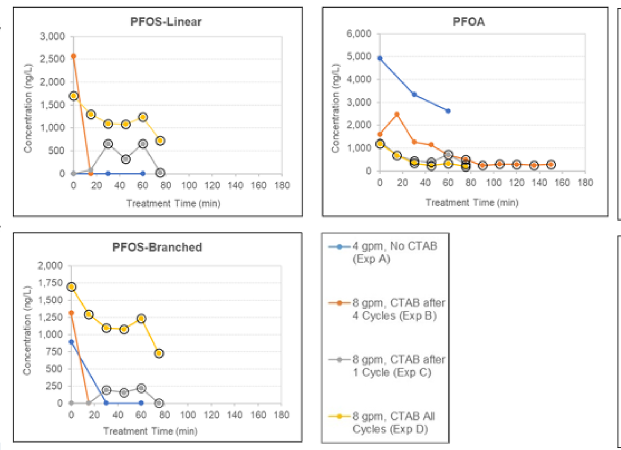
Precursors

- Destruction inhibited by CTAB (except 4:2 FTS)
- Best results with addition of CTAB after the first cycle



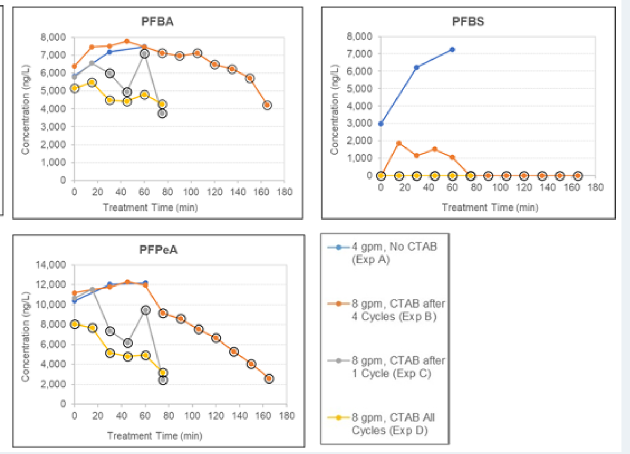
Long-Chain PFAS

- Destruction inhibited by CTAB
- Best results with addition of CTAB after the half of treatment time

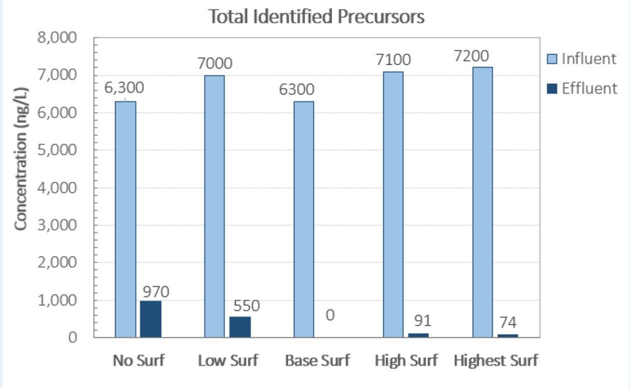


Short-Chain PFAS

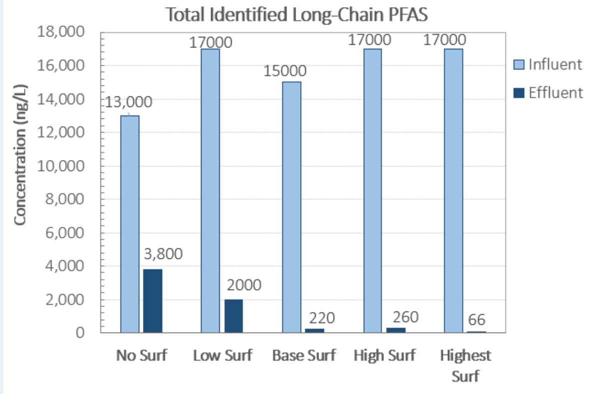
- Less removal efficiency of less hydrophobic compounds (PFBA)
- Best results with addition of CTAB after the half of treatment time



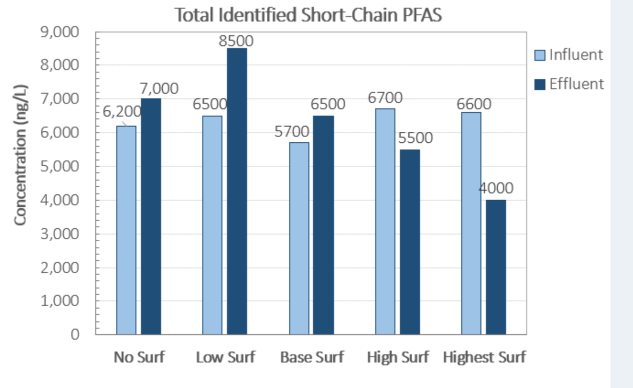
- Increased NS surfactant addition improved removal of the two detected precursors
- Greater removal of 4:2 FTS was observed; however, overall percent change remained low.



- Addition of NS surfactant greatly improved removal of PFHxS (both branched and linear)
- PFOA removal benefited from NS surfactant addition



- Improvement in removal of sulfonic acids and carboxylic acids, except for PFBA and PFPeA
- Interpretation of the results are complicated by generation of short-chain PFAS in the reactor



KEY RESULTS

Field Demonstration	Flowrates (gpm)	Volume Treated (gallons)	EE/O	Key Findings
Tyndall AFB	2 – 8	3,100	16-35	Addition of surfactant (CTAB) improved short-chain PFAS removal with some inhibition of long-chain PFAS removal in the presence of surfactant
Fort Leavenworth	2 – 10	5,700	6-19	Proprietary surfactant improved short-chain PFAS removal without sacrificing long-chain destruction

Summary of Results:

- More precursors = longer treatment times
- Higher concentrations = longer treatment times
- Co-contaminants not a major issue
- Plasma can efficiently treat precursors and long-chain PFAS (< 9 ng/L)
- Addition time is required to handle short-chain PFAS

$$EE/O = \frac{E \times 1000}{V \times \log\left(\frac{C_i}{C_f}\right)}$$

where E (kWh) is the energy consumed by the treatment system, V (L) is the total treated volume, and Ci and Cf are the average initial and final combined concentrations of PFOA+PFOS (ng/L) (Nau-Hix et al., 2021).

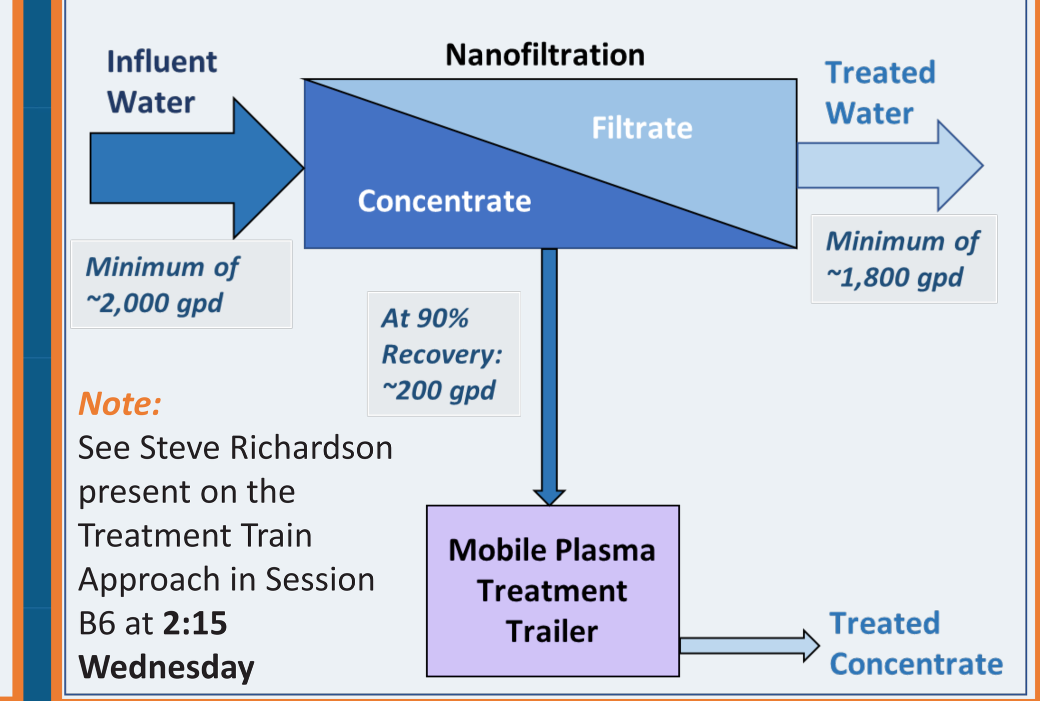
LESSONS LEARNED

▪*Treatment Performance:* At both sites, 6:2 FTS concentrations decreased by 98-100%. Some generation of 4:2 FTS was observed from the breakdown of longer chain precursors. PFOA and PFOS concentrations were reduced to below the detection limit (<9 ng/L) at optimal operating conditions. The addition of surfactant significantly improved removal of short-chain PFAS such as PFBS, PFPeA, PFPeS, and PFHxA. For example, at Tyndall AFB, short-chain PFAS removals of 77% to 100% were achieved after 75-165 minutes of total treatment time.

▪*Surfactant addition:* Addition of surfactant improved removal of short-chain PFAS by enhancing the transport of short-chain PFAS to the plasma-liquid interface. The time at which CTAB was added during treatment had a strong impact on short-chain removal likely due to slower long-chain removal if added too early. Overall, the addition of CTAB inhibited the removal of all long-chain PFAS, suggesting that CTAB should not be used until after the majority of long-chain PFAS mass has been removed. The addition of the NS surfactant provided equal or improved removal of short-chain PFAS compared to CTAB without sacrificing removal efficiency of long-chain PFAS.

NEXT STEPS

ESTCP Treatment Train: Nanofiltration + Plasma



Note:
See Steve Richardson present on the Treatment Train Approach in Session B6 at 2:15 **Wednesday**