Air Force Civil Engineer Center

Integrity - Service - Excellence

Technology Demonstration-Validation Projects for PFAS Remediation

Dr. Kent C. Glover
Remedial Systems SME
AFCEC/CZTE

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Purpose

Survey of AFCEC demonstration-validation projects related to PFAS remediation technology

- AFCEC role in technology development and technology transfer
- Summary of completed and continuing projects
- Examples
  - Source zone enhanced mass transfer and treatment
  - Electrochemical treatment
  - Enzymatic degradation

PFAS: per- and polyfluoroalkyl substances

Environmental Broad Agency Announcement (BAA)

- AFCEC environmental technology BAA projects
  - Address AFCEC-specific technology challenges for priority sites and contaminants
  - Emphasize field-scale technology demonstration and validation
  - Promote technology transfer from pilot testing to wide-spread use by remediation practitioners
  - Address technology needs for environmental restoration and compliance
- Current BAA initiatives for environmental restoration
  - High resolution site characterization
  - Remediation of persistent source zones

    e.g., DNAPL, low permeability
  - Characterization and remediation of emerging contaminants

    e.g., PFAS, 1,4-D

Competed BAA Projects: PFAS Initiative

Project Title	End Date
Chemical Treatment of Soil and Groundwater Contaminated with Perfluorinated Compounds found in Aqueous Fire Fighting Foams	2013
Chemical Oxidation and Inclusion Technology for Expedited Soil and Groundwater Remediation	2015
Use of Boron-Doped Diamond Electrodes for Treatment of Perfluorinated Compounds	2015
Is Bioremediation a Relevant Attenuation Mechanism for Perfluorinated Compounds?	2014
In-situ Enzymatic Oxidative Treatment for Perfluorinated Compounds	2017
Focused Remedial Investigation of Potential Ecological Effects of Perfluorinated Compounds and Associated Human Exposures from Fish Consumption	2015

- Available project information
  - Fact sheet and presentations
  - Journal article(s)
  - Final report

Enhanced Mass Transfer and Treatment of Source Zones

- Concept
  - Cyclodextrin (CD) to enhance contaminant availability
  - Advanced oxidation with liquid solution of dissolved ozone, hydrogen peroxide, buffered sodium persulfate
- Design
  - High resolution site characterization
  - Bench-scale testing
  - Field pilot tests with three treatment cells to optimize treatment sequence

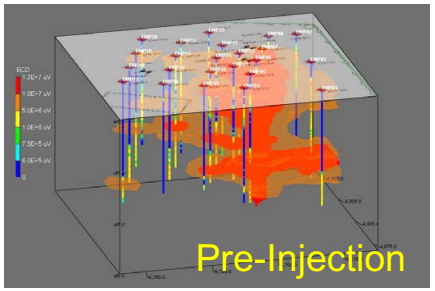
Langley-Eustis Fire Training Area

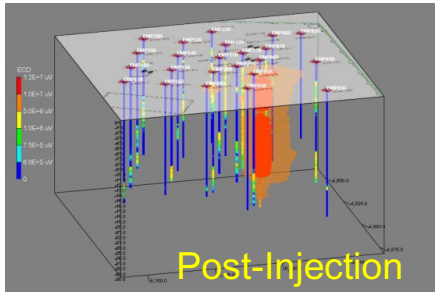
BAA FA8903-11-C-8004: Chemical Oxidation and Inclusion Technology for Expedited Soil and Groundwater Remediation

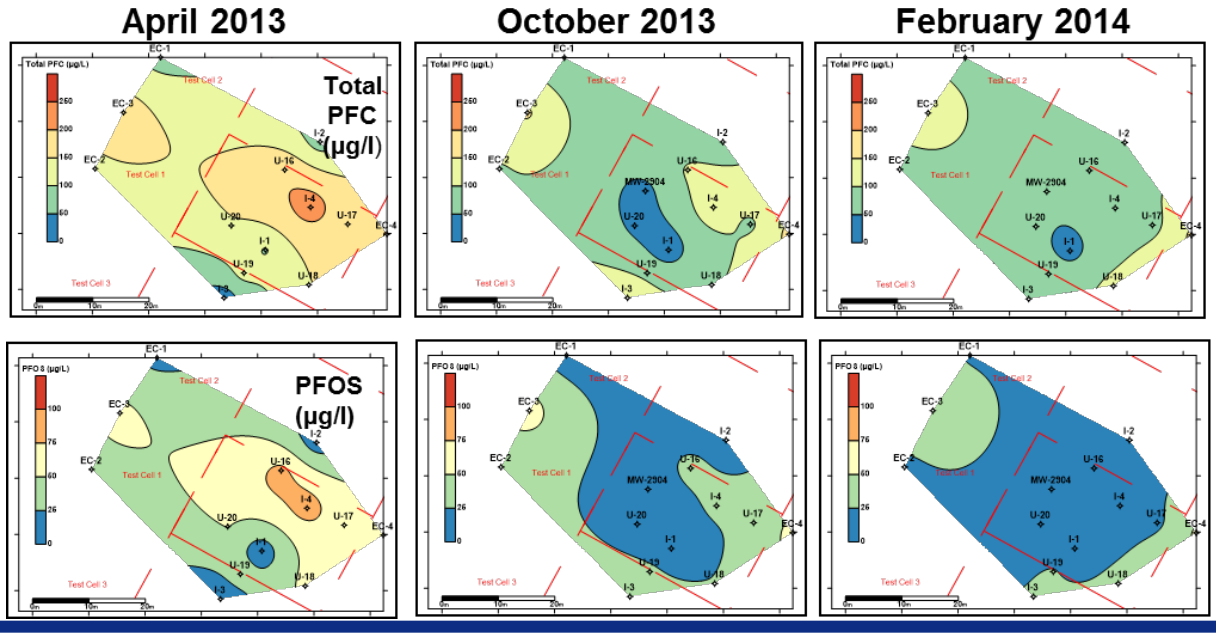
Enhanced Mass Transfer and Treatment: Results

- Optimal treatment: Sequential injections of oxidant, oxidant + CD, and oxidant
- Different PFAS responded differently: some created, some transformed, some destroyed
- Need to understand reaction chemistry

MIP ECD Data

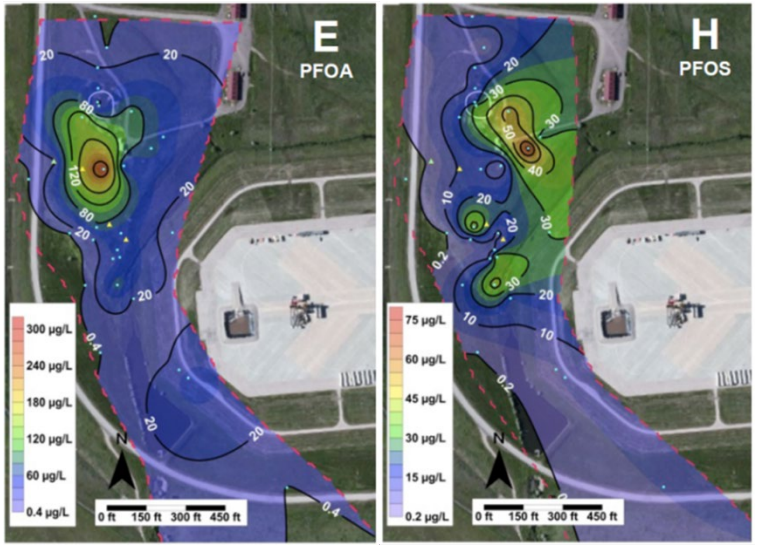






Electrochemical Treatment of Perfluorinated Compounds

- Concept
  - PFAS degradation on surfaces of non-consumable electrical anodes
  - Mechanisms: direct electron transfer, hydroxyl radical generation, oxidants generated from salts
  - Approach
    - Characterize PFAS at a FTA site
    - Lab tests with site groundwater
      - mixed metal oxide (MMO)
      - boron doped diamond (BDD)
    - Develop pilot-scale ex situ treatment unit

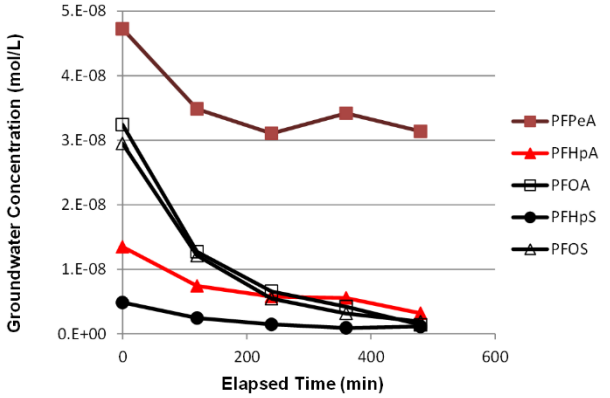


BAA FA8903-11-C-8008 : Use of Boron-Doped Diamond Electrodes for Treatment of Perfluorinated Compounds

Electrochemical Treatment: Results

- Laboratory results
  - BDD anode generated perchlorate (not recommended)
  - MMO anode made of Ti/RuO_2 was effective
    - PFOS: 98% mass recovery as fluoride
    - PFOA: 58% mass recovery as fluoride
- Pilot-scale demonstration was inconclusive
  - Operational complications at treatment facility
  - Other contaminant interferences
  - More work needed for field-scale implementation

Typical Lab Result



Pilot-Scale Treatment System

Ti: Titanium
Ru: Ruthenium

Enzymatic Degradation

- Concept
  - Highly reactive oxidizing agents for degradation (e.g. laccase)
  - Couple with GAC to destroy PFAS and delay breakthrough
- Approach
  - Laboratory testing

    Enzyme selection based on reactivity, stability/activity and cost
  - Pilot-scale demonstration

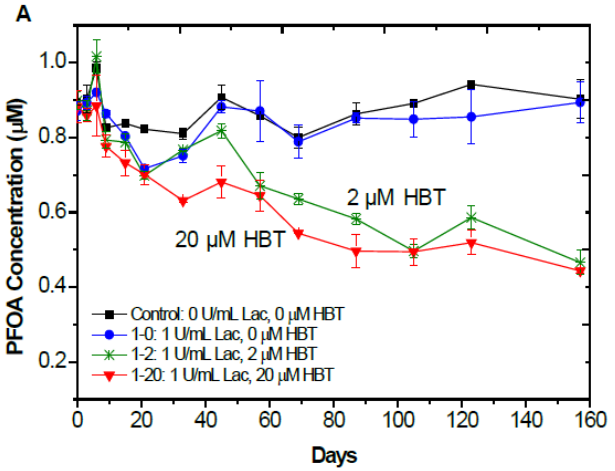
    Characterize GAC breakthrough (PFAS, precursors); Introduce enzyme to GAC column; Rest column (1 month); resume flow

BAA FA8903-12-C-0005: In-situ Enzymatic Oxidative Treatment for Perfluorinated Compounds

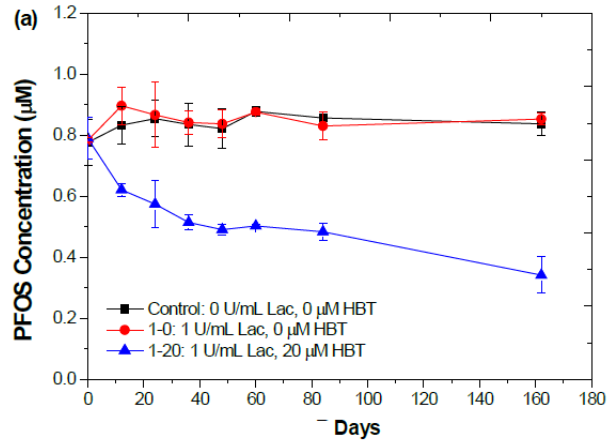
Enzymatic Degradation: Results

- Lab study shows reaction is very slow
  - Water: 40% PFOA and 60% PFOS
  - Soil slurry: 40% PFOA
  - Shows potential if coupled with separation technology to delay PFAS breakthrough
- Pilot test
  - Comparison of GAC breakthrough vs. GAC + enzyme-catalyzed degradation not promising
  - Benefit significant only for PFBA
  - Options for optimization: Add O_2, extend reaction time, mediator amendment

PFOA (**40%** removal in 156 days)



PFOS (**60%** removal in 162 days)



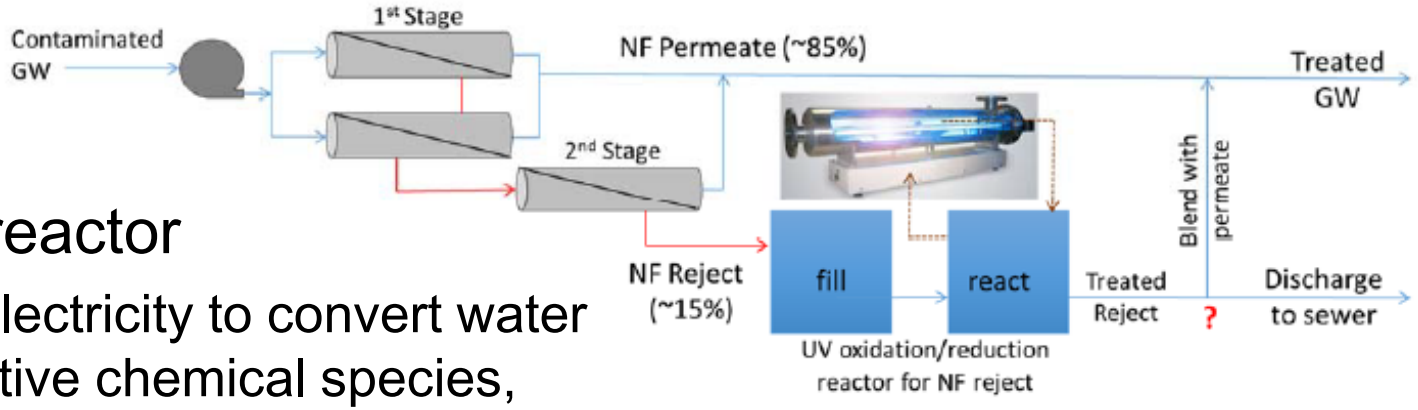
HBT: hydroxybenzotriazole
PFBA: perfluorobutyrate

Current BAA Projects: PFAS Initiative

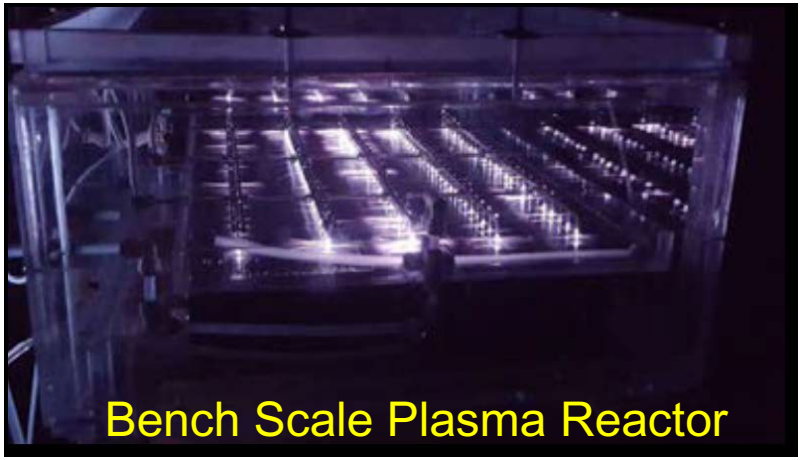
Project Title	Media	Status
Perfluorochemical Treatment by Nanofiltration Plus Sequential UV Oxidative/Reductive Treatment of Reject Water	Water (ex situ)	Lab phase complete. Pilot-scale system being constructed. Field-scale testing planned for FY2019.
Enhanced Contact Electrical Discharge Plasma Reactor	Water (ex situ)	Bench scale reactor successful. Pilot-scale skid being constructed. Field-scale testing ~ Feb 2019.
Field-Scale Comparison of Adsorbents for In Situ Stabilization of Poly- & Perfluorinated Alkyl Substances (PFAS)	Soil	Field demonstration complete. Post-treatment soil cores collected for lab analysis.
Coupling Ion-Exchange Resin with Electrochemical Treatment For Complete Separation and Destruction of PFOS and PFOA in Groundwater	Water (ex situ)	Lab testing phase complete. Pilot-scale system for treating resin still bottoms being developed.

PFAS Ex Situ Treatment Concepts in BAA Projects

- Nanofiltration + sequential UV oxidation/reduction



- Plasma reactor
  - Uses electricity to convert water to reactive chemical species, UV radiation and shockwaves for cavitation and thermal treatment
- Ion exchange + electrochemical treatment
  - On-site resin regeneration
  - PFAS degradation with ceramic titanium oxide electrode



Discussion and Questions

Air Force Civil Engineer Center (AFCEC)
Environmental Management Directorate
Technical Division (CZTE)

Kent Glover, Remedial Systems SME: kent.glover@us.af.mil
Monique Nixon, BAA Program Manager: monique.nixon@us.af.mil

AFCEC BAA email: afcec.czte.baa@us.af.mil
AFCEC web: https://www.afcec.af.mil/