Introduction to PFAS Remediation Approaches

Herwig Goldemund, Ph.D.
Geosyntec Consultants
Kennesaw, GA

April 11, 2019
Agenda

• PFAS Characteristics, Sources and Environmental Fate
• Overview of PFAS Toxicology
• Treatment Challenges and Methods
PFAS Characteristics

- **Per- and Polyfluoroalkyl Substances (PFAS)**
  - Family of synthetic organic compounds that contain multiple fluorine atoms
  - Incorrectly referred to as “PFCs”
    - Greenhouse gases regulated by Kyoto Protocol
    - PFCs are one of the families of PFAS (all PFCs are PFAS, not all PFAS are PFCs)
  - Most “famous” compounds are perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS)

Conder et al. (2008)

Example molecular structures for perfluorooctane sulfonate (PFOS)

[Chemical structures and molecular models showing PFAS compounds]
PFAS Uses

- **Surface treatment/coatings**
  - Carpet and upholstery
  - Apparel
  - Paper and packaging
  - Non-stick cookware

- **Performance chemicals**
  - Chromium plating (mist suppression)
  - Insecticides
  - Lubricants
  - Aqueous Film-Forming Foam (AFFF)

*Oil and water repellency = Excellent surfactants*
Potential Sources

- Sites with very high probability of screening or risk-based criteria exceedances
  - Airports
  - Fire-fighting training areas
  - Petrochemical/chemical plants
  - Chrome plating facilities
  - Textile/carpet manufacturers
  - Waste Water Treatment Plants (WWTPs) and sewage sludge land application areas
  - Landfills
- US Military proactive in PFAS investigation: more than 600 sites so far
Environmental Fate

- Extremely persistent or transformation to persistent PFAS
- Moderate-high water solubility/mobility
  - Groundwater plumes from contaminated areas many miles long
- Can also partition to soils and sediment
- Persistent PFAS at contaminated sites not volatile

Minnesota PFAS plumes in groundwater 10+ miles long, cover over 100 miles² (MDH, 2012)
Overview of PFAS Toxicology
Bioaccumulation of PFAS

- PFAS are detectable in nearly any biological tissue
- Many PFAS bioaccumulate, especially longer PFASs and sulfonated PFASs (e.g., PFOS)
- Partition to protein, not fat
  - Blood, liver, kidney, muscle are primary repositories
- Can also partition to soils and sediment
- Not metabolized, or metabolized to persistent PFASs

Conder et al., 2008. Environ Sci Technol. 42:995-1003
Human Exposure Pathways

• **Major**,\(^1,2\)
  -- Diet (bioaccumulation)
    -- Fish and seafood
    -- Homegrown produce
  -- Drinking water
  -- Incidental soil/dust ingestion

• **Usually insignificant or minor**
  -- Dermal absorption
  -- Inhalation

---

Perfect Storm of Environmental Challenges

- High Environmental Persistence
- High Toxicity & Potential Carcinogenicity
- Wide Variety of High-volume Releases
- Complicated and Expensive Remediation
- Range of Environmental Mobility
Treatment Challenges and Methods
Treatment Challenges

- PFAS have unique properties
  - Hydrophobic and oleophobic
  - Persistent, bioaccumulative and toxic
  - Moderate solubility – can be transported long distances
- Chemically and biologically stable
  - Resistant to typical environmental degradation processes
  - C-F bond is shortest and strongest in nature
- Treatment approaches challenging and costly
Treatment Approaches

- **Soils and sediments**
  - Typically soils are excavated (and treated/stabilized if needed) followed by off-site disposal or reuse
  - Other technologies are incineration, soil washing

- **Groundwater (ex situ)**
  - Full-scale PFAS treatment systems use granulated activated carbon (GAC) or ion exchange
  - Membrane treatment (e.g., nanofiltration [NF] or reverse osmosis [RO]) also effective but expensive
Granular Activated Carbon (GAC)

- The most widely used treatment technology
- Bituminous coal-based re-agglomerated GAC significantly outperforms coconut based GAC
- Less effective for short chain PFAS.
• Commercialized by Regenesis
• Liquid Activated Carbon™
• Colloidal carbon (1-2 µm) injected into subsurface
• PFAS sorb onto carbon in-situ

Images courtesy of Regenesis
Ion Exchange (IX)

- Reversible chemical reaction to remove ions
- Cationic or anionic exchange resins
- Contains solid phase (e.g. zeolites or synthetic resin) with functional group(s) and mobile ions
- Can be single use or regenerated

Source: USEPA – Water Treatability Database
Reverse Osmosis & Ultrafiltration

• **Design Considerations**
  – High pressure membrane
  – High energy usage
  – Typically used on lower flow rates
  – Reject water disposal

• **Cost**
  – High capital and O&M
Aqueous Persulfate Test

Source: Clarkson University
Some PFAS compounds are generated, not removed.
Sonolysis

- Use of ultrasound to degrade PFOA and PFOS
- Ultrasonic “cavitation” or “bubbles”
- Mainly thermal decomposition\(^1\)
- Major byproducts: Fluoride ions, fluorine gas, sulfate ion, carbon monoxide, carbon dioxide and shorter-chain PFASs
- Reported near complete transformation of PFOA/PFOS \(^2\)

---

1Moriwaki, H et al. ES&T, 2005

2Vecitis, C. D., Journal of Physical Chemistry, 2005
Electrochemical Oxidation

- Use of direct current (DC) to degrade PFAS
- Electrode material (Boron-doped diamond, MMO, lead-dioxide etc.)
- Major byproducts: Fluoride ions, shorter-chain PFAS

![Diagram of Electrochemical Oxidation](image)

Plasma

- Pulsed high voltage (16.5 to 25 kV) to generate plasma, which produces aqueous electrons to chemically degrade PFAS
- Reported 90% PFOA removal within 30 minutes
- 20 µM initial PFOA concentration
- Major byproducts: Fluoride ions, fluorinated gases and shorter-chain PFAS

Conclusions

• Removal of PFAS from aqueous waste streams is challenging and costly
• Proven technologies at full scale are limited to GAC, ion exchange, and membrane technology
• High-strength wastewater even more challenging
  – Proven technologies may only be applicable as a polishing step
Thank You

Herwig Goldemund, Ph.D.
678-202-9530
hgoldemund@geosyntec.com