Electrochemical Destruction of PFAS in Water

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Per- and Polyfluoroalkyl Substances (PFAS) is everywhere!

Source: Adapted from EWG 2021
Common PFAS treatment requires disposal

**GAC**

**Pros:**
- Industry standard
- Lowest CapEx
- Spent GAC is reactivated
- Established supply chain
- Familiarity of disposal

**Cons:**
- Fast breakthrough
- Ineffective for smaller-chain PFAS
- High OpEx
- Incineration or landfill

**IX**

**Pros:**
- Regenerable options
- Smaller infrastructure footprint
- Effective for wider range of PFAS

**Cons:**
- Limited capacity
- PFAS specific are expensive
- Less common
- High OpEx
- Incineration or landfill

**RO**

**Pros:**
- Removal of all-chain compounds
- Comprehensive process

**Cons:**
- Energy intensive
- Mineral stripping
- Highest OpEx and CapEx
- Incineration or landfill
Electrochemical Advanced Oxidation Processes (eAOP) are a Subset of AOPs

- **Advanced Oxidation Processes**
  - **Homogeneous Processes**
  - **Heterogeneous Processes**
    - **Chemical Only**
      - O3/High pH
      - O3/H2O2
      - H2O2/catalyst
    - **Catalytic ozonation**
    - **Photocatalytic ozonation**
    - **Homogenous Photocatalysis**
    - **Non-Thermal Plasma / Electrohydraulic Discharge**
    - **Light Process**
    - **Dark Process**

- **External Energy Added**
  - **Mechanical Energy**
    - Ultraviolet Radiation
      - O3/UV
      - H2O2/UV
      - O3/H2O2/UV
      - Cl2/UV
      - Photo-Fenton
    - Hydrodynamic Cavitation
      - H2O2/HDC
      - O3/HDC
    - Ultrasound Energy
      - H2O2/US
      - O3/US
  - **Electrical Energy**
    - Electrochemical Oxidation
    - Anodic Oxidation
    - Electro-Fenton
    - Non-Thermal Plasma / Electrohydraulic Discharge

- **Source:** Adapted from Sharma et al. 2011
eAOPs 101

- **Electrodes placed in water**
  - Heavy Metal Oxide Electrodes (SnO₂, Pt, TiO₂, IrO₂, etc.)
  - Boron Doped Diamond (BDD)

- **Electric potential above 1.23 V applied**
  - Surficial voltage at which water splits to O₂ and H₂

- **Mixed oxidant production with increasing voltage**
PFAS destruction is necessary but costly!

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Aclarity: most powerful, least expensive destruction solution on the market

- High oxidation potential
- 1/10\textsuperscript{th} cost BDD
- Low energy (<0.5 kWh/gal)
- Long-lasting electrodes (years)
- No moving parts
- Low maintenance
- No chemical storage
- Modular, stackable
- Suitable for low and high flows

<table>
<thead>
<tr>
<th>Electrode Material</th>
<th>Overpotential (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BDD</td>
<td>2.5+</td>
</tr>
<tr>
<td>Ti/SnO\textsubscript{2}-Sb\textsubscript{2}O\textsubscript{5}</td>
<td>2.2-2.6+</td>
</tr>
<tr>
<td>Ti/Pt</td>
<td>1.9-2.2</td>
</tr>
<tr>
<td>IrO\textsubscript{2}/Ta\textsubscript{2}O\textsubscript{5}</td>
<td>1.7-1.9</td>
</tr>
<tr>
<td>RuO\textsubscript{2}/TiO\textsubscript{2}</td>
<td>1.5-1.8</td>
</tr>
</tbody>
</table>

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Novel reactor design and electrodes

**Electrode materials**
Unique profile of inherent power, low cost anodes; pairing right cathodes increase this further

**Geometry**
Radial, porous shape with small band gap optimizes efficiency and speciation

**Reactor flow**
Flow-through path, mixing, and detention time ensure oxidants are used
PFAS at ppb range

PFOA brine pilot:
- Influent PFOA = 300 μg/L
- Treated via Aclarity Mobile Pilot System = 132 μg/L in closed loop for 80 minutes
- 0.36 log or 66% removal
- 890 A/m²
- 0.078 kWh/gal
PFAS at ppt range

PFAS pilot:
- Influent PFAS= 150 ng/L, each starting between 27 and 58 ng/L
- Treated via Aclarity Mobile Pilot System= 8 ng/L in closed loop for 180 minutes
- 1.5 log removal
- 605 A/m²
- 0.144 kWh/gal

Source: Alpha Analytical (report 5/4/20 with Aclarity samples); Bryan Cave Leighton Paisner, “State-by-State Regulation of Per- and Polyfluoroalkyl Substances (PFAS) in Drinking Water” (July 2019)
Note: EPA and MA levels are the sum of individual levels, shown here as the average allowed for each; median used if state has different limits for individual chemicals
Aclarity Mobile Pilot: 1-day pilot test for full-scale sizing
PFAS Destruction Economics

Example bench testing results with porous anode

- Initial concentration of PFAS: 50 ng/L
- Target concentration of PFAS: 5 ng/L
- Volume treated: 5 gallons
- Voltage: 15 V
- Amperage: 56 A
- Testing time required: 180 min

Conversion to full-scale using

**Porous Anode:**

- Design flow rate: 20,000 GPD
- Reactor CapEx + 10% redundancy: $325K
- Electrical cost per year: 0.093kWh/gal, $69K/yr
- Replacement cost per year: $32.5K

**Solid Anode:**

- Design flow rate: 20,000 GPD
- Reactor CapEx + 10% redundancy: $160K
- Electrical cost per year: 0.110kWh/gal, $82.6K/yr
- Replacement cost per year: $16K

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PFAS mineralization and byproducts study

Aclarity method for PFAS destruction:

- C-F bonds broken by free electrons
- Fragments mineralized by OH•
- CO₂, HF, F⁻, and leftover products in very small quantities
Ongoing PFAS pilots

Water Matrices:
- Landfill leachate
- Oil and Gas AFFF
- Military fire pit effluent
- Groundwater remediation
- Wastewater brines
- Municipal drinking water residuals
### AES is proven in different use cases

<table>
<thead>
<tr>
<th>Category</th>
<th>Examples</th>
<th>Status</th>
<th>Case Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organics</td>
<td>Bacteria, virus, algae, cysts</td>
<td>Live in field</td>
<td>NSF/ANSI P231 &gt;6.3 log removal for bacteria and viruses</td>
</tr>
<tr>
<td>Microbes</td>
<td>Bacteria, virus, algae, cysts</td>
<td>Live in field</td>
<td>Active municipal water system in Bamako, Mali</td>
</tr>
<tr>
<td>Chemicals</td>
<td>PFAS, VOCs, 1,4-dioxane, pesticides, pharmaceuticals, alcohols</td>
<td>Field tested</td>
<td>Sizing 2 full-scale systems for automotive wastewater reuse</td>
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<tr>
<td></td>
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<td>Groundwater VOC pilot for town wells</td>
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<td></td>
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<td>15 pilots for PFAS contaminated wastewater</td>
</tr>
<tr>
<td>Inorganics</td>
<td>Ammonia, nitrates, cyanide</td>
<td>Field tested</td>
<td>Treatment of ammonia in landfill leachate</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Destruction of cyanide and chelating agents in electroplating</td>
</tr>
<tr>
<td>Non-metals</td>
<td>Ammonia, nitrates, cyanide</td>
<td>Field tested</td>
<td>Treatment of ammonia in landfill leachate</td>
</tr>
<tr>
<td>Metals</td>
<td>Arsenic, hardness, iron</td>
<td>In development</td>
<td>TBD</td>
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<tr>
<td>Salinity</td>
<td>Sea water</td>
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<td>Future device</td>
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</tbody>
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Looking Forward

Applications
- Pharmaceuticals, reuse, pesticides
- Reduction processes— perchlorate, nitrate, hexavalent chromium, etc.

Engineering
- Testing 7-cell reactors to be ready for sale Q4 2021
- Manufacturing solid electrode reactor for high turbidity applications
- Find where economy of scale ends

Sales Channel Partners
- 1 day pilots for sizing full-scale systems
- Expanding partnerships with engineering firms, OEMs, and technology providers

Fundraising
- Awarded $1M NSF SBIR Phase II, raised $700K Seed VC
- New hires: Director of Industrial Sales, VP Finance, R&D Engineer II
Thank you!

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