Overview

Physical & chemical properties

Treatment approaches:

1. What *doesn’t* work
2. What we know *does* works
3. Case study
4. Innovative approaches
Unique Chemical Properties Drive Uses

<table>
<thead>
<tr>
<th>Properties</th>
<th>Desirable</th>
<th>Less Desirable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme Chemical Inertness</td>
<td>Fire Fighting</td>
<td>Difficult to Destroy</td>
</tr>
<tr>
<td>Hydrophobic and Lipophobic</td>
<td>Repels Stains &amp; Prevents Wrinkles</td>
<td>Accumulates in Protein Tissues &amp; Blood (not sequestered in fat)</td>
</tr>
<tr>
<td>Surface Active</td>
<td>Good Coating Material</td>
<td>Difficult to Measure / Sample Accurately</td>
</tr>
</tbody>
</table>

PFOA and PFOS are shown in the diagram with their chemical structures.
PFAS Treatment: Conventional Treatment Just Doesn’t Cut It

So... What Treatment Options *Do* We Have for PFAS?

- Carbon Adsorption (GAC)
- Ion Exchange (IX)
- Reverse Osmosis (RO or NF)

Other Options: Are They Ready for Prime Time?
## Process Selection Depends on Treatment Goals

<table>
<thead>
<tr>
<th>Process</th>
<th>Effective for...?</th>
<th>Capital Cost</th>
<th>Operation &amp; Maintenance Cost</th>
<th>Residual?</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAC</td>
<td>Long-chained PFAS and some short-chained PFAS</td>
<td>Lower</td>
<td>Low-Med</td>
<td>Spent carbon / regeneration ($)</td>
</tr>
<tr>
<td>AIX</td>
<td>Depends on resin</td>
<td>Lower</td>
<td>Low-Med</td>
<td>Spent resin / regeneration ($)</td>
</tr>
<tr>
<td>NF / RO</td>
<td>All (RO) Most (NF)</td>
<td>High</td>
<td>Med-High</td>
<td>Liquid concentrate ($$$)</td>
</tr>
</tbody>
</table>
Groundwater Case Study: GAC and IX
PFOS and PFOA Recently Detected in a Municipal Well Field

**Initial Detections:**
- PFOA ranged 5 – 200 ng/L
- PFOS ranged 6 – 50 ng/L

**EPA Health Advisory:**
PFOA + PFOS < 70 ng/L

**Initial Carollo Sampling Results:**
Carollo Developed a Plan to Remove PFOS and PFOA: Immediate and Long-term

- PFOS and PFOA Detected in Well Field
- Interim (short-term) Treatment Strategy

Long-Term Treatment and Operation Strategy Plan

1. Bench Testing
2. Projection Model
3. Full-scale Monitoring

- Long-term Ops Strategy
- Capital Costs
- O&M Costs
- Alternative Evaluation
- Well Head vs Centralized
- Well Field Modeling
- Conceptual Design
Two Types of Bench Testing Are Typically Conducted for GAC Adsorption Evaluation

<table>
<thead>
<tr>
<th>Type</th>
<th>Apparatus</th>
<th>Outcome</th>
<th>Level of Effort</th>
</tr>
</thead>
</table>
| Isotherm (jar testing) | ![Isotherm Apparatus](image) | • Assess theoretical total capacity  
• Compare different carbon or media relative to each other  
• Cannot correlate with full-scale operation | • Static and less sophisticated  
• Fast and cost effective  
• Easier to conduct  
  – 5+ gal sample  
  – Can perform in hours to days |
| RSSCT* (Column Testing) | ![RSSCT Apparatus](image) | • Correlates better with full scale operation  
• Answers adsorption rates  
• Instrumental for operation model calibration  
• Can be used to estimate change-out frequency | • Dynamic and more sophisticated  
• Need special training  
• More difficult to conduct  
  – 50+ gal sample  
  – Can perform in days to weeks |

*RSSCT = Rapid Small Scale Column Test*
Carbon Prep for Column Testing Considers Scale-up Hydraulic Conditions and Pore Structure

TACTIC Analysis = Total Adsorption Capacity with Temperature Influence Correction

Testing column
Column Testing: “Similar” Carbons Perform Very Differently!
Column Test Data Fed into Performance Projection Model
Performance Projection Model Predicts Change Out Frequency and Supports Cost Comparison, Design, and Future Operation

Estimated Media Replacement Frequency: 1 vessel per ~ 2.5 months

80% of Health Advisory Level: 56 ng/L

Non-Detect
Full-scale Operating Data on Interim Treatment Units (to date) Match Model Predictions

- Measured PFOA + PFOS (Lead Vessel Product)
- Measured PFOA + PFOS (Lag Vessel Product)

Vessel 1
Vessel 2
Final Effluent

80% of Health Advisory Level: 56 ng/L

Modeled PFOA + PFOS
- Vessel 1
- Vessel 2
- Final Effluent

Non-Detect
Second Phase Testing for Long-term Treatment: Purolite IX Resin > 3.4 x More Effective than GAC

45,000 BV start to break through

155,000 BV non-detectable at the end of testing

155k / 45k = 3.4+ times longer
Purolite IX Also Cost 3.4 x More than GAC...

<table>
<thead>
<tr>
<th></th>
<th>GAC</th>
<th>Ion Exchange</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retrofit Capital Costs</td>
<td>No cost, per vendor’s inputs</td>
<td></td>
</tr>
<tr>
<td>Media Replacement Costs</td>
<td>$33,000</td>
<td>$111,080</td>
</tr>
<tr>
<td>($/replacement)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost Ratio</td>
<td>1 : 3.4</td>
<td></td>
</tr>
<tr>
<td>Number of Bed Volume for</td>
<td>45,000</td>
<td>155,000</td>
</tr>
<tr>
<td>Vessel 1 Breakthrough</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breakthrough BV Ratio</td>
<td>1 : 3.4</td>
<td></td>
</tr>
</tbody>
</table>

*Additional Testing Was Recommended.*
Case Study & Groundwater PFAS Treatment Take-home:

1. “Conventional” treatment for PFAS trends toward adsorption
   - GAC is a great interim option for “emergency response”
   - Media (GAC or IX resin) selection for long-term treatment is site specific

2. Long-term economics can be evaluated through testing
   - Rapid small-scale column tests (RSSCTs)
   - Modeling to estimate O&M costs
   - Confirmation through pilot testing (single well location, e.g.)

3. RO is typically not implemented for two reasons:
   - Capital cost
   - Concentrate disposal
PFAS Are Not Just a Groundwater Contamination Issue...

**Effluent PFAS Removed Through GAC in pureALTA DPR (FL)**

**Effluent PFAS Removed by RO in Big Spring DPR Facility (TX)**

**GAC Cost for DC Tillman IPR (CA)**
Innovative Approaches
Innovation in “Conventional Treatment:”
Dynamic Model Optimizes PFAS Removal by GAC and IX

Typical IX Breakthrough Curve

Typical GAC Breakthrough Curve
Growing PFAS Breakthrough Dataset Improves Model Accuracy

Blue Plan-it® PFAS Breakthrough Data Base

- Over 40 sets of RSSCT breakthrough curves supplemented by available pilot and full scale testing data
- 15 water samples and blends with concentrations of PFAS ranging from 0 to 3,000 ng/L
- Tested 6 carbons and 2 resins to date
- PFOA, PFOS, and other Method 537 PFAS, including both long and short chain compounds
Coming Soon to Carollo: Collaboration with ASU Using Mobile NEWT Trailer

- Demonstration scale testing
- Continuous testing for IX, GAC, RO, and UV AOP*
- Fill in industry gap on
  - PFAS RSSCT Testing Accuracy
  - PFAS RSSCT using IX Resins

*UV AOP is for simultaneous treatment of other contaminants
Novel Adsorbents

DEXSORB™ by Cyclopure

OSORB® by ABS Materials

• Effective for short (C3) and long (C8) chain PFAS
• Selective adsorbents (minimal competition with NOM)
• Can be regenerated

Commercially available in 2020
Thank you!

Corin Marron, PE
cmarron@carollo.com
520-230-4714