Design & Operational Insights into Activated Carbon for PFAS Removal in Drinking Water Treatment

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CDM Smith

Presentation Overview

1. PFAS vocabulary (one slide!)
2. Activated carbon and anion exchange attributes
3. Pros and cons of activated carbon
4. Design considerations
5. CASE STUDY: Can activated carbon remove “high” levels of PFAS?
6. If you’re in a rush…
7. PFAS treatment operations
8. Pitfalls to avoid

PFAS Vocabulary

- Long-chain and short-chain
- Carboxylates and sulfonates

PFAAs	C4	C5	C6	C7	C8	C9	C10	C11	C12
Carboxylates	PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA
Sulfonates	PFBS	PFPeS	PFHxS	PFHpS	PFOS	PFNS	PFDS	PFUnS	PFDoS

Short-Chain PFAS: PFBA, PFPeA, PFHxA, PFHpA, PFBS, PFPeS

Long-Chain PFAS: PFOA, PFNA, PFDA, PFUnA, PFDoA, PFHxS, PFHpS, PFOS, PFNS, PFDS, PFUnS, PFDoS

Activated Carbon and Anion Exchange Attributes

Three Mainstream PFAS Treatment Technologies

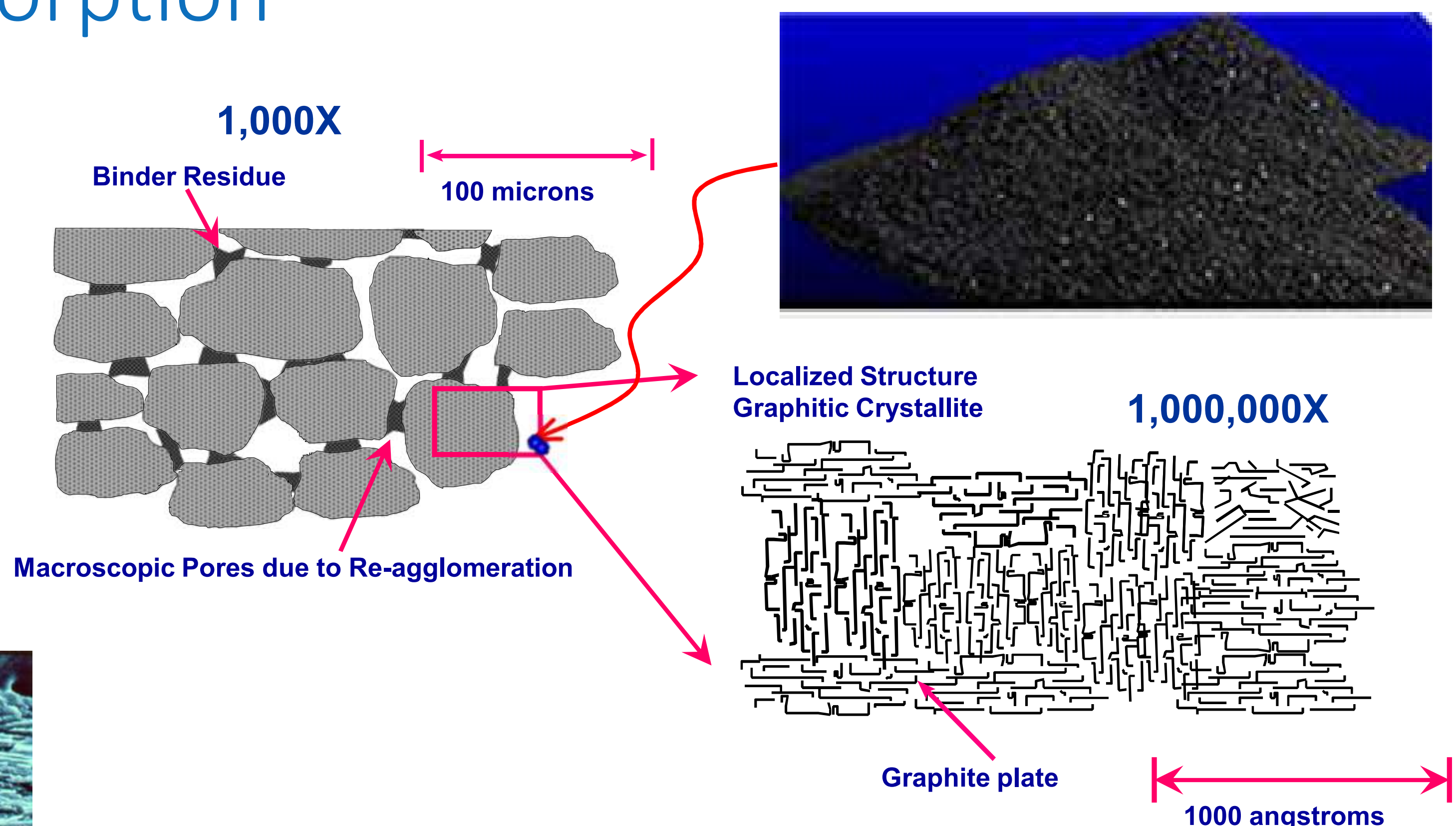
Granular Activated Carbon (GAC)

Ion Exchange Resin

Reverse Osmosis Membranes

PFAS are NOT removed appreciably by conventional drinking water treatment.
High doses of Powder Activated Carbon (PAC) can assist removal.

GAC Adsorption



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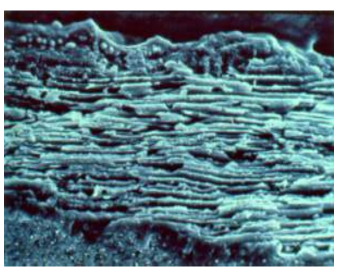
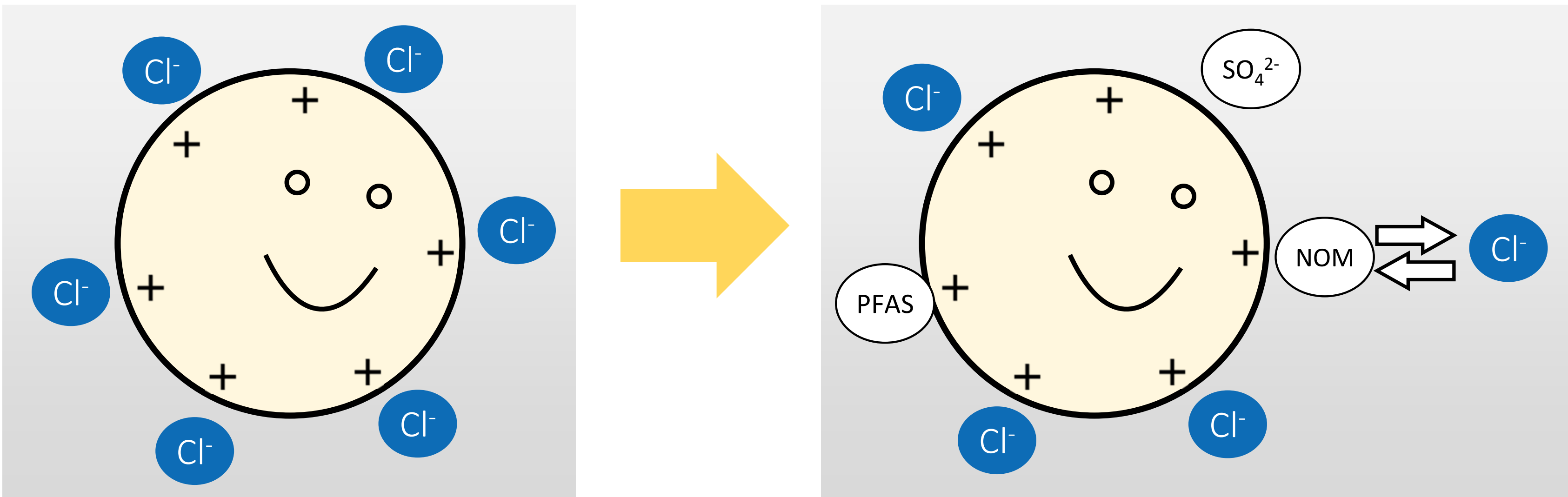


A<u>d</u>sorption vs. A<u>b</u>sorption…

Source – Calgon Carbon Corporation

Anion Exchange… "Exchanging what?"



- PFAS
- Nitrate (NO_3^-)
- Natural organic matter (NOM)
- Sulfate (SO_4^{2-})
- Bicarbonate (HCO_3^-)

The Pros and the Cons of Activated Carbon

Activated Carbon Effectiveness by Compound

Less Frequent Change-Out	=	More Cost-Effective

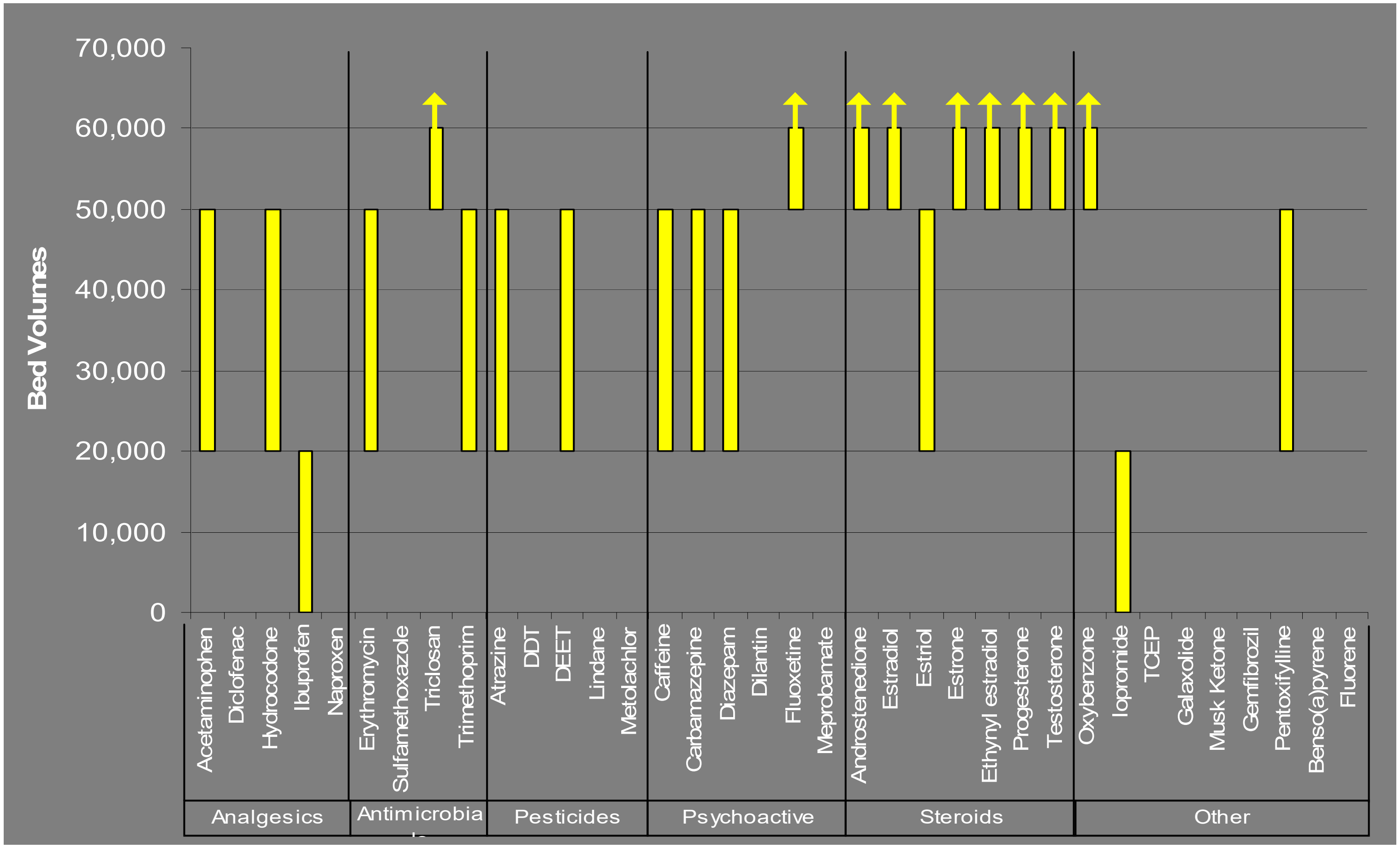
- Most PFAS compounds, particularly longer chain (higher MW) like PFOS and PFOA
- Taste/odor compounds, pesticides, and SOCs (including most EDCs & PPCPs) ↓
- Most drinking water regulated organic compounds
- Algal toxins
- THM and HAA precursors ↓using biofiltration plus adsorption, especially if after ozone
- Cl_2 demand ↓

Frequent Change-Out Required	=	Less Cost-Effective

(surface water tests)

- Short-chained PFAS - PFBA, PFPeA, GenX/mono-ether PFECAS, PFMOAA
- Iopromide, ibuprofen
- Nicotine and cotinine
- 1,4-dioxane and perchlorate
- NDMA (cold water – acclimates for bio-removal in warm water)
- TTHMs after formation
- Some VOCs, like vinyl chloride and dichloromethane

Granular Activated Carbon (10% Breakthrough, EBCT = 7.6 Minutes)



Source: AWWARF Removal of EDCs and Pharmaceuticals in Drinking and Reuse Treatment Processes 2007

Pros and Cons in Water Treatment

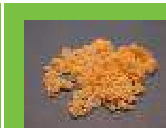
Advantages

- Helps remove taste and odor (Geosmin, MIB)
- Removes most SOCs
- Removes THM & HAA precursors
- Can be a biologically active filter
- Lowers Cl2 demand
- Post GAC gives extra particulate/ Cryptosporidium removal as secondary filter
- Can save PAC for as-needed use
- Does not generate a brine or concentrate needing disposal
- Does not change chloride-sulfate mass ratio

Potential Issues

- O&M cost for reactivation or new GAC
- Need for pumping to add post-GAC contactors
- Release of adsorbed compounds & bacteria = increased monitoring
- Limited effectiveness for a few organic compounds
- Not BAT for regulated inorganic compounds (except one of multiple BATs for Hg)
- Limited contact time as PAC for adsorption and bio-removal
- Elevated pH and arsenic possible at startup

GAC vs. Ion Exchange Resin (IX-R)

 GAC	 Single Use IX-R
7–20-minute EBCT	**2–3-minute EBCT**
Larger infrastructure footprint	Smaller infrastructure footprint
Typical bed life: 50-120,000 bed volumes	Typical bed life: 250-300,000 bed volumes
Media less expensive	Media more expensive
Less effective for short chain PFAS	Effective for a wider range of PFAS, but less effective for PPCPs
Well-established technology	Not as extensively practiced as GAC
Backwash available	Backwash not recommended
Life cycle costs often similar Neither very effective for 1,4 Dioxane Generate spent media requiring off-site reactivation (GAC) or incineration (IX-R) Pretreatment may be needed to increase media life span	

Design Considerations

The industry is getting smarter on PFAS technology selection

Engineering evaluation
- Treatment options
- New systems to remove PFAS

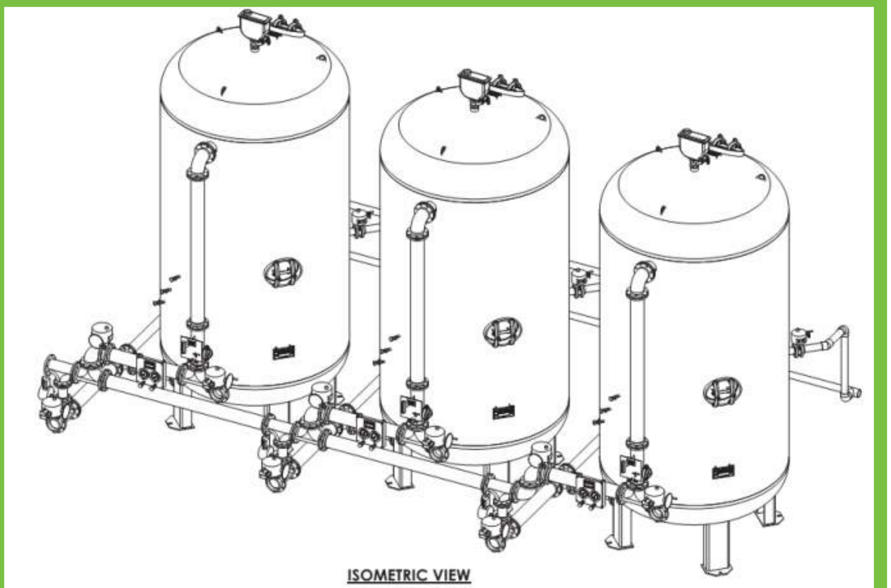
PFAS treatability study - assess compatibility with other existing treatment processes

Pilot tests and life cycle assessment

System design, permitting, construction, operation, maintenance, monitoring

→ Life cycle success

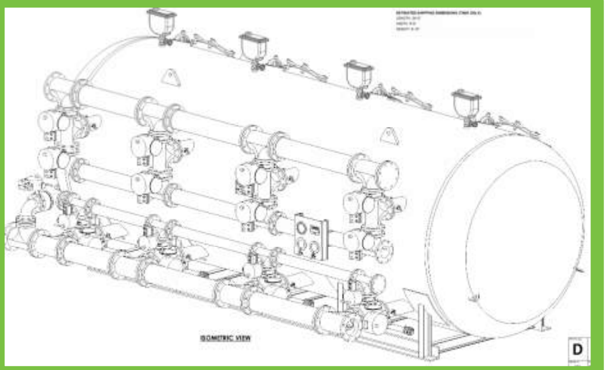
Vertical vs. Horizontal Vessels

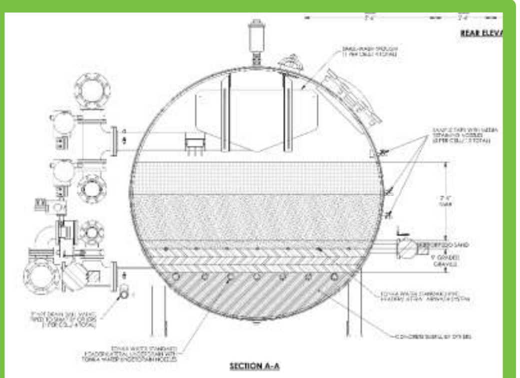


VERTICAL

- Facilitates long EBCT
- Uniform surface area through depth
- Backwashing freeboard easily accommodated
- Limited surface area
  - 12-foot-diameter
  - 113 square feet

Vertical vs. Horizontal Vessels

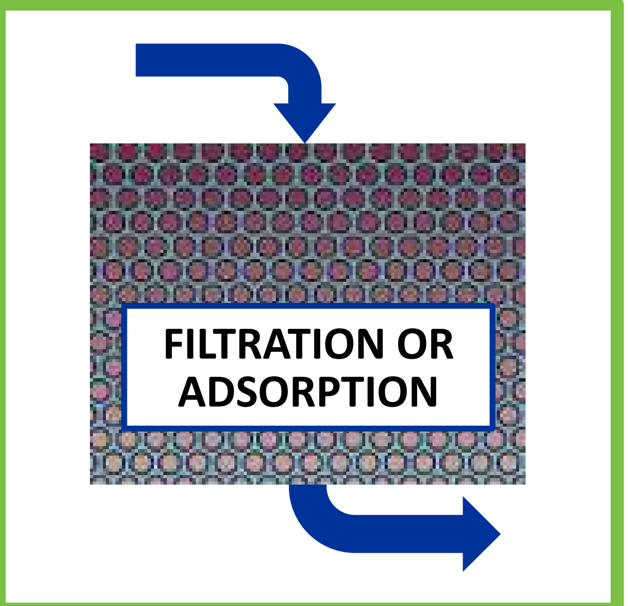




HORIZONTAL

- Large surface area
- Can compartmentalize
- Water tends to tunnel from initial surface area = “wide area” of the tank has the least (volumetric) exposure to water
- Freeboard for backwash difficult to achieve

Concrete Basins vs. Pressure Vessels



CONCRETE BASINS

- Can see water
- Filter adjacencies compress overall footprint
- Excavation, concrete work, pipe gallery
- Deep construction needed to achieve 10+ minutes EBCT

Concrete Basins vs. Pressure Vessels

PRESSURE VESSELS

- Slab on grade construction
- Typically, tall (deep) enough to achieve 10+ minutes EBCT
- Cannot see water
- Space between vessels = expanded overall footprint

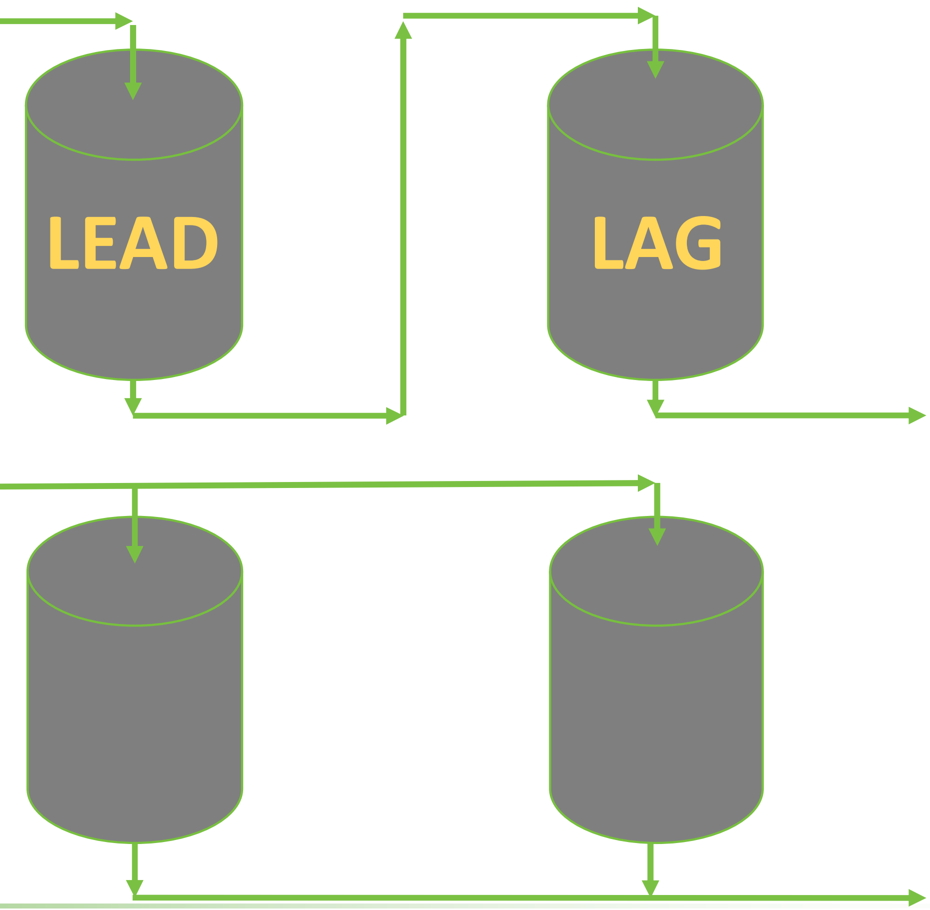
Vertical Pressure Vessel Size Offerings

Diameter (ft)	Surface Area (sf)	Potential Capacity and Other Comments
4	13	125 gpm/vessel
6	28	250 gpm/vessel
8	50	350 gpm/vessel
10	79	700 gpm/vessel
12	113	1,000 gpm/vessel
14	154	1,400 gpm/vessel; Over-the-road limit

Series vs. Parallel Operation

SERIES
(longer EBCT)

PARALLEL
(greater throughput)



PRESSURE VESSEL SAMPLING PORTS

- Influent
- ¼ through bed
- ½ through bed
- ¾ through bed
- Effluent

GAC Vessels and Future AIX Retrofit

- Underdrain opening size – be sure it's small enough!
  - e.g., Calgon's Stainless Steel Septa, 0.008-inch slots
- Plan for greater pressure drop in future
  - GAC particle size > AIX resin size
- Decreased (or no) backwashing of newly-installed media
- Stainless steel media fill and discharge lines

Activated Carbon vs. Anion Exchange Resin

Granular Activated Carbon (GAC)

- PFAS removal achieved by adsorption
- Most common treatment method for PFAS removal
- Can achieve effective removal of PFAS, especially long-chain
- Bituminous, lignite, or coconut-based
- Lack of waste stream
- Potential reactivation
- Possible competitive adsorption with other compounds in water
- Removal effectiveness for shorter-chained compounds may be limited

Anion Exchange Resin (AIX)

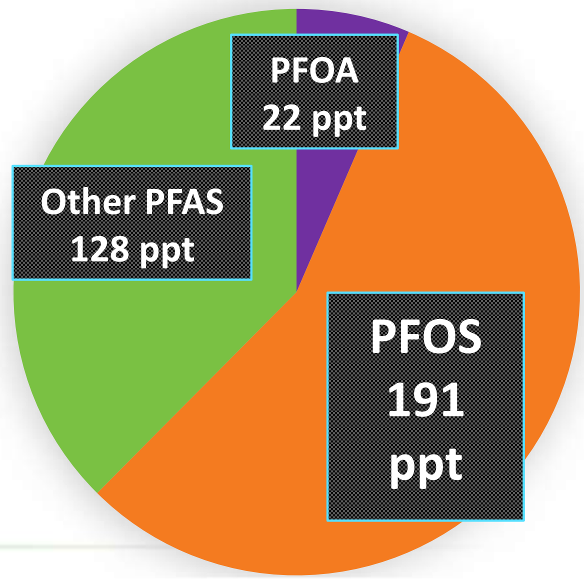
- PFAS removal achieved via synthetic resins with a fixed charge
- Can achieve effective removal of PFAS, especially long-chain
- More effective than GAC removing short-chain PFAS
- Higher capacities = less frequent changeouts
- Resin significantly more costly than GAC "pound for pound"
- Reduced space needs
- Comes pre-washed = may not need backwashing or rinsing
- Impacts corrosion control
- **Susceptibility to oxidants**
- Possible competitive adsorption with other compounds in water

CASE STUDY:
Can Activated Carbon Remove “High” Levels of PFAS?

Bench-Scale Testing – Well 8 Water Quality

- 10 detects out of 35 PFAS tested
  - Carboxylic acids, sulfonic acids, and fluorotelomer sulfonic acids
- Total PFAS Concentration = 341 ppt
  - Combined PFOA + PFOS (per EPA's advisory level) = 213 ppt

pH	7.9
Hardness	132 mg/L as $CaCO_3$
Alkalinity	94 mg/L as $CaCO_3$
Total Organic Carbon	< 1 mg/L
Iron & Manganese	Below detection



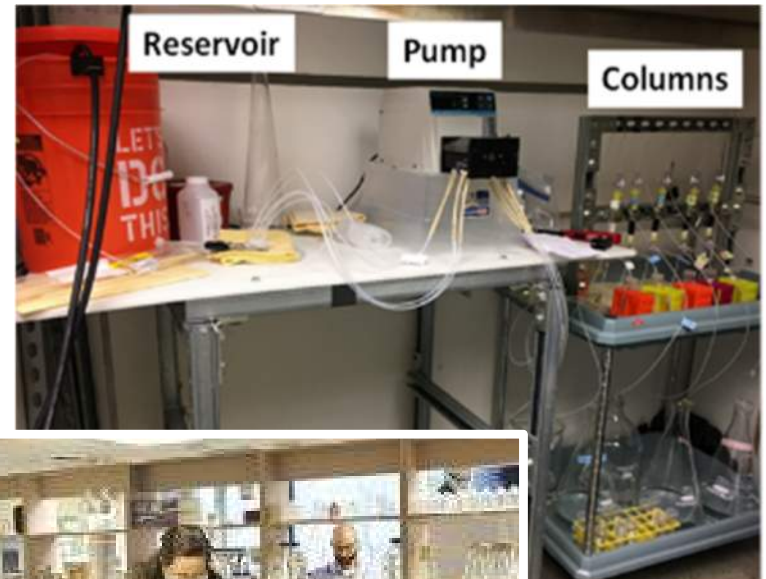
Bench-Scale Testing Study Objectives

1. Investigate **effectiveness of two commercially-available GAC products in removing PFAS:**
   A. Filtrasorb® 400-M (Coal-based from Calgon Carbon)
   B. Westates® Aquacarb (Enhanced coconut-based from Evoqua Water Technologies)
2. Determine design parameters and considerations for implementing full-scale GAC
3. Evaluate site-specific water treatment impacts using sodium hypochlorite and polyphosphate post-GAC

Bench-Scale Testing – Experimental Set-Up

Bench-scale column tests performed at CDM Smith's Bellevue, WA Research & Testing Laboratory

- ✓ 71-day experiment
- ✓ 8,900 empty bed volumes
- ✓ 9.8 minutes empty bed contact time
- ✓ Monitored: PFAS, flow rate, pH, anions, arsenic, & TOC
- ✓ Sodium hypochlorite & phosphate addition



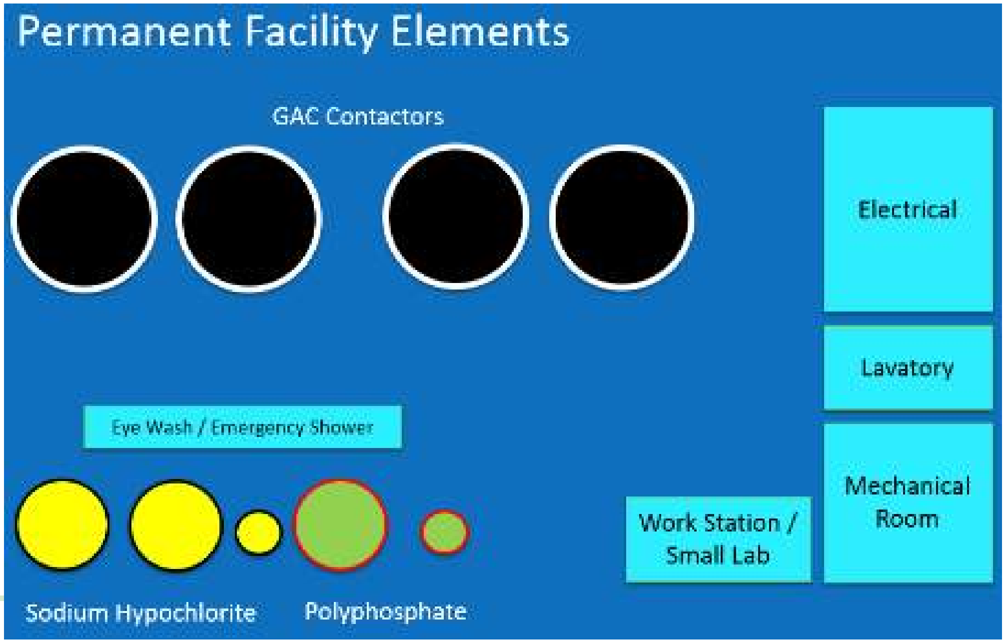
Bench-Scale Testing – Results

- **No measurable GAC breakthrough of any PFAS occurred following the flow of approximately 8,900 empty bed volumes through the GAC columns with both products**
  - No change in anions levels
  - No detect of arsenic
  - No generation of PFOA/PFOS from post-GAC treatment with sodium hypochlorite and phosphate
- Estimated GAC longevity = 27,000 bed volumes

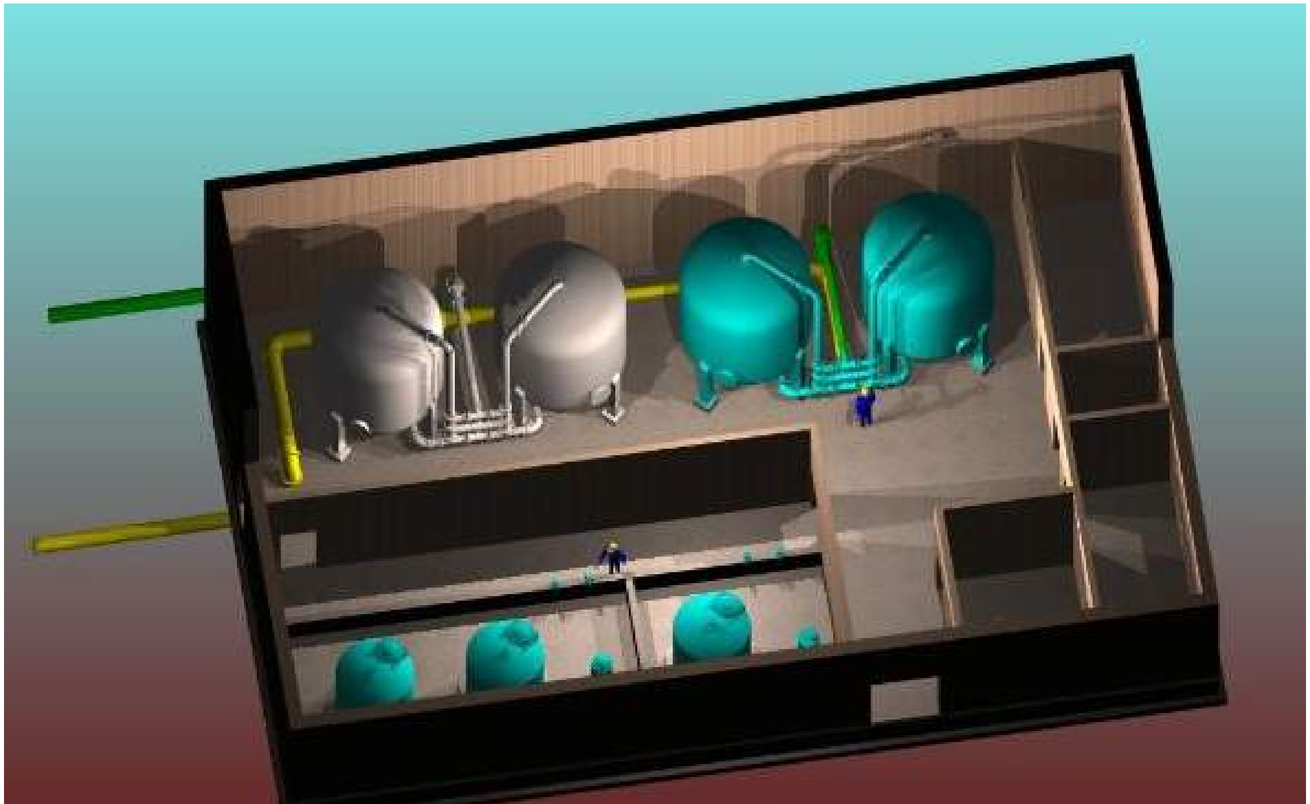
Conceptual Design
SITE OVERVIEW

Conceptual Design

- PFAS treatment facility: 2,700 gpm capacity
  - Sodium hypochlorite and phosphate chemical systems
  - Laboratory/office area
- Develop facility floor plan and site plan
- Cost estimate
- Permitting requirements



Conceptual Design



Conceptual Design – Construction Cost Estimate: $5.9 M

Schedule – Fast! (But Orderly)

- Conceptual Design and Cost Estimating
  - December 2016 – January 2017
- Bench Scale Testing Samples Collected
  - February 2017
- Land Survey and Geotechnical Borings
  - March 2017
- 60% Design Submittal – June 2017
- 90% Design Submittal – July 2017
- 100% Design Completion – September 2017

400,000,000 Gallons Treated, and Counting

If You’re in a Rush…

Interim / Temporary Treatment Considerations

- GAC, AIX, chemical feed, and UV/peroxide systems available
- The “ol’ bag filter/GAC combination”
- Skid-mounted systems on trailer
- Rental, or rent-to-own

PFAS Treatment Operations

Monitoring During Operation

PFAS Treatment Monitoring/Sampling Plan

Sampling Event/Frequency	PFAS	pH	Chloride
End of 1st week	Influent, Midfluent, Effluent	Influent, Effluent	Influent, Effluent
End of 3rd week	Influent, Midfluent, Effluent	Influent, Effluent	Influent, Effluent
Monthly	Influent, Midfluent, Effluent	Influent, Effluent	Influent, Effluent

Carbon Life and Delivery

- 27,000 empty bed volumes, (or over a year of carbon life) anticipated for Westfield's source water
- Bulk truck (no supersacks) delivery anticipated




Photographs courtesy of Calgon Carbon

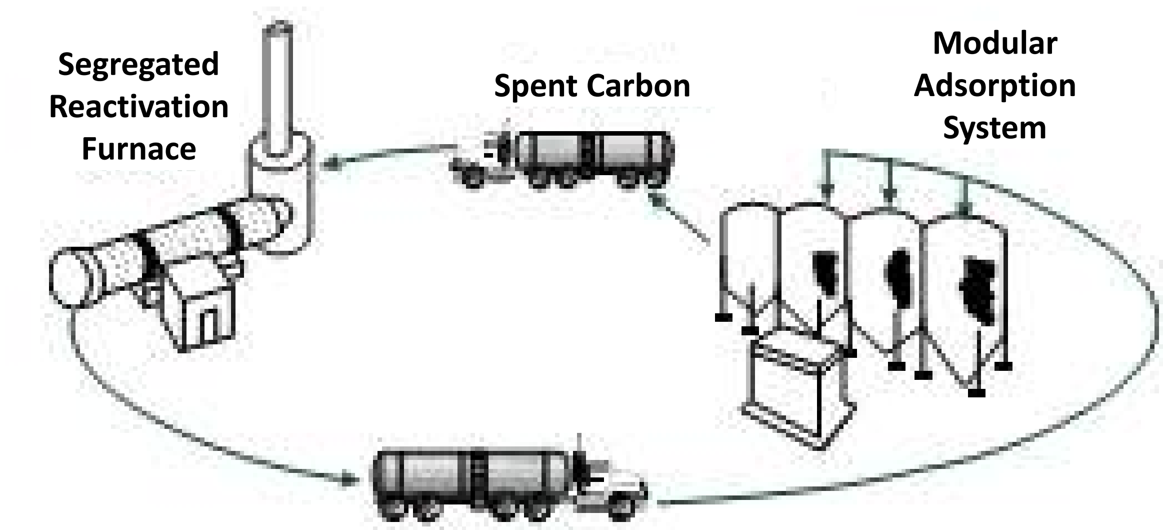
Carbon Removal

Requirements from customer for carbon removal include:

- Carbon vessel full of water and isolated
- 185 cfm at 75 psi compressed air supply (compressor can be rented)
- ¾- to 1-inch utility water source and hose to rinse carbon vessel
- 2-inch utility water source at trailer to hydrate fresh carbon
- Dewatering sump or storage tank, estimated dewatering volume: 4,000 – 6,000 gallons for 20,000-pound carbon slurry

Procedure courtesy of Evoqua

Carbon's "Circle of Life"



Graphic courtesy of Evoqua

Pitfalls to Avoid

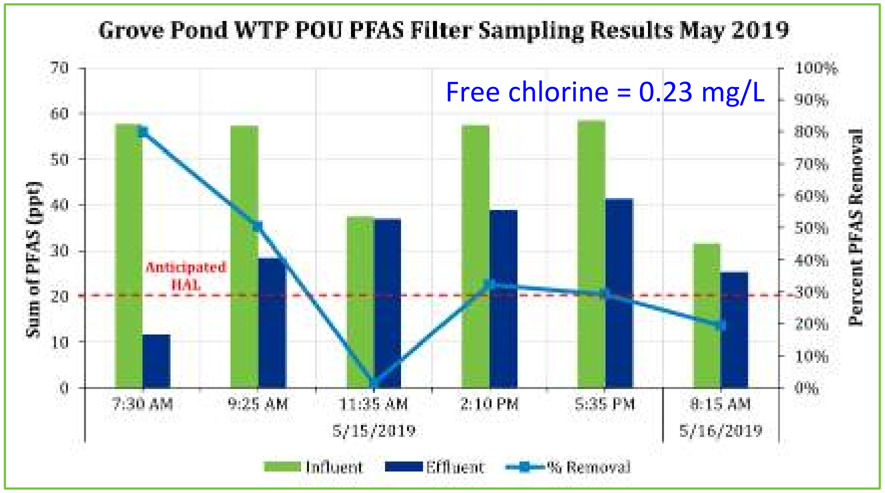
Planning is EVERYTHING

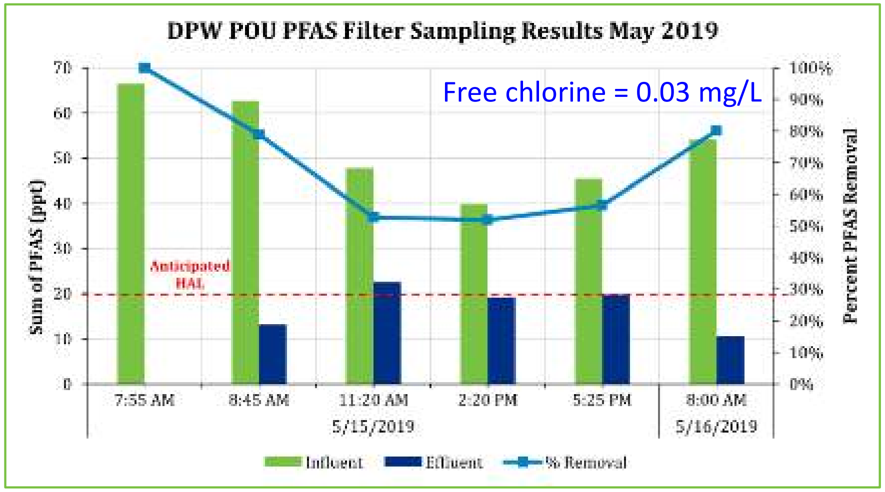
Potential Pitfalls with Activated Carbon

1. Inattention to non-PFAS water quality
2. GAC fines (fines = headloss)
3. Initially-high pH
4. Initially-high arsenic
5. Radioactivity
6. Rupture discs on pressure vessels
7. Poor distribution at low flows
8. Blind trust in point-of-use filters…

Point-of-Use (POU) Filter Testing

- POU home faucet filter system testing at WTP vs. in distribution system
- Monitored flow and various water quality parameters
- Cold water testing results = significant impact of chlorine residual
- Not beneficial for Ayer's use





- pH, iron, manganese, temperature and influent PFAS comparable
- Influent PFAS = PFOA, PFOS, PFHpA & PHHxS *(PFNA & PFDA = ND)*

QUESTIONS?

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