



Thermal Destruction of PFAS during full-scale reactivation of PFAS-laden granular activated carbon

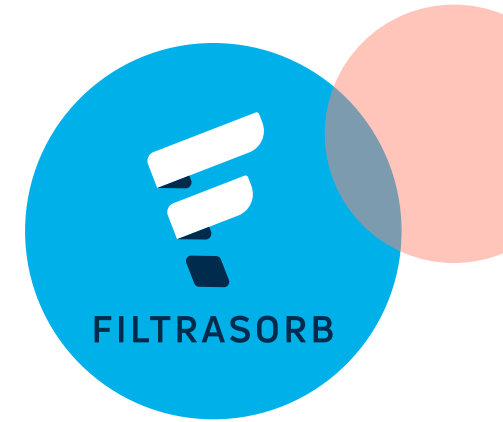
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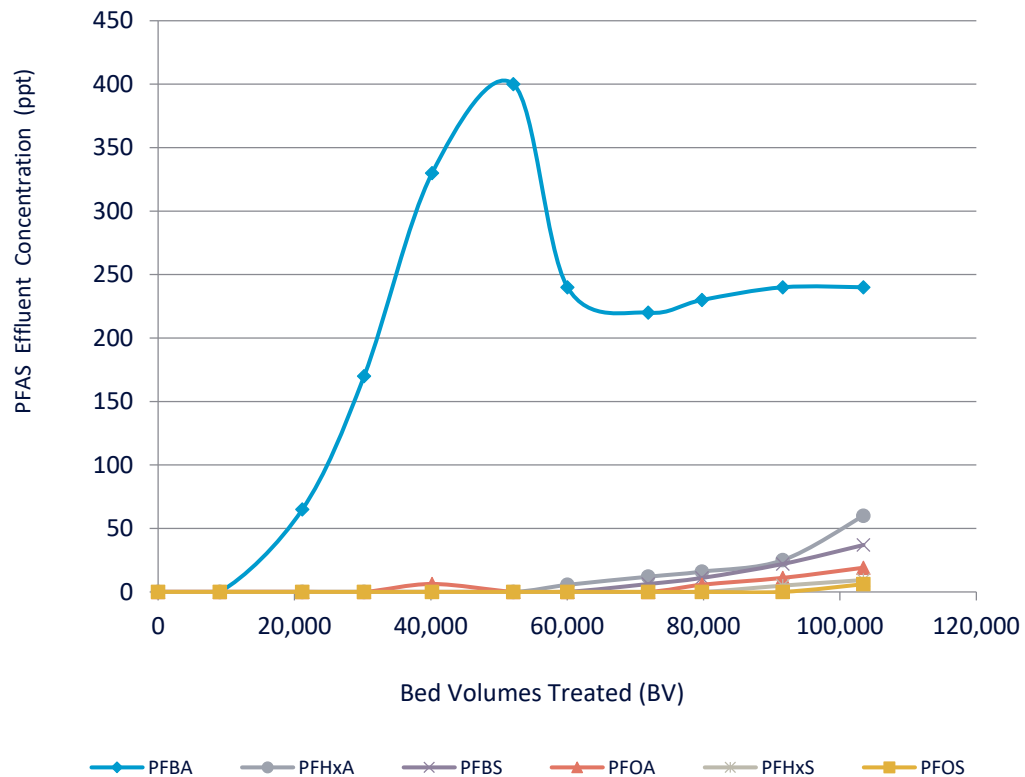
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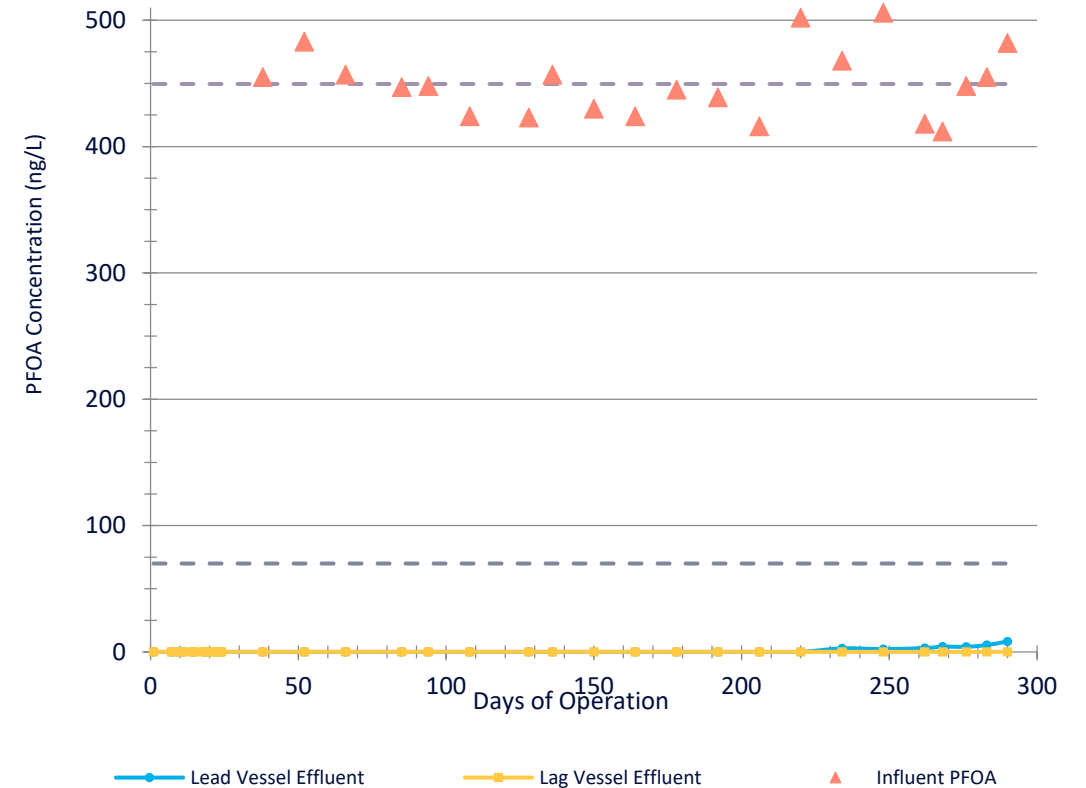
Calgon Carbon's FILTRASORB[®] product is proven and capable of meeting non-detect for a range of PFAS



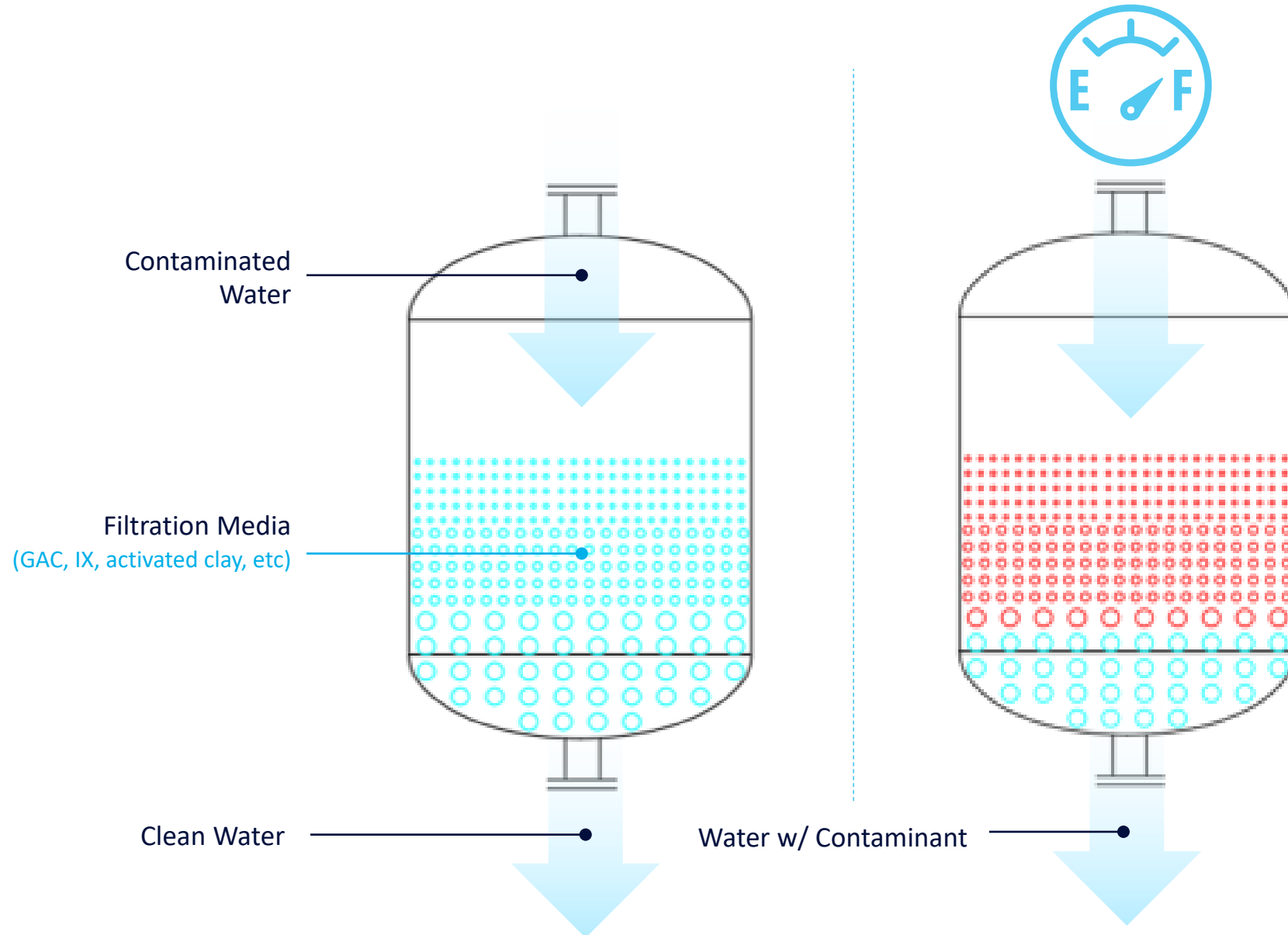
Peer Reviewed Lab-Scale Testing demonstrating FILTRASORB's effectiveness for PFAS



Full-Scale Model 10 System
10 minutes EBCT



Water treatment removes contaminants from water



What happens to the media once its useful life is over?

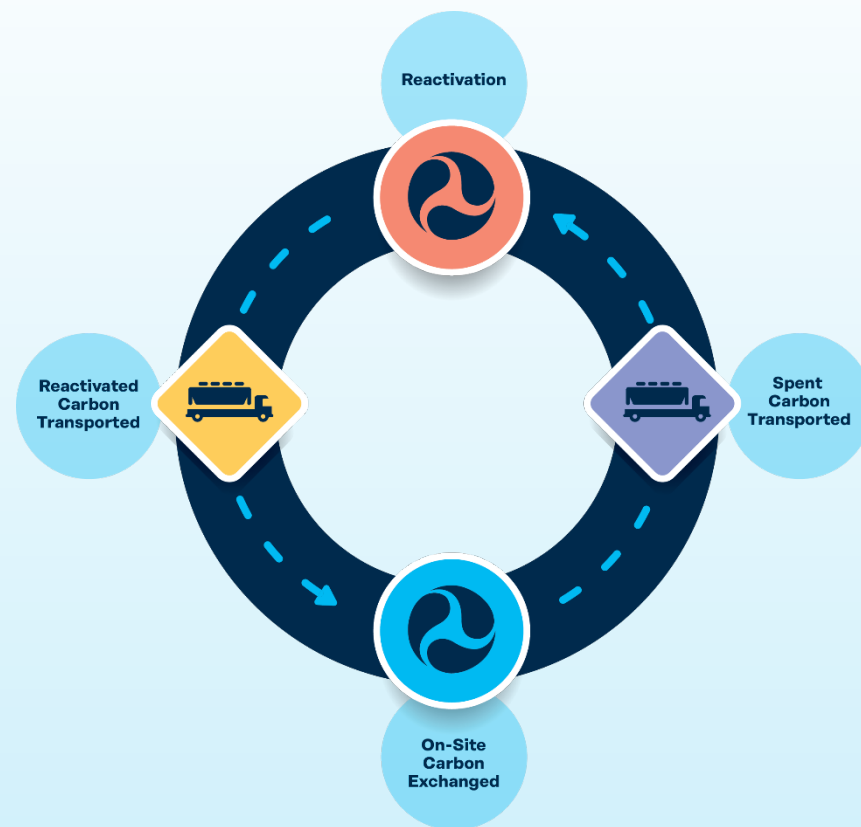
Reactivation is a unique disposal & reuse for GAC ONLY



Common methods used by many technologies (IX resin, Clay-based or novel sorbents) :



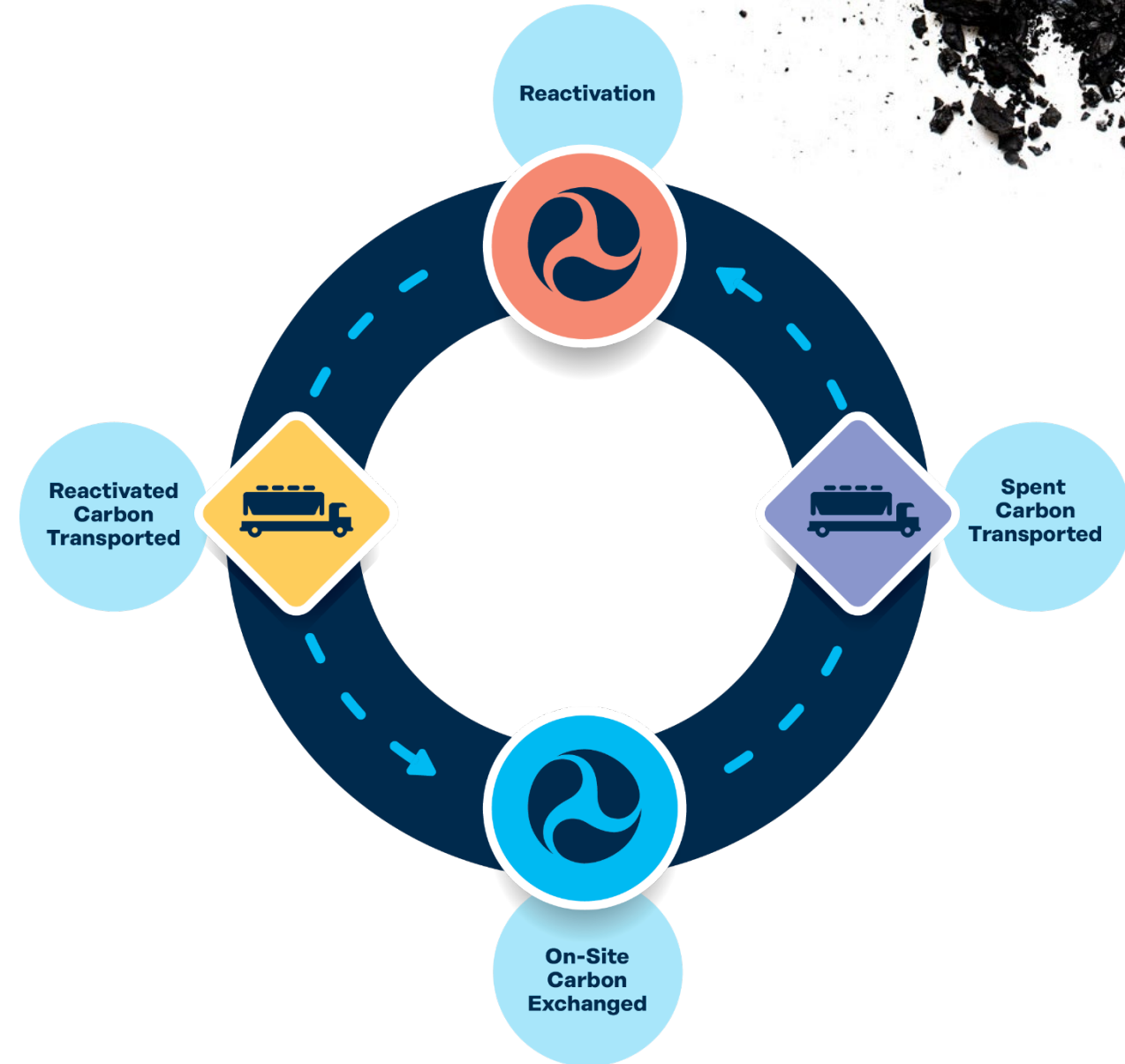
Unique to Activated Carbon:



Reactivation

How Our Products Help Customers and Society

- No landfill liabilities
- Certified destruction of the adsorbed materials (which may be classified as hazardous (CERCLA or RCRA)) – NO LIABILITY
- 80% Reduction in CO₂ vs. the production of virgin carbon
- Lower cost than incineration
- More sustainable
 - Cost
 - Resources (energy, material)
 - Environmental
- Can be reused for multiple applications



Reactivation

Global Reactivation Capacity

UNITED STATES

- **5 Reactivation sites**
 - 2 RCRA facilities
 - 3 Potable facilities
 - 4 sites are CERCLA Approved

UNITED KINGDOM

- **2 Reactivation sites**

BELGIUM

- **World's largest reactivation site**

CHINA

- **2 Reactivation sites**

Calgon Carbon reactivates over 254 million pounds of activated carbon every year!

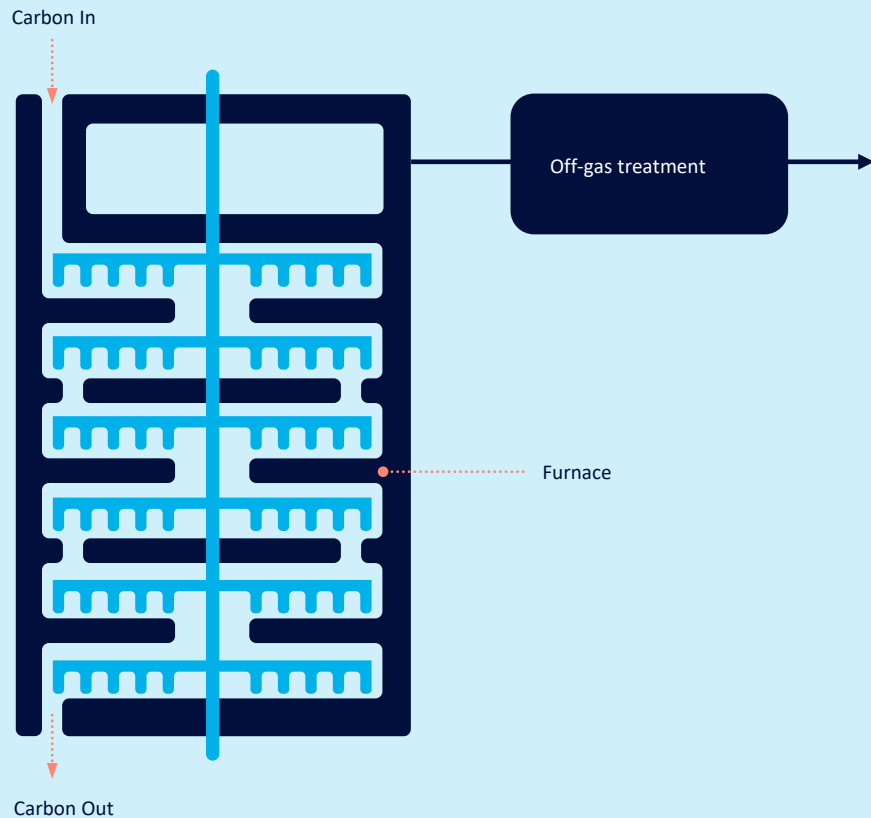
Over 30 years of reactivation experience globally!



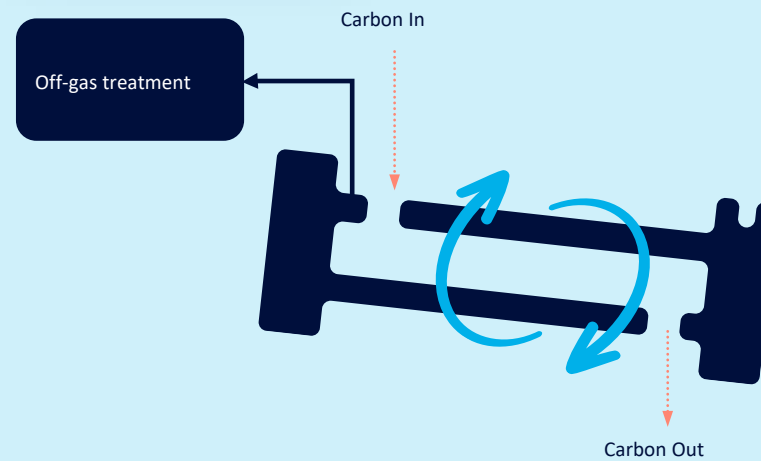
Reactivation Systems

There are two primary types of reactivation systems:

1 Multiple Hearth Furnace

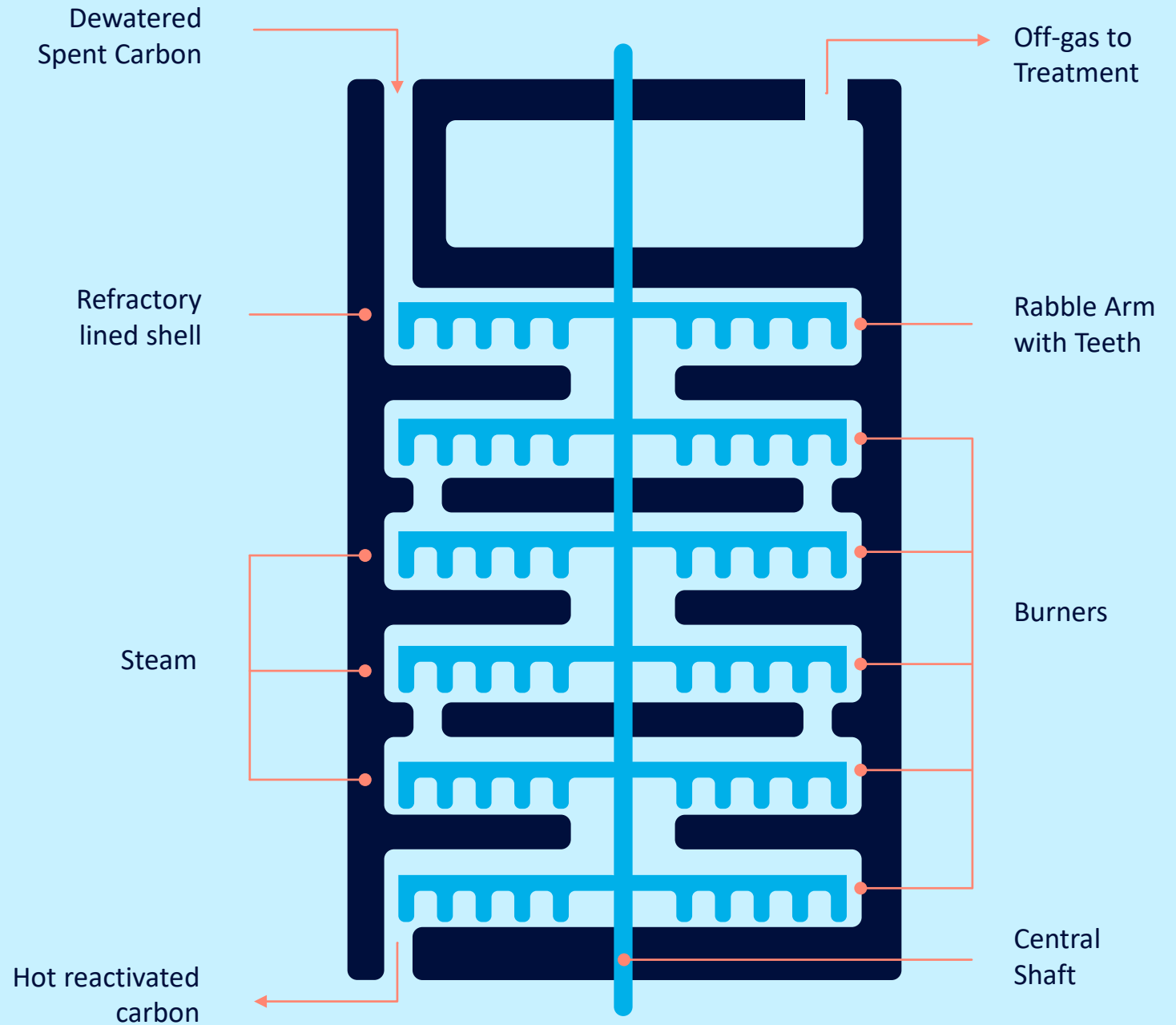
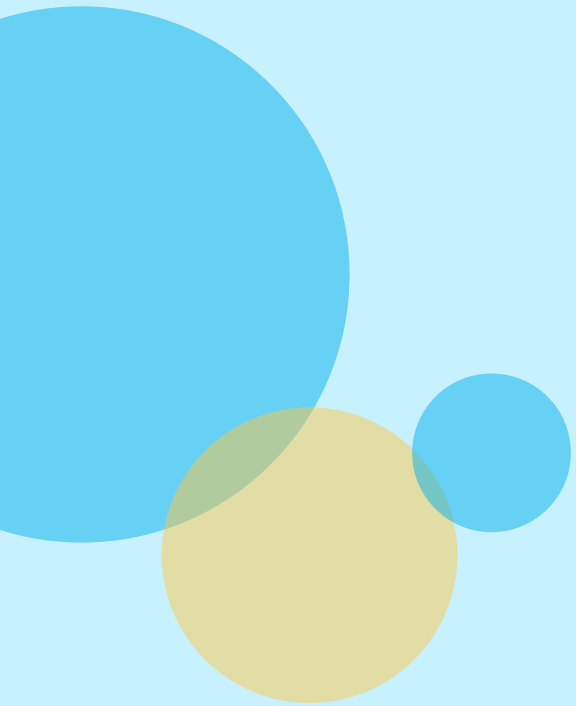


2 Rotary Kiln



Reactivation equipment and conditions are CRITICAL

- *Temperature*
- *Time*



Reactivation Systems

Rotary Kiln

- Batch operation
- Simplest type of furnace to operate
- Easier product segregation



Reactivation Chemistry

Low temperature pre-treatment

- Drying of water at 100°C

Physical processes and reactions

- Thermal Devolatilization and Desorption at 100-250°C

High temperature carbon condensation reactions

- High temperature pyrolysis/ calcination chemistry at 200-750°C

High temperature carbon gas/solid reactions

- Chemical reactions for Carbon Gasification with water vapor, carbon dioxide, or oxygen at 800-1000°C



Multi-hearth furnace

Carbon Acceptance Testing Objectives

Carbon Acceptance testing includes a series of evaluations to confirm a spent carbon can be effectively and safely reactivated.

Each project is thoroughly evaluated to ensure it meets CCC's requirements for:

Safety/Toxicity
Regulatory Compliance
Protection of:

- The Environment
- Plant Personnel
- Process Equipment
- Quality of React Product



Robust Carbon Acceptance Testing is conducted before GAC is approved for reactivation

- **Apparent Density (AD)**
- **pH**
- **Ignitability**
- **Reaction with water**
% Moisture
- **Radiation Screening**

Nature of spent carbon:

% Halides (Cl, F, Br)

% Sulfur

Inorganics

Quality of Reactivated Product

Liquid phase applications only


ICP Metals including lead, mercury

% hex chrome

BTU content (RCRA-hazardous only)

GAC Reactivation is a mature, sustainable, destructive end-of-life for PFAS

Technology	Matrix	Level of Tech	Destructive	Recyclability
Landfill	Solids	Mature	No	No
Incineration	Solids & Liquids	Mature	Yes	No
SCWO	Solids & Liquids	Pilot/Lab Scale	Yes	No
Plasma	Solids & Liquids	Pilot/Lab Scale	Yes	No
GAC Reactivation	Spent GAC	Mature	Yes	Yes



GAC Reactivation is the only technology that allows reuse of the media!

Reactivation is a Unique Process

United States Code of Federal Regulations, 40 C.R.F. 260.10 defines an **incinerator** as “any enclosed device that: Uses controlled flame combustion and neither meets the criteria for classification as a boiler, sludge dryer, or carbon regeneration unit, nor is listed as an industrial furnace; or meets the definition of infrared incinerator or plasma arc incinerator.”

A carbon regeneration unit is defined as “any enclosed thermal treatment device used to regenerate spent activated carbon” (Hazardous Waste Management, **2022**)

<https://www.calgoncarbon.com/app/uploads/PFAS-Reactivation-Memo-06022020.pdf>

Reactivation ≠ Incineration
Reactivation ≠ Regeneration



From: Dr. Richard Mimna
Date: June 2, 2020
Subject: Reactivation of Activated Carbon for Per- and Polyfluoroalkyl Substances (PFAS) Removal

Calgon Carbon recently received a number of questions regarding the fate of PFAS after carbon adsorption, including whether reactivation/regeneration is sufficient for removing PFAS from activated carbon, and if incineration is necessary for complete destruction of these compounds. The purpose of this letter is to explain the difference between reactivation and regeneration and to clarify any misconceptions associated with the process of reactivating spent activated carbon used for PFAS removal.

Spent activated carbon is a well established, high temperature process for the thermal destruction of adsorbed chemicals, after which the reactivated carbon can be reused. The desorbed chemical compounds are destroyed in the process and the reactivation of spent carbon containing PFOS, PFOA, and other PFAS is practiced for over 15 years.

Reactivation units, often called "Carbon Regeneration Units" (CRU's) by the EPA, the reactivation process is different from typical regeneration processes. Though CRU's are designed to meet the same performance standards of 40 CFR 264 Subpart G, the reactivation process and regeneration process are fundamentally different. The reactivation process involves the use of a reactivation furnace, which is designed to operate at temperatures up to 1000°C, and the reactivation process is a thermal treatment process that involves the use of a reactivation furnace, which is designed to operate at temperatures up to 1000°C, and the reactivation process is a thermal treatment process that involves the use of a reactivation furnace, which is designed to operate at temperatures up to 1000°C.

DOD mandate that restricts incineration of PFAS laden material does not apply to reactivation since it is classed separately, even though it is incorrectly called “regeneration” in federal code

Regeneration vs. Reactivation for GAC

Reactivation

Reactivation is a high-temperature thermal process that removes and destroys contaminants from the carbon's pore structure allowing the product to be reused fully.



Regeneration

Regeneration utilizes steam, solvents, or a low temperature process to remove a portion of the adsorbed species, allowing the product to be re-used. Typically results in a waste stream as this is not a destructive process.

Will often only remove ~70% or less of contaminants.



Reactivation's conditions are unique for destruction of PFAS vs. Incineration



Can reuse carbon

Reactivation

Condition	Parameter
Residence Time	1.5 h (5400 second)
Temperature	700-950 C°
Catalytic Effect	GAC

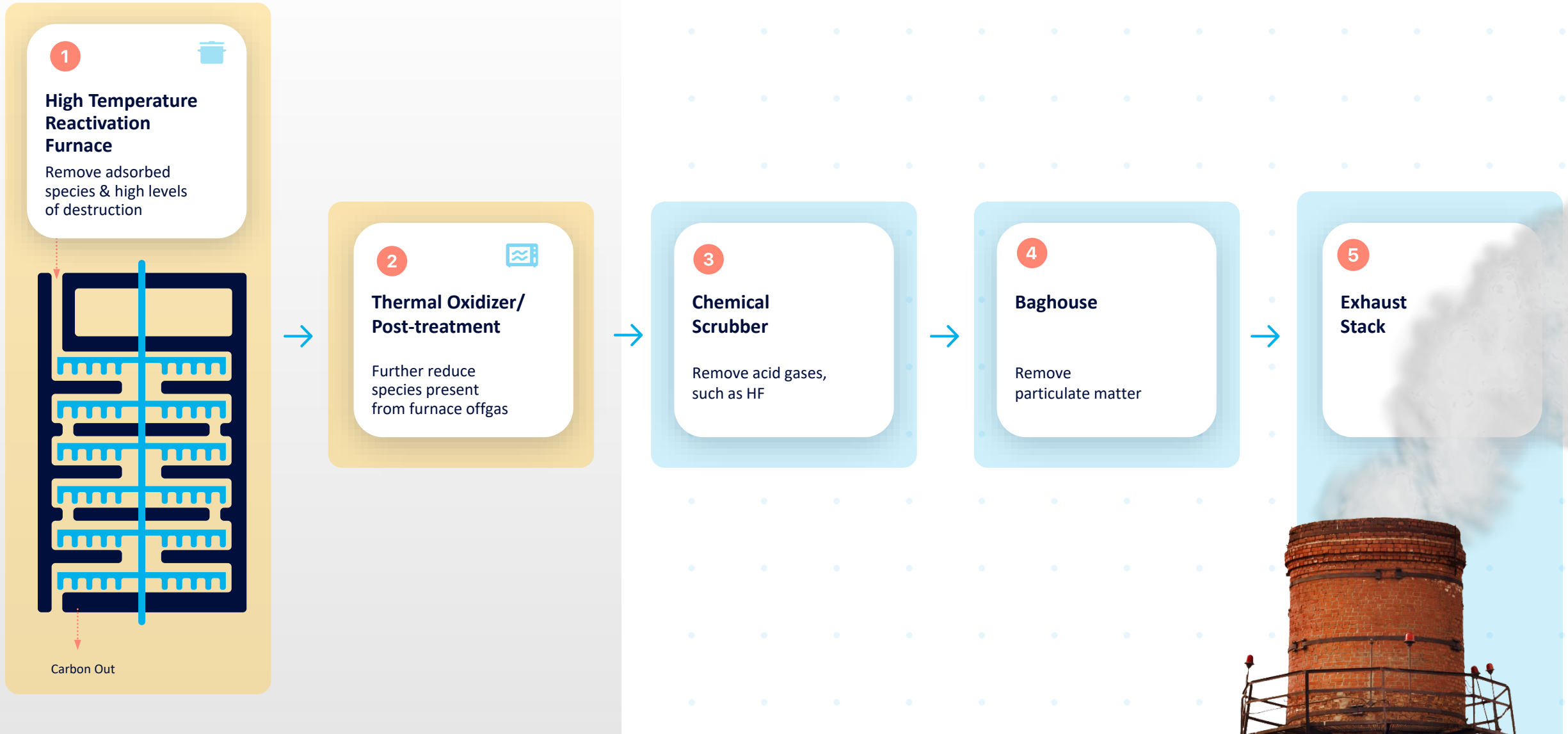


Carbon is destroyed

Incineration

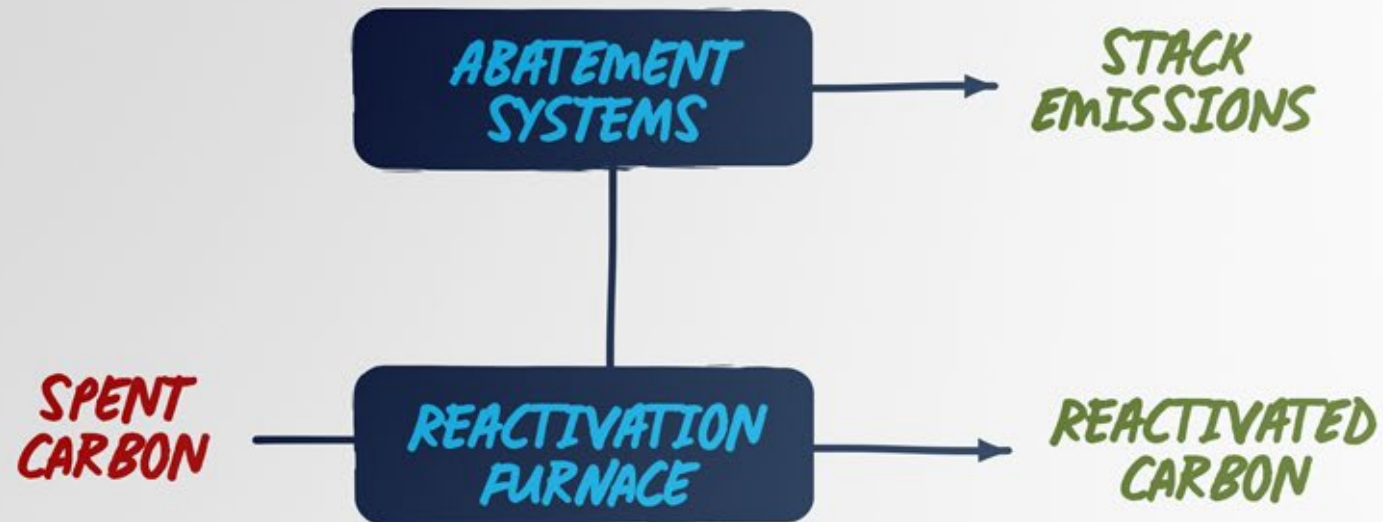
Condition	Parameter
Residence Time	1-3 seconds
Temperature	1,000 – 1,440 C°
Catalytic Effect	No catalytic effect

Calgon's Reactivation is a unique process with multiple destructive technologies

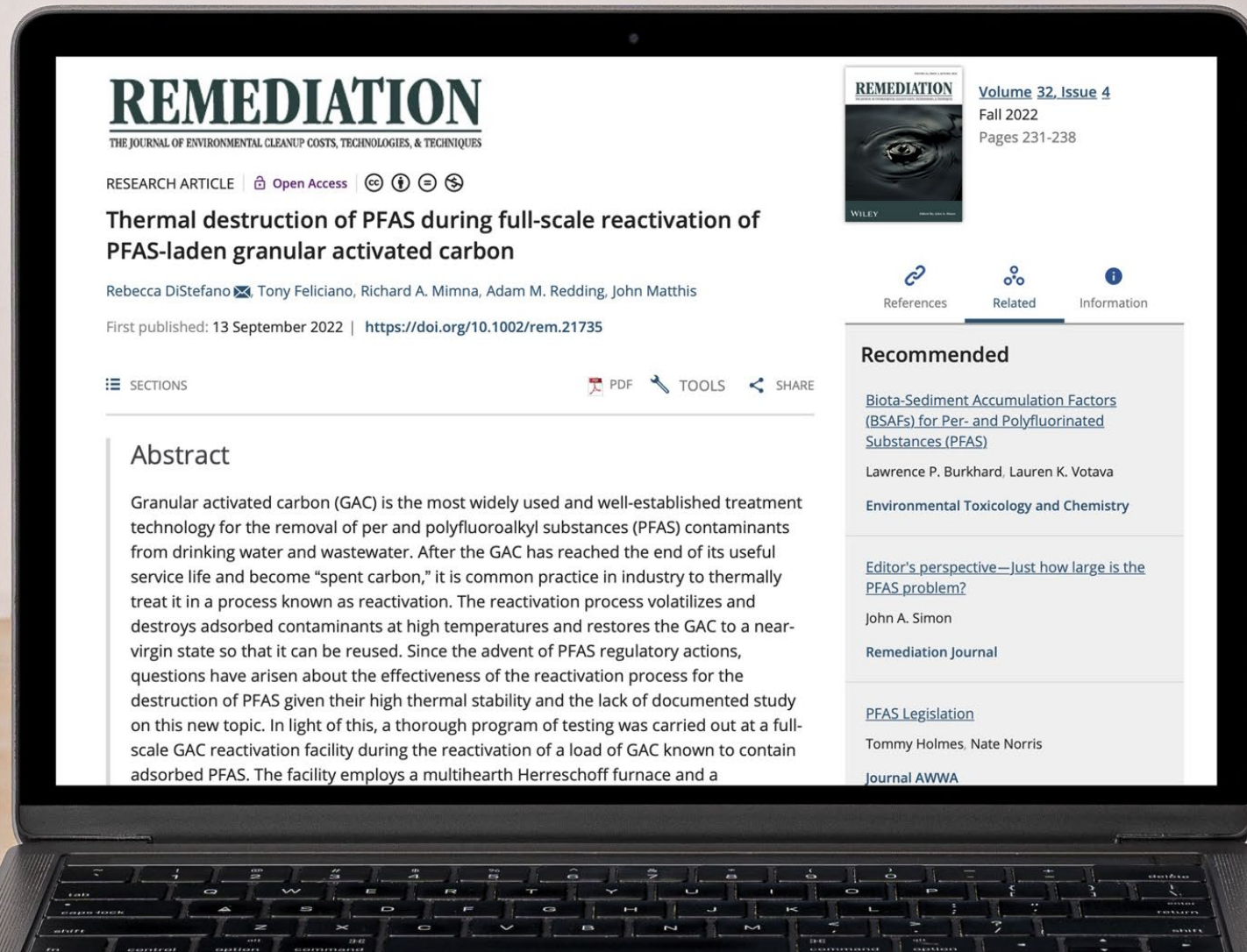


Destruction Removal Efficiency Calculations


$$\text{DESTRUCTION REMOVAL EFFICIENCIES (DRE)} = \frac{\text{INPUT} - \text{OUTPUT}}{\text{INPUT}} \times 100$$




Recent Peer Reviewed Journal Article Demonstrating Calgon Carbon's Reactivation Effectiveness







REMEDATION
THE JOURNAL OF ENVIRONMENTAL CLEANUP COSTS, TECHNOLOGIES, & TECHNIQUES

RESEARCH ARTICLE | [Open Access](#) | 

Thermal destruction of PFAS during full-scale reactivation of PFAS-laden granular activated carbon

Rebecca DiStefano , Tony Feliciano, Richard A. Mimna, Adam M. Redding, John Matthis




First published: 13 September 2022 | <https://doi.org/10.1002/rem.21735>

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Abstract

Granular activated carbon (GAC) is the most widely used and well-established treatment technology for the removal of per and polyfluoroalkyl substances (PFAS) contaminants from drinking water and wastewater. After the GAC has reached the end of its useful service life and become “spent carbon,” it is common practice in industry to thermally treat it in a process known as reactivation. The reactivation process volatilizes and destroys adsorbed contaminants at high temperatures and restores the GAC to a near-virgin state so that it can be reused. Since the advent of PFAS regulatory actions, questions have arisen about the effectiveness of the reactivation process for the destruction of PFAS given their high thermal stability and the lack of documented study on this new topic. In light of this, a thorough program of testing was carried out at a full-scale GAC reactivation facility during the reactivation of a load of GAC known to contain adsorbed PFAS. The facility employs a multihearth Herreschoff furnace and a

REMEDATION
Volume 32, Issue 4
Fall 2022
Pages 231-238

 References  Related  Information

Recommended

[Biota-Sediment Accumulation Factors \(BSAFs\) for Per- and Polyfluorinated Substances \(PFAS\)](#)
Lawrence P. Burkhard, Lauren K. Votava
Environmental Toxicology and Chemistry

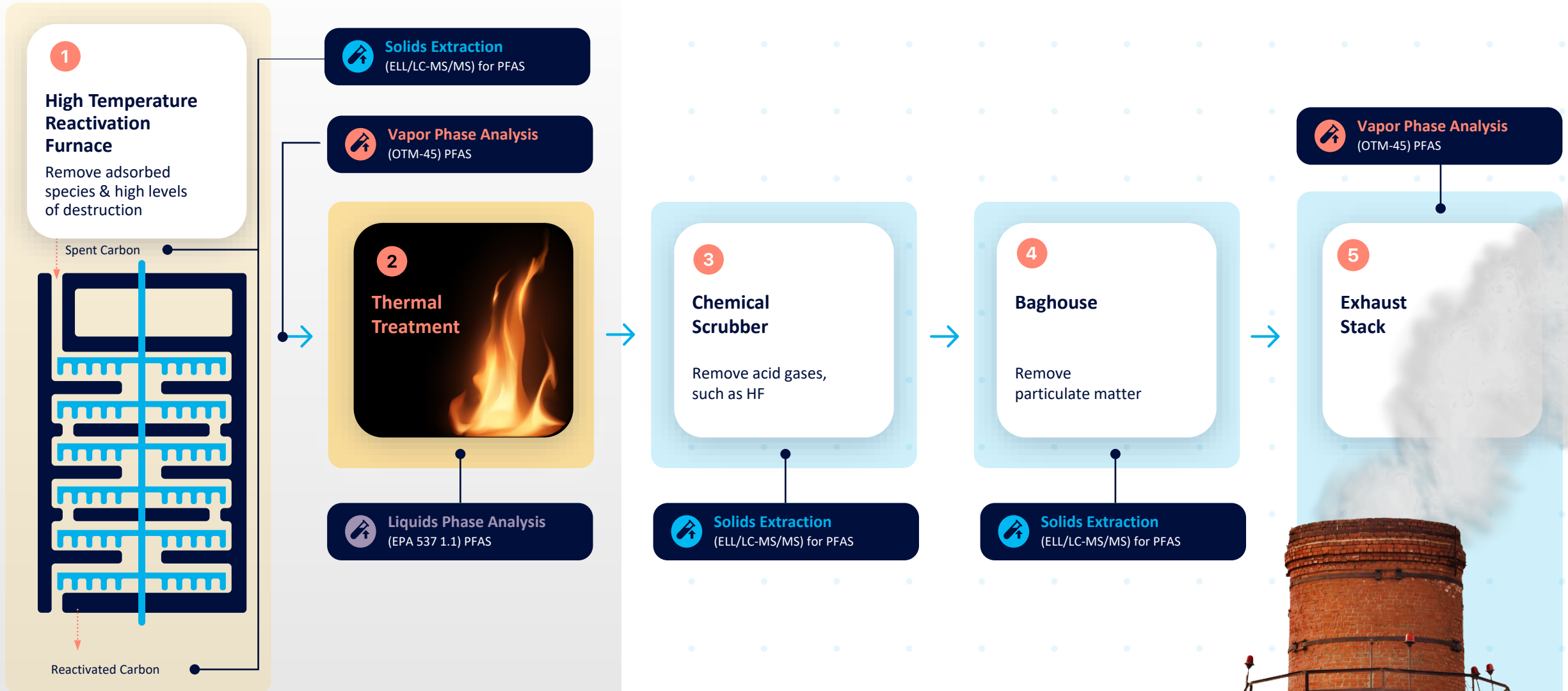
[Editor's perspective—Just how large is the PFAS problem?](#)
John A. Simon
Remediation Journal

[PFAS Legislation](#)
Tommy Holmes, Nate Norris
Journal AWWA

Published
Open Access
13-Sept-2022



Calgon's Reactivation is a Unique Process with Multiple Destructive Technologies



Best Commercially Available Analytical for PFAS was used



Destruction Removal Efficiency

	Total PFAS (lb/hr)	Incremental Destruction Removal Efficiency (DRE)	Overall DRE
Spent Carbon (29 compound list) ¹	0.748		
Furnace off-gas (36 compound list) ²	8.41×10^{-5}	99.989%	
Stack emissions (36 compound list) ²	4.88×10^{-5}	42.024%	99.993%

Reactivation Demonstrated >99.99% Destruction for Total PFAS

Calgon's Furnace & Abatement System PFAS DREs

DRE PFAS: >99.9%

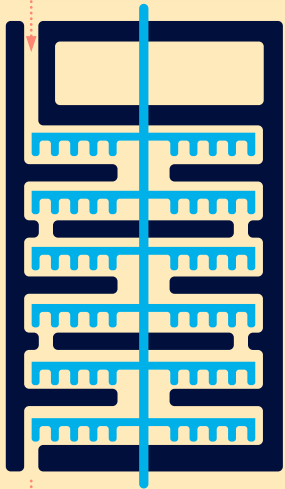
Total DRE PFAS: >99.99%

1

High Temperature Reactivation Furnace

Remove adsorbed
species & high levels
of destruction

Spent Carbon



Reactivated Carbon

2

Thermal Treatment

Further reduce
species present
from furnace offgas

3

Chemical Scrubber

Remove acid gases,
such as HF

4

Baghouse

Remove
particulate matter

5

Exhaust Stack

Robust, Additional Abatement Systems



Calgon's Reactivation effectively removes PFAS below detection limits!

	NG/G	Spent Carbon			Reactivated Carbon		
		Composite Sample for Each Emissions Test			Composite Sample for Each Emissions Test		
		TEST 1	TEST 2	TEST 3	TEST 1	TEST 2	TEST 3
PERFLUOROBUTANOIC ACID	PFBA	6300	6700	4700	<1.9	<1.9	<1.9
PERFLUOROPENTANOIC ACID	PFPEA	2600	2500	1500	<0.58	<0.58	<0.58
PERFLUOROHEXANOIC ACID	PFHXA	3700	2900	1600	<0.58	<0.58	<0.58
PERFLUOROHEPTANOIC ACID	PFHPA	1600	1300	620	<0.58	<0.58	<0.58
PERFLUOROOCCTANOIC ACID	PFOA	18000	14000	5800	<0.58	<0.58	<0.58
PERFLUORONONANOIC ACID	PFNA	88	72	53	<0.58	<0.58	<0.58
PERFLUORODECANOIC ACID	PFDA	71	51	21	<0.58	<0.58	<0.58
PERFLUOROUNDECANOIC ACID	PFUNDA	45	24	24	<0.58	<0.58	<0.58
PERFLUORODODECANOIC ACID	PFDODA	<9.7	<9.1	<9.6	<0.58	<0.58	<0.58
PERFLUOROTRIDECANOIC ACID	PFTRIDA	59	30	28	<0.58	<0.58	<0.58
PERFLUOROTETRADECANOIC ACID	PFTETDA	<9.7	<9.1	<9.6	<0.58	<0.58	<0.58
PERFLUOROBUTANESULFONIC ACID	PFBS	11000	8200	6300	<1.9	<1.9	<1.9
PERFLUOROPENTANESULFONIC ACID	PFPEs	6700	4700	1200	<0.58	<0.58	<0.58
PERFLUOROHEXANESULFONIC ACID	PFHXS	33000	22000	5900	<0.58	<0.58	<0.58
PERFLUOROHEPTANESULFONIC ACID	PFHPS	5100	3100	810	<0.58	<0.58	<0.58
PERFLUOROOCCTANESULFONIC ACID	PFOS	16000	12000	6700	<0.58	<0.58	<0.58
PERFLUORONONANESULFONIC ACID	PFNS	40	27	9.9	<0.58	<0.58	<0.58
PERFLUORODECANESULFONIC ACID	PFDS	180	110	37	<0.58	<0.58	<0.58
PERFLUORODODECANESULFONIC ACID	PFDOS	<32	<30	<32	<1.9	<1.9	<1.9
PERFLUOROOCCTANESULFONAMIDE	PFOSA	340	340	380	<0.58	<0.58	<0.58
NMEFOSAA	NMEFOSA	720	550	560	<1.9	<1.9	<1.9
NETFOSAA	NETFOSAA	610	520	440	<1.9	<1.9	<1.9
HFPODA	GENX	6500	40000	55000	<1.9	<1.9	<1.9
4:2 FLUOROTELOMER SULFONIC ACID	4:2 FTS	<32	<30	<32	<1.9	<1.9	<1.9
6:2 FLUOROTELOMER SULFONIC ACID	6:2 FTS	290	110	800	<1.9	<1.9	<1.9
8:2 FLUOROTELOMER SULFONIC ACID	8:2 FTS	<48	<46	<48	<2.9	<2.9	<2.9
10:2 FTS	10:2 FTS	<32	<30	<32	<1.9	<1.9	<1.9
PERFLUOROHEXADECANOIC ACID		<9.7	<9.1	<9.6	<0.58	<0.58	<0.58
PERFLUOROOCCTADECANOIC ACID		<9.7	<9.1	<9.6	2.2 / <0.57	<0.58	<0.58
SUM 29 PFAS COMPOUNDS:		112943	119234	92483	2.2	0	0

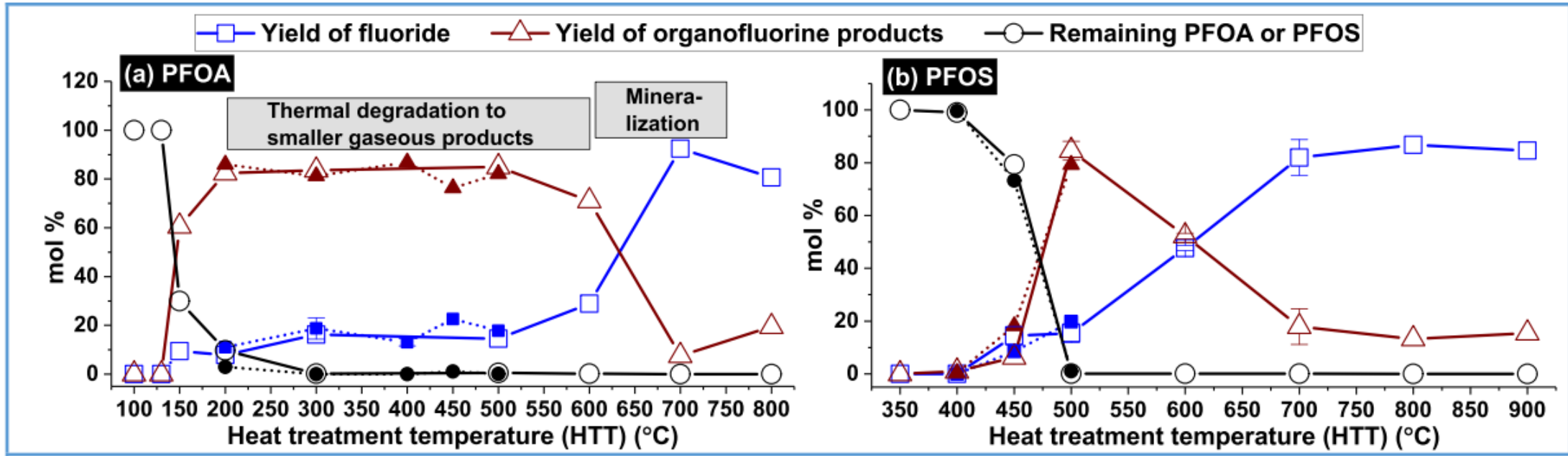
Fluoride Measurements

	Total PFAS (lb/hr)	Calculated Total Fluoride from PFAS (lb/hr)	Measured Total Fluoride (lb/hr)
Spent Carbon	0.748	0.396	9.05
Reactivated Carbon	0.000	0.000	2.61
Furnace off-gas	8.41E-05	5.47E-05	2.95
Abatement Dust	0.000	0.000	1.26

- **Mass balance at 61.4% on total fluoride**
- **Fluoride is very reactive with furnace linings, process equipment, EVERYTHING!**
- **Indicates mineralization of PFAS to fluoride**

Fluoride Mass Balances are very difficult to achieve in full-scale, real-world conditions.

Lab Scale Work Supports Higher Mineralization



Xiao, F., et al. Thermal stability and decomposition of perfluoroalkyl substances on spent granular activated carbon. *Environmental Science & Technology Letters*, 2020, 7, 343-350.

- Shows PFAS remineralization during GAC reactivation at a lab scale
 - PFAS can be remineralized at lower temperatures
- Fluoride is very reactive with furnace linings, process equipment, EVERYTHING!
 - Fluoride balances easier to obtain and measure at lab scale

Conclusions & Key Findings



Calgon's Reactivation is a unique process that thermally removes PFAS and achieves high destruction in the reactivation furnace and our robust abatement systems



Reactivation is very different than Regeneration



Reactivation is very different than Incineration



Calgon Carbon's proprietary reactivation process and conditions achieved > 99.99% PFAS destruction for total PFAS



Calgon Carbon's proprietary reactivation process and conditions achieved > 99.999% destruction for PFAS with a current EPA Health Advisory Limit (PFOA, PFOS, GenX, PFBS)



High levels of fluoride generated support mineralization of these compounds



Reactivation is a safe, proven, simple, cost-effective and fully commercial offering



Reactivation is sustainable process that has 80% reduction in CO₂

Benefits of Reactivation for PFAS

- Disposal through reactivation is an accepted disposal method for other CERCLA sites.
- Reactivation maintains low O&M costs and keeps the source of supply flexible.
- IX Resin cannot be reactivated and must be disposed of through incineration or landfill.
- Sub-bituminous and other non bituminous GAC materials present a low yield through reactivation, meaning incineration and landfill are the only disposal options.
- The liability of PFAS disposal lies with the reactivation service supplier and not on the material generator.
- Reactivated GAC will perform similar as virgin GAC for several, if not all cycles.
- Cost of reactivated material is ~30% that of virgin material.

Thank you for your time.
Questions?

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