PFAS: Significant progress in industrial wastewater and sludge management in response to the global environmental challenge

SUEZ

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PFAS management: beyond removal

Removal is not sufficient if the final fate is not controlled

Detect → Separate/ Concentrate → Immobilize / Destroy → Verify

- Separation may transfer PFAS from water to another phase or residual stream.
- End-of-life technologies must **prove** destruction, absence of by-products and controlled fluorine fate.
- Industrial wastewater and sludge are strategic matrices for source control and residual management.

Matrix-specific treatment strategy

Technology selection must start from the matrix

Dilute liquid effluent	→	**Separation / concentration** *before final treatment*
Mineral waste	→	**Stabilization / solidification** *when destruction is not appropriate*
Sludge or concentrated liquid	→	**Thermal or hydrothermal destruction** *verified destruction pathways*

Comparing technologies without considering the matrix and the treatment endpoint can lead to misleading conclusions.

Analytical backbone

Matrix-specific analytics are the basis of process validation

Up to 68
PFAS analysable, depending on matrix
incl: TFA, DFA, 6:2 FTS, 6:2 FTAB…

30
PFAS routinely monitored in waste, effluent, and sludge matrices

Participation in XP X43-126
Gaseous emissions

Extraction optimized by

- solvent
- sample-to-solvent ratio
- agitation
- pH
- extraction time
- extraction cycles
- dilution strategy

Adapted per matrix — water, sludge, leachates, mineral waste and spent activated carbon behave very differently.

HPLC/MS/MS Givors (69)

2 HPLC/MS/MS Le Pecq (78)

- TOP assay
- Non targeted analysis
- Bioassays
- Field kit test

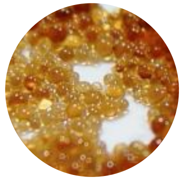
UPLC-Orbitrap, ThermoFisher Scientific®

FREDsense

Grapheal

Separation / Concentration technology toolbox

Separation reduces mobility but generates secondary streams



Resins / GAC

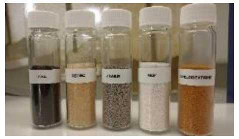
Performance depends on chain length, functional group and organic matter; resins may outperform GAC for some short-chain PFAS.

Membranes

Effective concentration tools — but the PFAS-rich concentrate still requires further treatment.

Foam fractionation

Exploits surface activity; strong for longer-chain PFAS



Coagulants / alternative adsorbents

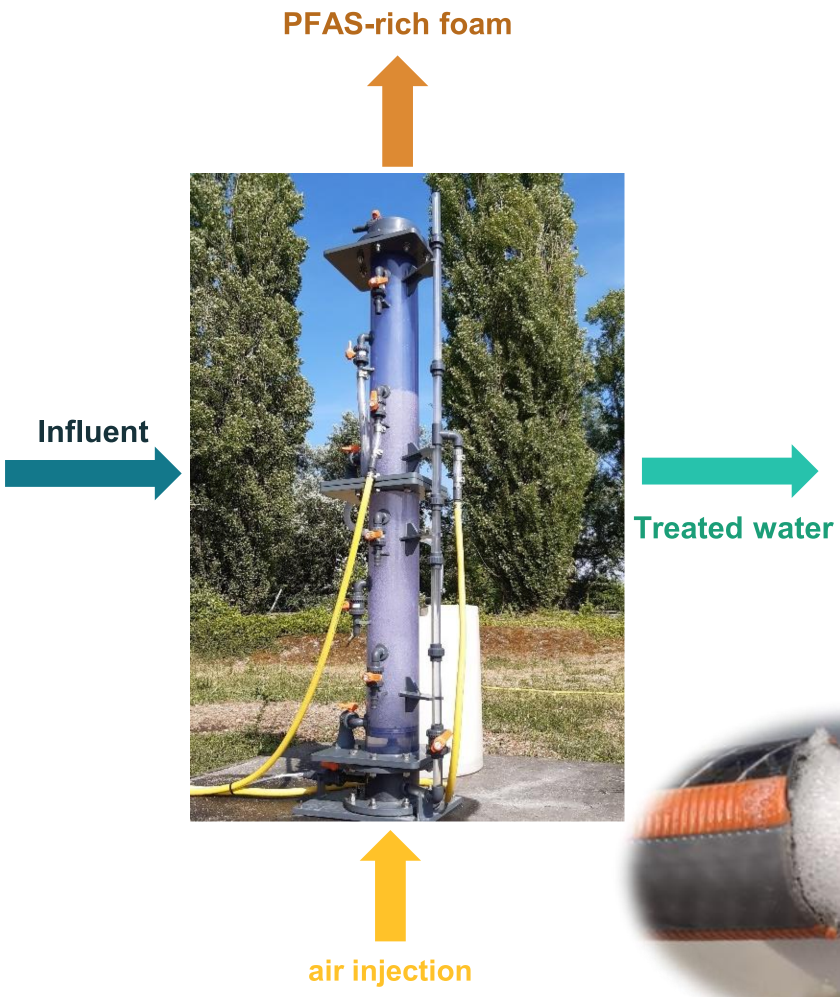
Targeted options matched to the site-specific PFAS profile.

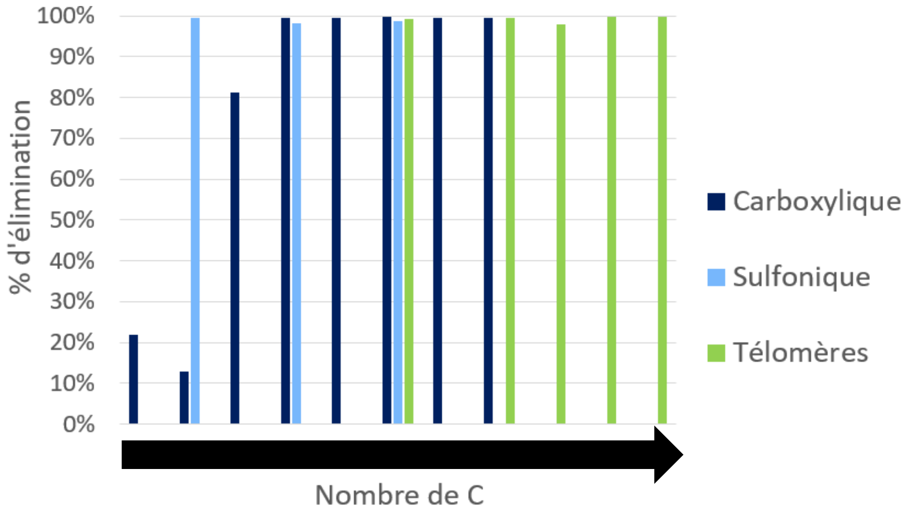
TFA and small carboxylic acids remain difficult targets for adsorption.

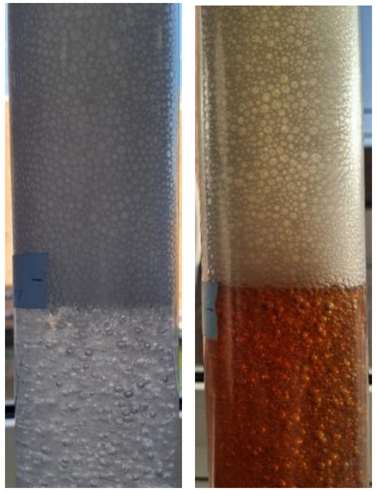
→ Focus on Foam Fractionation which is a promising and specific technology for PFAS concentration (liquid/liquid)

Foam fractionation for volume reduction

Concentrates PFAS into a smaller stream







- Pilot-scale tests conducted on industrial wastewater treatment plants.
- Air-water ratio, residence time and surfactant addition assessed to optimize separation.
- Relevant as a pre-treatment step before destruction of the concentrated fraction.
- A high PFAS concentration factor with a low discharge volume

Foam fractionation: compound-dependent performance

Removal efficiency increases with PFAS chain length

< C4

Limited or no removal
Reduction rate: < 20%

→

C4 – C5

Intermediate behaviour
Reduction rate: 73 – 93%

→

≥ C6

Good elimination
Reduction rate: 96-99,9%

up to 10 000

volume reduction factors

Ultra-short and short-chain PFAS are the hardest to capture by foam → Innovative surfactants have been tested

Two-stage configurations are being investigated to further reduce foam volume.

Stabilization / Thermal destruction technology toolbox

For a complete solution

Stabilization / solidification

for PFAS-contaminated mineral waste

> 97%
immobilization efficiency

Hydrothermal gasification (SCWG)

for PFAS-contaminated wet /water-mixable organic waste

> 99.99%
destruction for most tested PFAS

High-temperature incineration

for PFAS-contaminated liquid waste

DRE > 99.9999%
DE > 99.99%

Sludge pyrocarbonisation

for urban sludge

DE 99.99%

Stabilization/ solidification

A containment route for PFAS-contaminated mineral waste

> 100
formulations tested

> 97%
immobilization efficiency

- Hydraulic binders, mineral waste types, mixing liquids and additives screened.
- Leaching behaviour assessed according to NF X31-211.
- A containment option — relevant when thermal treatment is not suitable or proportionate.

High-temperature incineration

Validated for concentrated liquid PFAS waste

DRE

> 99.9999%

Destruction efficiency DE > 99.99%

flue gases · aqueous effluents · residues monitored

> 1100 °C

typically 1150–1400 °C

> 2 s

residence time

Wet flue-gas treatment

For catching HF

Full monitoring

of all output streams

- Tested across PFAS concentrations from hundreds of µg/L to tens of g/L,
- Spanning carboxylic, sulfonic, telomer-based and ultra-short-chain compounds.

Analytical challenge: PFAS in the aqueous discharge were traced to the industrial water used for wet flue-gas washing — blanks and full-chain monitoring are essential.

Hydrothermal gasification (SCWG)

Treats wet waste while recovering value

Wet, water-mixable waste → **Supercritical water reactor** →

- **H_2 / CH_4-rich gas**
- **Recovered salts**
- **Treated water**

- Suited to wet waste containing both organic and mineral fractions.
- Organic matter is converted into valuable gaseous products.
- Minerals can be recovered as recyclable salts.
- A reductive medium (unlike oxidation routes) favours H_2 and CH_4 formation.

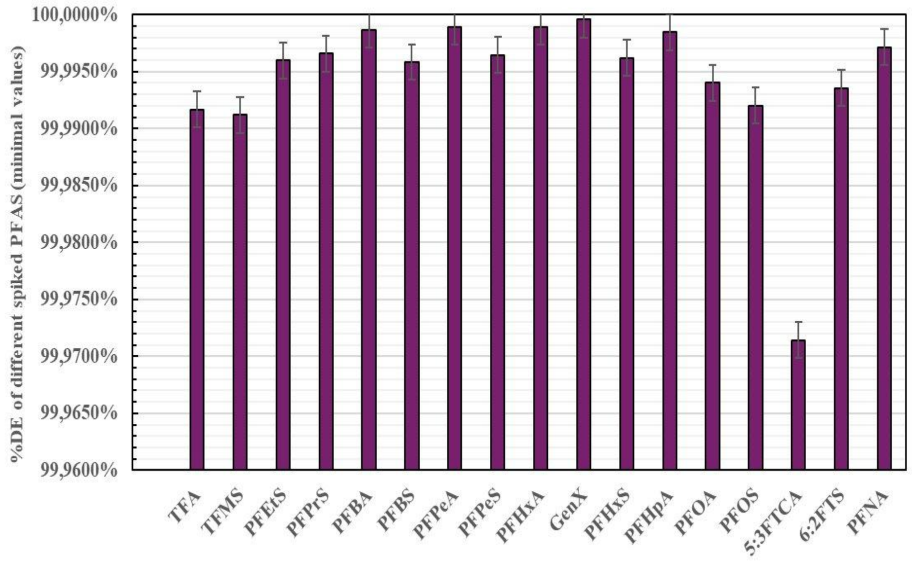
SCWG: destruction and fluorine fate

High PFAS destruction with evidence of mineralization

17 PFAS → **Pilot** *15l/h 270 bar 515–530 °C* → **Mineral fluoride (F⁻)**

- *C1–C9*
- *Carboxylic acids, sulfonic acids, GenX, 5:3 FTCA and 6:2 FTS*
- *Total PFAS ≈ 4,900 to 12,000 µg/L*

- *Pilot capability: up to 30 MPa and up to 600 °C*
- *Residence times around 3.75 – 4.5 minutes*
- *Continuous flow*



> 99.99%
destruction for most tested PFAS

≈ 96.2%
defluorination (fluorine mass balance)

✓ Target PFAS ✓ AOF ✓ Fluoride balance ✓ Non Targeted PFAS

No residual organic fluorine · no new PFAS among the 60 screened compounds · no additional UPLC-MS/MS signal.

Sludge pyrocarbonisation

Dried sludge
90% solids

→

Pyrocarbonisation
600 °C · low O_2

→

PFAS-free biochar

↓

Pyrolysis gas → oxidation ≈ 1000 °C

Highly dense PFAS monitoring network: 10 measurement points across the process

Near-complete PFAS elimination at full scale

DE 99.99%

overall destruction efficiency — full-scale evidence

16 → 0

16 PFAS in dried sludge; none detected in biochar or dust (of 50 screened)

No TFA detected in pyrolysis gas & fumes

Carbon-negative

biochar with fertilizer potential — PFAS elimination plus nutrient recycling

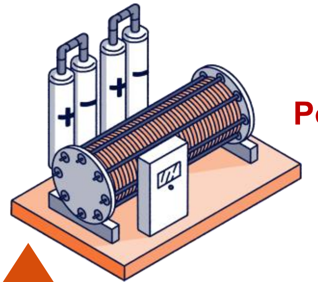
Sludge pyrocarbonisation

Only PFHxDA detected in fumes, non quantif (86 studied)

7 PFAS detected (4 quantified) in pyrolysis gas (86 studied)

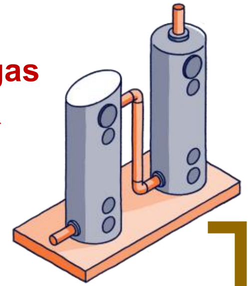
PFBA, PFPeA, PFOA, PFHxA, 8:2 FTUCA; 5:3 FTCA (FPePA); 7:3 FTCA (FHpPA)

GASEOUS PHASE



Fumes

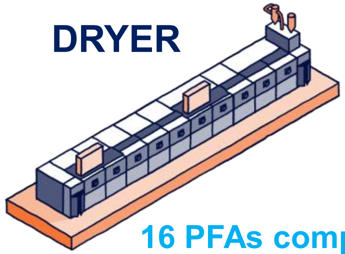
Post combustion gas



Pyrolysis gas

COMBUSTION CHAMBER

DRYER

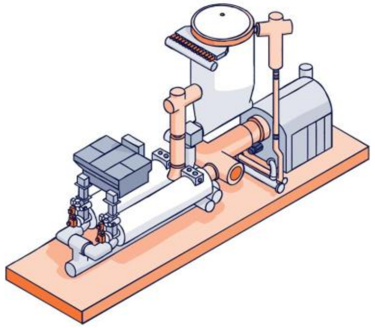


Dewatered sludge

SOLID PHASE

16 PFAs compounds detected in sludge (50 studied)

PFHxA; PFOA; PFNA, PFOS, PFDA; PFUnDA, PFDoDA; H4PFDS, 8:2 FTS; 10:2 FTS; N-MeFOSAA ; N-EtFOSAA; PFOSA ; 5:3 FTCA ; 7:3 FTCA; PFTeDA; 6:2 FTS



PYROLYSIS REACTOR

Biochar

0 PFAS detected in biochar (50 studied)

Siloxanes

0 PFAS compounds detected (50 studied)

Abstract published in proceeding RBITT Kensas City (May 2026)

Conclusions & perspectives

1. Detection must be **matrix-specific** and broad enough to support treatment validation.
2. Separation and concentration technologies are useful **only if connected to validated residue management.**
3. High-temperature incineration is validated for concentrated waste, while **SCWG and pyrocarbonisation expand the portfolio** toward wet-waste valorization and sludge recovery.
4. Destruction technologies for PFAS are still under research; new technologies are emerging and **testing with partners is ongoing**.
5. Future technology selection should **compare molecule range, cost and environmental impact.**

PFAS fate management portfolio

Matrix	liquid / mineral waste / sludge
Endpoint	concentrate / immobilize / destroy
Verification	PFAS / fluoride / emissions

PFAS treatment is not only about removal — it is about scientifically verified fate control.

Thanks

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