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Large scale study: thermal reactivation of PFAS contaminated granular activated carbon originating from drinking water production

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REMOVAL OF PFAS FROM GROUNDWATER WITH GAC

Waterwork profile:

- Type of raw water: Groundwater
- 7 wells; production for 55000 cit.
- Purification steps: de-ironing filters. aeration basins
- PFAS
 - groundwater contamination first detected in 2020 (up to 5 µg/l)
 - Origin: Firefighting foam used at nearby airbase before 2011
 - Major incident: 1999 plane crash



Pic.: Aachener Zeitung. 12.4.2023

REMOVAL OF PFAS FROM GROUNDWATER WITH GAC

2021 Installation 6 GAC Filter

- Installation 06.2021
- 6 mobile filters in parallel
- Activated carbon Product: AquaSorb™ 6300 12x40
- Flow rate: 60 m³/h (per filter)
- EBCT of 20 min
- PFAS concentration in raw mixed water: 0.5-0.7 µg/l



Mean values Jun 2021 – Dec 2022			Influent concentration
	ADONA	µg/l	0.000
	HFPO-DA (GenX)	µg/l	0.000
Perfluorobutane acid	PFBA	µg/l	0.028
Perfluorobutanesulfonic acid	PFBS	µg/l	0.040
Perfluorodecanoic acid	PFDA	µg/l	0.000
Perfluorododecanoic acid	PFDODA	µg/l	0.000
Perfluorododecanesulfonic acid	PFDODS	µg/l	0.000
Perfluorodecanesulfonic acid	PFDS	µg/l	0.000
Perfluoroheptanoic acid	PFHpA	µg/l	0.037
Perfluoroheptanesulfonic acid	PFHpS	µg/l	0.002
Perfluorohexanoic acid	PFHxA	µg/l	0.171
Perfluorohexanesulfonic acid	PFHxS	µg/l	0.169
Perfluoropentanoic acid	PFNA	µg/l	0.010
Perfluorononanesulfonic acid	PFNS	µg/l	0.000
Perfluorooctanoic acid	PFOA	µg/l	0.039
Perfluorooctanesulfonic acid	PFOS	µg/l	0.030
Perfluoropentanoic acid	PFPeA	µg/l	0.063
Perfluoropentanesulfonic acid	PFPS	µg/l	0.033
Perfluorotridecanoic acid	PFTTrDA	µg/l	0.000
Perfluoroundecanoic acid	PFUDA	µg/l	0.000
Perfluorotridecanesulfonic acid	PFTTrDS	µg/l	0.000
Perfluoroundecanesulfonic acid	PFTUdS	µg/l	0.000

Sum parameters

PFAS 20 = 0.622 µg/l

PFAS 4 = 0.248 µg/l

German limit values (DW)

- PFAS 20: 0.1 µg/l (2026)
- PFAS 4: 0.02 µg/l (2028)

Main substances:

- PFHxA and PFHxS: ca. 55%
- PFPeA: ca. 10%
- PFOS and PFOA: ca. 11%

REMOVAL OF PFAS FROM GROUNDWATER WITH GAC

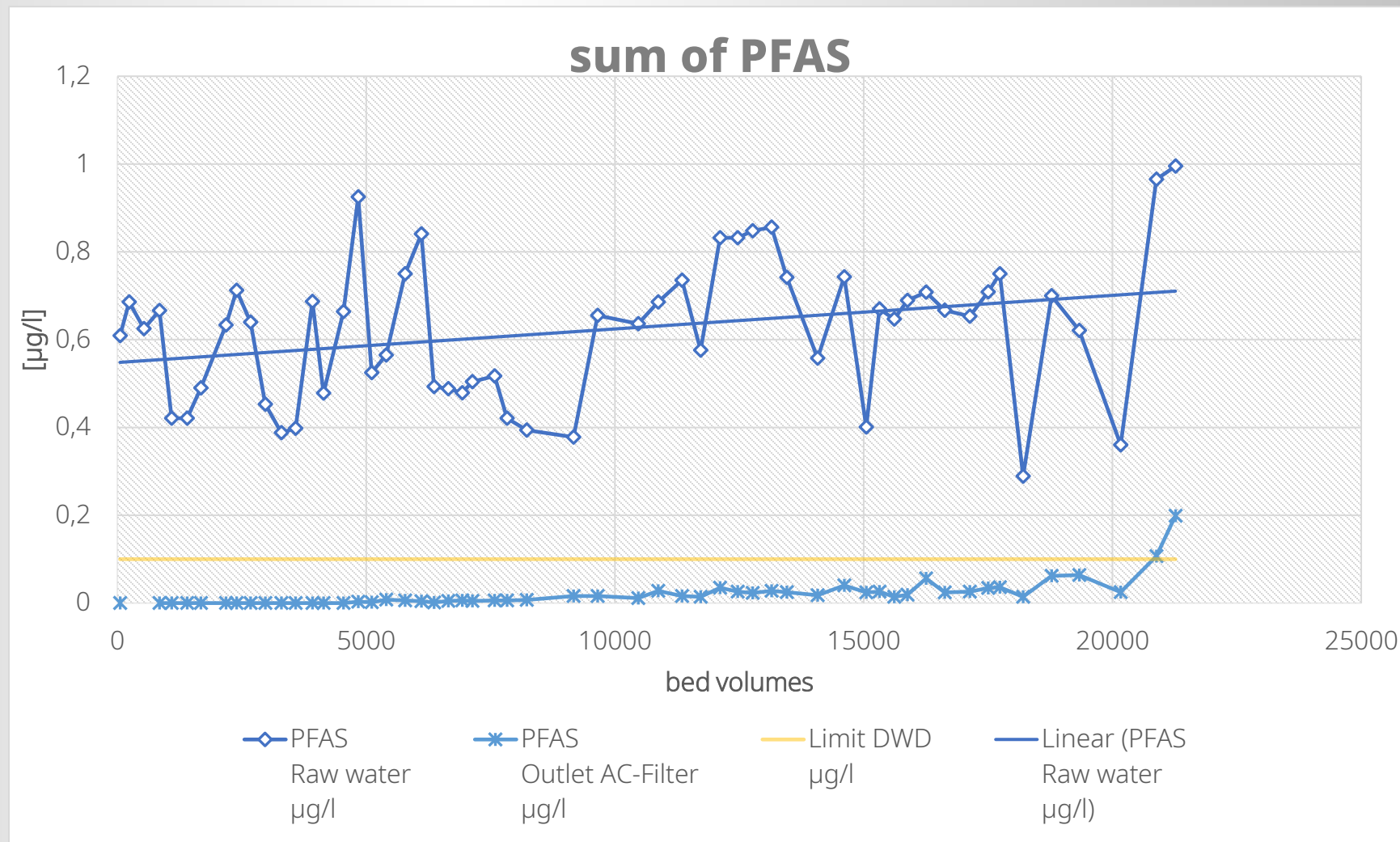
Mean concentrations

PFAS 20 = 0.622 µg/l

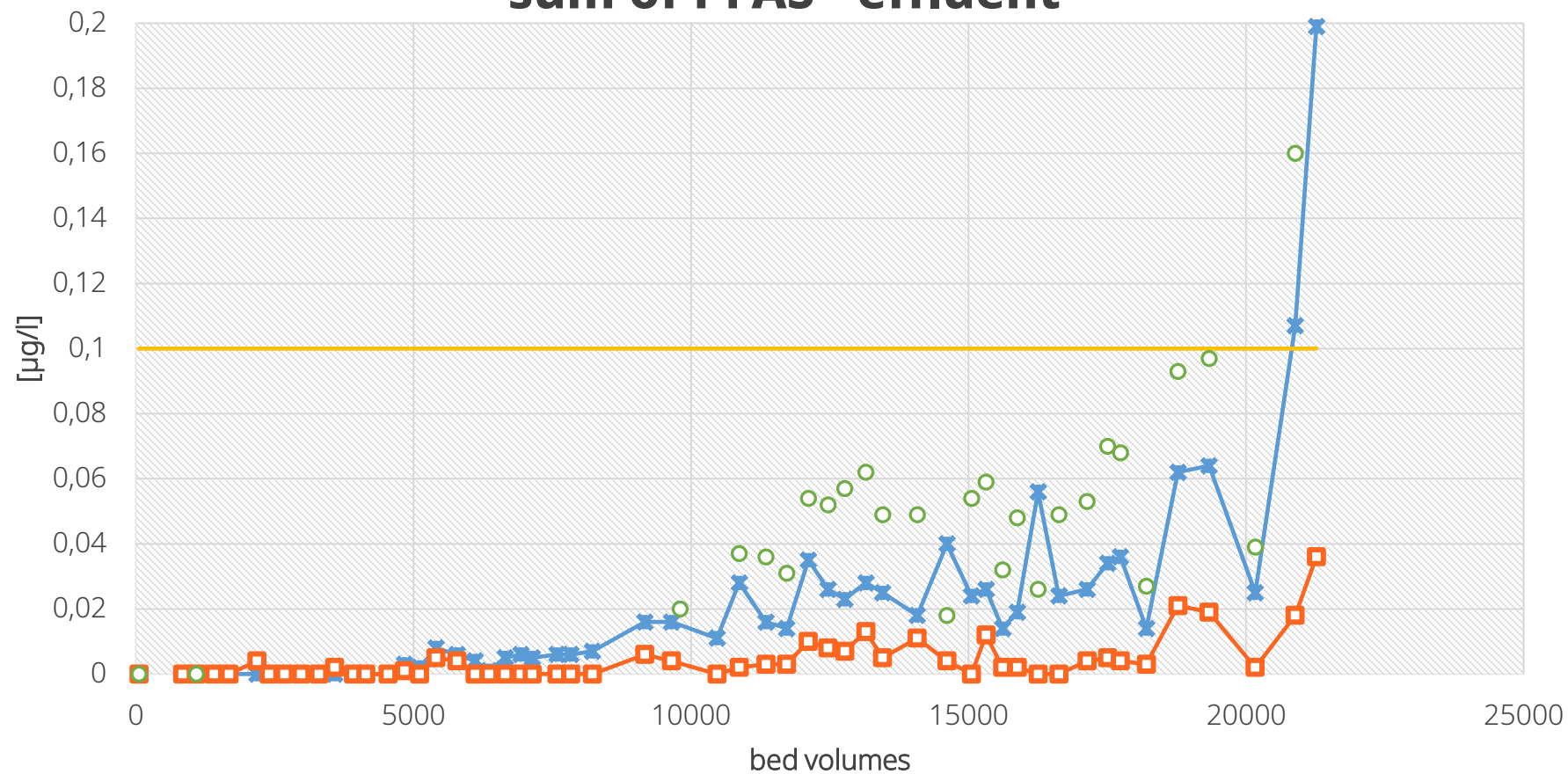
PFAS 4 = 0.248 µg/l

Main substances

- PFHxA and PFHxS: ca. 55%
- PFPeA: ca. 10%
- PFOS and PFOA: ca. 11%
- PFBA: 4.5%
- Others: 19.5%



sum of PFAS - effluent



Legend

- Outlet AC-Filter: effluent of 6 GAC filters in parallel
- Waterwork: mix of GAC filtration step and clean wells
- Outlet F2: effluent of Filter 2 (lead filter)
- Limit DWD: Sum of PFAS 20 EU Drinking Water Directive

PFAS
 Outlet AC-Filter
 µg/l

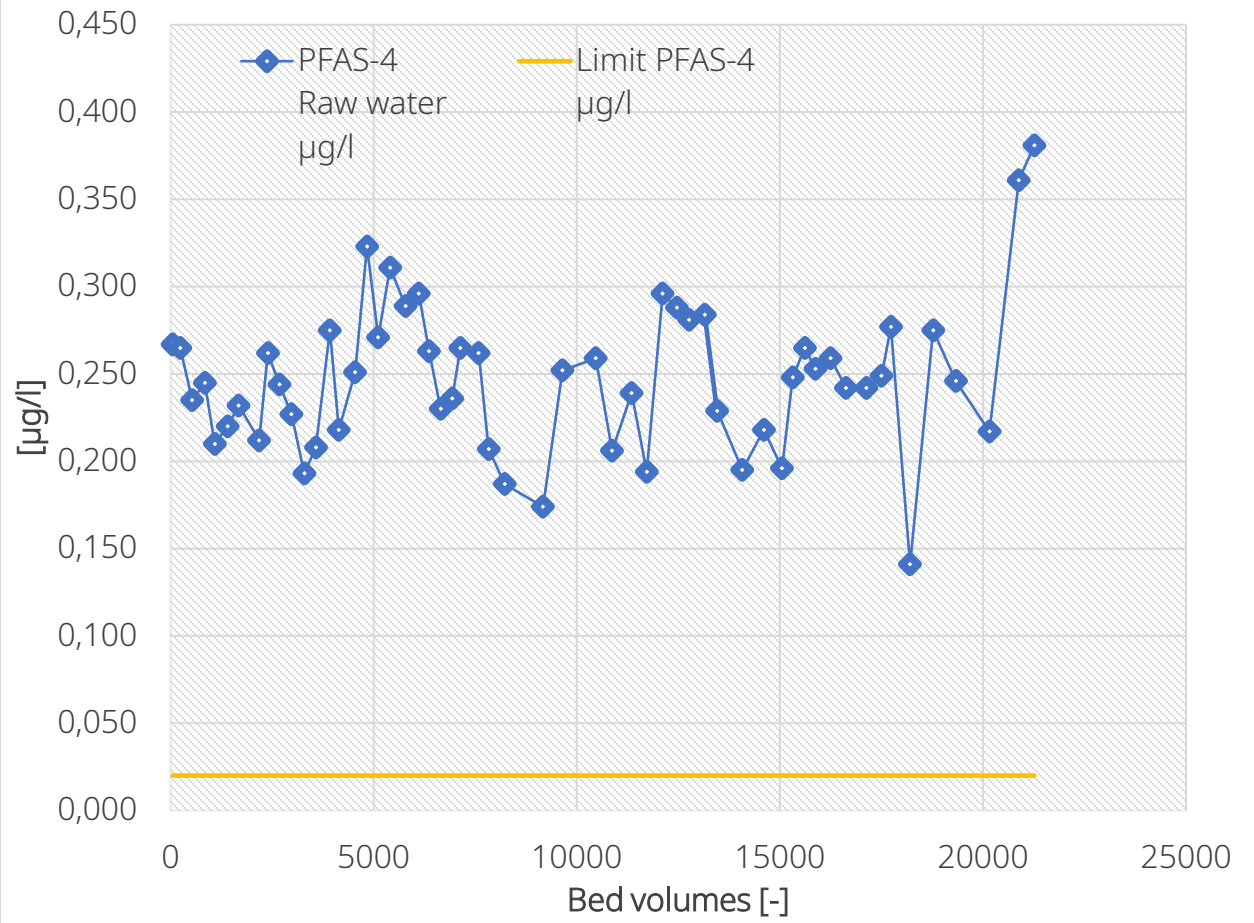
PFAS
 Outlet Waterwork
 µg/l

Limit DWD
 µg/l

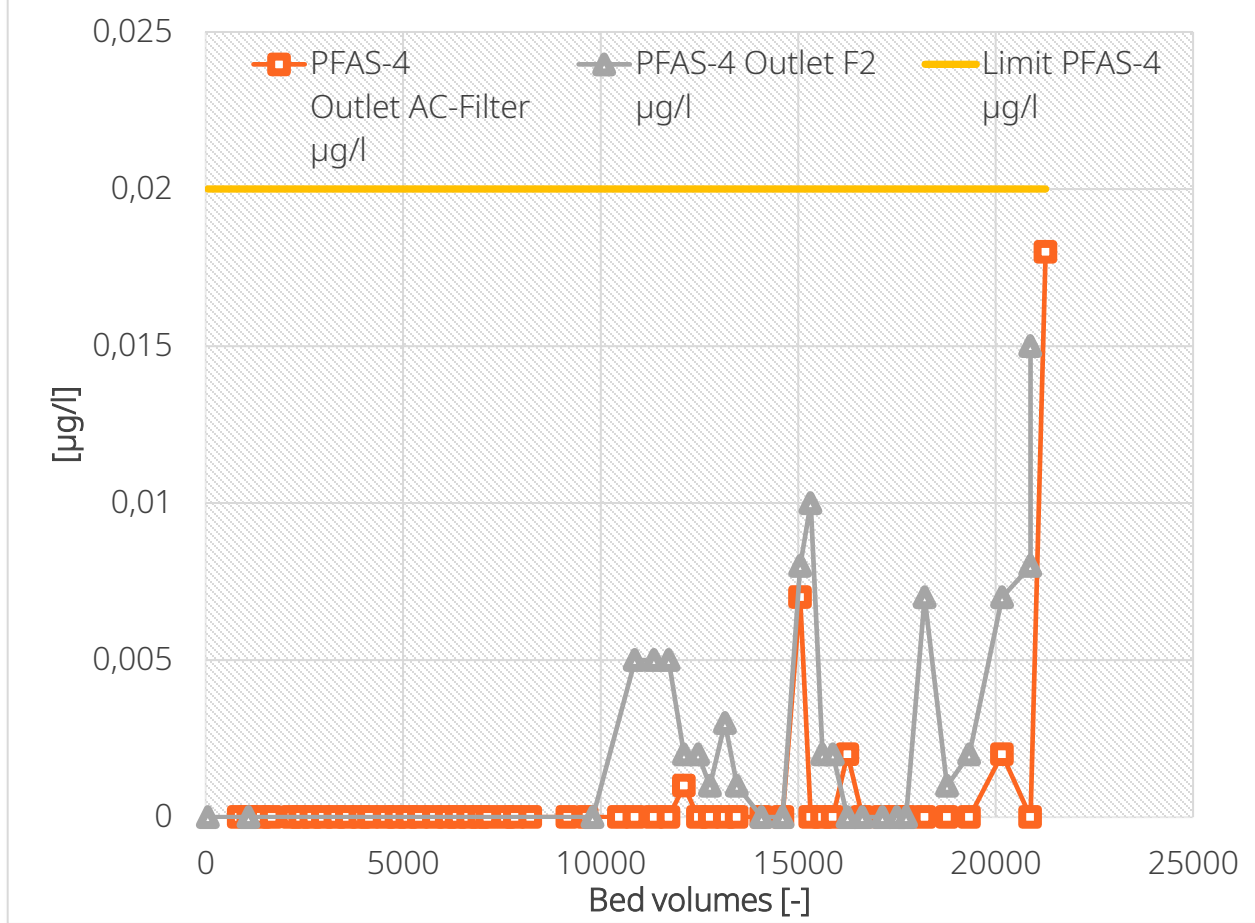
PFAS
 Outlet F2
 µg/l



Sum of PFAS 4 Raw water



Sum of PFAS 4 effluent



Sum of PFAS 4

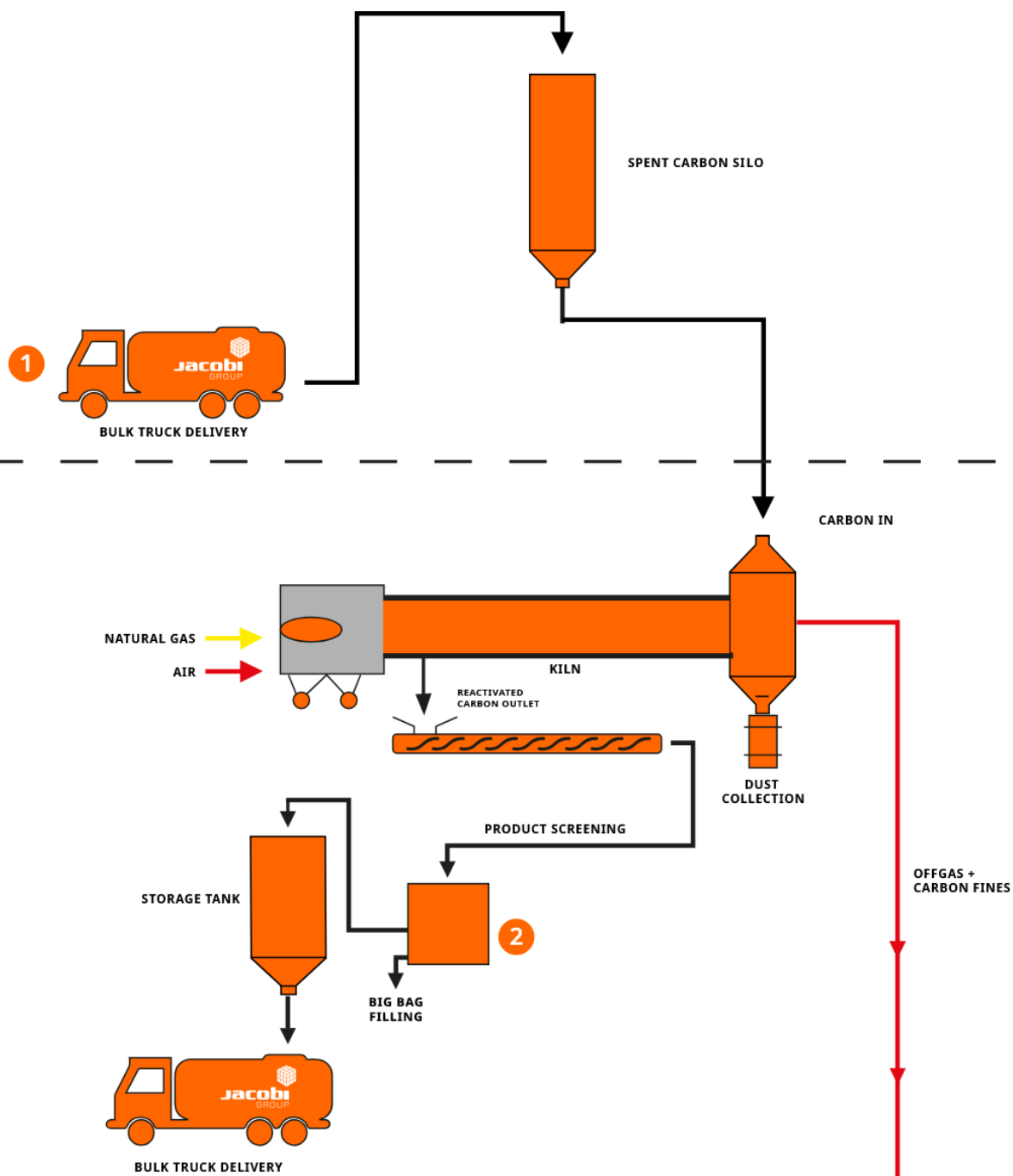
- Sum of PFHxS, PFNA, PFOA, PFOS
- Limit German Drinking Water Ordinance (2028): 20 ng/l
- Recommended limit EFSA (European Food Safety Authority): 2 ng/l






Reactivation of PFAS contaminated GAC

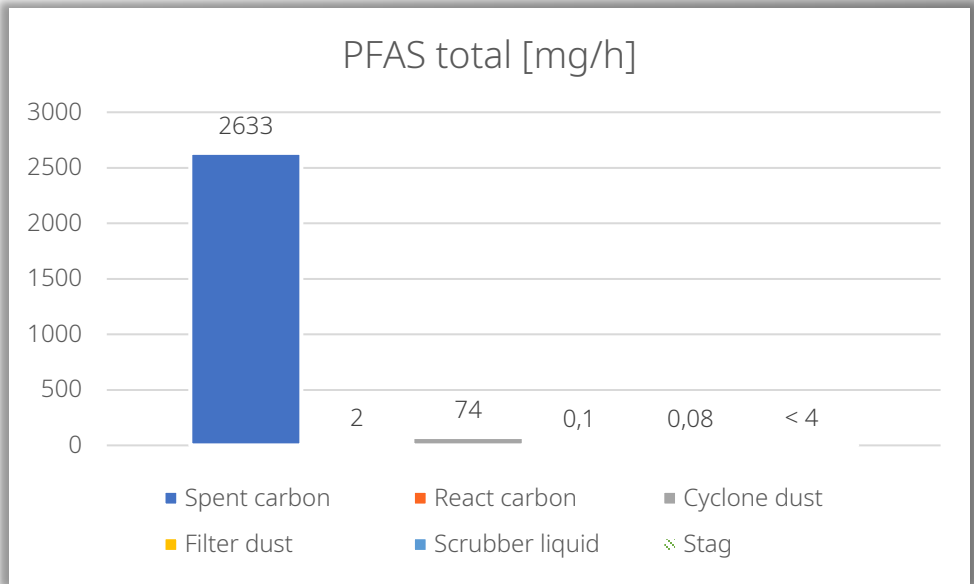
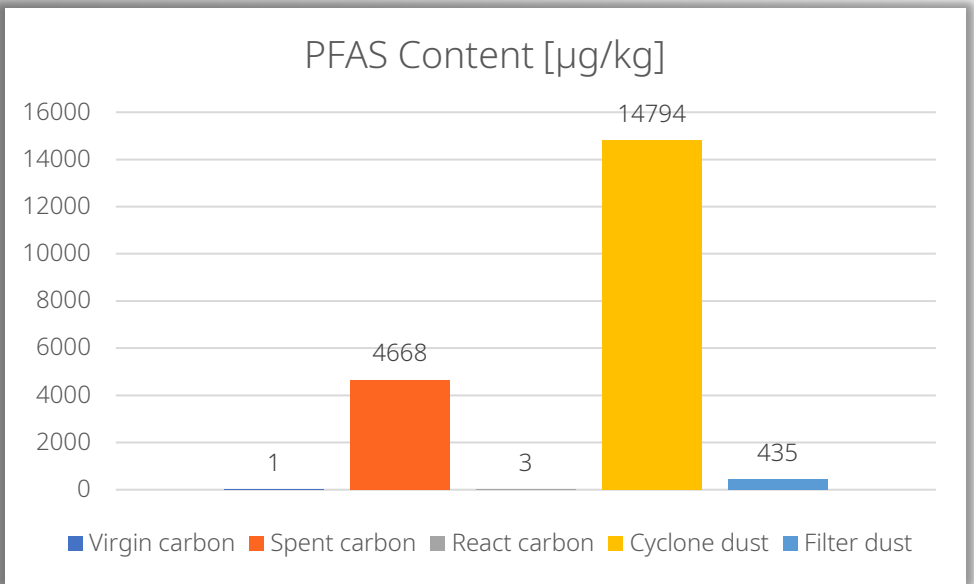
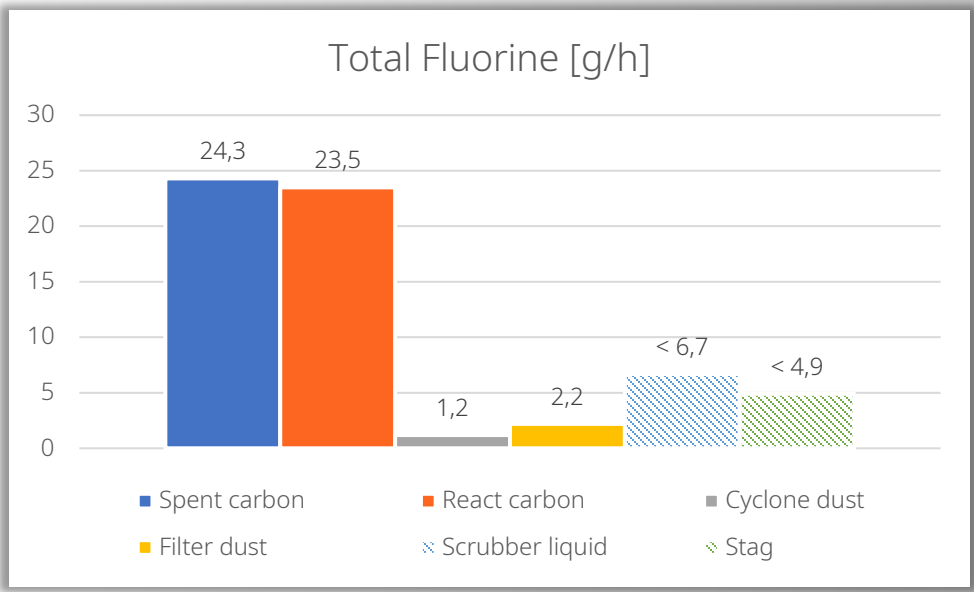
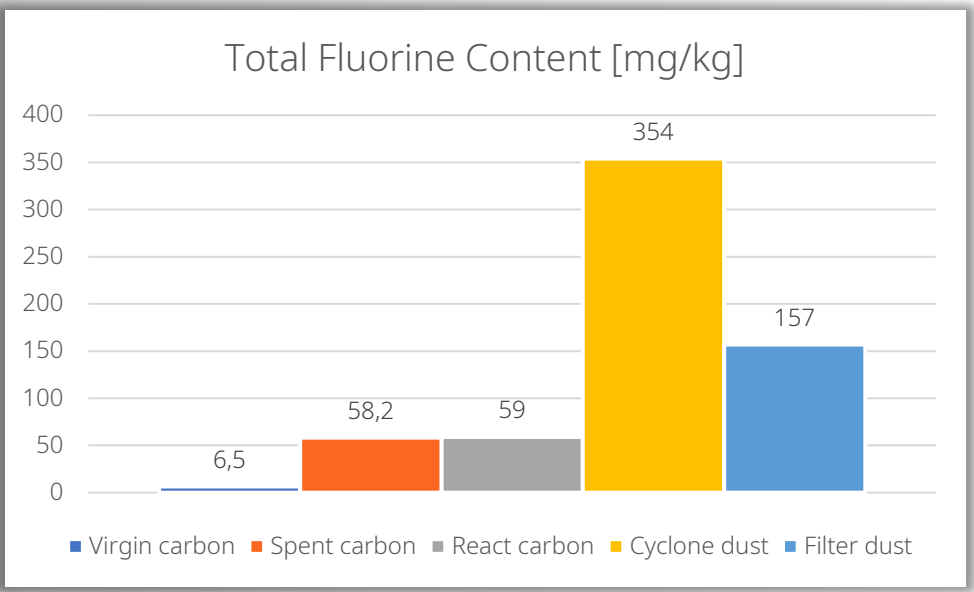
2023 Premnitz, Germany

Test methods

- PFAS in **solution**: DIN 38407-42:2011 (HPLC-MS/MS); 32 substances (PFAS32); measured in external lab. TÜV Rheinland and TZW
- PFAS in **activated carbon**: proprietary lab test method for extraction (boiling in methanol) in combination with DIN 38407-42:2011; 32 substances (PFAS32); measured at TÜV Rheinland
- Total fluorine of **activated carbon** (AOF and inorganic fluorides): proprietary lab test method for use in combination with CIC (combustion ion chromatography); TÜV Rheinland and TZW
- HF in **gas stream**: proprietary lab test method in accordance with DIN EN 1911:2010; measured at TÜV Rheinland
- PFAS and AOF in **gas stream**: DIN CEN/TS 13649*DIN SPEC 33969:2015 for adsorption and release and DIN 38407-42:2011 for analysis of PFAS and CIC for analysis of total fluorine; measured in external lab, TÜV Rheinland.



1	SPENT CARBON		CARBON
2	REACTIVATED CARBON		GAS
3	CYCLONE DUST (POWDER AC)		WATER
4	VENTURI WASHER (LIQUID)		WASTE WATER
5	ROTATION WASHER (LIQUID)		NATURAL GAS
6	OUTLET STACK (EXHAUST GAS + LIQUID)		



- Mean values based on minimum of 3 samples
- Repeated reactivation tests showed no PFAS on reactivated carbon
- Theoretical amount of adsorbed PFAS based on water samples: 26.5 mg/kg

Literature review

- Decomposition with increasing temperatures:
- PFCA → PFSA
 - C4 → C8

temperature (°C)	perfluoroalkyl carboxylic acids (PFCA)		perfluoroalkyl sulfonic acids (PFSA)		GAC properties	
	decomposition	defluorination	decomposition	defluorination	surface area recovery	micropore recovery
175	high	-	low	-	-	-
200	high	-	low	-	-	-
300	high	-	-	-	low	low
400	high	-	-	-	low	-
500	high	-	high	-	-	moderate
600	high	-	-	-	moderate	moderate to high
700	high	moderate	-	moderate to high	moderate to high	moderate to high
800	-	moderate to high	-	high	high	high
900	-	moderate to high	-	high	moderate to high	high
1000	-	high	-	high	moderate to high	high
1200	-	-	-	-	moderate to high	high

Reactivation temperature

^{22-24,27-29,101-103,105} "The ranges in the above table are as follows: very low, < 20%; low, 20–40%; moderate, 40–60%; moderate to high, 60–80%; and high, 80–100%. Dash = No data.

Conclusion

- No PFAS detected on reactivated carbon
→ most relevant information for customers that purify drinking water
- We have an official permit at our German site for the reactivation of PFAS loaded GAC from drinking water and industrial applications.



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