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Foam fractionation for efficient PFAS treatment

Frédéric Bossert

Hans-Georg Edel

Züblin Umwelttechnik GmbH
Germany · France · Switzerland · Italy
www.zueblin-umwelttechnik.com

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WORK ON PROGRESS

Our PFAS treatment plants for water

- Efficient and cost-effective
- More than 70 plants in Germany, France, Italy and Switzerland

Former refinery, groundwater

Soil washing, process water

Stuttgart Airport, groundwater

Sprinkler system, extinguishing water

Drinking water protection area, groundwater

Agriculture, groundwater

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Our PFAS treatment plants for water (selection)

Year	Project	Medium	Technology	Flowrate
2024-2025	Nürnberg, airport	groundwater	**FF** , GAC	2 m³/h
2024	Northern Germany, airport	extinguishing water	GAC	4 m³/h
2024	Katterbach (Ansbach),military site	groundwater	**IEX** / GAC-IEX	7,2 m³/h
since 2023	CH-Collombey, former refinery	groundwater	GAC	180 m³/h
06/2023	Augsburg, pilot test	leachate	**FF**, GAC	1,5 m³/h
05/2023	Hechingen, industry	extinguishing water	GAC	2 m³/h
since 2023	Region Düsseldorf, chem. industry	groundwater	SF, GAC	150 m³/h
2022	F-Haute Savoie, industry	groundwater	GAC	0,15 m³/h
since 2022	Northern Germany, soil washing	soil, process water	pretreatment, GAC	200 m³/h
since 2022	Berlin, water work	groundwater	SF, GAC	150 m³/h
since 2022	Rheinmünster, agriculture	groundwater → Irrigation	GAC	2 m³/h
since 2022	Bayern, pilot test/concept	leachate	pretreatment, GAC	0,15 m³/h
since 2022	Coburg, pilot test/concept	leachate	pretreatment, GAC	1 m³/h
since 2022	CH-Monthey, chemical industry	groundwater	GAC	50 m³/h
since 2022	Bremen, airport	groundwater	SF, GAC	14 m³/h
since 2021	Röthenbach, industry	groundwater	GAC	50 m³/h
since 2021	Sinzheim, stadium	groundwater → Irrigation	GAC	8 m³/h
since 2020	I-Spinetta, chemical industry	groundwater	GAC	40 m³/h
since 2020	Nürnberg, airport	groundwater	GAC	25 m³/h
since 2020	BW, vehicle manufacturer	groundwater	GAC	30 m³/h
2019 - 2021	Baden-Baden, F+E agriculture	groundwater → Irrigation	GAC	12 m³/h
2018 - 2021	Ingolstadt, soil washing	soil, process water	pretreatment, GAC	200 m³/h
since 2018	Ingolstadt, former refinery	groundwater	SF, GAC	210 m³/h
since 2016	Stuttgart, airport	groundwater	GAC	5 m³/h
since 2015	Rastatt, tunnel South	construction water	pretreatment, GAC	200 m³/h
2015	Frankfurt, airport	extinguishing water	GAC	1 m³/h
since 2014	NRW, chemical industry	groundwater	GAC	70 m³/h
since 2013	Lower Saxony, refinery	groundwater	GAC	5 m³/h
since 2010	NRW, Chem. industry	groundwater	GAC, 3-stage	360 m³/h

Treatment methods, relevant to practice

- Activated carbon adsorption (GAC)
- Ion exchange (IEX)
- **Foam fractionation (FF)**
- Membrane process

Aqueous media

- Groundwater
- Leachate
- Extinguishing water
- Process water

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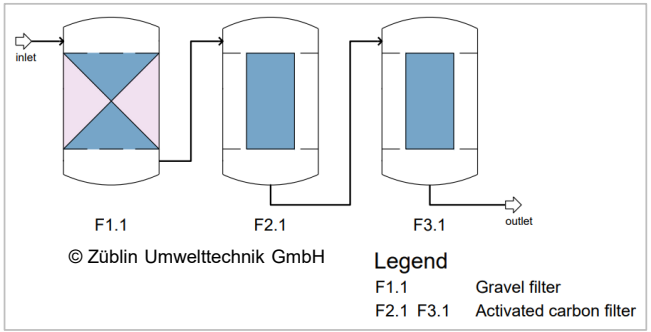
Basic technology - GAC adsorption



- GAC filter, two-stage (multi-stage)
  → Working filter / police filter
  Gravel filter for pre-treatment
- Granulated activated carbon (GAC)
  PFAS optima® (own brand Züblin UT)
  reactivatable
- PFAS loading 0.1 - 0.01 % by weight
- Competition for adsorption sites
  DOC (ppm) >>> PFAS (ppb)
- Filtrate quality:
  < 1 ng/l (!) per individual compound possible,
  also for short-chain PFAS (e.g. PFBA)

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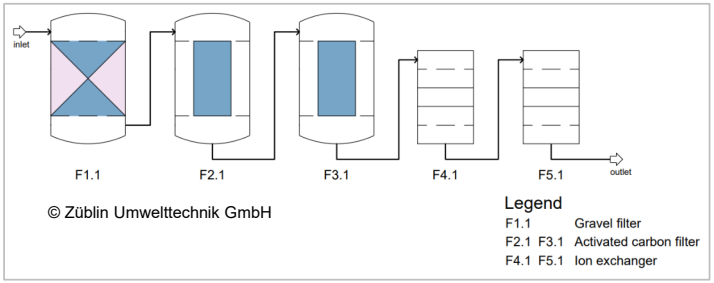
Combination - GAC adsorption + ion exchange



- Combination GAC filter and IEX
- Anion exchanger, usually single use resin
- Competition for IEX spaces
  - anions (ppm) >>> PFAS (ppb)
- Loaded IEX only partially regenerable
  → Disposal in HT incineration
- Efficiency
  GAC: long-chain > short-chain PFAS
  IEX: short-chain > long-chain PFAS

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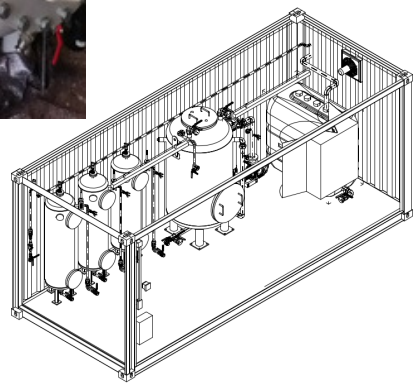
Case study IEX - US Army, Germany



Measure
- Hydraulic barrier

Pollutant
- PFAS (PFOS, PFHxS > H4PFOS > PFHxA)

Flow rate
- Ø 1,3 m^3/h

Process
- Ion exchanger (3 x 150 l)
- GAC filter (1 x 1 m^3) – Standby

Operation (status 01.05.2025)
- since 10/2024 (approx. 7 months)
  IAT resin: changes (6 x 150 l)

Discharge limit (cleaning performance) [µg/l]
- ∑ $PFAS_{13}$: ≤ 0,2 (≤ 0,01)
- PFOS : ≤ 0,02 (≤ 0,01)

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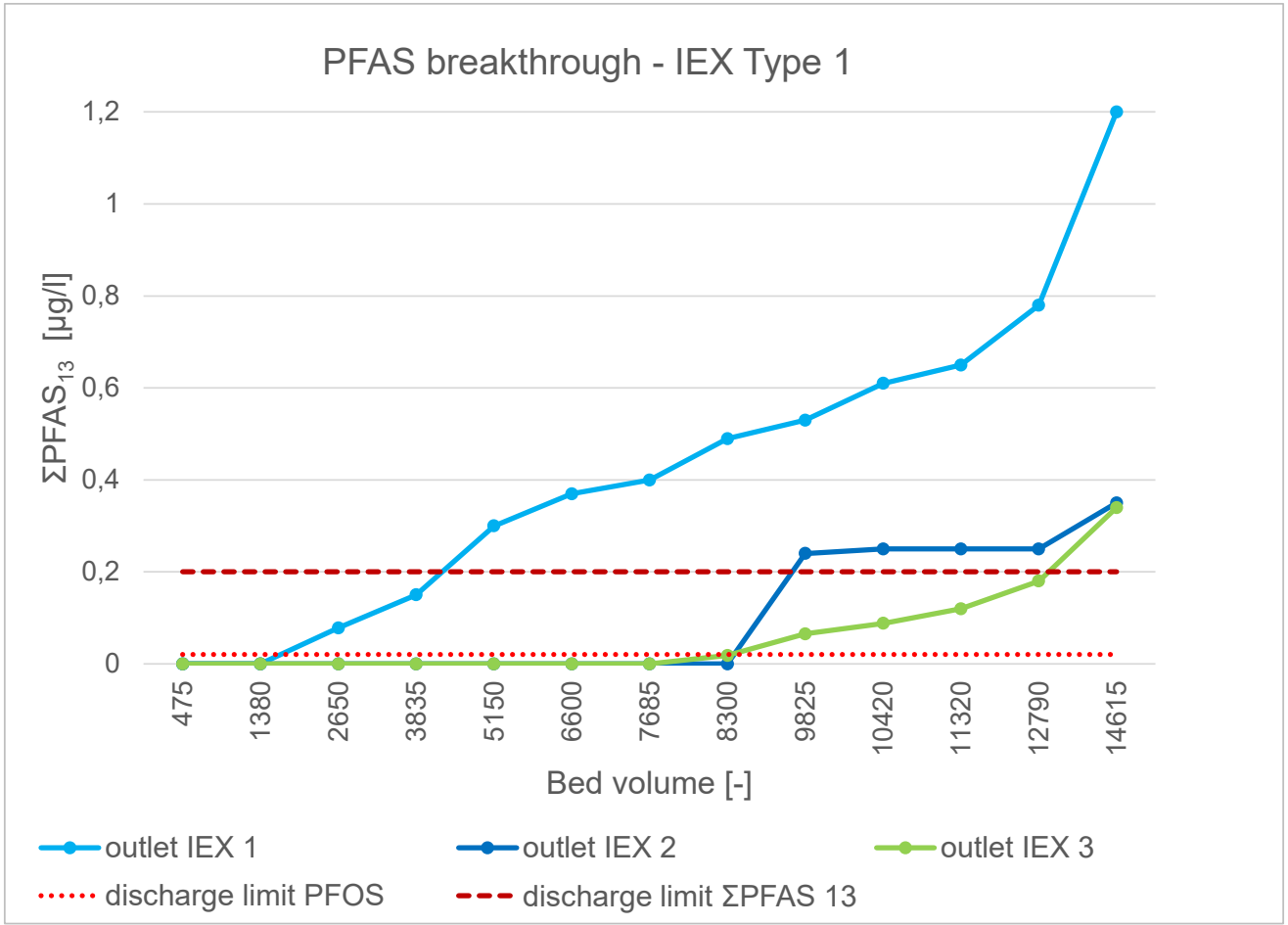
Ion exchanger - results



Verbindung	c [µg/l]	Anteil [%]
PFBA	0,26	1,1
PFBS	0,6	2,5
PFPeA	0,85	3,5
PFHxA	1,5	6,3
PFHxS	**9,0**	**37,5**
PFHpA	0,35	1,5
PFHpS	0,35	1,5
PFOA	0,8	3,33
H4PFOS	2,2	9,2
PFOS	**8,0**	**33,3**
PFOSA	0,0	0
PFNA	0,5	2,0
PFDA	0,0	0
Σ $PFAS_{13}$	**24,0**	**100**

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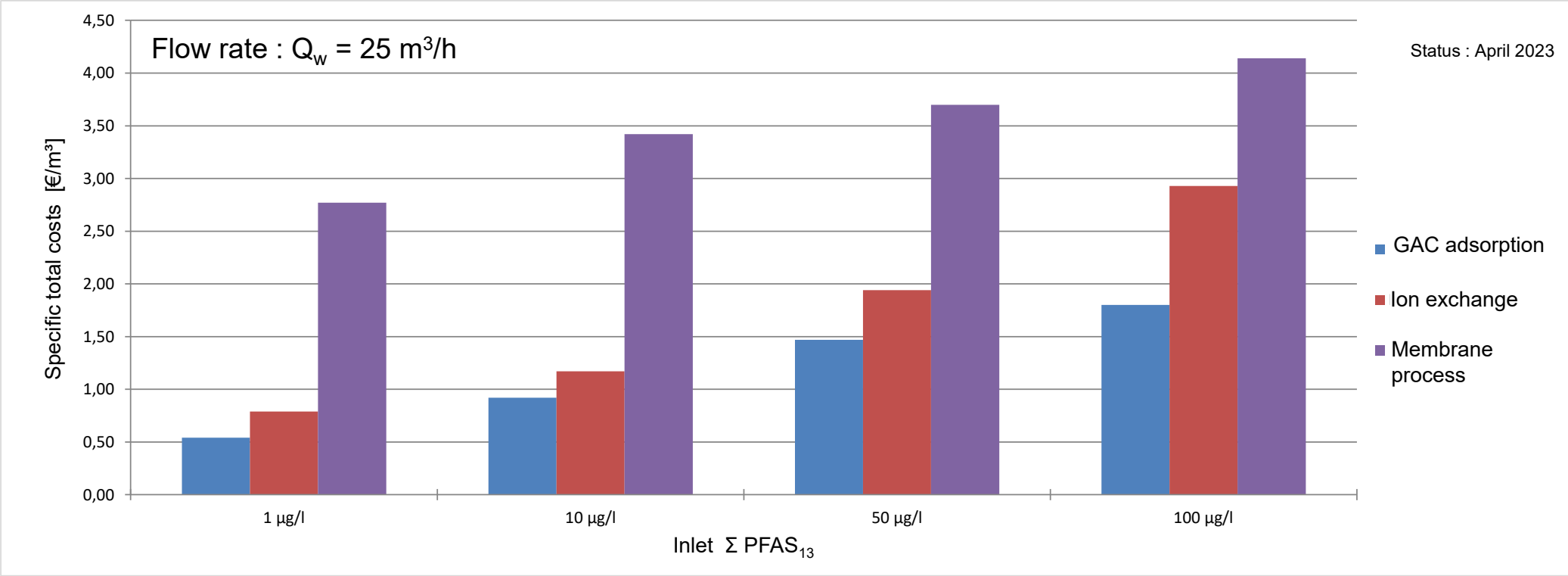
Treatment methods - specific total costs*



* Plant engineering (provision, maintenance, repairs, servicing, monitoring), electrical energy, operating equipment incl. reactivation and disposal

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PFAS - Foam fractionation

Foam fractionation - basics

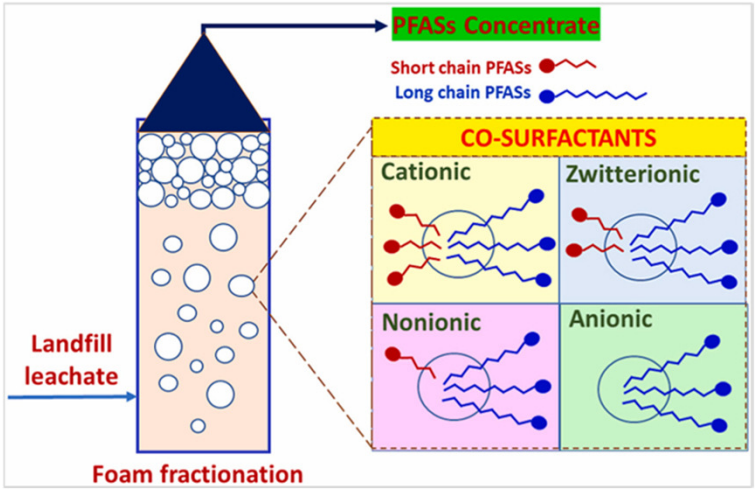
Foam fractionation

- First patent in 1918, Wilhelm Ostwald
- Adsorption of surface-active compounds on the hydrophobic surface of gas bubbles

→ Separation of the foam, removal of the surfactants

Application

- Protein separation
- Fish farming
- PFAS removal



Source: Vo P et al. (2023)

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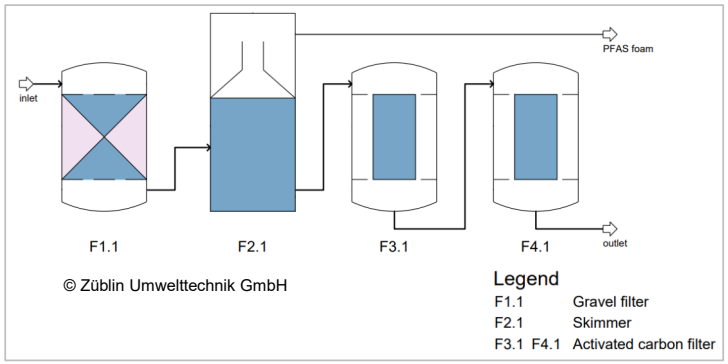
Laboratory and pilot tests



- Chwalek C (2022) Masterthesis HS Reutlingen/Züblin
- Hermann T (2023) Bachelorthesis HS Esslingen/Züblin
- Rösner S (2024) Bachelorthesis HS Heilbronn/Züblin
- Mayer J-E (2025) Masterthesis HS Esslingen/Züblin

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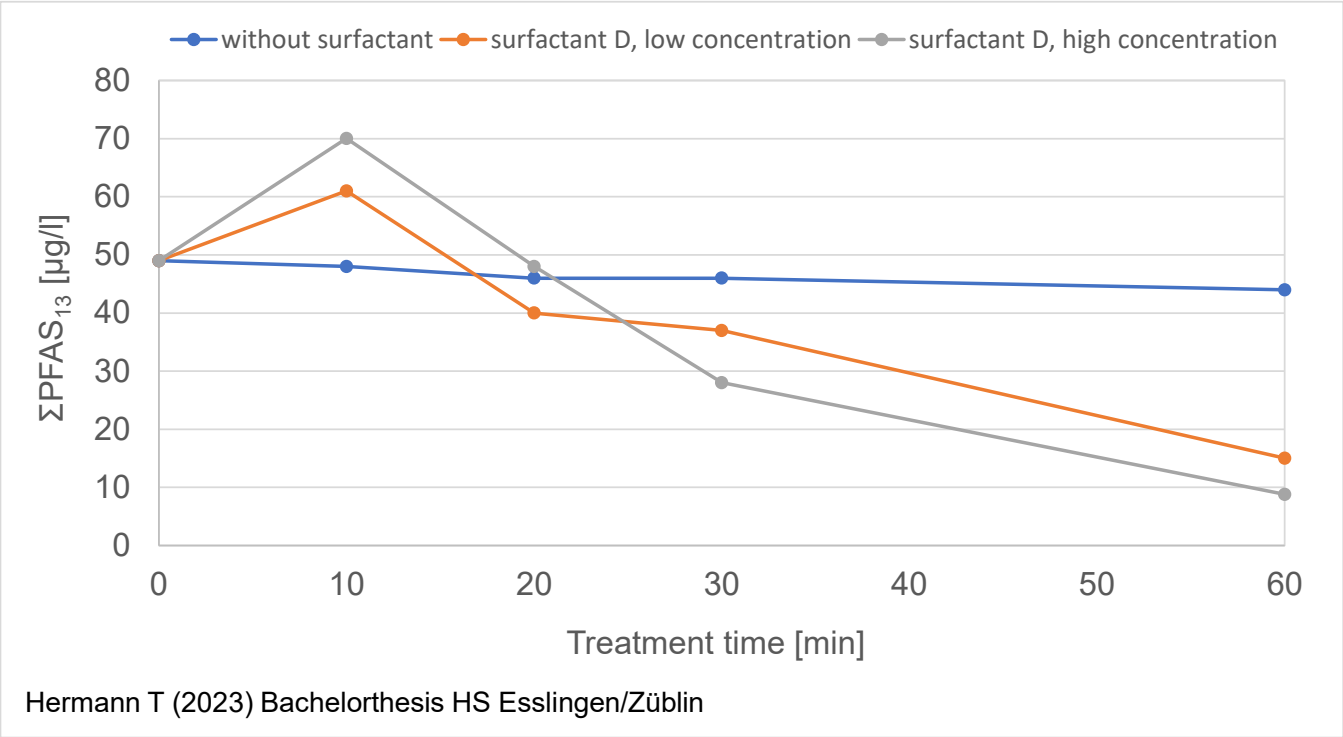
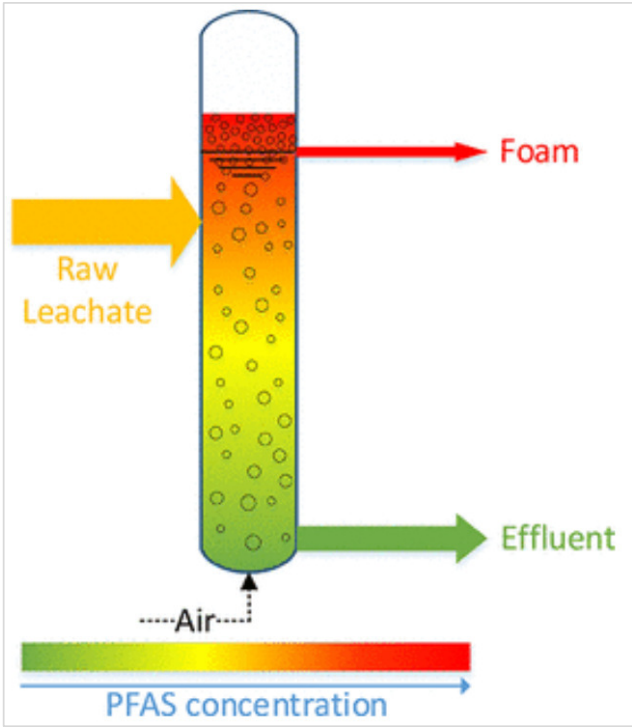
Foam fractionation - leachate



Hermann T (2023) Bachelorthesis HS Esslingen/Züblin



Source: Smith SJ et al. (2022)

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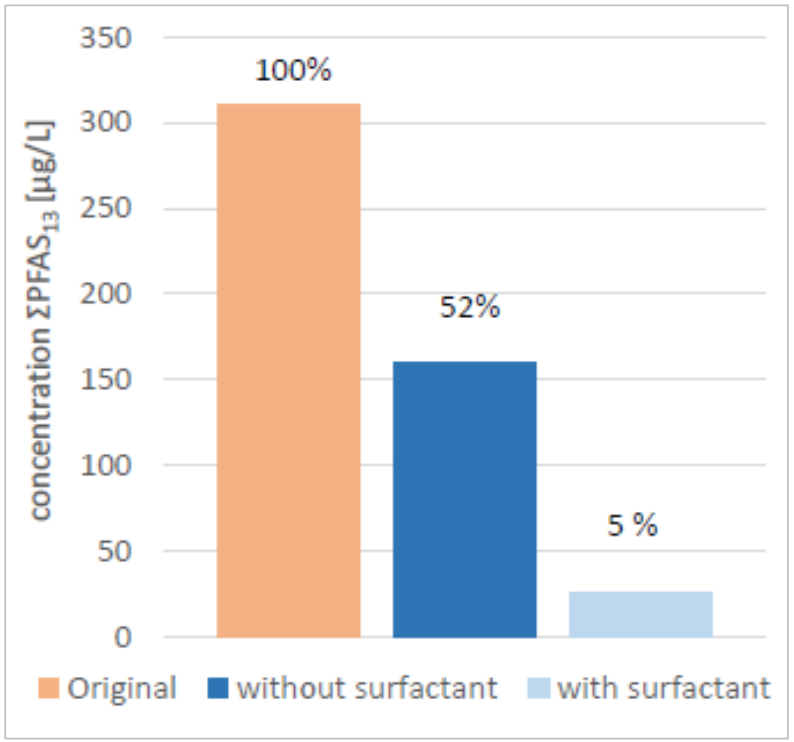
Foam fractionation - extinguishing water

Sprinkler system - foam fractionation unit



Foam fractionation - treatment performance

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Case study GAC / FF - Nuremberg Airport

Measure
- Hydraulic barrier

Pollutant
- PFAS (PFOS, PFHxS > PFHxA, PFPeS)

Flow rate
- ~ 20 m^3/h

Verfahren
- GAC filter (2 x 15 m^3)
- Foam fractionation (Pilot test)

Operation (state 01.05.2025)
- since 09/2020 (ca. 56 months)
- GAC : changes (3 x 15 m^3)

Discharge limit (cleaning performance) [µg/l]
- $\sum PFAS_{13}$: ≤ 0,2 (≤ 0,01)
- PFOS : ≤ 0,02 (≤ 0,01)

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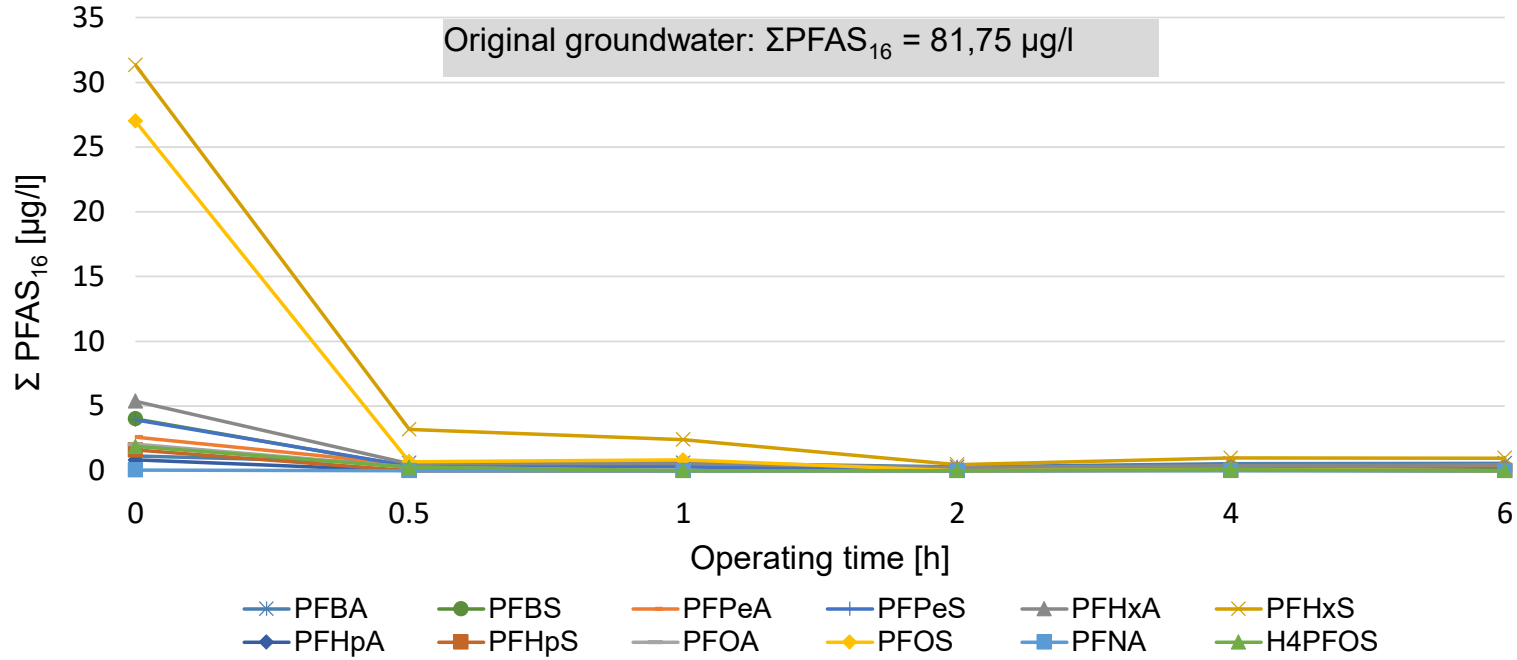
Foam fractionation - groundwater



Rösner S (2024) Bachelorthesis HS Heilbronn/Züblin

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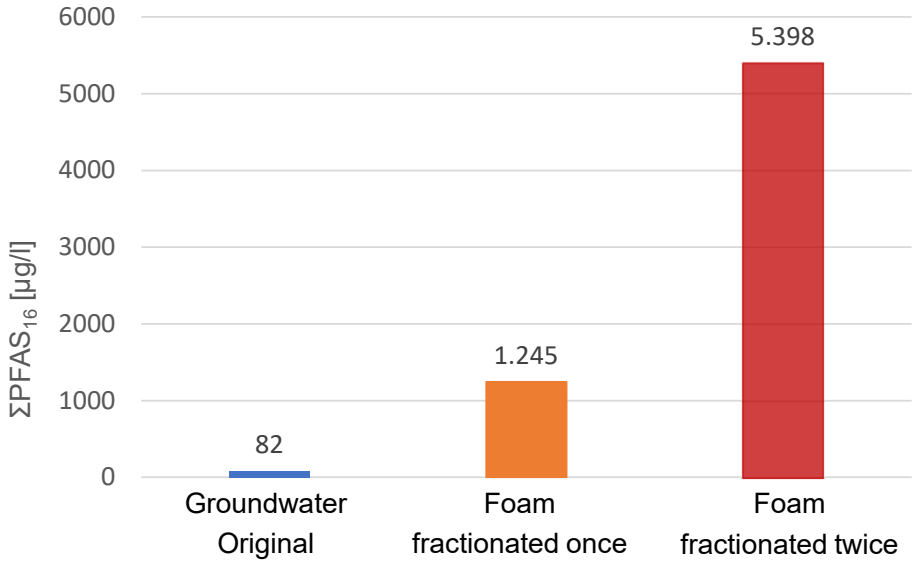
Foam fractionation - groundwater



Rösner S (2024) Bachelorthesis HS Heilbronn/Züblin

Enrichment factor		
Groundwater Original	Foam fractionated once	Foam fractionated twice
1	15	66

Volume		
Groundwater Original	Foam fractionated once	Foam fractionated twice
100%	24%	2.9%

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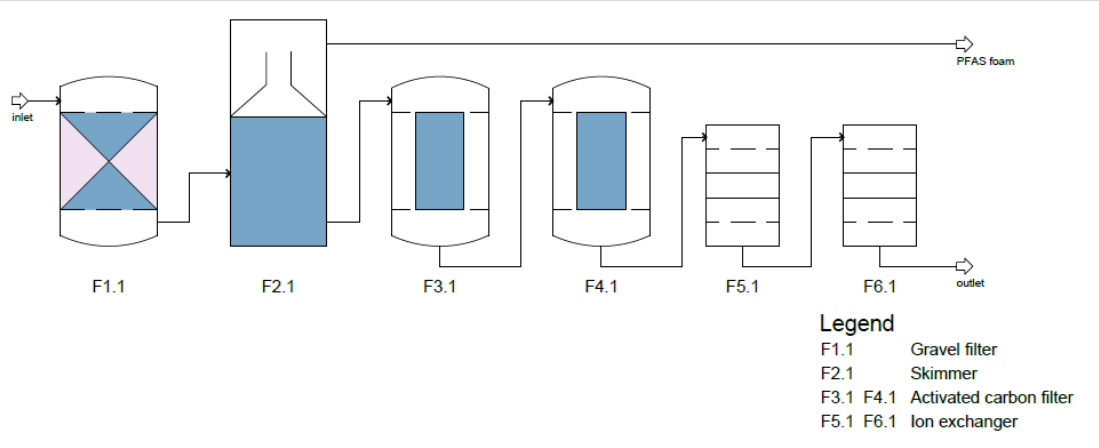
Combined treatment procedure



Foam fractionation

- high PFAS concentrations → reduction of PFAS load

Activated carbon adsorption

- low PFAS concentrations → polishing

Ion exchange (option)

- low PFAS concentrations, short-chain PFAS → polishing

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Summary and outlook

PFAS foam fractionation

- Suitable and reliable method for removing high PFAS concentrations
- Application for aqueous media
  - leachate
  - groundwater
  - extinguishing water
  - process water
- Combination with GAC adsorption and/or IEX
  - economical operation
  - low target values in the nanogram range

→ Ongoing research/development leads to further advances in PFAS treatment technologies

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Any questions ?

Thank you for your attention !

Frédéric Bossert
Phone +33 3 8868-7991
E-Mail: frederic.bossert@zueblin.de

Dr. Hans-Georg Edel
Phone +49 7145 9324-249
E-Mail: hans-georg.edel@zueblin.de

www.zueblin-umwelttechnik.com/fr