SAFF – Surface Active Foam Fractionation

Envytech offers the SAFF - Surface Active Foam Fractionation technology, created by OPEC systems. The first sustainable treatment method for PFAS-contaminated water. SAFF does not use filter materials, only air and electricity, and is completely unaffected by other pollutants such as metals or organic substances, particles, pH, nutrients or other water chemistry.

Figure 1: Photo of a SAFF40 treatment plant

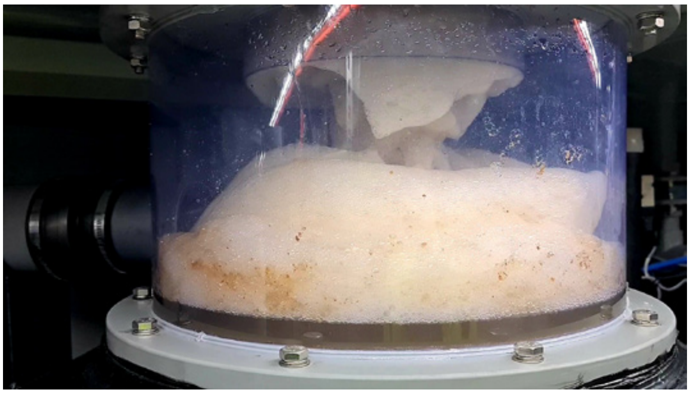

Figure 2: Photo taken during the first fractionation step in a full-scale plant. Here we see the "flow over weir" approach in the primary vessel. You can also see the foam that accumulates during the separation and the top section where the less foaming PFAS substances accumulate.

SO HOW DOES SAFF WORK?

The SAFF process utilizes the physio-chemical properties of PFAS compounds to attach to fine air bubbles as a result of its hydrophobic and hydrophilic properties. When accurately controlled bubbles are introduced and allowed to rise in a narrow column of water, the bubbles become exceptionally effective in collecting PFAS compounds that are loosely bound to the water molecules. Once at the surface, PFAS can easily be removed by separation and concentration through a passive "spill over weir" system, and an active vacuum system. Treated (aerated) water can then be released to the recipient. The collected PFAS concentrate is passed on to further fractionation steps to become a high concentration liquid of relatively small volume suitable for destruction via permanent destruction techniques such as high temperature thermal combustion, Super Critical Water Oxidation (SCWO) or Electrochemical Oxidation (EO).

The system has significant advantages compared to all other technologies on the market as the process is very robust. SAFF works without reduced effect, regardless if the water contains large amounts of suspended solids and contaminants of various kinds, including oil and biological substances. The system is not sensitive to high concentrations and is not pH sensitive. The system is not in need of any pre-treatment systems, but to minimize service work, water comprising larger suspended particles can advantageously pass via some form of separation e.g. a lamella separator.

The SAFF system works by accumulating the PFAS compounds at the top of the first treatment column where the first fractionation step takes place. When air is injected at the bottom of the column and rises in a created vortex, the PFASs attach to the bubbles and flow with them to the surface. Foam and water flow over a "weir design" at the top of the column (see figure 2) and therefore called "the wet cut", as both the created foam and the underlying water are removed. This underlying water is removed as PFAS stratifies at the top of the column as the shorter chain PFAS do not have the same foam potential as the longer chains.

Before the end of the first fractionation step, the water level in the column is raised, forcing the water in the top of the column to be collected, so that as much of the stratified PFAS substances as possible are included in step two. The first fractionation step increases the PFAS concentrations by about 10-fold.

In the second fractionation step, the same process takes place as in step 1, but as concentrations of PFAS are now around 10 times higher, a drier foam is obtained which is removed with vacuum. The vessel where the second fractionation step is performed is equipped with carefully calibrated sensors that control a vacuum pump and its distance to actual process foam levels. The hyperconcentrate generated by this process is led to a collection container where it is stored pending step 3. In this second fractionation step, the concentration is further increased by up to 1,500 times, which means that the total concentration increase is now around 10,000 times initial levels.

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Figure 3: Photo taken during the second fractionation step in a full-scale plant. The dry foam can be seen being removed by vacuum.

In the third fractionation step, which is performed in the same way as step 2, further concentration increases are obtained. The total increase in concentration obtained over the three steps is between 50,000 - 2,000,000 times initial concentrations in the untreated water. The hyperconcentrate waste volumes are therefore this same factor less than the processed feed water volume. Expected amounts of waste depend on the type of water that is treated, but from projects carried out we see that the expected amount of waste for landfill leachate are less than 1m^3 per 40,000m^3 of treated water, and for groundwater about 10 liters per 40,000m^3 of treated water.

The table (below) summarizes the concentration increases at each stage:

First stage:	**10 x initial concentration**
Second stage:	**1 500 x initial concentration**
Third stage:	**50–200 x initial concentration**
Possible total concentration:	**50 000–2 000 000 x initial concentration**

EXPECTED RESULTS

To date (Oct 2021), 3 full-scale projects comprising PFAS have been carried out with SAFF. OPEC Systems has treated PFAS-contaminated groundwater using a SAFF system for over 2,5 years at an active military air base in Australia where extensive fire drills have been carried out. In total, more than 60,000m^3 of water has been treated during this period, which has included drought times. Outgoing water has never exceeded the levels of Australia's drinking water guidelines. In Södertälje, Envytech is treating leachate from the Telge Landfill, and since February 2021, more than 90,000 m^3 of water has been treated down below treatment targets. Envytech is also treating leachate at the NSR landfill in Helsingborg where approx. 10,000 m^3 of water has been treated since August 2021.

All projects have been carried out without pre-treatment systems or filter materials. Treatment results using SAFF are similar regardless of which water is put through the system.

For summary of treatability, based on the PFAS-11 included in Swedish guide lines, see Table 1. Note that all results are obtained without pre-treatment, pH correction or other complementary measures. The waters include high BOD, COD and DOC levels, suspended solids, other pollutants, different pH and both high and low levels of PFAS. Something that the SAFF efficiency is not affected by.

Ämne (ng/l)	Längd kolkedja	Removal % Max
PFDA (Perflourdekansyra)	C10	100%
PFNA (Perflournonansyra)	C9	100%
6:2 FTS (Flourtelomer sulfonat)	C8	100%
PFOA (Perflouroktansyra)	C8	100%
PFOS (Perflouroktansulfonsyra)	C8	100%
PFHpA (Perflourheptansyra)	C7	67%
PFHxS (Perflourhexansulfonsyra)	C6	97%
PFHxA (Perflourhexansyra)	C6	20%
PFPeA (Perflourpentansyra)	C5	24%
PFBA (Perflourbutansyra)	C4	21%
PFBS (Perflourbutansulfonsyra)	C4	22%

Table 1: Table summarizing SAFF treatability of groundwater for PFAS substances included in the Swedish SLV Total PFAS-11. The table shows the maximum reduction obtained for each substance.

CAPACITY

The capacity of a 40-foot SAFF40, with the possibility of three fractionation steps and internal storage of hyperconcentrate, depends on the type of water you want to and treat and PFAS concentration blend. This is because different PFAS require different cycle times, and the water's potential to foam determines how much energy the pumps need to provide. From experience we see that a SAFF40 can treat leachate with a capacity of 20-40m^3/h subject to the water's tendency to foam, while for groundwater it is possible to treat about 40m^3/h with the same equipment and a focus only on PFAS substances with 6 carbon atoms or more (<C6). When treatment of shorter chain substances is required, longer batch treatment times may be needed, which results in reduced flow capacity. Envytech also offers SAFF20 systems with a maximum capacity of 20 m^3/h.

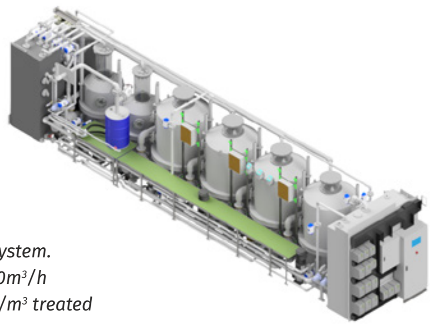

Figure 4: SAFF40-System.
Flow Rate: up to 40m^3/h
OPEX: 0,4–0,7 kWh/m^3 treated

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COST

The cost for treating water is usually made up of the following:

- **Mobilization**
- **cost SAFF system (Purchase OR Rental)**
- **Operating and service costs**

Below we present estimates for pricing for each step

Mobilization

Mobilization includes transport of equipment as well as deployment and commissioning of the treatment system. This can be carried out in 3–5 days at a cost of between 5,000 - 10,000Euro (subject to transport distance and local lifting costs)

Pre-treatment

As SAFF is an extremely robust technology that takes advantage of PFAS strong bonding ability to air, no pre-treatment is usually needed, but for water with larger suspended particles, a lamella separator or other particulate separation can be used to minimize the need for cleaning during operation. (An existing filtration system, if it exists on site could be utilized).

Operating and Service costs (OPEX)

An important cost to include in the calculations when comparing different treatment techniques is operating costs and the need for service work. The operating cost for SAFF20 and SAFF40 are between 0.4–0.7 kWh per treated cubic meter of water. As different PFASs require different cycle times, the costs vary per cubic meter.

For shorter chains, longer cycle times and more electricity are required. For the longer chains (C6 and above) shorter cycle times are needed, meaning that more water can be treated per kWh.

Costs for service work at a SAFF treatment plant are minimal. This is because all pumps, valves and sensors are connected to a digital monitoring and logging program where Envytech and OPEC can follow the plant's operating and power data. In the event that a fault is noted with a pump or valve, we immediately get informed and can rectify this, often through adjustments in the made remotely, or alternatively a site visit is arranged. Therefore, routine service visits can be less frequent, thus reducing the overall service costs.

The system is also easy to operate, a so-called "Plug and play" system, and we can train the client's own staff for ongoing supervision, operation and care, as required. Estimated service time is about 8 hours per month once commissioning & optimization periods are complete.
During service visits, the status of all pumps and valves are noted, and parts replaced if necessary.

All components are sourced from the agricultural / construction / processing industry and are available from regular spare part dealers, and care has been taken to use European specification parts. In the event that something breaks, this means it can be readily sourced locally; no wearing parts need to be specially adapted or specially ordered.

Case Study Telge

Client: Telge Återvinning

Location: Södertälje, Sweden

Type of water: Landfill Leachate

Pre-treatment: None

Treatment: SAFF40

Average flow: 20m³/h
120 000m³/year

Waste: <1m³/40 000m³
Treated

OPEX: 0,7 kWh/m³ treated
8h service/month

Substance	Ex of concentration untreated leachate	Ex of concentration treated leachate	Average Removal Rate 70 000 m³
PFDA (Perflourdekansyra)	2,4	1	66%
PFNA (Perflournonansyra)	54	1	98%
6:2 FTS (Flourtelomer sulfonat)	45	1	97%
PFOA (Perflouroktansyra)	510	1	100%
PFOS (Perflouroktansulfonsyra)	110	1	99%
PFHxS (Perflourhexansulfonsyra)	84	1	98%
PFHpA (Perflourheptansyra)	450	1,7	94%
PFHxA (Perflourhexansyra)	1100	340	50%
PFPeA (Perflourpentansyra)	590	460	13%
PFBA (Perflourbutansyra)	310	330	4%
PFBS (Perflourbutansulfonsyra)	170	97	98%
PFAS11	**3400**	**1200**	**57%**

Case Study NSR

Client: NSR Återvinning

Location: Helsingborg, Sweden

Type of water: Landfill Leachate

Pre-treatment: None

Treatment: SAFF40

Average flow: 10–20m³/h

Waste: <1m³/40 000m³
treated

OPEX: 0,7 kWh/m³ treated
8h service/month

Substance		NSR SAFF 002	NSR SAFF 002	NSR SAFF 002
		2021-10-07	2021-10-07	2021-10-07
		Treated volume: 200 m³	Treated volume: 200 m³	Treated volume: 200 m³
	Unit	IN	OUT	Removal Rate
PFDA	ng/l	10	1,0	90%
PFNA	ng/l	34	1,0	97%
6:2 FTS	ng/l	8800	9,5	100%
PFOA	ng/l	2400	2,6	100%
PFOS	ng/l	110	1,6	99%
PFHxS	ng/l	2200	2,8	100%
PFHpA	ng/l	6900	96	99%
PFHxA	ng/l	1100	510	54%
PFPeA	ng/l	520	650	0%
PFBA	ng/l	260	240	8%
PFBS	ng/l	210	120	43%
Sum PFAS SLV 11		**22 544**	**1634**	**93%**

Case Study Swedavia

Client: Swedavia

Location: Arlanda, Sweden

Type of water: Run off water

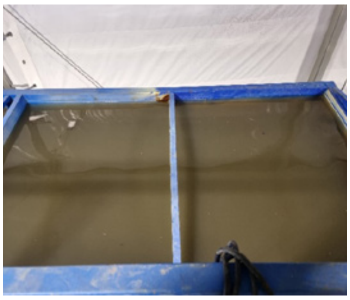
Pre-treatment: None

Treatment: SAFF40

Average flow: 35–40m³/h

Waste: <10 liter/50 000m³
treated

OPEX: 0,7 kWh/m³ treated
8h service/month



Substance	Unit	Untreated	Treated	Removal Rate %
PFDA	ng/l	0,67	<0,30	55%
PFNA	ng/l	3,7	0,62	83%
6:2 FTS	ng/l	<0,30	<0,30	0%
PFOA	ng/l	71	2	97%
PFOS	ng/l	650	2,2	100%
PFHxS	ng/l	38	8,4	78%
PFHpA	ng/l	220	2,1	99%
PFHxA	ng/l	210	80	62%
PFPeA	ng/l	190	130	32%
PFBA	ng/l	86	52	40%
PFBS	ng/l	22	27	0%
Sum PFAS (TOP)		**1491**	**304**	**80%**