Subcritical Water Oxidation of high TFA waste streams – a case study

PFAS is a present and known environmental problem. Currently the regulation of PFAS is a hot topic at the European chemicals agency (ECHA)[1]. Trifluoroacetic acid, TFA, is one of the smallest molecules containing persistent carbon-fluorine bonds. As of September 2025, TFA is included in the sum 25 PFAS by the European Council[2]. However, regulation cannot stand alone and at Aquarden Technologies we are committed to handling these tough wastewaters.

According to ECHA, TFA is manufactured and imported with more than 100-1000 tonnes per year into the EU and is primarily used in the chemical industry[3]. Many PFAS compounds and fluorine containing pesticides degrade into TFA with time adding to the environmental load. A poor regulation of TFA contributes to the growing pollution, so minimizing the release of TFA to the environment is of utmost importance[4].

At Aquarden we believe in dealing with the issues at the source. Aquarden conducted a case study of industrial process wastewater having high concentrations of TFA. The Aquarden SuperOx® system proved its capabilities in successfully destroying TFA without generating toxic by-products in the gaseous and liquid exit streams.

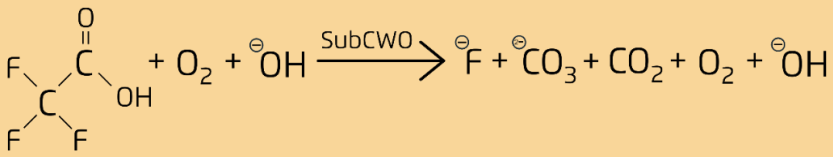
SuperOx® at Aquarden facilities in Denmark.

SuperOx® a solution to TFA wastewaters

Pressurizing and heating water will change its chemical and physical properties. The critical point of water is at a temperature of 374 °C and a pressure of 221 bar. When using subcritical water oxidation we are working below the critical temperature (i.e., < 374 °C) but keeping a high pressure (i.e., > 221 bar). This way we utilize the unique properties of water, where the solubility of salt is higher compared to that of ambient temperature and pressure.

Why do we need this high solubility?
We need high solubility to be able to treat waste streams with high salt concentration, while allowing for neutralization of the oxidation products.

What happens to the TFA in the SuperOx® system?
TFA oxidizes to more benign salts as seen on the reaction scheme below. The products in the exit stream consist of fluoride (F^-) and carbonate (CO_3^{2-}) salts, as well as excess base (OH^-) in the liquid phase. Where carbon dioxide (CO_2), excess oxygen (O_2), and water vapor (H_2O) is seen in the gaseous exit stream.



TFA Reaction Scheme in subcritical water oxidation. The reaction is unbalanced and highlights the primary reaction species.

Industrial wastewater with high TFA concentrations

Industrial wastewater from an undisclosed site with high concentrations of TFA was the inlet stream (also called *feed*) with a concentration within the range of 1.0-6.1 wt% in a strongly alkaline solution. Furthermore, the concentration of other salts was of significant magnitude.

A total volume of 4 m^3 was treated in this case study, with natural process variations in the feed composition. An illustration of the concept behind the SuperOx® system is seen in Figure 2.

Adjusting the alkalinity was found to be important for optimal operation of the unit and improved uptime. The 4 m^3 was treated in batches to determine the destruction efficiency under varying feed compositions and residence times. Gaseous and liquid exit streams were analyzed for fluorine-compounds, and for TFA and free fluoride, respectively.

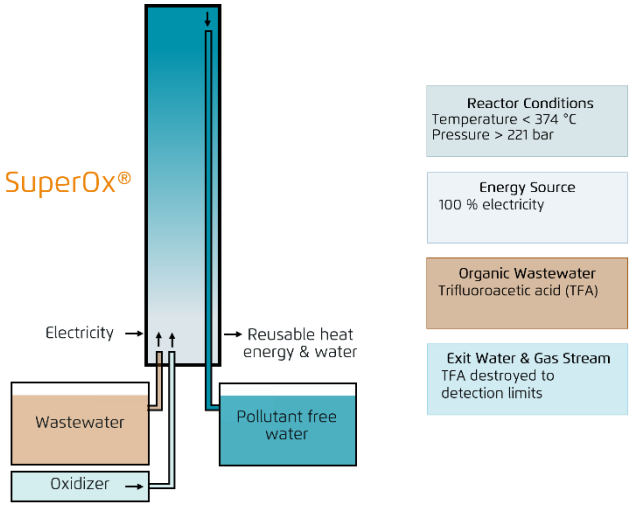


Figure 1 Illustration of the SuperOx® concept.

More than 99.99% oxidation of TFA, (i.e., all TFA destroyed) occurred in all concentration ranges. The efficiency of the process was indifferent to the variation of the feed composition as all analysis showed final TFA concentrations near the detection limit of 1 ppm. As seen in Table 1, significant reductions of TFA were achieved. The measured free fluoride emphasized the complete oxidation of TFA as per the previous reaction scheme. The fluorine mass balance showed a recovery of 90-99 % of the estimated free fluoride in all concentration ranges. Most importantly, there were no traces of any unwanted fluorine-containing compounds in the exhaust gas. A low power consumption of 80-100 kWh/m^3 was used during operation.

Table 1 Results from subcritical water Oxidation of TFA. ˣThis is the theoretical fluoride concentration based on the measured TFA.

	Low TFA		High TFA	
	Inlet stream	Exit stream	Inlet stream	Exit stream
TFA [ppm]	23520	1.4	61500	< 1
Fluoride ion [g/L]	ˣ11960	11100	ˣ29700	27400
Fluorine (gas) [ppm]	NA	0	NA	0
pH	13.4	9.4	≥14	9.4

SuperOx® - A viable solution

This case study proved that Aquardens SuperOx® system is a viable solution to treating concentrated TFA wastewater. The takeaways from this case study are:

- >99.99% oxidation of TFA was achieved.
- No toxic and unwanted fluorine containing byproducts were generated in the exhaust gas or liquid exit stream.
- Low energy consumption (< 100 kWh/m^3).

Resources

1 European Chemicals Agency. (2025) *Per- and polyfluoroalkyl substances (PFAS) – ECHA*. Available at: https://echa.europa.eu/hot-topics/perfluoroalkyl-chemicals-pfas (Accessed: October 2025)

2 Consilium. (2025). *Water pollution: Council and Parliament reach provisional deal to update priority substances in surface and ground waters*. Available at: https://www.consilium.europa.eu/en/press/press-releases/2025/09/23/water-pollution-council-and-parliament-reach-provisional-deal-to-update-priority-substances-in-surface-and-ground-waters/. (Accessed October 2025)

3 European Chemicals Agency. (2025). *Trifluoroacetic Acid.* Available at: https://echa.europa.eu/substance-information/-/substanceinfo/100.000.846?_disssubsinfo_WAR_disssubsinfoportlet_backURL=https%3A%2F%2Fecha.europa.eu%2Finformation-on-chemicals%3Fp_p_id%3Ddisssimplesearchhomepage_WAR_disssearchportlet%26p_p_lifecycle%3D0%26p_p_state%3Dnormal%26p_p_mode%3Dview%26_disssimplesearchhomepage_WAR_disssearchportlet_sessionCriteriaId%3D (Accessed: October 2025)

4 Arp, H. P. H., Gredelj, A., Glüge, J., Scheringer, M., & Cousins, I. T. (2024). *The Global Threat from the Irreversible Accumulation of Trifluoroacetic Acid (TFA)*. Environmental Science and Technology, 58(45), 19925–19935. https://doi.org/10.1021/acs.est.4c06189

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