MICROPOLLUTANT AND PFAS REMOVAL FROM WATER
Operational Experiences from Pilot and Full-Scale Solutions

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SUMMARY

The rising presence of micropollutants, including PFAS (Per- and Polyfluoroalkyl Substances), in groundwater, surface water, and wastewater poses a growing challenge for utilities. With tightening European regulations, including forthcoming EU-wide PFAS restrictions, utilities must adopt effective, robust, and future-proof treatment solutions.

The revised EU Urban Wastewater Treatment Directive introduces a mandatory fourth treatment stage in large plants to remove micropollutants such as pharmaceuticals and cosmetics. Implementation will occur between 2033 and 2045, starting with cities above 150,000 population equivalent. Under the extended producer responsibility principle, pollutant producers must fund at least 80% of treatment costs (European Union, 2024).

Full-scale installations in the Netherlands using Nijhuis Saur Industries' technologies have demonstrated effective micropollutant removal through adsorption and advanced oxidation. For PFAS, combining concentration and destruction methods offers the most efficient management. Concentration processes—such as granular and micro-grain activated carbon (GAC), ion exchange, reverse osmosis, and vacuum foam fractionation—enable targeted removal. Vacuum-enhanced foam fractionation shows strong selectivity for mid- and long-chain PFAS with minimal energy use.

To avoid PFAS disposal liabilities, destruction is crucial. Electrochemical oxidation achieves over 99% degradation, including ultra-short chains, with no harmful by-products. These insights support Portuguese utilities in developing resilient, future-proof solutions to protect water quality and public health.

Keywords: PFAS removal, Micropollutants removal, Ozone, biological Activated Carbon, Electrochemical oxidation

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1. INTRODUCTION

The presence of micropollutants and per- and polyfluoroalkyl substances (PFAS) in water resources has become a critical challenge for utilities across Europe. These contaminants, originating from pharmaceuticals, industrial chemicals, and consumer products, pose significant risks to ecosystems and human health due to their persistence and toxicity. In response, regulatory frameworks such as the EU Water Framework Directive and the Drinking Water Directive have introduced stringent removal targets, compelling utilities to adopt advanced treatment solutions.

This paper presents operational experiences from full-scale and pilot installations in the Netherlands and France, focusing on innovative technologies for micropollutant and PFAS removal. The examples from the Netherlands demonstrate with national objectives for pharmaceutical reduction through innovative ozonation and biologically active activated carbon systems. For PFAS removal, it is important to validate the performance of concentration and destruction technologies to select the right combination. These case studies provide practical insights into technology selection, performance optimization, and regulatory alignment, offering valuable guidance for portuguese utilities preparing for similar challenges.

2. MICROPOLLUTANT TREATMENT

In the Netherlands, wastewater management is primarily the responsibility of the regional water boards, who aim to safeguard water quality in rivers, lakes, and groundwater. Increasing concern about pharmaceuticals, pesticides, and other micropollutants has led to stricter national and EU regulations, as well as public pressure to reduce ecological and health risks. Removing micropollutants at wastewater treatment plants (WWTPs) helps protect sensitive aquatic ecosystems, maintain compliance with the Water Framework Directive, and secure safe drinking water sources. Additionally, Dutch water boards see micropollutant removal as part of their broader ambition to innovate and lead in sustainable water management. In this chapter we will present two full-scale references.

2.1. Regulatory background

In the Netherlands, WWTP's are expected to achieve a 70–80% reduction of 7 out of 11 guiding substances. This removal performance is assessed based on the influent of the sewage treatment plant combined with an additional tertiary treatment step. At the European level, regulations require 80% removal of 6 out of 12 guiding substances (European Union, 2024). Also, the effluent in the mixing zone must meet a bromate concentration of less than 1 µg/L. Finally, treatment should lead to at least a 50% reduction of ecotoxicity, as determined by the Simoni bioassay test.

Table 1 – list of 11 guiding micropollutants

Benzotriazole: An industrial chemical used as an anti-corrosive agent.
Carbamazepine: An anti-epileptic drug.
Diclofenac: A common non-steroidal anti-inflammatory drug (NSAID).
Irbesartan: An angiotensin II receptor blocker (ARB) used to treat high blood pressure.
Gabapentin: An anti-convulsant drug used for epilepsy and nerve pain.
Metoprolol: A beta-blocker used to treat cardiovascular conditions.
Hydrochlorothiazide: A diuretic used to treat high blood pressure and edema.
4- and 5-methylbenzotriazole mixture: Related industrial chemicals, similar to benzotriazole.

Sotalol: A beta-blocker used to treat heart rhythm disorders.
Trimethoprim: An antibiotic.
Venlafaxine: An antidepressant.

2.2. WWTP Houten

The wastewater treatment plant (WWTP) in Houten was identified as a hotspot for pharmaceutical residues and was therefore selected for an advanced treatment upgrade. A full-scale ozonation system with a capacity of 870 m^3/h was constructed by a consortium called CLC including Nijhuis Saur Industries, Pannekoek GWW, and Witteveen+Bos.

The installation applies ozone oxidation to break down pharmaceuticals, endocrine disruptors, and other micropollutants into less harmful or more biodegradable compounds. The modular system was designed with attention to energy use, operational costs, and safe reactor access, making it the first full-scale ozone installation for micropollutant removal in the Netherlands.

Figura 1 – View of the MicroOxi ozone treatment system at WWTP Houten.

The full-scale ozonation system at the Houten WWTP was designed for a treatment flow of 870 m^3/h. The installation applies the MicroOxi technology, targeting a 70% removal of 7 out of 11 guiding substances in line with Dutch requirements. Ozone is dosed within a range of 0.2–1.0 g O_3/g DOC, with a maximum production capacity of 9.1 kg O_3 per hour. The system was successfully realised and commissioned in February 2022.

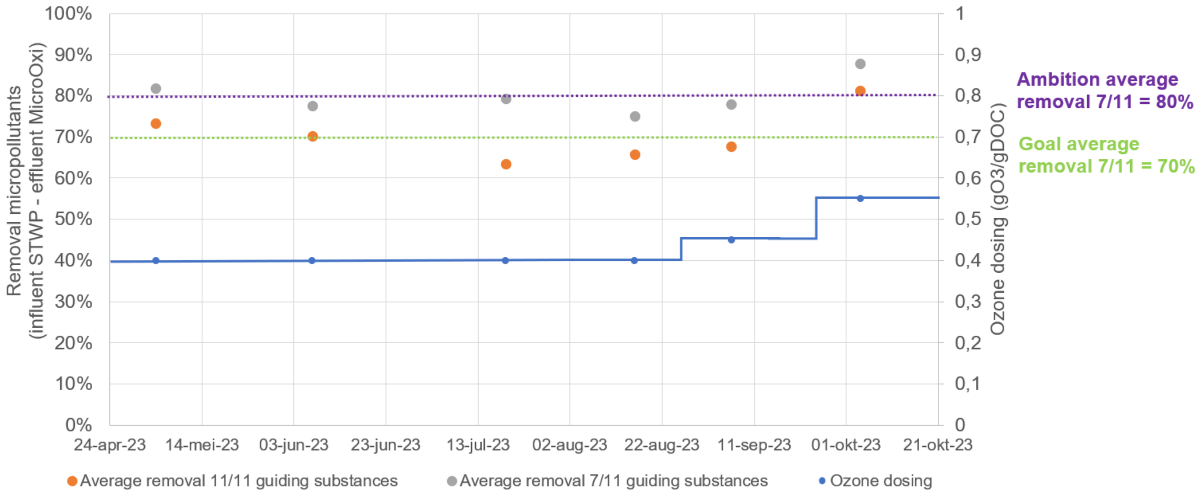

Figura 2 – Graph showing the removal % of the guiding micropollutants vs the ozone dosage at the WWTP Houten

As demonstrated in figure 2, the installation is able to consistently meet the 70% removal target using 0.4 gO3/gDOC.

2.3. WWTP Winterswijk - Netherlands

WWTP Winterswijk was identified as a local hotspot for pharmaceutical residues and other micropollutants during national screening and prioritisation work, prompting the water authority to trial an additional quaternary treatment step to reduce the load of medical residues discharged to receiving waters.

The project is part of the Dutch national innovation programme on micropollutant removal (IPMV/STOWA), which promotes pilots and full-scale implementations to evaluate effectiveness, by-product formation and lifecycle impacts before broader roll-out.

CLC-Water supplied and commissioned the treatment modules and monitoring regime, enabling Winterswijk to move from pilot testing toward a robust full-scale quaternary solution aligned with forthcoming regulatory requirements.

The wastewater treatment plant in Winterswijk has a treatment capacity of 92,000 population equivalents (PE) and a design flow of 860 m³/h. To meet national objectives for micropollutant abatement, the installation was designed to achieve a 70% removal of 7 out of 11 guiding substances, while also contributing to the reduction of ammonia and total phosphorus (TP). The selected solution applies the MicroNutri – O_3-BACF technology, which combines ozonation with downstream treatment by activated carbon filtration for improved nutrient and micropollutant removal. The system was successfully realised in Q3 2024.

Figura 3 – View of the MicroNutri – O_3-STEP treatment system at WWTP Winterswijk.

Technically, the Winterswijk WWTP extenssion combines ozonation followed by aerated activated-carbon filtration (eight GAC tanks at the site): ozone provides oxidative transformation of persistent pharmaceuticals and other organics, and the subsequent activated carbon adsorbs residual parent compounds and oxidation products, improving overall removal and reducing downstream toxicity.

This combined approach (oxidation + adsorption) is explicitly recommended by Dutch technical guidance and STOWA literature because partially removing dissolved organic carbon before or after oxidation lowers specific ozone demand and mitigates formation of unwanted oxidation by-products (e.g., bromate), while maximising micropollutant abatement.

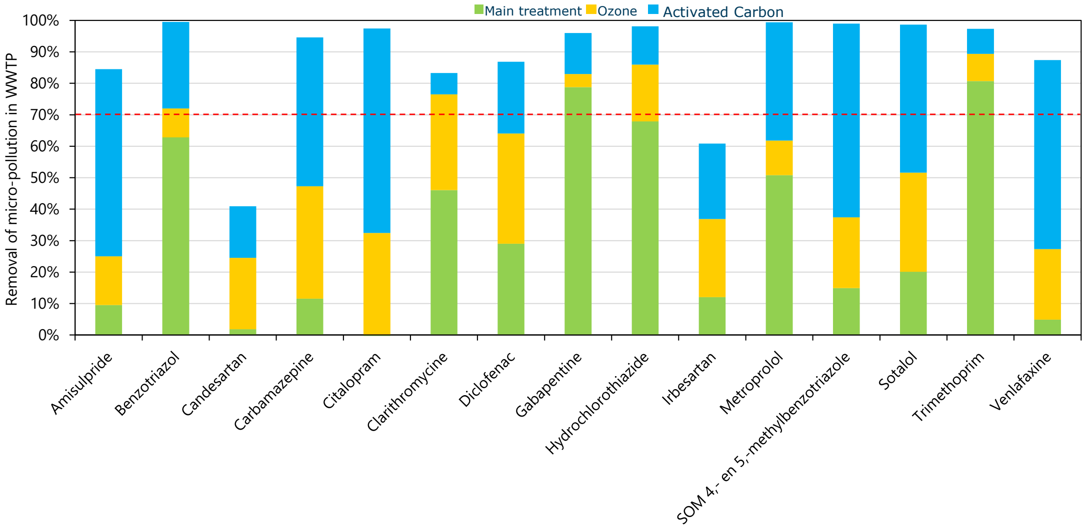

Figura 4 – Graph showing the removal % of the guiding micropollutants per process step at WWTP Winterswijk.

As demonstrated in figure 4, over 90% average removal of 7 out of 11 key substances. Furthermore, no bromate detected during commissioning; bromate reduction was even observed under anaerobic conditions. Also, the ecotoxicity was reduced by ≥50%, meeting targets. Finally, phosphorus and ammonium levels reached within required limits.

3. PFAS TREATMENT

3.1 Regulatory Overview

Across Europe, regulatory attention to per- and polyfluoroalkyl substances (PFAS) has intensified as evidence of their persistence, toxicity, and widespread occurrence in drinking water continues to grow. The EU Drinking Water Directive (Directive (EU) 2020/2184) introduced binding limits for PFAS, setting a maximum concentration of 0.1 µg/L for each individual PFAS and a 0.5 µg/L limit for the sum of all PFAS in drinking water.

In Portugal, the transposition of the Directive has put PFAS firmly on the regulatory agenda, with the Portuguese water authorities actively monitoring sources and preparing utilities for necessary treatment upgrades. This legal framework is driving both immediate measures to ensure safe drinking water and long-term investments in sustainable solutions to manage PFAS risks.

3.2 General PFAS Treatment Considerations

Treating PFAS is technically challenging due to the chemical stability of the carbon-fluorine bond, which resists conventional water treatment processes. Effective approaches typically follow a two-step strategy: first concentration and separation, to capture PFAS from large water flows into a manageable waste stream; and second destruction, to break down the molecules and eliminate the environmental burden. Optimal technology selection depends on many factors such as: the water composition, types and concentrations of PFAS, treatment targets, and economic factors.

Adsorptive and separation methods such as activated carbon, ion exchange resins, and membrane filtration are widely applied, but they merely transfer PFAS into secondary waste. Nijhuis Saur Industries (NSI) has developed a portfolio that addresses both steps: concentration solutions such as vacuum foam fractionation, (regenerable) ion exchange and reverse osmosis to separate PFAS efficiently, combined with advanced destruction technologies including electro- to permanently degrade PFAS in the concentrate. This integrated approach enables utilities and industries to not only meet current regulations but also work toward a true zero-PFAS discharge goal.

3.3 Water treatment plant Rumilly - France

A notable reference is the treatment installation in Rumilly, France, where a municipal potable water treatment plant faced the challenge of removing PFAS from contaminated groundwater to protect consumers. This initiative was driven by evolving regulations, including the French decree of December 2022 and the EU Water Framework Directive, which set strict limits for PFAS in water intended for human consumption (e.g., 0.1 µg/L for the sum of 20 PFAS). The site in question, Rumilly – Terre de Savoie, faced significant contamination, particularly with PFOA, necessitating urgent action.

To meet these requirements, a mobile GAC unit was deployed as an emergency solution. The installation consisted of two mobile GAC units (each with an 18 m³ volume), operating at daily production rates between 1,800 and 3,330 m³/day, with nominal flow rates of 2 × 80 m³/h. The system was commissioned in September–October 2023, with full-scale production starting in mid-December 2023.

The Monitoring campaigns from December 2023 to April 2025 demonstrated the effectiveness of the GAC units. The installation consistently achieved compliance with the regulatory threshold of 0.1 µg/L for the sum of 20 PFAS, and individual concentrations of PFOA, PFOS, and PFHxS were maintained at a few ng/L or not detected at all as shown in figure 5.

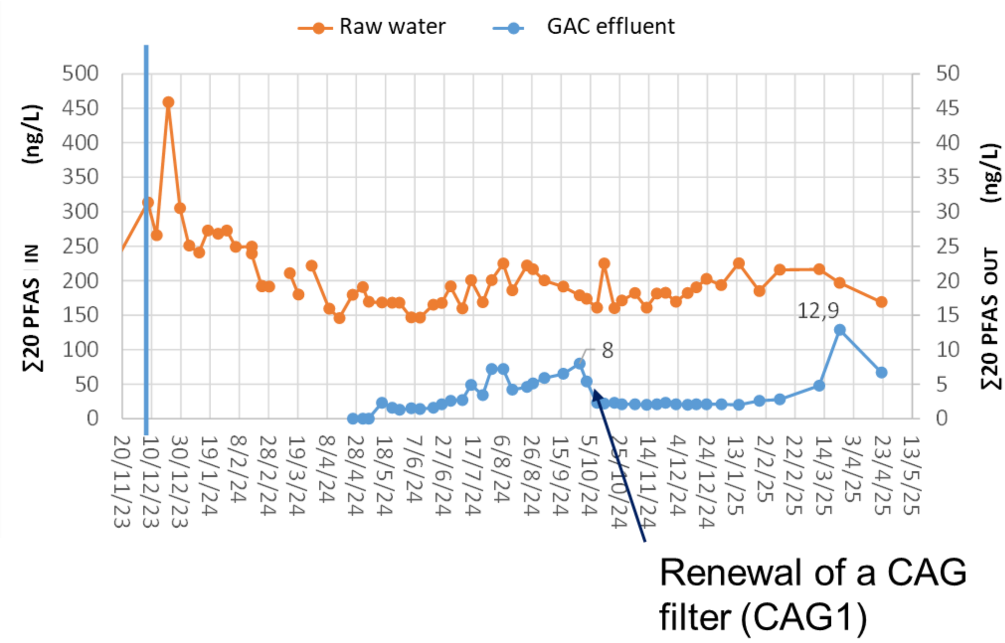

Figura 5 – Graph showing influent and effluent SUM20 PFAS concentrations at the Rumilly PFAS treatment plant

Over 18 months, the mobile units treated approximately 480,000 m³ of water. Organic matter loads were moderate (TOC = 0.6–0.8 mg/L; UV 254 nm = 1–1.3 m^{-1}). Fast breakthrough of short-chain PFAS (notably PFBA) was observed, but the system maintained control over long-chain PFAS. The first renewal of GAC1 occurred after 8,230 bed volumes (V/V), while GAC2 continued after 13,260 V/V. PFOA leakage remained low (≤ 7 ng/L for 55 g GAC/m³, ≤ 4 ng/L for 34 g GAC/m³).

This projects highlights the importance of selecting appropriate activated carbons and suggested a preference for reactivated over directly activated carbon, both for sustainability and performance. Used GACs can potentially be reactivated, provided residual PFAS concentrations remain below regulatory thresholds imposed by the Stockholm POP.

Finally, the project stands as a successful reference for the elimination of PFOA and other PFAS using a temporary, adaptable GAC treatment solution. The installation demonstrated robust performance in meeting stringent regulatory limits, though some limitations were noted for short-chain PFAS like PFBA. The potential for GAC reactivation offers a sustainable path forward, and the experience provides valuable insights for future PFAS remediation projects.

3.4 PFAS Destruction Case study

In this case study, an on-site electrochemical oxidation system was deployed at an anonymous chemical company to destroy PFAS in their wastewater. Electrochemical oxidation (EOx) is a treatment process that uses electrical current and specialized electrodes to generate powerful oxidizing agents directly in water. These oxidants, such as hydroxyl radicals and mixed oxidants, attack PFAS molecules at the molecular level, breaking the strong carbon-fluorine bonds that make PFAS so persistent. The process involves both direct oxidation at the anode surface and indirect oxidation through the generation of oxidants in the water.

As a result, PFAS compounds are destroyed and mineralized into harmless end products like carbon dioxide, water, and fluoride ions, leaving no hazardous residuals and minimizing environmental risk. This technology enables the complete destruction of PFAS, rather than just transferring them to another waste stream.

The results showed highly effective PFAS removal, with total PFAS removal rates exceeding 99%. The process demonstrated its flexibility, as power input can be adapted to match the desired treatment target.

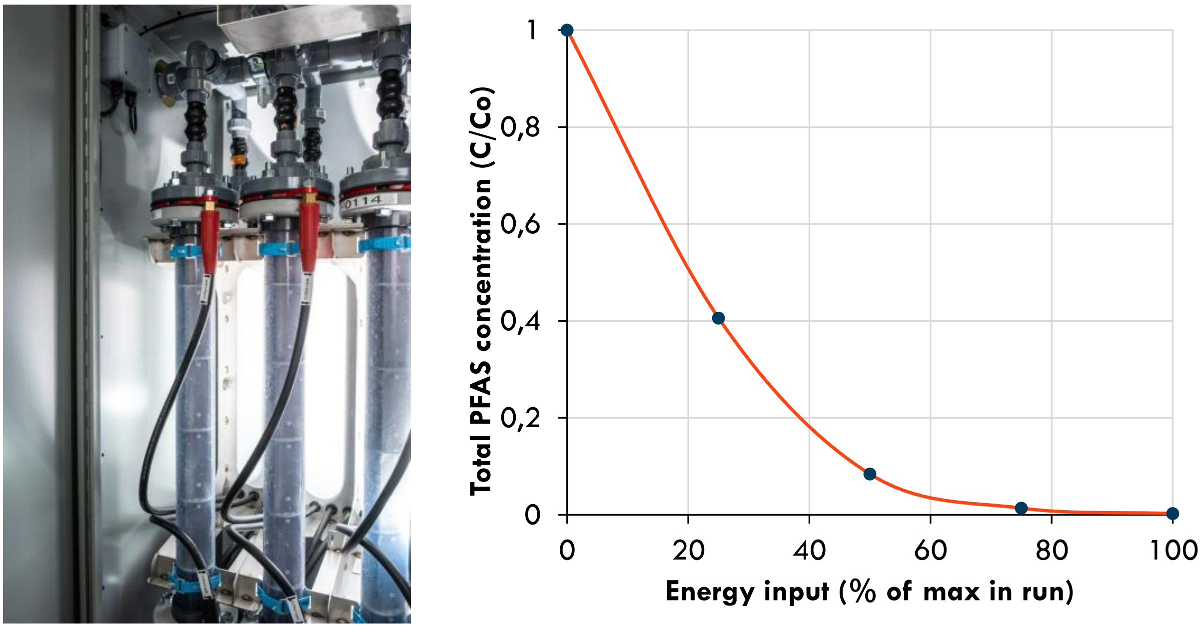

Figura 6 – Picture of Axine's ElectraClear^{TM} Electro-oxidation cells used for PFAS destruction (left) and PFAS destruction performance vs energy input (right).

Most importantly, the system demonstrated the ability to treat both long- and short-chain PFAS at varying concentrations, providing a robust and scalable solution for industrial PFAS destruction. This case highlights the practical application and effectiveness of electrochemical oxidation for on-site PFAS remediation in challenging industrial environments.

4. CONCLUSIONS

The case studies demonstrate that advanced treatment technologies are essential to meet current and upcoming regulatory requirements for micropollutants and PFAS. For wastewater treatment plants, combined oxidation and adsorption processes—such as ozonation followed by biologically activatd granular activated carbon—achieve high removal efficiencies while minimizing by-product formation.

In drinking water applications, GAC remains a reliable solution for PFAS control; however, its performance can be significantly enhanced by complementing it with ion exchange resins, particularly for the removal of short-chain PFAS, which are more mobile and harder to capture with carbon alone. For PFAS destruction, electrochemical oxidation has proven effective in eliminating both long- and short-chain compounds, offering a sustainable alternative to conventional disposal. These experiences underline the importance of integrated approaches that combine concentration and destruction steps, ensuring environmental safety and operational resilience.

Portuguese utilities can leverage these lessons to design future-proof systems that address both micropollutant and PFAS challenges in a cost-effective and sustainable manner.

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We also acknowledge **Axine Water Technologies** for their pioneering work in electrochemical oxidation, which enabled us to demonstrate effective on-site PFAS destruction. This collaboration has been key to advancing sustainable solutions that go beyond conventional treatment, ensuring complete elimination of persistent contaminants.

These joint efforts exemplify the importance of strategic partnerships in driving innovation and achieving shared goals for water quality, environmental protection, and regulatory compliance.

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