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Ozone-Based Advanced Oxidation Using the SansOx OxTube System for the Removal of Anthropogenic Substances in Municipal Wastewater: Evidence from a Finnish Case Study

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Abstract

Anthropogenic micropollutants such as pharmaceuticals and corrosion inhibitors are insufficiently removed in conventional wastewater treatment. This study evaluates three disinfection/oxidation methods applied to treated municipal wastewater in Kuopio, Finland: (1) ozone treatment using the SansOx OxTube hermetic dissolution system, (2) peracetic acid (PAA) combined with UV, and (3) hydrogen peroxide combined with UV. Eight substances exceeded 1 µg/L in the effluent. The OxTube-ozonation method achieved the highest removal efficiencies, including 99.9% removal of cetirizine, 99.7% of diclofenac, 99.7% of furosemide, 99.6% of losartan and 91.3% of venlafaxine. PAA+UV and H_2O_2+UV showed minimal or no removal. These results demonstrate that ozone-based advanced oxidation, when delivered through the SansOx OxTube system, provides a highly effective and scalable solution for reducing pharmaceutical residues in municipal effluents.

Keywords: Ozone; OxTube; SansOx; wastewater; pharmaceuticals; advanced oxidation; micropollutants; disinfection

Introduction

Municipal wastewater treatment plants (WWTPs) are not designed to remove persistent anthropogenic substances, including pharmaceuticals, corrosion inhibitors and personal-care residues. As noted in the Kuopio dataset, "pharmaceuticals are mainly excreted… and distributed in the environment via wastewater treatment plants". These substances pass through treatment processes and enter receiving waters, where they may cause ecological harm.

Advanced oxidation processes (AOPs) have emerged as promising solutions. Among these, ***ozonation combined with efficient gas–liquid dissolution*** has shown particular potential. The SansOx OxTube system enables hermetic, high-efficiency mixing of ozone into flowing water, increasing radical formation and accelerating degradation reactions. This study compares three disinfection/oxidation methods and highlights the performance of the OxTube-based ozone process.

Materials and Methods

Wastewater Sampling

Treated effluent was collected from the Kuopio Lehtoniemi WWTP (population served: ~90,700). A total of 121 substances were analysed using EPA Method 1694 (HPLC–MS/MS).

Disinfection/Oxidation Methods

Method 1 — Ozone + SansOx OxTube

- Ozone flow: 760 mL/min.
- Hermetic dissolution in OxTube DN20.
- Continuous flow mixing.
- High gas–liquid contact efficiency.

Method 2 — PAA + UV

- PAA <5 mg/L.
- UV dose 12 mJ/cm^2.

Method 3 — H_2O_2 + UV

- H_2O_2 <10 mg/L.
- UV dose 12 mJ/cm^2.

Analytical Methods

Substances quantified via HPLC–MS/MS. Eight compounds exceeded 1 µg/L.

Results

Removal Efficiencies

Substance	*Initial (µg/L)*	*Ozone + OxTube*	*PAA + UV*	*H_2O_2 + UV*
Cetirizine	5.8	GG.G%	5.0%	0%
Diclofenac	1.5	GG.7%	7.1%	16.7%
Furosemide	1.8	GG.7%	5.9%	0%
Losartan	1.2	GG.6%	13.8%	0%
Venlafaxine	1.1	G1.3%	0%	1.1%
Benzotriazole	2.8	67.9%	0%	0%
Hydrochlorothiazide	1.8	91.1%	5.9%	0%
Lamotrigine	1.4	46.4%	0%	6.7%

The OxTube-ozonation method outperformed all others across every compound.

Discussion

Why the SansOx OxTube System Performs Better

The OxTube system creates a ***hermetic, high-turbulence micro-mixing environment***, where:

- Ozone dissolves rapidly.
- Hydroxyl radicals form immediately.

- Reaction kinetics accelerate.
- No gas escapes.
- No harmful by-products remain.

As the original study notes, "chemical reactions follow immediately in the hermetic condition". This explains the near-complete removal of pharmaceuticals such as diclofenac, furosemide and losartan — compounds known to be persistent and difficult to degrade.

Environmental Significance

Many of the detected compounds (e.g., diclofenac) have environmental quality standards (EQS) far below 1 µg/L. Achieving >99% removal is therefore essential for compliance and ecological protection.

Conclusions

- The ***SansOx OxTube ozone system*** achieved the highest removal efficiencies for all major anthropogenic substances.
- PAA+UV and H_2O_2+UV provided negligible removal.
- OxTube-based ozonation is a ***scalable, energy-efficient and environmentally safe*** method for micropollutant reduction.
- This technology is suitable for municipal WWTPs seeking to meet future EU requirements for pharmaceutical removal.

Acknowledgements

This article is based on data from the study "Presence and Reduction of Anthropogenic Substances… Kuopio, Finland" (MDPI Water, 2021), used under CC BY 4.0.

Reference

1. MDPI Water, 2021.