

## Executive summary

### Introduction

Ozone ( $O_3$ ) is widely used in water treatment as disinfectant and oxidant. Transformation of organic compounds with  $O_3$  occurs either via direct reaction with  $O_3$  or with hydroxyl radicals ( $\cdot OH$ ). The enhanced formation of  $\cdot OH$  comprises an Advanced Oxidation Process (AOP). The most promising AOPs for water treatment are  $O_3/H_2O_2$  and UV/ $H_2O_2$ . The efficiency of ozonation and AOPs is greatly dependent on the water matrix composition (particularly on the concentrations of NOM and alkalinity which control the oxidant exposure) and the type of micropollutant to be treated (chemical structure determines the reactivity towards ozone and  $\cdot OH$  and the degree of photochemical degradation). These factors can influence the energy requirements for efficient water treatment.

### Approach

We examined the oxidation of p-chlorobenzoic acid (pCBA), atrazine (ATZ), sulfamethoxazole (SMX) and N-nitrosodimethylamine (NDMA) as representative micropollutants. The experiments were performed in four different water matrices, 3 lake waters and a wastewater after secondary treatment (Table 1). The waters spiked with the micropollutants were treated with conventional ozonation,  $O_3/H_2O_2$ , low pressure LP-UV and LP-UV/ $H_2O_2$ .

**Table 1.** DOC and alkalinity concentration of waters used in this study, calculated rate constants for the reaction of NOM with OH-radicals and scavenging rate resulting from NOM.

|                                       | Lake Zürich<br>water<br>(ZH)<br>Switzerland | Lake<br>Greifensee<br>water<br>(GF)<br>Switzerland | Lake<br>Jonsvatnet<br>water<br>(NW)<br>Norway | Wastewater<br>Dübendorf<br>(WW)<br>Switzerland |
|---------------------------------------|---|--|---|--|
| DOC (mg/L)                            | 1.3   | 3.1  | 3   | 3.9  |
| Alkalinity (mM)                       | 2.6   | 4.0  | 0.35  | 6.5  |
| $k_{OH,NOM}$ (L mg s <sup>-1</sup> )  | $2.7 \times 10^4$                           | $2.1 \times 10^4$                                  | $1.95 \times 10^4$                            | $3.5 \times 10^4$                              |
| Scavenging rate<br>(s <sup>-1</sup> ) | $6.1 \times 10^4$                           | $1.1 \times 10^5$                                  | $6.2 \times 10^4$                             | $2.0 \times 10^5$                              |

### Results

The results show that for 90% transformation of the ozone-resistant compound pCBA, the  $O_3$  consumption was roughly 2 mg/L for ZH and NW waters and approximately 2.7 mg/L for GF water. In the wastewater, we did not achieve more than 80% transformation with 10 mg/L  $O_3$ . For an initial spiked bromide concentration of 80  $\mu g/L$ , bromate formation in ZH water was much higher than in GF and NW waters and exceeded the drinking water standard of 10  $\mu g/L$  for all examined  $O_3$  doses (1-4 mg/L) and pH values (7-9). The energy requirement to achieve 90% transformation was calculated in the range 0.02-0.04 kWh/m<sup>3</sup> for

conventional ozonation of ZH-water. The use of the ozone-based AOP O<sub>3</sub>/H<sub>2</sub>O<sub>2</sub> increased the energy requirements by 20% due to the addition of H<sub>2</sub>O<sub>2</sub> but diminished bromate formation by 70%. The examination of compounds which are susceptible to direct oxidation with ozone (e.g., sulfamethoxazole) showed that it required smaller ozone doses and about 10 times less energy for 90% transformation and consequently less bromate was formed. The use of UV/H<sub>2</sub>O<sub>2</sub> as an alternative to O<sub>3</sub>/H<sub>2</sub>O<sub>2</sub> is roughly 10 times more energy intensive than ozonation but circumvents bromate formation. In all cases, the scavenging rate of the water played a major role and relates directly to the energy required for a certain extent of transformation of a micropollutant.

### **More information**

Preliminary results were presented in the 3<sup>rd</sup> International Conference on Water Science and Technology with emphasis on water & climate which was held in Athens, Greece, 16-19 October 2008.

A full paper is in preparation for Water Research.

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