Executive summary

Introduction
Ozone (O₃) is widely used in water treatment as disinfectant and oxidant. Transformation of organic compounds with O₃ occurs either via direct reaction with O₃ or with hydroxyl radicals (•OH). The enhanced formation of •OH comprises an Advanced Oxidation Process (AOP). The most promising AOPs for water treatment are O₃/H₂O₂ and UV/H₂O₂. 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 •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, O₃/H₂O₂, low pressure LP-UV and LP-UV/H₂O₂.

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.

<table>
<thead>
<tr>
<th></th>
<th>Lake Zürich water (ZH) Switzerland</th>
<th>Lake Greifensee water (GF) Switzerland</th>
<th>Lake Jonsvatnet water (NW) Norway</th>
<th>Wastewater Dübendorf (WW) Switzerland</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOC (mg/L)</td>
<td>1.3</td>
<td>3.1</td>
<td>3</td>
<td>3.9</td>
</tr>
<tr>
<td>Alkalinity (mM)</td>
<td>2.6</td>
<td>4.0</td>
<td>0.35</td>
<td>6.5</td>
</tr>
<tr>
<td>k_OH,NOM (L mg s⁻¹)</td>
<td>2.7 x 10⁴</td>
<td>2.1 x 10⁴</td>
<td>1.95 x 10⁴</td>
<td>3.5 x 10⁴</td>
</tr>
<tr>
<td>Scavenging rate (s⁻¹)</td>
<td>6.1 x 10⁴</td>
<td>1.1 x 10³</td>
<td>6.2 x 10⁴</td>
<td>2.0 x 10³</td>
</tr>
</tbody>
</table>

Results
The results show that for 90% transformation of the ozone-resistant compound pCBA, the O₃ 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 O₃. For an initial spiked bromide concentration of 80 µg/L, bromate formation in ZH water was much higher than in GF and NW waters and exceeded the drinking water standard of 10 µg/L for all examined O₃ 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/m³ for
conventional ozonation of ZH-water. The use of the ozone-based AOP O₃/H₂O₂ increased the energy requirements by 20% due to the addition of H₂O₂ 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/H₂O₂ as an alternative to O₃/H₂O₂ 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 3rd 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.

Ioannis A. Katsoyiannis, Urs von Gunten
Eawag, Swiss Federal Institute of Aquatic Science and Technology
Ueberlandstr. 133, Dübendorf, CH-8600, Switzerland
Tel: 0041 44 823 5270
Email: vongunten@eawag.ch