Full scale ozonation of WWTP effluent followed by sandfiltration

Saskia Zimmermann,
S. Brocker, B. Escher, P.A. Hansen, J. Hollender, S. Koepke,
M. Krauss, H.F. Larsen, A. Magdeburg, C.S. Mc Ardell,
J. Oehlmann, C. Ort, D. Rensch, H. Siegrist, H. Singer,
D. Stalter, M. Suter, U. von Gunten

• 5500 m³ wastewater per day
  under dry weather conditions
  (25,000 population equivalents)
Ozonation

Ozone dosing
- DOC-load proportional
- flow proportional

Sampling
- 11 sampling campaigns (0 – 1.16 gO₃/gDOC)
- 24h- or 48h-volume proportional composite samples
- Filtration on-site (0.7 μm glassfiber filters)

Elimination efficiency – micropollutants
5 sampling campaigns: 0.62 ± 0.05 gO₃/gDOC
Elimination efficiency – micropollutants

5 sampling campaigns: $0.62 \pm 0.05 \text{ gO}_3/\text{gDOC}$

<table>
<thead>
<tr>
<th>Micropollutant Type</th>
<th>Number</th>
<th>Secondary Effluent &gt; 15 ng/L</th>
<th>Ozonation effluent &gt; 15 ng/L</th>
<th>Ozonation effluent &gt; 100 ng/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pharmaceuticals</td>
<td>14</td>
<td>13</td>
<td>4</td>
<td>Atenolol</td>
</tr>
<tr>
<td>Antibiotics</td>
<td>10</td>
<td>6</td>
<td>0</td>
<td>Diatrizoate, Iopromide</td>
</tr>
<tr>
<td>X-Ray contrast media</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>Mecoprop</td>
</tr>
<tr>
<td>Biocides/Pesticides</td>
<td>10</td>
<td>5</td>
<td>3</td>
<td>(Methyl)-Benzotriazol</td>
</tr>
<tr>
<td>Corrosion inhibitor</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Endocrine disruptors</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Metabolites</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>53</td>
<td>34</td>
<td>15</td>
<td>6</td>
</tr>
</tbody>
</table>

Load reduction per year:
- ~ 1 kg Carbamazepine
- ~ 2 kg Diclofenac
- ~ 6 kg Benzotriazole

Effect of ozone concentration on elimination efficiency

Calculation: $100 - 100 \times \frac{c_{\text{after ozonation}}}{c_{\text{secondary effluent}}}$

- Diclofenac: $g_{\text{O}_3}/g_{\text{DOC}} = 1.16$
- Trimethoprim: $g_{\text{O}_3}/g_{\text{DOC}} = 0.79 \pm 0.02$
- Sulfapyridine: $g_{\text{O}_3}/g_{\text{DOC}} = 0.62 \pm 0.05$
- Carbamazepine: $g_{\text{O}_3}/g_{\text{DOC}} = 0.40 \pm 0.06$

Elimination (%)
Cancerogenic nitrosamines - byproducts of ozonation?

- Mean values of 9-11 sampling campaigns

Bromate
- Influent bromide levels ~30 μg/L
- 7.4 μg/L for the highest ozone dose of 1.2 gO₃/gDOC
- Bromate < drinking water standard (10 μg/L)
- Bromate < proposed ecotoxicological threshold (3 mg/L)

Oxidation by-products

Assimilable Organic Carbon (AOC)
- Influent AOC levels 100 – 200 μg/L
- Increases up to 700 μg/L
- SF decreases it by max. 50%
### Disinfection

**Total cell counts**

<table>
<thead>
<tr>
<th>gO₃/gDOC</th>
<th>Final sedimentation</th>
<th>Ozonation</th>
<th>Sand filtration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>1</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>0.60</td>
<td>0.0</td>
<td>0.0</td>
<td>0.36</td>
</tr>
<tr>
<td>0.74</td>
<td>1.000</td>
<td>10.000</td>
<td>100.000</td>
</tr>
</tbody>
</table>

**E. coli**

<table>
<thead>
<tr>
<th></th>
<th>Final sedimentation</th>
<th>Ozonation</th>
<th>Sand filtration</th>
</tr>
</thead>
<tbody>
<tr>
<td>[cells/ml]</td>
<td>0.0</td>
<td>0.0</td>
<td>0.36</td>
</tr>
<tr>
<td>gO₃/gDOC</td>
<td>0.0</td>
<td>0.60</td>
<td>0.74</td>
</tr>
<tr>
<td>1.07</td>
<td>1.000</td>
<td>10.000</td>
<td>100.000</td>
</tr>
</tbody>
</table>

### Toxic effects: mode-of-action based battery

**Extraction of organic micropollutants and effect assessment of extracts**

<table>
<thead>
<tr>
<th>Mode of action</th>
<th>Bioassay</th>
<th>Targeted chemicals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non specific toxicity</td>
<td>baseline toxicity</td>
<td>all chemicals</td>
</tr>
<tr>
<td>Specific toxicity</td>
<td>Bioluminescence inhibition</td>
<td></td>
</tr>
<tr>
<td>Reactive toxicity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receptor (CO₂ + NH₃)</td>
<td>Imaging-PAM</td>
<td>Triazine and phenylurea herbicides</td>
</tr>
<tr>
<td>Acetylcholinesterase (AChE)</td>
<td>YES</td>
<td>Estrogens, estrogenic industrial chemicals</td>
</tr>
<tr>
<td>Genotoxicity</td>
<td>AChE</td>
<td>Organophosphates, carbamate insecticides</td>
</tr>
<tr>
<td>Mutagenicity (umuC)</td>
<td></td>
<td>Chlorinated byproducts, aromatic amines, PAH</td>
</tr>
</tbody>
</table>
Elimination efficiency – toxic effects

- at 0.62 g O₃/g DOC 65- 95 % elimination of the toxic effect
- Specific, receptor-mediated effects better removed than non-specific toxicity (ozone causes transformation not mineralisation)
- no significant formation of toxic or genotoxic byproducts

Fish early life stage toxicity test
Swim-up and biomass comparison
(Onchorhynchus mykiss larvae)

- Delayed swim-up after OZ
- Reduced biomass after OZ
- No significant effect after sand filtration
**Lumbriculus toxicity test**

Biomass comparison

- Considerable decrease of biomass and reproduction after OZ
- No significant effect after sand filtration

**Energy consumption for O\textsubscript{2} and O\textsubscript{3}**

**Energy consumption (15m\textsuperscript{3} process gas h\textsuperscript{-1})**

- Total: O\textsubscript{3} process + O\textsubscript{2} production + transport
- O\textsubscript{3} process: Container + online probes + computers
- Container: O\textsubscript{3} production + thermal ozone distructor + cooling aggregate
- O\textsubscript{2} production: dielectric barrier discharge, control system
Estimated yearly costs ozonation step at WWTP Regensdorf

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment (15a / 4%) +</td>
<td>€105'000</td>
</tr>
<tr>
<td>Personnel</td>
<td>€20'000</td>
</tr>
<tr>
<td>Maintenance</td>
<td>€20'000</td>
</tr>
<tr>
<td>Oxygen</td>
<td>€24'000</td>
</tr>
<tr>
<td>Energy</td>
<td>€7'000</td>
</tr>
<tr>
<td>Total</td>
<td>€178'000</td>
</tr>
</tbody>
</table>

Spec. Costs (for 3 Mio. m³ wastewater / a) 0.06 €/m³ wastewater

- **without sand filtration**

LCA impact profiles (weighting factor = 1 for all impact categories)

Avoided: 14,6 µPET/m³
Induced: 8,9 µPET/m³
Environmental sustainability profiles: ozonation

(22 micropollutants (only significant ones shown); weighting factor = 1 for all impact categories)

Induced Avoided
2.8g O3 Ozonation

Environmental sustainability profiles: ozonation + sand filtration

(31 micropollutants + P (only significant ones shown); weighting factor = 1 for all impact categories)

Secondary effluent After sandfiltration Removal rate
Tot-P (mg/l) 0.8 0.3 0.625

260
240
220
200
180
160
140
120
100
80
60
40
20
0
Induced Avoided
2.8g O3 Ozonation + sand filtration
Conclusions

- Efficient technique for the transformation of micropollutants and for disinfection purposes
- Ecotoxicity results are controversial (improvement vs. no effect); ongoing need for clarification
- Sand filtration recommended as barrier for the elimination of some oxidation by-products formed during ozonation (NDMA, AOC)
- Specific costs ~0.06 €/m³ wastewater (ozonation without sand filtration; including both investment and operation costs)
- LCA: Ozonation most probably environmentally sustainable; including sand filtration significantly improves sustainability profile

Acknowledgments

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Thank you for your attention!

Eawag: Swiss Federal Institute of Aquatic Science and Technology