Combined Ozonation-Nanofiltration for Drinking Water Treatment

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Chlorination Disinfection Byproducts (DBPs)

• Disinfection byproducts are formed by the reaction of chlorine with natural organic matter.

• The compounds formed include
  – trihalomethanes (THMs; e.g., chloroform, chlorodibromomethane, bromoform)
  – haloacetic acid (HAAs) (e.g., dichloroacetic acid)
  – chloropicrin and dichloroacetonitrile
Technologies for the reduction of DBP formation

- Enhanced coagulation
- Granular activated carbon
- Membrane filtration
- Alternate disinfectants
  - Chlorine dioxide
  - Chloramines
  - UV radiation
  - Ozone
Ozone

- Ozonation decreases the formation of chlorinated DBPs
- Leads to the formation of other DBPs, including
  - ketones, aldehydes, bromate
  - biodegradable organic carbon (BDOC)
- In high TOC waters, ozonation
  - is expensive
  - leads to excessive DBP formation
Membrane filtration

• Nanofiltration can remove >90% of natural organic matter (NOM)
  – Extent of removal depends upon operational conditions, including molecular weight cutoff and water quality

• Problems
  – low permeate flux
  – fouling
  – cleaning of membranes
Combined Ozonation / Nanofiltration

- Aim is to combine both processes to reduce problems associated with the use of the processes individually
- Ceramic membranes
  - resistant to degradation by ozone
  - less subject to NOM fouling than many polymeric membranes
  - costly compared to polymeric membranes
Experimental apparatus

- Oxygen Cylinder
- Moisture Adsorbent
- Ozone Generator
- Waste Gas
- Spectrophotometer
- KI
- Water Tank
- Membrane
- Permeate
- Pressure gauge
- Flow meter
- Pump
- Valve
Experimental details

Membrane

• TiO$_2$ filtration layer on an AZT (Aluminum/Zirconium/Titanium Oxide) support
• MWCOs 1 kD, 5 kD and 15 kD
  • pore size ca. 1 nm, 3 nm and 10 nm

Experimental conditions

• Cross flow filtration – cross flow velocity 1.5 m/s
• Ozone: 1.0 to 12.5 g/m$^3$ @ 100 ml/min
• Trans-membrane pressure – 0.21-0.23 bar
• Temperature – 20ºC
• All samples pre-filtered through a 0.45 µm filter
Water source

Lake Lansing (Haslett, MI)

- borderline eutrophic
- algal blooms occur in Summer
- hardness - 150 mg/L as CaCO₃
- high dissolved organic carbon - 8 to 11 mg/L

Potential for membrane fouling is high
Effect of ozone dosage on permeate flux
Refouling after ozonation

Permeate flux, L/hr-m2-bar

Time, hr

Ozone 12.5 g/m³
TTHM precursor removal
Effect of MWCO

Filtered raw water - 236 μg/L O₃ - 2.5 g/m³

<table>
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<tr>
<th>MWCO (kD)</th>
<th>µg/L SDS THM</th>
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<tr>
<td>15</td>
<td>120</td>
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<tr>
<td>5</td>
<td>80</td>
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<td>20</td>
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O₃ - 2.5 g/m³
HAA precursor removal: Effect of MWCO

Filtered raw water – 89  5 µg/L  O₃ - 2.5 g/m³
Effect of ozone dosage on DBP precursor removal

![Bar chart showing the concentration of TTHMs and HAAs at different ozone concentrations (1.5, 2.5, 10 g/m³). The chart illustrates the removal efficiency of DBP precursors at various ozone doses.](chart.png)
Ozone DBP removal

Conc’n µg/L

15 kD  5 kD  1 kD

0  200  400  600  800

Ketones  Aldehydes  Ketoacids

O₃ - 2.5 g/m³
Summary – Fouling Studies

• Ozonation at low dosages reduces fouling; if ozone dosage is high enough no fouling occurs

• The reaction of ozone with foulants appears to be enhanced at the membrane surface, presumably due the catalytic degradation of ozone by TiO$_2$
Summary – DBP studies

• The combined process yields better results than for ozone alone

• Lower DBP concentrations are obtained with tighter membranes

• In the range studied, ozone dosage has little effect on THM or HAA precursor removal

• 1 kD MWCO membrane gives good removal for all the DBPs studied; 5 kD gives good removal of chlorinated DBPs