Impact of UV/H$_2$O$_2$ on subsequent chlorine stability and DBP Formation

Sophie Pantin, Ron Hofmann
Department of Civil Engineering
University of Toronto
What is an Advanced Oxidation Process?

- Remove pollutants that cannot be removed by conventional treatment
- Involves the production of hydroxyl radicals $\text{OH}^-$
  - Short lived (1/1,000,000 second)
  - Very strong oxidant
  - Non-selective reagent
UV/H$_2$O$_2$ Treatment
UV lamps

$H_2O_2$
UV/H$_2$O$_2$ Treatment

- $\text{H}_2\text{O}_2 + \text{UV} \rightarrow 2 \text{OH}^-$
- UV doses used are higher than in disinfection process
  - $\checkmark$ 600 mJ/cm$^2$ vs. 40 mJ/cm$^2$
- Peroxide dose $\sim$ 1-10 mg/l
Cornwall (Ontario) Water Purification Plant

• First plant in the world to use UV-H$_2$O$_2$ for periodic taste and odor (T&O) control
• Why?
  – Operation based on needs (turn on or off)
  – UV disinfection was installed for primary disinfection
Coagulation/Flocculation
Sedimentation/Filtration
UV lamp
Distribution system
Chlorine addition
Peroxide addition
Cornwall Water Purification Plant

• Leader in the implementation of UV-H$_2$O$_2$ for T&O removal
• Use their experience for future guidance
  – Integration of UV-H$_2$O$_2$ into an existing DWTP train
  – Impact on downstream process (secondary disinfection)
Integration of UV-H$_2$O$_2$ into an existing WTP train
Raw water → Coagulation/Flocculation → Clarification

Filter 1 → Filter 2 → Filter 3 → Filter 4

UV reactor → UV reactor → UV reactor → UV reactor

Chlorine addition → Clearwell
T&O Event

• When a T&O event occurs
  – Fluence is increased (from 40 to 600 mJ/cm²)
  – H₂O₂ is added

• Depending on the severity of the event
  – 5 levels of treatment (1, 2, 4, 8, and 15 mg-H₂O₂/l)

• BUT H₂O₂ needs to be quenched
H₂O₂ quenching

- Only ~10% of the initial H₂O₂ is consumed through UV treatment
- Chlorine is added to:
  - Quench H₂O₂ (H₂O₂/Cl₂ ratio = 1:2)
  - Maintain a residual of 0.8 ppm
H$_2$O$_2$ quenching

- No on-line H$_2$O$_2$ measurement

- Implementation:
  - Control panel that gives the predicted amount of H$_2$O$_2$ added
  - Calculate an expected H$_2$O$_2$ residual
  - Inject enough chlorine to quench the expected H$_2$O$_2$ residual and maintain chlorine residual
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taste and Odour Event Scale Setting</td>
<td>1 - Target Log Reduction of 0.2</td>
</tr>
<tr>
<td>Inlet Chlorine Concentration (mg/L)</td>
<td>0.00</td>
</tr>
<tr>
<td>Inlet Peroxide Concentration (mg/L)</td>
<td>1.32</td>
</tr>
<tr>
<td>EED (kWh/kgal)</td>
<td>0.34</td>
</tr>
<tr>
<td>H2O2 Dosed (mg/L)</td>
<td>1.32</td>
</tr>
<tr>
<td>Residual H2O2 (mg/L)</td>
<td>1.27</td>
</tr>
</tbody>
</table>
H$_2$O$_2$ quenching

- Really delicate operation:
  - Flow-rate is constantly changing
  - Filter backwash

$\Rightarrow$ H$_2$O$_2$ residual is constantly changing
Impact on disinfection

- OH• radicals oxidize T&O compounds but also the natural organic matter (NOM)

- No mineralization—only alterations
  - UV and peroxide doses too low
  - Scavengers
  - OH• reacts with almost anything!
UV lamp 40 mJ/cm²

NOM

Pathogens
UV lamp 600 mJ/cm²

H₂O₂ → OH•

Pathogens

NOM
Different Chlorine dose?

Disinfection by-products (DBPs)

UV

Different amount?

OH•

Need tools to predict reactivity of this new altered organic matter

Water (NOM)

Disinfection by-products (DBPs)

Different amount?
Case study at Cornwall

- Sampling before and after UV/H$_2$O$_2$ and UV treatment alone
- Assess the impact of the process on:
  - NOM alterations
  - Chlorine demand
  - DBP Formation
- Sampling campaigns performed during fall 2007 and fall 2008

Lab Tests
Results

- NOM characteristics, DBPs and chlorine demand are not affected by UV disinfection
- UV-H$_2$O$_2$ treatment (Dose = 600 mJ/cm$^2$)
  - ✓ No mineralization of the NOM
  - ✓ pH, alkalinity, TOC are not affected
  - ✓ NOM spectral properties are not significantly affected
Influence of UV-$\text{H}_2\text{O}_2$ on chlorine demand: Fall 2007

Chlorine demand increases
Influence of UV-H$_2$O$_2$ on chlorine demand: Fall 2008

Chlorine demand increases.
Influence of UV/H$_2$O$_2$ on THM formation: Fall 2007

THM formation decreases.
Influence of UV/H$_2$O$_2$ on THM formation: Fall 2008

THM formation increases

THM formation (µg/l)

Contact time (hr)

0 20 40 60 80

THM formation before UV-H$_2$O$_2$ THM formation after UV-H$_2$O$_2$
Influence of UV/H$_2$O$_2$ on disinfection

- UV-H$_2$O$_2$ process affects NOM characteristics
- Altered NOM is more reactive towards chlorine
- UV-H$_2$O$_2$ treatment affects THM formation

UV-H$_2$O$_2$ impacts behaviour of Cl$_2$ and DBPs

BUT we don’t have tools to predict these impacts

More research is needed!!!
Ongoing experiments

• 2009 campaign:
  – Spiking Geosmin and MIB upstream from one reactor
  – Study the impact of different levels of treatment on T&O removal, DBP-FP and chlorine demand
Acknowledgments

• Morris McCormick and the operators at Cornwall Water Purification Plant

• Canadian Water Network (CWN)

• Trojan Technologies
Removal of Geosmin by UV-H$_2$O$_2$ treatment

![Bar chart showing the removal of Geosmin over time before and after UV-H$_2$O$_2$ treatment.](image)
Removal of MIB by UV-H$_2$O$_2$ treatment

![Graph showing MIB levels before and after UV-H$_2$O$_2$ treatment from 08-Sep-08 to 29-Sep-08.](image-url)