Performance Evaluations on the Removal of Synthetic Hormones by Advanced Oxidation Processes in Drinking Water Treatment

Jennifer L. Fuller
Department of Civil and Environmental Engineering | Michigan Technological University

Motivation

- Pharmaceuticals and personal care products (micropollutants) enter the water cycle and are derived from various anthropogenic sources.
- Many micropollutants are unaffected by conventional wastewater treatment (WWT) processes and are discharged to the environment.

EE2 has been detected in ng/L concentrations in surface water, groundwater, WWT effluents, and even drinking water. There is growing concern about the potential impacts of EE2 and other micropollutants on human health, especially in highly water-stressed areas where there is potential for indirect or direct reuse of wastewater effluents for drinking water.

The City of San Diego imports approximately 85-90% of its water supply from the Colorado River and Northern California to serve its population of 1.3 million people. Environmental stresses and pumping restrictions continually reduce the amount of water that can be delivered. The City of San Diego, along with many other areas, are currently studying the possibilities for recycled water to meet their current and future water needs. Thus a sustainable treatment process is sought to protect the public from source water contaminants such as EDCs including EE2.

Background

Drinking water treatment plants were not designed to remove the myriad of pharmaceutical compounds detected in today’s water sources. There is interest in modifying plant processes to improve micropollutant removal. Potential removal mechanisms include:

- Sorption to particles (activated carbon)
- Coagulants and chemical softening (alum and ferric chloride)
- Chlorination and ozonation
- Advanced Oxidation Processes (AOP)

The efficiency of a treatment process is dependent on the chemical properties of the target compound (Fig. 1).

Objective

To determine the effects of water quality on the efficiency of an Advanced Oxidation Process (AOP) using hydrogen peroxide (H₂O₂) with ultraviolet light (UV) for removal of synthetic hormone EE2 in drinking water. Efficiency is determined by:

- Ability to achieve maximum contaminant level goal (MCLG) = 0.1 ng/L with and without pretreatment options
- Reducing H₂O₂ residue by determining optimal dosage
- Achieving energy (EE/O) value between -0.5 to 2 kWh/m³

Approach

A mathematical model created by the instructor was used to assess the performance of AOP using H₂O₂ with low pressure (254 nm) UV lamps [3].

\[
H₂O₂ \rightarrow 2HO \cdot
\]

This AOP process works by:
1. UV converts H₂O₂ into highly reactive hydroxyl radicals (HO•)
2. Hydroxyl radicals attack and decompose contaminants

Two different sources for water quality were compared:
- SW: surface water (indirect reuse)
- WW: wastewater effluent (direct reuse)

The initial concentration of EE2 was 10 ng/L.

The reactor was modeled as a tanks-in-series (TIS, n=10) reactor, volume 6 m³ with a drinking water treatment plant flow rate = 0.28 m³/s.

Table 1: Characterization of source waters for model

<table>
<thead>
<tr>
<th>Water Source</th>
<th>pH</th>
<th>DOC, mg/L</th>
<th>HCO₃⁻, mM</th>
<th>CO₃²⁻, mM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Water</td>
<td>7.2</td>
<td>0.122</td>
<td>5.62x10⁻⁵</td>
<td>7.59x10⁻²</td>
</tr>
<tr>
<td>Wastewater Effluent</td>
<td>7.4</td>
<td>0.425</td>
<td>4.31x10⁻²</td>
<td>1.2x10⁻¹</td>
</tr>
</tbody>
</table>

Hydroxyl radicals are very reactive and react with other compounds present in the water. Therefore, a pre-assessment of each source water was performed to determine competing reactions for HO•. Quenching ratios for each compound were calculated to determine the distribution of HO• (Fig. 3 & 4).

\[
Q_n = k_{\text{HO}} C_n + \sum k_{\text{C}} C_n
\]

Discussion and Conclusion

The AOP process was not efficient for either source water without pretreatment (EE/O > 2 kWh/m³) and did not meet the MCLG for EE2 effluent concentrations. Although the EE/O values were ideal for both source waters with pretreatment and MCWG was met, there were high residual concentrations of hydrogen peroxide which is toxic to microorganisms and must be additionally removed by energy-intensive treatment processes. In conclusion, AOP using H₂O₂ and low pressure UV was not an efficient process to remove environmental concentrations of EE2 from drinking water for an MCLG = 0.1 ng/L.

Results

Various pretreatment technologies for water quality were applied to the model parameters to increase the efficiency of AOP based on the quenching ratios shown in Fig. 3 and 4. Treatment scenarios include:

1. AOP (H₂O₂ w/UV) [MAX H₂O₂ dose = 50 mg/L]
2. Decarbonation + AOP (H₂O₂ w/UV)
3. Decarbonation + Reverse Osmosis (RO) + AOP (H₂O₂ w/UV)
4. Decarbonation + Ion Exchange + RO + AOP (H₂O₂ w/UV)

Neither source water achieved the MCLG = 0.1 ng/L without employing all pretreatment options.

The efficiency of AOP based on energy consumption was calculated by the EE/O value for varying doses of H₂O₂ plotted against concentration of H₂O₂ residual (Fig. 3 & 6).

\[
EE/O = \frac{P \text{ (production of } H₂O₂ \text{ and UV)}}{Q \times \log \left(\frac{C}{C_0}\right)}
\]

Table of References