UV as a Disinfection Barrier and as a Barrier Against Emerging Contaminants

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Jennifer I. Kintzer, P.E.
Municipal Sales Engineer
Engineered Treatment Systems (ETS)
Program Outline

- UV Fundamentals
- Disinfection with UV
- Emerging Contaminants
- Advanced Oxidation with UV
UV Fundamentals
Where is UV Used?

- Drinking Water
- Wastewater & Reuse Water
- Swimming Pools & Spas
- Aquaculture & Fish Farms
- Marine & Offshore
- Soft Drinks & Breweries
- Food Production
- Electronics & Pharmaceuticals
When is UV Used?

• When chemical disinfection is not accepted
• Against pathogens that are tolerant to chlorine
  – Cryptosporidium
  – Giardia
  – Viruses
• Any chlorine, ozone, or chloramine intolerant process
Primary Disinfection Range (UVC) = 200 to 280 nm
UV Technology

Increasing Water Penetration

Increasing Energy

Clean, safe environments
How Does UV Work?

- UV is a physical rather than chemical process
- UV harnesses the power and energy of photons to effect destruction of pathogenic microorganisms and break apart chemical bonds of pollutants

Karl Linden
What Does UV Do in the Water?

Photochemistry

• Photons of UV light absorbed by molecules such as chloramines or NDMA lead to chemical change, resulting in their destruction.

Disinfection of microorganisms

• Photons absorbed by DNA in microorganisms lead to inactivation (inability to replicate) by altering of thymine base units in the DNA.
What Does UV Do in the Water?

“In order for UV to be effective, the photons both have to be absorbed by the target contaminant and pack enough energy to cause a lasting photochemical effect.” Karl Linden

- Need to determine the peak UV wavelengths for absorbance for the targeted contaminant
- Need to determine the UV dose required to cause enough damage that it cannot be repaired
How is UV Light Generated?

Voltage is applied across the electrode, exciting the mercury to create UV
Types of UV Lamps

- **Low Pressure Lamps** - High electrical efficiency, low UV-C output per unit length, Monochromatic (254 nm wavelength), photorepair mechanisms exist for low dose damage
- **Amalgam Low Pressure** - Good electrical efficiency, medium UV-C output per unit length, Monochromatic (254 nm wavelength), photorepair mechanisms exist for low dose damage
- **Medium Pressure** - Low electrical efficiency, very high UV-C output per unit length, Polychromatic (the higher pressure excites more energy levels producing more spectral lines), no photorepair mechanisms known to exist
# Lamp Comparison

<table>
<thead>
<tr>
<th></th>
<th>Low Pressure</th>
<th>Low Pressure High Output</th>
<th>Medium Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lamp Power (W)</strong></td>
<td>40 to 80</td>
<td>100 to 1000</td>
<td>400 to 25000</td>
</tr>
<tr>
<td><strong>Efficiency (%)</strong></td>
<td>35 to 40</td>
<td>30 to 40</td>
<td>10 to 15</td>
</tr>
<tr>
<td><strong>Lamp Life (hrs)</strong></td>
<td>8,000 to 12,000</td>
<td>8,000 to 12,000</td>
<td>3,000 to 8,000</td>
</tr>
<tr>
<td><strong>Internal Gas Pressure (Torr)</strong></td>
<td>$10^{-2}$ to $10^{-3}$</td>
<td>$10^{-2}$ to $10^{-3}$</td>
<td>$10^2$ to $10^4$ (atmospheric)</td>
</tr>
<tr>
<td><strong>Lamp Surface Temperature (F)</strong></td>
<td>110</td>
<td>110</td>
<td>1500</td>
</tr>
<tr>
<td><strong>Wavelengths</strong></td>
<td>Monochromatic</td>
<td>Monochromatic</td>
<td>Polychromatic</td>
</tr>
<tr>
<td><strong>Efficiency vs. Water Temp. (F)</strong></td>
<td>60</td>
<td>&gt; 60</td>
<td>Any</td>
</tr>
</tbody>
</table>
Applying UV Light

- The target dose is dependent on the challenge faced (both quantity and organism)
- The quality of the water affects the performance of a UV system. UV transmittance at 254 nm (UVT) related to the origin and treatment of water is the key indicator.
- Dose = intensity x contact time for specific transmittance
- Greater dose = greater inactivation/destruction
- Systems are dose paced with lamp output feedback to verify performance
- Performance is validated by 3rd party
Applying UV Light

- UV lamps are installed directly in the water flow, protected by quartz sleeves.

- Usually a wiping system is employed to ensure the sleeves and intensity sensors remain clear and can provide maximum treatment and accurate lamp output.
Disinfection with UV
Microbial Response to UV

UV photons are absorbed by the DNA of a microorganism, damaging the DNA by causing thymine base units to bond with each other rather than across the “ladder”, causing a bulge in the DNA. The distorted DNA can not function properly (it is prevented from replicating)
Microbial Response to UV
# LT2ESWTR Log Inactivation

<table>
<thead>
<tr>
<th>Log Inactivation</th>
<th>UV Dose Values (mJ/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryptosporidium</td>
<td>1.6 2.5 3.9 5.8 8.5 12 15 22</td>
</tr>
<tr>
<td>Giardia</td>
<td>1.5 2.1 3.0 5.2 7.7 11 15 22</td>
</tr>
<tr>
<td>Virus</td>
<td>39  58  79  100 121 143 163 186</td>
</tr>
</tbody>
</table>

clean, safe environments
Emerging Contaminants
Emerging Contaminants

- Often man made
- Examples:
  - Endocrine disrupting compounds (EDCs)
  - Pharmaceutical and Personal Care Products (PPCPs)
- Conventional drinking water and wastewater treatment cannot effectively remove
- Present in most surface waters
- Long lasting
- EPA debate regarding cost benefit for removal
EDCs

• 3 Major Classes of EDCs:
  – Estrogenic (compounds that mimic or block natural estrogen)
  – Androgenic (compounds that mimic or block natural testosterone)
  – Thyroidal (compounds with direct or indirect impacts to the thyroid)

• Sources of EDCs:
  – Some compounds occur naturally
  – Industrial uses and discharges
    • Detergents
    • Resins
    • Plasticizers
  – Municipal wastewater treatment discharge
  – Agricultural and urban use on crops and plants
    • Insecticides
    • Herbicides
    • Fumigants
PPCPs

• PPCPs include:
  – Sun screen products
  – Prescription and over-the-counter therapeutic drugs
  – Diagnostic agents
  – Veterinary drugs
  – Fragrances
  – Cosmetics
  – Nutraceuticals (vitamins)

• Sources of PPCPs:
  – Agribusiness
  – Hospital residues
  – Human activity
  – Pharmaceutical manufacturing residues (well defined and controlled)
  – Illicit drugs
  – Veterinary drug use (antibiotics and steroids)
UV and Emerging Contaminants

- **Direct Photolysis** – photons of UV light absorbed by the target pollutant break apart their chemical bond, resulting in their destruction.
  - The target UV wavelength is dependent upon the absorbance feature of the target pollutant.
  - Not very efficient against many pollutants since it requires very high levels of UV energy.
  - Very effective against NDMA in the 228 nm range.

- **Advanced Oxidation Processes**
Advanced Oxidation with UV
What is Advanced Oxidation?

• It “typically involves the formation of hydroxyl radicals that carry out the oxidation and degradation of target species.” Sarathy & Mohsens

• It is a “near ambient temperature and pressure water treatment process which involves the generation of hydroxyl radicals in sufficient quantities to effect water purification.” Glaze et al
## Oxidation Power

<table>
<thead>
<tr>
<th>Species</th>
<th>Relative Oxidation Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine</td>
<td>1.00</td>
</tr>
<tr>
<td>Hypochlorous Acid</td>
<td>1.10</td>
</tr>
<tr>
<td>Permanganate</td>
<td>1.24</td>
</tr>
<tr>
<td>Hydrogen Peroxide</td>
<td>1.31</td>
</tr>
<tr>
<td>Ozone</td>
<td>1.52</td>
</tr>
<tr>
<td>Atomic Oxygen</td>
<td>1.78</td>
</tr>
<tr>
<td>Hydroxyl Radical</td>
<td>2.05</td>
</tr>
<tr>
<td>Positively charged hole on Titanium Dioxide, TiO2+</td>
<td>2.35</td>
</tr>
</tbody>
</table>
UV / Hydrogen Peroxide

- UV with hydrogen peroxide ($\text{H}_2\text{O}_2$) is the most widely used advanced oxidation process (AOP)

- One mole of $\text{H}_2\text{O}_2$ yields 2 moles of hydroxyl radical ($\bullet\text{OH}$)

$$\text{H}_2\text{O}_2 + \text{hv} \rightarrow 2 \bullet\text{OH}$$
“When hydrogen peroxide is added to water in the presence of UV photons, the peroxide is split into 2 hydroxyl radicals by the photons and the radicals react rapidly (less than micro-seconds) with organic molecules in the water and thus degrade pollutants.” Karl Linden
UV/H$_2$O$_2$

- Need to be aware that hydroxyl radicals will also be consumed by other compounds in water (natural organic matter, carbonate species, even peroxide itself)
- Perform testing to determine the optimum UV dose and hydrogen peroxide dose combination to get the required treatment at lowest cost
- Find a peroxide source
Examples

- **Atrazine**: 6 mg/l $\text{H}_2\text{O}_2$ with 600 mJ/cm$^2$ UV dose achieved 80% reduction of atrazine
- **Ibuprofen**: 6 mg/l $\text{H}_2\text{O}_2$ with 600 mJ/cm$^2$ UV dose achieved 70% reduction of ibuprofen
- **EE2 (Contraceptive)**: 10 mg/l $\text{H}_2\text{O}_2$ with 500 mJ/cm$^2$ UV dose achieved 99% reduction of EE2
- **Dilantin (Anti Epileptic Drug)**: 10 mg/l $\text{H}_2\text{O}_2$ with 500 mJ/cm$^2$ UV dose achieved 87% reduction of dilantin
Questions????

Jennifer I. Kintzer, P.E.
Municipal Sales Engineer
Engineered Treatment Systems
238 Commercial Drive
PO Box 392
Beaver Dam, WI 53916
Phone: 877-885-4628
Cell: 920-344-7901
Fax: 920-885-4386
Email: jkintzer@ets-uv.com
Web: www.ets-uv.com