Local Section Seminar

Basics of UV Disinfection

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Presentation Outline

Basics of Ultraviolet (UV) Disinfection

Components of UV Disinfection Equipment

Design Considerations

UV Dose

True Cost of Ownership
Basics of UV Disinfection
### What is Disinfection?

Disinfection is the reduction of harmful (=pathogenic) microorganisms to a concentration which is not harmful anymore.

### Examples of the most dangerous pathogens in drinking & waste water:

<table>
<thead>
<tr>
<th>Group</th>
<th>Kind</th>
<th>Disease</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BACTERIA</strong></td>
<td>Coliforms</td>
<td>Fever, intestinal disease</td>
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<tr>
<td></td>
<td>Salmonella</td>
<td>Typhoid fever</td>
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<tr>
<td></td>
<td>Vibrio</td>
<td>Cholera</td>
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<td></td>
<td>Legionella</td>
<td>Pneumonia</td>
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<td></td>
<td>E.coli</td>
<td>Fever, gastro enteral disease</td>
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<td><strong>VIRUSES</strong></td>
<td>Hep A</td>
<td>Hepatitis</td>
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<td></td>
<td>Polio</td>
<td>Polio</td>
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<tr>
<td><strong>PARASITES</strong></td>
<td>Cryptosporidias</td>
<td>Intestinal disease</td>
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<tr>
<td></td>
<td>Amoeba</td>
<td>Amebiasis</td>
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</table>
The Principle of UV Technology

Inactivation of pathogenic microorganisms due to photooxidation of DNA

- X-rays
- Ultraviolet
  - Vacuum-UV
  - UV-C
  - UV-B
  - UV-A
- Visible Light
- Infrared

Wavelength (nm)

Hg-Low pressure Lamp 254 nm
HOW UV WORKS

• UV light penetrates the cell walls of bacteria, virus and protozoa

• The UV energy permanently alters the DNA of the microorganism

• Microorganisms are “inactivated” and unable to reproduce or infect
The Mechanism

Effects of UV irradiation on DNA

UV-light $h\nu$
The Result

Pure and safe water with UV

Distinct from chlorine and membrane filtration:

- Easy and reliable to apply
- No change of water chemistry
- No disinfection by-products (DBPs) or residuals
- No effect on odor and taste
- No regrowth of viruses, bacteria and parasites
- No corrosion
- No hazardous chemicals
- No resistance as with chlorine and antibiotics
- No concentration, no sludge
## Comparison to Other Disinfection Technologies

<table>
<thead>
<tr>
<th></th>
<th>Toxic by-products (DBP)</th>
<th>Requires chemical inventory</th>
<th>Biofilm removal</th>
<th>Residual disinfectant</th>
<th>Disinfection</th>
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<td></td>
<td></td>
<td>Bacteria</td>
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<td>Virus</td>
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<td>Crypto</td>
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<td><strong>Ozone</strong></td>
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<td><strong>UV</strong></td>
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<td><strong>Chlorine</strong></td>
<td>Yes</td>
<td>Yes</td>
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<td><strong>Chlorine dioxide</strong></td>
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<td>Yes</td>
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<td><strong>Membrane filtration</strong></td>
<td>No</td>
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<td><strong>Other chemicals</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
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Components of UV Disinfection Equipment
Open Channel UV Unit

- Banks with modules
- UV lamps in quartz sleeves
- Automatic mechanical wiping system or chemical dip tanks
- UV intensity sensor / flow meter (dose pacing)
- Level control
- Ballast cards / controls
- Air compressor for wiping system
- One or multiple channels
- Lifting equipment
Closed Vessel UV Unit
Open Channel UV Equipment - 45°

- 45° vertical incline staggered lamp system to reduce footprint
- Automatic built-in lifting device
- Automatic mechanical wiping system
Open Channel UV Inserts

- Small to medium flow wastewater applications (up to 5 MGD)

- 1 or 2 banks, up to 48 lamps

- Reduced installation cost

- Options available:
  - Indoor vs. outdoor cabinet
  - Concrete, SS, or PE channel
  - Sensor-based control
  - Automatic mechanical wiping system
  - SCADA Communication
Comparison Between Low Pressure High Output (Lo-Hi) and Medium Pressure (MP) Lamps

Lo-Hi lamps are concentrated in the 254 nm wavelength making them very efficient = less power for the same disinfection.
## Ultraviolet Lamp Technology Comparison

<table>
<thead>
<tr>
<th>Lamp Type</th>
<th>Low Pressure Lo-Lo</th>
<th>Low Pressure Lo-Hi</th>
<th>Medium Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power Consumption</strong></td>
<td>40 to 80 W</td>
<td>250 to 315 W</td>
<td>3000 to 9000 W</td>
</tr>
<tr>
<td><strong>UV-C output</strong></td>
<td>15 to 35 W</td>
<td>100 to 150 W</td>
<td>300 to 900 W</td>
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<tr>
<td><strong>UV-C Output Efficiency</strong></td>
<td>38%</td>
<td>41 to 48 %</td>
<td>10-15%</td>
</tr>
<tr>
<td><strong>Output Adjustment</strong></td>
<td>100%</td>
<td>50-100%</td>
<td>30-100%</td>
</tr>
<tr>
<td><strong>Operating Temp.</strong></td>
<td>90°C</td>
<td>100°C</td>
<td>600-1000°C</td>
</tr>
<tr>
<td><strong>Lamp Life (hours)</strong></td>
<td>9,000</td>
<td>12,000 to 14,000</td>
<td>3,000 to 8,000</td>
</tr>
</tbody>
</table>
Design Considerations
UV Design Considerations

Flow Rate – average and peak
Channel Hydraulics (width, depth and headloss)

Water quality:
- Inlet and effluent fecal coliform (log reduction)
- Total suspended solids
- Iron, manganese, hardness
- Ultraviolet transmittivity (UVT) @ 254 nm wavelength

One or multiple channels (or flow streams)

Redundancy Requirements (which flow?)
Key Design Points of UV Equipment

• **UV Dose** (10 States, Point Source Summation and Bioassay)

• **UV lamp aging factor** (end of useful life)
  Typically max of 0.85 to 0.88

• **Quartz sleeve fouling factor**
  Typically 0.90

• **Results in number of UV lamps**
UV Dose for Wastewater

UV Dose = Quantity of Cell Inactivation
UV Dose = UV Intensity x Retention Time

\[ \text{[mJ/cm}^2\text{]} = \text{[}\mu\text{W/cm}^2\text{]} \times \text{[s]} \]

Intensity is a function of:
- lamp output
- lamp age
- quartz sleeve transmissivity (coating)
- water quality (UV transmittance)
UV Dose Calculation Approaches for Wastewater

**Regulatory (10 States Standards)**

- minimum UV dose of 30,000 $\mu W$ s/cm$^2$ (or 30 mJ/cm$^2$)

**Calculated sizing models:**

- PSS (Point Source Summation) - theoretical

**Biologically verified methods (bioassays):**

- Based on real data / Target a specific microorganism (MS2 or T1)

- Should be validated by 3rd party
PSS (Point Source Summation)

- Purely mathematical approach
- Not based upon a site-specific water quality and target organism
- Not based upon microbiological data
- Adjustment for lamp ageing and fouling
- Introduced in 1986 EPA design manual
Bioassays for Wastewater

• Based on real data
• Take hydraulic performance into account
• Take real intensity distribution into account
• Target a specific microorganism (T1 or MS2)
• Site-specific (water quality/organism)
• Adjustment for lamp ageing and fouling
Using a Surrogate of Similar Sensitivity as the Target Microorganism Provides an Accurate UV-Dose Response Design
Bioassay Doses Can Be Equated to PSS Calculated UV Dose Methodology to Satisfy Necessary Guidelines

10 State Standards

This process should be limited to a high quality effluent having at least 65% ultraviolet radiation transmittance at 254 nanometers wave length, and BOD and suspended solids concentrations no greater than 30 mg/L at any time. The UV radiation dosage shall be based on the design peak hourly flow. As a general guide in system sizing for an activated sludge effluent with the preceding characteristics, a UV radiation dosage not less than 30,000 μW·s/cm² may be used after adjustments for maximum tube fouling, lamp output reduction after 8760 hours of operation, and other energy absorption losses.

<table>
<thead>
<tr>
<th></th>
<th>T1 Bioassay Dose</th>
<th>PSS Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example project</td>
<td>12.6 mJ/cm²</td>
<td>40 mJ/cm²</td>
</tr>
</tbody>
</table>
UV Bioassay Validation

- Procedure to determine the performance of a UV system
- Required because no methodology for direct measurement of microorganisms is available
- Combination of laboratory bench scale testing (Collimated Beam Device) and UV reactor field test
- Because the target organism is too dangerous (e.g. Cryptosporidium) or shows too much variability (e.g. Fecal coliforms), microbial surrogates (e.g. MS2, T1) are being used
- Ideally, the microbial surrogate should have the same sensitivity to UV light as the target pathogen
Fecal Coliform UV Dose Response Curve

Figure 3.7: Fecal Coliform Dose-Response Curve for Theresa St. Wastewater
UV Protocols

• National Water Research Institute (NWRI) Guidelines
  o 2003 (updated in 2012)

• EPA UV Disinfection Guidance Manual (UVDGM)
  o 2006

• International UV Association Protocol (IUVA)
  o 2011
Cost of Ownership
UV Cost of Ownership

Equipment Capital Cost

Installation

Electrical Costs

Equipment Consumables
- UV Lamps – 10,000 to 15,000 hours (1 ½ to 2 years)
- Ballast Cards – estimate 5 to 8 years

Equipment Replacement (at end of Equipment Life)
Thank You!

QUESTIONS