Wastewater UV Disinfection

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Presentation Outline

- Safety Moment
- Technology overview
- Regulatory challenges
- Technology challenges
- Design & operational challenges
- Closing thoughts
Safety Moment: Motion Induced Blindness
Motion Induced Blindness

• When driving, if you fix your gaze on the road straight ahead, you may suffer a momentary loss of peripheral vision & may not see a vehicle or person approaching from the side.

• Always use the “eyes moving” technique when driving, to reduce the risk of motion induced blindness.

• Now reverse the picture! If you are crossing a road on foot and you see a car approaching, there’s a very good chance you may be in that drivers blind zone!!
History of Wastewater UV Disinfection

• UV light discovered over 150 years ago
• Hg lamp: 1905
• Quartz sleeve: 1907
• First used in water disinfection in 1910 (France)
• Application in wastewater disinfection:
  – Low pressure low output: 1970s
  – Medium pressure: 1995
  – Low pressure high output: 1999
• Present: Used in approx. 20% of WWTPs
What is UV Light?

- **Vacuum UV**: 100 nm - 200 nm
- **UVC**: 200 nm - 280 nm
- **UVB**: 280 nm - 315 nm
- **UVA**: 315 nm - 400 nm

**Optimum Wavelength**: 254 nm

**Energy (kJ/mol)**:
- **Vacuum UV**: 1196
- **UVC**: 598
- **UVB**: 427
- **UVA**: 380

**Germicidal Range**: 200 nm - 260 nm

**UV Absorbance (Relative Scale)**: DNA peak at 260 nm.
What is UV Dose?

UV Dose = $I \times t$

$I$  = UV intensity (mW/cm$^2$)
$t$  = Exposure time (seconds)
Dose  = mW-sec/cm$^2$
      = mJ/cm$^2$
# UV vs. Chemical Disinfection

<table>
<thead>
<tr>
<th>Property</th>
<th>Chemical</th>
<th>UV Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathogen</td>
<td>Mixed &amp; flows with the disinfectant</td>
<td>Flows through a fixed UV field</td>
</tr>
<tr>
<td>Residual</td>
<td>Very important. Measure of disinfection efficacy</td>
<td>None</td>
</tr>
<tr>
<td>Residence time</td>
<td>Very important. Measure of disinfection efficacy</td>
<td>Very short. Not as important</td>
</tr>
<tr>
<td>Concentration / light intensity</td>
<td>Relatively uniform concentration</td>
<td>Uneven intensity distribution</td>
</tr>
<tr>
<td>Inactivation mechanism</td>
<td>Physical damage. No reactivation</td>
<td>DNA restructured. Reactivation possible</td>
</tr>
<tr>
<td>Reactivation potential</td>
<td>None</td>
<td>Yes</td>
</tr>
</tbody>
</table>
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- **Regulatory challenges**
  - Technology challenges
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Regulatory Challenges

• Indicator organism
  – Total coliform
  – Fecal coliform
  – E. Coli
  – Enterococci
  – Viruses?

• Reuse
  – Getting closer to drinking water standards
  – Disinfection by products
  – Microconstituents
  – Emerging pathogens

• Wet weather disinfection
Current Regulatory Scene

- The 2012 Recreational Water Quality Criteria recommendations have been adopted by many (not all) states

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Recommendation 1 (Illness rate: 36/1,000)</th>
<th>Recommendation 2 (Illness rate: 32/1,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Geometric Mean</td>
<td>Statistical Threshold Value</td>
</tr>
<tr>
<td>Enterococci (marine &amp; fresh)</td>
<td>35</td>
<td>130</td>
</tr>
<tr>
<td><em>E. Coli</em> (fresh)</td>
<td>126</td>
<td>410</td>
</tr>
</tbody>
</table>

STV: Not to be exceeded by >10% of the samples
The Need for Virus Indicator

- USEPA’s position:
  - Viruses are the leading cause of recreational water borne diseases
  - Bacterial indicators provide protection against bacterial pathogens not viruses
- To enhance public health protection, USEPA will be revising the WQ criteria to include viral indicator
- Focus is on coliphages - viruses that infect coliforms
Future Virus Criterion

Potential impact on disinfection
- Viruses generally more resistant to disinfection compared to bacteria
- Combined chlorine less effective on phages than free chlorine
- Significantly higher UV dose required for certain viruses

Schedule
- EPA has released the literature review of scientific information in support of its position
- Draft criteria for public comment expected in 2018-2019
- Final criteria expected in 2019-2020?
Presentation Outline

• Technology overview
• Regulatory challenges

• **Technology challenges**
  • Design & operational challenges
  • Closing thoughts
# Comparison of Different Lamp Orientations

<table>
<thead>
<tr>
<th>Horizontal Lamp System</th>
<th>Vertical &amp; Inclined Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completely submerged electrical connectors</td>
<td>Electrical connectors not submerged</td>
</tr>
<tr>
<td>Lower hydraulic head loss</td>
<td>Higher hydraulic head loss</td>
</tr>
<tr>
<td>Smaller modules; multiple modules form a bank</td>
<td>Larger modules; one module can form a bank</td>
</tr>
<tr>
<td>Small davit crane for module lifting</td>
<td>Minimum 1-ton crane required</td>
</tr>
<tr>
<td>Lamp replacement; Module removal from the channel</td>
<td>Lamp replacement: without module removal</td>
</tr>
<tr>
<td>Short circuiting with a single lamp out of service</td>
<td>No short circuiting even with multiple lamps out of service</td>
</tr>
<tr>
<td>Sensitive to water level change; large fixed weir</td>
<td>High allowable water level change; small fixed weir</td>
</tr>
<tr>
<td>Flow pacing: On/Off the entire bank</td>
<td>Flow pacing: On/Off row(s) of lamps &amp; banks</td>
</tr>
</tbody>
</table>
# Comparison of Commonly Used UV Technologies

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>LPHO Horizontal</th>
<th>LPHO Vertical</th>
<th>LPHO Inclined</th>
<th>Medium Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectrum</td>
<td>Monochromatic</td>
<td>Monochromatic</td>
<td>Monochromatic</td>
<td>Polychromatic</td>
</tr>
<tr>
<td>Power, W/lamp</td>
<td>250 - 600</td>
<td>400</td>
<td>1,000</td>
<td>2,500</td>
</tr>
<tr>
<td>Germicidal efficiency, %</td>
<td>35 - 40</td>
<td>35 - 40</td>
<td>N/A</td>
<td>15 - 20</td>
</tr>
<tr>
<td>Operating temperature, °C</td>
<td>100</td>
<td>100</td>
<td>&gt;140</td>
<td>600 - 900</td>
</tr>
<tr>
<td>Lamp turndown, %</td>
<td>100 - 60</td>
<td>100 - 10</td>
<td>100 - 30</td>
<td>100 - 60</td>
</tr>
<tr>
<td>Lamp life, hrs</td>
<td>12,000</td>
<td>12,000</td>
<td>12,000</td>
<td>5,000</td>
</tr>
<tr>
<td>Lamps/MGD</td>
<td>~10</td>
<td>~10</td>
<td>~3</td>
<td>~2</td>
</tr>
<tr>
<td>No. of facilities</td>
<td>&gt;300</td>
<td>&gt;100</td>
<td>&gt;10</td>
<td>&gt;75</td>
</tr>
<tr>
<td>CH2M design experience</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Emerging Technologies
Light Emitting Diode Lamp

- LEDs use alloys such as aluminum nitride (AlN) and gallium nitride (GaN) to generate UV light
- Emission wavelength can be selected by varying the relative amounts of AlN and GaN.

Benefits:
- Hg-free
- No warm-up
- Energy savings
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What is UV Dose?

\[
\text{UV Dose} = I \times t
\]

\[
\begin{align*}
I & = \text{UV intensity (mW/cm}^2) \\
t & = \text{Exposure time (seconds)} \\
\text{Dose} & = \text{mW-sec/cm}^2 \\
& = \text{mJ/cm}^2
\end{align*}
\]

Delivered UV Dose ≠ Calculated UV Dose

Due to:
- Uneven intensity variation
- Non-ideal flow conditions
UV Intensity Distribution Within a Reactor
Delivered UV Dose is Path-Dependent

All microorganisms do not receive the same dose.

Blatchely, et al., 1998
Dose Delivered Is a Complex Function of Several Factors

- UV intensity distribution
- Flow hydraulics
- Water quality (UV transmittance)
- Organism’s dose-response characteristics
- Lamp type
- Lamp age
- Sensor performance

*Issue*: The dose delivered by a UV reactor can not be measured or calculated!

*How can a UV system be designed & operated to ensure compliance?*
What is Equipment Validation?

Method of demonstrating the disinfection efficacy of a given UV system.

- Performance-based testing
- Focus: Inactivation of target organism
- Purpose: Define the operating window of a UV reactor in terms of 3 measurable variables
  - Flow
  - UVT
  - Power setting (lamp output)
Bioassay-based Validation Approach

Develop a family of curves by varying:
- Flow
- UVT
- Power Input

Collimated Beam Test

Bioassay Dose

Full-scale testing

UV Reactor

Log $N/N_0$ vs. UV dose (mJ/cm$^2$)
Example Validation Curves

Bioassay Dose (mJ/cm²) vs. Flow (mgd)
Impact of Upstream Processes
Impact of Effluent Solids

First-order kinetics

Dose-response with no particle interference

Tailing region

Plateau region

UV dose, mJ/cm²

Log microbe concentration
Power Quality is Crucial for Reliable UV Disinfection

- Brownout: Voltage fluctuations ± 10-15%

- Cycle interruption: 1 cycle = 0.017 sec

- Sources of poor PQ
  - Power supply: Overloaded grid
  - VFDs at WWTPs generate harmonics that can degrade power quality
Other Key Design Factors

- Hydraulics:
  - Headloss
  - Flow distribution
- Algae control
- Solids deposition
- Redundancy
  - Channel redundancy
  - Bank redundancy
Closing Thoughts

- UV disinfection is a mature technology
- Safety & environmental protection favor UV over chlorine
- As regulations evolve, UV technology is likely to become more viable
- High costs remain a barrier

- Historical flow and UV Transmittance data are crucial for ‘right sizing’ UV facilities
Questions?
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