How Old Are Your Lamps: Cost Effectively Upgrading Your UV System

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Principal Engineer
Presentation Overview

• UV Disinfection Overview
• Low Pressure, High Output UV Systems
• Case Study: Butler County UV Replacement
UV Disinfection Overview
Why Consider UV Disinfection?

• May have lower cost
  • Capital costs
  • Annual costs
• Predictable annual costs
• Reduce use of chemicals
• Eliminate dechlorination
• Fast acting, small footprint
• May fit in existing chlorine contact tank
UV Fundamentals – UV Inactivation

- Ultraviolet light is electromagnetic radiation with a wavelength from 10 to 400 nm
  - Germicidal 200-300 nm
  - Low Pressure Lamps: 254 nm
- Direct damage to cellular nucleic acids
- Does not kill microorganisms
  - Prevents accurate DNA synthesis
UV Disinfection – Common Terms

• UV Transmittance
• UV Intensity
• UV Dose
  • Theoretical
  • Point Source Summation
  • Reduction Equivalent Dose
  • Sensitivity Based Reduction Equivalent Dose
• Collimated Beam Test
Common Terms – UV Transmittance (UVT)

- Percent of UV light at 254 nm that passes through 1 cm of water
- Deionized water = 100% UVT
- UVT has huge effect on size, kW of UV systems
- UVT 65% typical for wastewater, but not always
- Percent of UV light drops for every cm of pathlength – further from lamp, less UV exposure

<table>
<thead>
<tr>
<th>Pathlength</th>
<th>Transmittance</th>
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</thead>
<tbody>
<tr>
<td>1 cm</td>
<td>65%</td>
</tr>
<tr>
<td>2 cm</td>
<td>42%</td>
</tr>
<tr>
<td>3 cm</td>
<td>27%</td>
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<tr>
<td>4 cm</td>
<td>18%</td>
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<tr>
<td>5 cm</td>
<td>12%</td>
</tr>
</tbody>
</table>
UVT Varies: Domestic vs Industrial, Upstream Processes, Wet Weather, Seasons

Sample UVT Data for Filtered Effluent

- Hourly UVT
- Design UVT

UVT (percent)

- 1/1/2013
- 2/1/2013
- 3/1/2013
- 4/1/2013
- 5/1/2013
- 6/1/2013
- 7/1/2013
- 8/1/2013
- 9/1/2013

UVT (percent)
Common Terms – UV Intensity (UVI)

• UV Intensity is UV energy in mW/cm² at a UV sensor at a point in a UV system

• UVT vs. UVI
  • UVT is a property of the water, independent of equipment
  • UVI is affected by lamp power, location, aging and fouling…and UVT

• UVI may be used for dose monitoring
Common Terms – Theoretical UV Dose

- Dose = Intensity x Time
- mJ/cm² = (mWatt/cm²) x seconds
Common Terms – Reduction Equivalent Dose (RED)

- **Bioassay**
  - Infer UV dose using log inactivation of test organism in full scale system, compared to dose vs log inactivation data developed in lab
  - Dose = Intensity x Time = OK in lab setting
  - MS2 coliphage most common test organism

- **Test organism must be stated with any RED**
  - MS2 coliphage most common test organism
  - T1 coliphage REDs – lower number

- **Ten State Standards – 30 mJ/cm² minimum dose**
  - Need to account for lamp fouling and age
  - Lower dose possible for high quality BNR, tertiary processes
Collimated Beam Test

- Allows accurate measurement of UV Dose = UV Intensity x Time
- Private lab ($1000+)
- UV manufacturers (may do for free)
- Identify lowest effluent coliform achievable
- Apply safety factors to results
  - Single sample window in time
  - Peak flow, high solids events
  - Plants want to be under permit limits, not right at them
Economic Drivers

Favors UV:
- High UVT, low TSS
- Coagulant use
- Inexpensive power
- High cost of hypo
- High dose of hypo
- Fits in existing CCT
- TRC, DBP limits

Does not favor UV:
- Low UVT, high TSS
- Dissolved iron
- High cost of power
- Low cost of hypo
- Low dose of hypo
- Low indicator limits
- High risk of floods
Low Pressure, High Output UV Systems
Established Products

- Low Pressure, High Output Lamps
- Horizontal lamps – Trojan UV3000plus, Wedeco TAK55
- Vertical lamps – Suez/Ozonia Aquaray 3X
Newer Products

- Inclined Low Pressure, High Output Lamp Systems
- Wedeco Duron, Trojan UVSigna
- **TRENDS** – Ballasts in panels, UV intensity in dose monitor
- **TRENDS** – Integrated lifting devices
- **TRENDS** – Fewer lamps per bank
Typical Maintenance Tasks

Primary maintenance activities:
• Lamp replacement
• UVT sensor cleaning and checks
• UVI sensor cleaning and checks
• Quartz sleeve cleaning
• Cleaning agents and wiper replacement

TREND:
Annual service agreements
### UV Manufacturer/System Comparison

<table>
<thead>
<tr>
<th>Item</th>
<th>Trojan Technologies UV3000Plus</th>
<th>Trojan Technologies UVSigna</th>
<th>Suez/Ozonia Aquaray 3X</th>
<th>Xylem/ Wedeco TAK55HP</th>
<th>Xylem/ Wedeco Duron</th>
<th>Calgon Carbon C\textsuperscript{2}500D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamp Orientation</td>
<td>Horizontal</td>
<td>Inclined Vertical</td>
<td>Vertical</td>
<td>Horizontal</td>
<td>Inclined Vertical</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Nominal Water Depth at UV Lamps</td>
<td>24”-34”</td>
<td>63” (2-Row) 87” (4-Row)</td>
<td>61”</td>
<td>24”-47”</td>
<td>42”</td>
<td>24”-48”</td>
</tr>
<tr>
<td>Power / Lamp (W)</td>
<td>250</td>
<td>1000</td>
<td>400</td>
<td>360</td>
<td>660</td>
<td>575</td>
</tr>
<tr>
<td>Ballast Location</td>
<td>Integral to Module</td>
<td>In Ballast Cabinets</td>
<td>In Ballast Cabinets</td>
<td>In Ballast Cabinets</td>
<td>In Ballast Cabinets</td>
<td>In Ballast Cabinets</td>
</tr>
<tr>
<td>Automated Cleaning</td>
<td>O-ring Wipers with Chemical Gel Between</td>
<td>O-ring Wipers with Chemical Gel Between</td>
<td>Teflon Ring Wiper</td>
<td>Teflon Ring Wiper</td>
<td>Teflon/Viton Ring Wiper</td>
<td>Stainless Steel Wire Ring Wiper</td>
</tr>
<tr>
<td>Variable Power</td>
<td>60–100%</td>
<td>30–100%</td>
<td>60–100%</td>
<td>50–100%</td>
<td>50–100%</td>
<td>60–100%</td>
</tr>
<tr>
<td>Wiper Driver</td>
<td>Hydraulic</td>
<td>Hydraulic</td>
<td>Electric</td>
<td>Pneumatic</td>
<td>Electric or Pneumatic</td>
<td>Electric</td>
</tr>
<tr>
<td>Removal from Channel</td>
<td>Overhead Hoist</td>
<td>Automatic Lift</td>
<td>Overhead Hoist</td>
<td>Overhead Hoist</td>
<td>Integral Lift</td>
<td>Overhead Hoist</td>
</tr>
<tr>
<td>Guaranteed Lamp Life (hrs)</td>
<td>12,000 (prorated after 9,000 hrs)</td>
<td>15,000</td>
<td>14,000</td>
<td>14,000 (prorated after 9,000 hrs)</td>
<td>14,000 (prorated after 9,000 hrs)</td>
<td>16,000 (prorated after 10,000 hrs)</td>
</tr>
<tr>
<td>Guaranteed Ballast Life (yrs)</td>
<td>5 (prorated after 1yr)</td>
<td>10 (prorated after 2yrs)</td>
<td>5 (prorated after 1yr)</td>
<td>5 (prorated after 1yr)</td>
<td>5 (prorated after 1yr)</td>
<td>10 (prorated after 2yrs)</td>
</tr>
</tbody>
</table>
Case Study: Butler County
Project Background

• Upper Mill Creek WRF (UMC)
  • 16 MGD rated capacity
  • 9.1 MGD average, 40 MGD peak

• LeSourdsville WRF (LES)
  • 15 MGD rated capacity
  • 8.5 MGD average, 35 MGD peak

• UV3000 systems by Trojan Technologies Inc.
  • Low pressure, high output lamps
  • UMC – 1992 & 1999
  • LES – 1994
Past Issues / Concerns

- Automatic cleaning of lamps
- Removal of lamps, modules, and banks
- Ballast location (flooding)
- Turndown capabilities
- Reliable control system

<table>
<thead>
<tr>
<th>Item</th>
<th>LES WRF</th>
<th>UMC WRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Channels</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Number of Banks per Channel</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total Number of Lamps</td>
<td>1056</td>
<td>1408</td>
</tr>
<tr>
<td>Channel Width</td>
<td>72”</td>
<td>66”</td>
</tr>
<tr>
<td>Nominal Water Depth</td>
<td>24”</td>
<td>24”</td>
</tr>
</tbody>
</table>
Design Considerations

- Ease of operations and maintenance
- Flexibility and energy efficiency
- Current and future NPDES permit compliance
- Updated controls and automation
Design Considerations (cont’d)

• Horizontal vs. Vertical vs. Inclined
• Lift mechanism
• Ballast location
• Cleaning mechanism
• PLC and SCADA connection
• Plant hydraulics/modifications to channels
• Future capacity
• Manufacturer experience / service
• Installation lists
• Site visits
System Alternatives

TrojanUV3000Plus – Horizontal
Wedeco TAK55 – Horizontal
Calgon Carbon C3500D – Horizontal
Wedeco Duron – Inclined
TrojanUVSigna – Vertical
Suez/Ozonia Aquaray 3X – Vertical
System Alternatives Eliminated (Channel Depth)

- TrojanUV3000Plus – Horizontal
- Wedeco TAK55 – Horizontal
- Calgon Carbon C3500D – Horizontal
- Wedeco Duron – Inclined
- TrojanUVTerna – Vertical
- Suez/Ozonia Aquaray 3X – Vertical
System Alternatives Eliminated (Site Visits)

TrojanUV3000Plus – Horizontal
Wedeco TAK55 — Horizontal
Calgon Carbon C3500D — Horizontal
Wedeco Duron — Inclined
TrojanUVSigna — Vertical
Suez/Ozonia Aquaray 3X — Vertical
Design Approach

LeSourdsville and Upper Mill Creek WRFs

• Analyze hydraulics at each plant
• Collect UVT and E. coli data at each plant
• Site visits
• Develop design criteria and sent to manufacturers
  • “Apples to apples” proposal comparison
• Pre-select UV Equipment
  • Cost proposal
  • Number of channels, lamps and ballasts required
  • Power consumed at average and peak flow
  • Guaranteed life of replacement parts
  • Replacement part cost

Used to determine life cycle cost
Pre-Selection Benefits

- Pre-selection is not pre-purchase
- Open competitive bid for UV equipment package
- Life cycle cost evaluated – guaranteed power use
- Guaranteed prices for replacement lamps, parts
- Non-cost factors can be considered:
  - Vendor experience and customer satisfaction
  - Service team location and availability
  - Equipment unique features
  - Head loss differences
- Expandability
Data Needed for Vendor Quote

- **Key Parameters**
  - Peak flow
  - Minimum UV Transmittance
  - Design UV Dose (MS2 bioassay based)
  - Indicator organism permit limits

- **Additional Data**
  - Redundant banks or channel required
  - Minimum number of banks in series
  - Upstream processes (SBR, BNR, Filters) and chemicals

- **Project-specific specification as early as possible**
Design Criteria

LeSourdvsville and Upper Mill Creek WRFs

- 10 State Standards
- National Water Research Institute (NWRI)
- Peak Flow Rate
- Effluent TSS – 30 mg/L
- 2 banks per channel
- Reduction Equivalent Dose – 30 mJ/cm² based on MS2 bioassay validation
- UV Transmittance (UVT) – 65%
Trojan UV 3000Plus

- Horizontal
- Fit is existing water depth
- Ballasts on top of module in channel (but can be extended)
- Extensive installation list; serviced well by HPT
- Chemical cleaning system concerns
- Need separate lifting system
- Extra cost for rack to lift entire bank
- Requires 2 channels at both plants
Wedeco Duron

- Vertical/Inclined
- Modifications required to deepen and narrow channels
- Ballasts in panels away from channel
- Gaining experience/installation list; good references; serviced by Wedeco from North Carolina
- Mechanical only cleaning
- Unit lifts lamps out of channel (equipment in channel for lift)
- Requires 3 channels at both plants
Non-Economic Factors

- Ease of operation and maintenance
  - Location of ballast
  - Automatic cleaning of lamps
  - Removal and cleaning of lamps
  - Seasonal storage of lamps
- Staff familiarity
- Constructability
- Reliability
Economic Considerations

• Construction costs (up-front)
  • Equipment cost
  • Modifications to accommodate new equipment
    • Structural and Electrical for Wedeco

• Operations and maintenance costs (annual)
  • Electrical
  • Lamp and ballast replacement
  • Maintenance and operations
  • Lamp cleaning chemical
## Construction Cost Comparison

<table>
<thead>
<tr>
<th>Item</th>
<th>Trojan UV3000Plus</th>
<th>Wedeco Duron</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV equipment cost</td>
<td>+$184,000</td>
<td></td>
</tr>
<tr>
<td>Outdoor ballast panel cost</td>
<td>+$132,000</td>
<td></td>
</tr>
<tr>
<td>Structural channel mods</td>
<td>+$150,000</td>
<td></td>
</tr>
<tr>
<td>Electrical cost</td>
<td>+$100,000</td>
<td></td>
</tr>
<tr>
<td>Instrumentation cost</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>UV channel roof covering and monorail improvements</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td><strong>Cost difference</strong></td>
<td></td>
<td>+$566,000</td>
</tr>
</tbody>
</table>

Note: Trojan UV3000Plus deduct for cleaning system $194,200, but more lamps required to account for lower fouling factor.
### Annual O&M Cost Comparison

<table>
<thead>
<tr>
<th>Item</th>
<th>Trojan UV3000Plus</th>
<th>Wedeco Duron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical demand</td>
<td>$0</td>
<td>$6,500</td>
</tr>
<tr>
<td>Maintenance materials cost</td>
<td>$6,200</td>
<td>$0</td>
</tr>
<tr>
<td>Labor costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical costs</td>
<td>$200</td>
<td>$0</td>
</tr>
</tbody>
</table>

**Notes:**
1. Electrical demand saving estimated at $15,000 per year over existing systems.
2. Wedeco must save nearly $50,000 a year to cover up-front cost difference.
## Non-Economic Comparison

<table>
<thead>
<tr>
<th>Item</th>
<th>Trojan UV3000Plus</th>
<th>Wedeco Duron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ease of operation and</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>maintenance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturer support</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Staff familiarity</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Constructability</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Reliability</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>
Pre-Selection

- Trojan UV3000Plus selected
  - Economic Factors
  - Non-economic Factors
- New system has many upgrades over existing system – many past issues addressed
  - Less lamps
  - Automatic cleaning
  - Variable power
  - Improved controls
Pre-Negotiation

- Prices from competitively bid projects of similar size
- Guaranteed power usage
- Guaranteed lamp and ballast life
- Guaranteed spare parts cost for 20 years
- Compare prices to past design projects
- Spare parts / cost adders
Construction Considerations

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Bidding</td>
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<tr>
<td>Construction</td>
<td></td>
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<tr>
<td>-NTP</td>
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<tr>
<td>-Shop drawings</td>
<td></td>
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<tr>
<td>-UV system fabrication</td>
<td></td>
<td></td>
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<tr>
<td>-Equipment installation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Start up</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPDES disinfection season</td>
<td></td>
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</tr>
</tbody>
</table>

Construction during non-disinfection season
Construction Discoveries

- UMC Flow Splitting
  - Baffle wall openings across from effluent pumps to dampen velocity
Construction Discoveries

- **UMC Flow Splitting**
  - Pumps further from channels operating – flow did not split evenly between channels
  - Blocked far baffle wall opening for better flow distribution
Construction Discoveries

• Higher channel velocity, higher turbulence
  • UV bank rack caused turbulence at high flow
  • UV system turning off
  • Relocated low water level rods

• Automatic Level Controller Gates
  • Client preferred over modulating weir gate
  • Weights used to adjust gate to regulate flow
  • Higher range of flow with new systems
  • During high flows, don’t regulate flow as well
Conclusion

• Many factors to consider with UV system
  • Plant-specific considerations for cost effectiveness

• No two UV systems are the same
  • Operator input needed for configuration and feature preferences
  • New construction vs. retrofit may favor one system over the other

• Work with manufacturers early
  • Uniform design criteria
  • Project-specific specification
Questions

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