Selection of UV Disinfection Systems for Achieving Class A Reuse Water at Small MBR plants

Li Lei, Douglas Berschauer, Elizabeth Hill, and Tom Moore
Outline

• Introduction (UV, WWTPs)
• Regulations on UV Disinfection for Reuse
• Design Criteria
• Selection of UV Disinfection Systems
  • Lamp types
  • Reactor configurations: open- or closed
  • Lamp arrangement: H or V
• Design Optimizations
• Conclusions
Introduction – What is UV

Germicidal Range

- UV-A (300nm)
- UV-B (200nm)
- UV-C (200nm)

Radio | IR | Visible Light | UV | X-Rays

λ (wavelength)
Introduction - Mechanisms of UV

- How does UV Work?
  - photochemically damages the pathogen’s DNA
  - inability to reproduce = non-infective
- Used for Wastewater since 1980s
- Use for water more recent and rapidly accelerating
Introduction – UV, Advantages

• Effective against bacteria and protozoa; more effective than chlorine for most viruses, spores and cysts.

• Environmental benefits
  – Eliminate/significantly reduce the need for toxic/hazardous/corrosive chemicals
  – No harmful residuals
  – Can destruct organic constituents of concerns, e.g. NDMA

• Operator-friendly: safer and simpler O&M

• Smaller footprint/space
  – short contact times (20 – 30 s for LP)
  – no need for dechlorination and chemical storage
Introduction – UV, Disadvantages

• Not as cost-effective as chlorination, but costs are competitive when dechlorination is needed and fire codes are met
• No residual to maintain in conveyance system for reuse application
• Fouling of UV sleeves - cleaning
• May not be effective for some viruses at low dosages
• Changing market, guidelines, regulations – need for validation/performance testing
Introduction - Case Studies

• Design of Belfair WRF
  – Mason County, WA
  – Currently on bid

• Schematic Design of Cascadia WWTP
  – Cascadia Development Corporation
  – To be owned & operated by Pierce County, WA
  – Engineering report done in 2009

• Common Features
  – Replace septic systems with MBR
  – Class A effluent for maximum reuse potential
  – Facility Plans recommend UV disinfection
  – Current phase capacity 0.5 mgd, 1 mgd peak
Introduction - Case Studies, Belfair WRF
Regulations – Performance/Tests (1)

- Reuse projects in WA are jointly regulated by
  - DOE, Criteria for Sewage Works Design
  - DOH, Water Reclamation and Reuse Standards
- Performance Validation/Commissioning Tests
  - Field validation test if not previously validated
  - Field commissioning test only if previously validated
- Design and Operations per adopted third party validation protocols
  - NWRI/AWWRF 2003 Guidelines
  - EPA ETV Guidance
  - German DVGW validation protocols
  - Austrian ONORM validation protocols
Regulations – Performance/Tests (2)

• Validation process: critical, best known approach to minimize design uncertainty
  – quantifies the inactivation of a virus surrogate, e.g. MS2 bacteriophage
  – defines key parameters
    – representative test water, UVT, Temp, etc.
    – system configuration: # of reactors, etc
    – hydraulics: loading/lamp, velocity uniformity
  – typically consists of
    – develop inactivation-dose responses using simultaneous laboratory collimated-beam test
    – measure pilot reactor inactivation and assign UV doses to the reactor accordingly
  – costly, unjustifiable for small projects
Regulations – Performance/Tests (3)

- Commissioning Test (NWRI/AWWRF 2003)
  - functional + verifies inlet/outlet velocity profiles consistent with the validated reactor
- Our design required accepted validation
  - allow comparison of competing reactors to uniform performance
  - ensure adequate sizing and performance of the UV disinfection system
  - achieve regulatory acceptance without extensive validation
Regulations – Reliability

- A minimum of two UV reactors must operate simultaneously in any on-line reactor train
- A standby reactor for each reactor train or a standby reactor train (alternative or storage)
- Contingency plan for excessive turbidity, low transmittance, etc.
Regulations – Reliability (2)

- Power Supply Contingency Plan
- Instrumentation and Control
  - monitoring
    - reactor/lamp status, lamp age, # of reactor cycles, liquid level, etc.
    - continuous: flow, turbidity, UV intensity, UVT, and operational UV dose for each reactor
  - Minimal Alarms for Monitored Key Parameter
## Design Criteria – Belfair WRF

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Future</th>
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<tbody>
<tr>
<td>Peak Day/Hour Flow, mgd</td>
<td>1.0</td>
<td>2.8</td>
</tr>
<tr>
<td>Max. Month Flow, mgd</td>
<td>0.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Min. Flow, mgd</td>
<td>0</td>
<td>0</td>
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**Influent**

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Min. UVT,%</td>
<td>65</td>
</tr>
<tr>
<td>Temperature, °C</td>
<td>12 - 26</td>
</tr>
<tr>
<td>TSS, mg/L</td>
<td>&lt;5</td>
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<tr>
<td>Max. Turbidity, NTU</td>
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**Effluent Total Coliform, MPN/100 mL**

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<tr>
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<tbody>
<tr>
<td>7-day Median,</td>
<td>2.2</td>
</tr>
<tr>
<td>Single Sample Max</td>
<td>23</td>
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</tbody>
</table>

**Min. UV Dose, mJ/cm²**

|                          | 80     |

**Validation**

Compliant with DOH Guidelines

**Cleaning**

On-line automatic to minimize O&M and operator’s attention
### Design Criteria – Cascadia WWTP

<table>
<thead>
<tr>
<th></th>
<th>Initial Phase</th>
<th>Phase III (2027)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Day/Hour Flow, mgd</td>
<td>1.0</td>
<td>11.2</td>
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<tr>
<td>Max. Month Flow, mgd</td>
<td>0.5</td>
<td>5.6</td>
</tr>
<tr>
<td>Min. Flow, mgd</td>
<td>0</td>
<td>1.7</td>
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</table>

#### Influent

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#### Effluent Total Coliform, MPN/100 mL

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</table>

**Validation**

Compliant with DOH Guidelines

**Cleaning**

On-line automatic to minimize O&M and operator’s attention
Selection – Lamp Types

• Based on internal operating parameters
  – Low pressure low intensity (LPLI)
    • low Hg vapor pressure, ~ 40°C
    • primarily monochromatic radiation
  – Low pressure high intensity (LPHI)
    • similar to LPLI, but higher pressure → 2-4 times the intensity of LPLI lamps, ~ 90 - 150°C
    • amalgam → constant level of mercury → better stability over temp. range → 25% longer life
  – Medium pressure high intensity (MPHI)
    • medium Hg vapor pressure, ~ 600 to 800 °C
    • polychromatic radiation → less efficient
    • ~15 times output of LPHI lamps → less lamps
Selection – Lamp Types, efficiency

260 nm: most effective in disinfection

UVDGM (EPA, 2003)

LP: 85 – 88% of output

MP: 27 – 44% of output
Selection – Lamp Types, LPHI (1)

• High efficiency
  – LP lamps are 2-3 times as efficient as MP Lamps
  – MP lamps: more used for big plants

• Higher UV intensity
  – 2 to 4 times as intensive as LPLI lamps → less lamps

• Greater lamp life
  – 25% higher than LPLI lamps
Selection – Lamp Types, LPHI (2)

• More choices
  – LPHI lamps: both open-channel and closed-vessel
  – LPLI: mostly just in open channel system

• Compared with LPLI lamps, systems with LPHI lamps offer O&M cost saving through better availability in
  – Automatic cleaning → require less or no manual, off-line, cleaning
  – capacity of dose pacing → less power
Selection- Open Channel vs. Close Vessel
## Selection of UV System – Capital, Belfair

<table>
<thead>
<tr>
<th></th>
<th>Open Channel</th>
<th>Closed Vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supplier</strong></td>
<td>Trojan*</td>
<td>Wedeco</td>
</tr>
<tr>
<td><strong>Unit Model</strong></td>
<td>3000Plus</td>
<td>TAK 55 HP</td>
</tr>
<tr>
<td><strong>Lamp Type</strong></td>
<td>LPHI</td>
<td>LPHI</td>
</tr>
<tr>
<td><strong># of Reactors</strong></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong># of Parallel Trains</strong></td>
<td>1</td>
<td>2/3</td>
</tr>
<tr>
<td><strong># of Lamps/Reactor</strong></td>
<td>18/48</td>
<td>24/60</td>
</tr>
<tr>
<td><strong>Total # of Lamps</strong></td>
<td>54/144</td>
<td>72/180</td>
</tr>
<tr>
<td><strong>Redundancy</strong></td>
<td>50%/50%</td>
<td>50%/50%</td>
</tr>
<tr>
<td><strong>Capital Cost</strong></td>
<td>$250,000</td>
<td>$252,000</td>
</tr>
<tr>
<td><strong>Annual O&amp;M</strong></td>
<td>$10,800</td>
<td>$14,500</td>
</tr>
<tr>
<td><strong>Validation</strong></td>
<td>CA Title 22 2003 NWRI</td>
<td>CA Title 22 2003 NWRI</td>
</tr>
<tr>
<td><strong>Indoor/Outdoor</strong></td>
<td>Outdoor</td>
<td>Outdoor</td>
</tr>
</tbody>
</table>

**Notes:**
- Capital Cost for Outdoor: $250,000
- Capital Cost for Indoor: $252,000
- Annual O&M for Outdoor: $10,800
- Annual O&M for Indoor: $14,500

Corrected for errors in bioassay validation
<table>
<thead>
<tr>
<th>Supplier</th>
<th>Trojan</th>
<th>Wedeco</th>
<th>Wedeco</th>
<th>Aquionics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Model</td>
<td>3000Plus</td>
<td>TAK 55 HP</td>
<td>LBX</td>
<td>InLine 5000+</td>
</tr>
<tr>
<td>Online automatic cleaning</td>
<td>Mechanical/chemical</td>
<td>mechanical</td>
<td>mechanical</td>
<td>mechanical</td>
</tr>
<tr>
<td># of operating lamps</td>
<td>36</td>
<td>40</td>
<td>40</td>
<td>16</td>
</tr>
<tr>
<td>Ave. lamp power, kw</td>
<td>0.240</td>
<td>0.270</td>
<td>0.245</td>
<td>3.55</td>
</tr>
<tr>
<td>Electricity</td>
<td>$6,055</td>
<td>$7,592</td>
<td>$6,868</td>
<td>$39,946</td>
</tr>
<tr>
<td>Lamps</td>
<td>$4,680</td>
<td>$5,997</td>
<td>$5,997</td>
<td>$6,750</td>
</tr>
<tr>
<td>Wiper Rings</td>
<td>$584</td>
<td>$1,167</td>
<td>$288</td>
<td></td>
</tr>
<tr>
<td>Quartz Sleeves</td>
<td></td>
<td>$360</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartz Sleeve Seals</td>
<td></td>
<td>$50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor ($25/hr)</td>
<td>$2,600</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ballast</td>
<td>$351</td>
<td>$351</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$10,800</td>
<td>$14,500</td>
<td>$14,500</td>
<td>$50,000</td>
</tr>
</tbody>
</table>
Selection of UV System – Belfair

• Closed-vessel systems
  – have not been validated at the time of the design, creating potential risk of
    • not delivering the required performance
    • the need for extensive on-site validation that could cost up to $100K
  – do not have carry cost advantages
    • comparable (LPHI systems) or much more expensive (MPHI) than open channel

• Open channel systems: LPHI, Horizontal
• Trojan and Wedeco specified, similar enough to design for one and allow
• Apply to Cascadia WWTP
Selection of UV System – Cascadia, Vertical Lamp Arrangement

• Drivers: operators’ interest in potential advantages of vertical systems

• Major suppliers contacted
  – Ozonia (Ondeo Degremont Inc.)
    • CA Title 22 accepted per NWRI 2003
    • Approved for flow ranges meeting the criteria
  – Severn Trent Services
    • CA Title 22 accepted per NWRI 2003
    • Not suitable for the flow range (up to 11.2 mgd peak)
Selection of UV System – Cascadia, Ozonia Aquaray 40 HO VLS

(3) 24” W x 72” H x 40’ L
## Selection - Horizontal vs. Vertical (1)

<table>
<thead>
<tr>
<th></th>
<th>Horizontal</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foot print</td>
<td>Small</td>
<td>Smaller - deeper channel</td>
</tr>
<tr>
<td>Dose pacing</td>
<td>Good – by banks</td>
<td>Potentially better – by rows or modules</td>
</tr>
<tr>
<td>Lamp replacement</td>
<td>• By module with davit crane</td>
<td>• By individual lamps</td>
</tr>
<tr>
<td></td>
<td>• need to turn off the bank (eff. quality &amp; safety)</td>
<td>• need to turn off the bank (safety)</td>
</tr>
</tbody>
</table>
### Selection - Horizontal vs. Vertical (2)

<table>
<thead>
<tr>
<th></th>
<th>Horizontal</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EOLL factor</strong></td>
<td>0.98 @ 12,000 hours (3000Plus)</td>
<td>0.90 @ 9,400 hours (Ozonia)</td>
</tr>
<tr>
<td><strong>Hydraulics</strong></td>
<td>• Lower head loss</td>
<td>• Higher head loss</td>
</tr>
<tr>
<td></td>
<td>• More uniform water level</td>
<td>• Larger variation of water level</td>
</tr>
<tr>
<td></td>
<td>• Less transverse mixing</td>
<td>• Increased transverse mixing</td>
</tr>
<tr>
<td><strong># of installations</strong></td>
<td>Numerous</td>
<td>Relatively Less</td>
</tr>
<tr>
<td>for reuse</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Evaluation of Vertical UV System – Cascadia

• Ozonia Aquaray 40 HO VLS system represents a viable option
  – validated for reuse applications
  – meets design criteria
  – budget cost $250 K comparable to horizontal systems
  – Smaller foot prints: about 25% smaller
  – Easier replacement
  – More flexible dose pacing

• Disadvantages include
  – Lack of market competition if only vertical system specified
  – # of lamps are 3 times of horizontal systems
  – likely higher O&M cost than horizontal systems
    • more lamps
    • fixed UVT and EOLL
Evaluation of Vertical UV System – Cascadia

• **Recommended approach:**
  – to maximize competitions and choices
    • take advantage of the fast advancing UV market
    • include both horizontal and vertical into a prequalification process
    • make selection early in the detailed design to allow for design around a selected system, or a couple of similar systems
  – selection should be based on
    • Costs (capital, O&M)
    • historical records
    • operators’ experience and preference
Design Optimizations (1)

• Hydraulics
  – Stilling well and perforated diffuser plate at front
  – Serpentine weir at end to control water level

• Contingency plan – emergency overflow pond
  – during short-time power outage
  – when MBR effluent is unsuitable for disinfection
  – when there is released mercury due to lamp breakage

• Electrical Contingency Plan
  – Switching to Generator during long-time failure
  – Divert to emergency storage during short-time failure
Design Optimizations (2)

• Preventing recontamination/re-growth
  – Surveyed reuse installations in NWR/VBC for need of buildings/canopy
  – Higher degree of satisfaction for in building - costly
  – Outdoor installations sufficient to meet Class A with additional care taken to avoid recontamination from run off, bird droppings, etc.
    • Periodic hypochlorite addition to minimize algae growth in channels
    • Cover channel: grates over lamps/checked plates elsewhere
    • Canopy: avoid places for bird nesting, standing, e.g. enclosed soffit
Design Optimizations (3)

- Controls for Optimized Electricity Usage and Lamp Life
  - Dose-pacing: flow & UVT
  - Modulate Number & Intensity of lamps
  - Alternate duty banks and minimize cycle times

- Monitoring to ensure compliance and prompt operator intervention
  - Major Alarms: indicates UV disinfection is not being met; alternate equipment requested online (storage); immediate attention
  - Minor Alarms: indicates conditions that may need attention; UV disinfection likely OK
Conclusions

• Selecting from previously validated UV equipment allows for uniform comparisons of competing reactors, ensures performance, and facilitate regulatory acceptance with minimized testing requirements.
• Open-channel systems with LPHI lamps were found more cost-effective than close-vessel systems.
• Horizontal and vertical lamp arrangements offer different advantages in footprint and operations and maintenance, and have generally comparable capital costs.
• To maximize competition and selection, both types can be included in a prequalification process. Selection should be made early in detailed design.
• Out-door installations are capable of generate Class A reuse water, with diligence in preventing re-contamination/regrowth.