Impact of Low Wavelength UV Light on UV Dose Monitoring with Medium Pressure UV Systems

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UV Disinfection Credit Based on Validated Algorithm

\[ RED = 10^A \times UVA^B \times \left( \frac{S}{S_0} \right)^C \times Q^D \times Banks^E \]

- UV Dose
- UV Absorbance
- Flowrate
- Bank of Lamps
- UV Lamp Output

A, B, C, D, and E – constants defined by UV validation
UVDGM: MS2 Phage and Crypto Have Similar Wavelength Response

<table>
<thead>
<tr>
<th>Microorganism</th>
<th>Type / Nucleic acid (SS = single strand, DS = double strand)</th>
<th>Germicidal Output (W/cm²)</th>
<th>Germicidal Output Relative to Cryptosporidium (Action Spectra Correction Factor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryptosporidium oocysts</td>
<td>Protozoa / DS DNA</td>
<td>5.64</td>
<td>1.00</td>
</tr>
<tr>
<td>Trichomonas</td>
<td>Animal virus / DS DNA</td>
<td>5.46</td>
<td>0.98</td>
</tr>
<tr>
<td>R. subtillis spores</td>
<td>Aerobic spore / DS DNA</td>
<td>5.56</td>
<td>0.99</td>
</tr>
<tr>
<td>E. coli</td>
<td>Animal virus / RNA</td>
<td>5.53</td>
<td>0.96</td>
</tr>
<tr>
<td>MS-2, R-17, fr. 7-S</td>
<td>Bacteriophage / SS RNA</td>
<td>5.78</td>
<td>1.04</td>
</tr>
<tr>
<td>M. luteus</td>
<td>Bacteroid / SS DNA</td>
<td>6.05</td>
<td>1.10</td>
</tr>
<tr>
<td>E. coli</td>
<td>Animal virus / SS RNA</td>
<td>5.98</td>
<td>1.07</td>
</tr>
<tr>
<td>Giardia</td>
<td>Bacteriophage / DS DNA</td>
<td>6.53</td>
<td>1.16</td>
</tr>
<tr>
<td>Polymyx</td>
<td>Animal virus / DS DNA</td>
<td>6.74</td>
<td>1.18</td>
</tr>
<tr>
<td>Hepatitis simplex</td>
<td>Human virus / DS DNA</td>
<td>7.00</td>
<td>1.26</td>
</tr>
<tr>
<td>Reovirus-3</td>
<td>Animal virus / DS RNA</td>
<td>7.46</td>
<td>1.32</td>
</tr>
</tbody>
</table>

\[ P_G = \sum_{\lambda=200nm}^{320} P(\lambda) G(\lambda) \Delta\lambda \]

Ratio = \frac{P_g^{MS2}}{P_g^{Crypto}}
UVDGM: Apply Action Spectra Correction Factor is Ratio ≥ 1.06

- UVDGM Ratio considers impact of:
  - Validation microbe and pathogen wavelength response
  - Lamp output
- UVDGM Ratio does not consider impact of:
  - Quartz sleeve type
  - Water UV absorbance
  - Reactor configuration and UV dose distribution

MP UV Lamps Emit Low Wavelength UV Light

[Graph showing lamp output vs. wavelength for UVDGM MP Lamp and Modern MP Lamp]
Synthetic Quartz Sleeves Maximize Low Wavelength UV

Big Differences with MS2 and Crypto at Low Wavelengths ...

So MS2 REDs can overstate Crypto
... and MS2 and Adenovirus at Low Wavelengths

So MS2 REDs can understate Adenovirus

UV Sensor Systems Do Not Monitor Below 240 nm

Online UVT monitors only measure at 254 nm
Lamp Aging/Fouling Impacts Lower Wavelengths More

UV sensors will not capture this affect

Water Absorbance Spectra Can Change Over Time

UV254 does not capture this affect
How Big is the Issue?

- Data from validation study used to show impact with MS2, T1UV and T7 phage
- CFD-based UV dose models used to quantify differences between Crypto and validation microbes

Validation of the ITT-WEDICO Quadron Reactor

- Validated Fall 2010 at Portland Test Facility
- 5 MP Lamps
- ONORM UV sensors
- Three test microbes
  - MS2, T1UV and T7
Quadron Validated with Three Sleeve Types

Quadron Validated Using Different Water UVA Spectra
**REDs Impacted by Sleeve Type and Water UVA Spectra**

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>RED Ratios 214:219</th>
<th>RED Ratios Synthetic:219</th>
</tr>
</thead>
<tbody>
<tr>
<td>SGA Aquifer</td>
<td>1.18 to 1.44</td>
<td>1.37 to 1.60</td>
</tr>
<tr>
<td>BLA Aquifer</td>
<td>1.02 to 1.17</td>
<td>1.06 to 1.18</td>
</tr>
</tbody>
</table>

- Sleeve type and water UVA spectra can have a significant impact on validation
- Impacts on UV system sizing and selection can be significant

**CFD-Based UV Dose Models Developed for 3 MP Reactors**

- Reactor 1 - 5 MP Lamps
- Reactor 2 - 10 MP Lamps
- Reactor 3 - 3 MP Lamps
- Hydraulics modeled using Fluent software
- UV Intensity and dose distributions modeled using UVXPT software
- Calibrated only by UV sensor readings
Good Agreement Between CFD and Validation

**Reactor 1**

![Graph showing the relationship between Predicted and Measured RED for Reactor 1. The graph includes trend lines and R² values for both BLA and SGA.]

- Reactor 2
- Reactor 3

CFD Models Must Be Proven by Comparison to Validation Data
## RED Ratios Based on MS2 and Crypto Action Spectra

<table>
<thead>
<tr>
<th>Sleeve</th>
<th>Water</th>
<th>Reactor 1 Ratios</th>
<th>Reactor 2 Ratios</th>
<th>Reactor 3 Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>219</td>
<td>SGA Aquifer + SH</td>
<td>1.08 – 1.11</td>
<td>1.06 – 1.09</td>
<td>TBD</td>
</tr>
<tr>
<td>219</td>
<td>BLA Aquifer + SH</td>
<td>1.06 – 1.10</td>
<td>1.05 – 1.07</td>
<td>TBD</td>
</tr>
<tr>
<td>214</td>
<td>SGA Aquifer + SH</td>
<td>1.31 – 1.64</td>
<td>1.30 – 1.46</td>
<td>1.16 – 1.44</td>
</tr>
<tr>
<td>214</td>
<td>BLA Aquifer + SH</td>
<td>1.10 – 1.40</td>
<td>1.07 – 1.13</td>
<td>1.05 – 1.18</td>
</tr>
<tr>
<td>Synth.</td>
<td>SGA Aquifer + SH</td>
<td>1.34 – 1.74</td>
<td>1.37 – 1.53</td>
<td>1.17 – 1.48</td>
</tr>
<tr>
<td>Synth.</td>
<td>BLA Aquifer + SH</td>
<td>1.10 – 1.39</td>
<td>1.08 – 1.14</td>
<td>1.05 – 1.19</td>
</tr>
<tr>
<td>214</td>
<td>NY + LSA</td>
<td>TBD</td>
<td>1.07 – 1.28</td>
<td>1.06 – 1.31</td>
</tr>
<tr>
<td>Synth.</td>
<td>NY + LSA</td>
<td>TBD</td>
<td>1.07 – 1.32</td>
<td>TBD</td>
</tr>
</tbody>
</table>

## Comparison of UVDGM ASCF to CFD-Based ASCF

<table>
<thead>
<tr>
<th>Sleeve</th>
<th>Water</th>
<th>Reactor 1 Ratios</th>
<th>UVDGM ASCF No Sleeve Impact</th>
<th>UVDGM ASCF With Sleeve Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>219</td>
<td>SGA Aquifer + SH</td>
<td>1.08 – 1.11</td>
<td>1.76</td>
<td>1.05</td>
</tr>
<tr>
<td>219</td>
<td>BLA Aquifer + SH</td>
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<td>1.64</td>
</tr>
<tr>
<td>Synth.</td>
<td>SGA Aquifer + SH</td>
<td>1.34 – 1.74</td>
<td>1.76</td>
<td>1.75</td>
</tr>
<tr>
<td>Synth.</td>
<td>BLA Aquifer + SH</td>
<td>1.10 – 1.39</td>
<td>1.76</td>
<td>1.75</td>
</tr>
</tbody>
</table>
Model Predicting RED Ratio Similar to RED Algorithm

\[ RED = D_L \times 10^a \times UVA^{B \times UVA} \times \left( \frac{S}{S_0} \right)^{C+D \times UVA+E \times UVA^2} \]

\[ Ratio = 10^a \times UVA^{B \times UVA} \times \left( \frac{S}{S_0} \right)^{C+D \times UVA+E \times UVA^2} \]

Ratio Model Should Use Statistically Significant Terms

\[ BLA \ Ratio = 10^a \times \left( \frac{S}{S_0} \right)^{C+D \times UVA} \]

\[ SGA \ Ratio = 10^a \times UVA^{B \times UVA} \times \left( \frac{S}{S_0} \right)^{C+D \times UVA+E \times UVA^2} \]
**Low Wavelength UV Impacts UV Dose Delivery**

- Issue with MP systems, NOT an issue with LP systems
- Impact depends on:
  - Lamp output below 240 nm
  - Sleeve type – 219 vs. 214 vs. synthetic
  - Water UVA spectra during validation
  - Reactor configuration
- Impacts pathogen disinfection and competition between UV vendors

**UV Sensor Systems Do Not Measure Low Wavelength UV**

- UV sensors have max response near 260 nm, minimal response below 240 nm
- Online UVT monitors only measure at 254 nm
- At WTP, UV sensor systems will not respond to lamp aging, fouling and changing water UVA at low wavelengths
- Need to consider impact of sensor response on adenovirus and Crypto credit, and MS2 RED
**Solutions to Low Wavelength Issue with MP Systems**

- For Crypto credit, apply action spectra correction factor based on UVDGM
  - Can be highly conservative - does not account for water UVA and reactor configuration
- Apply action spectra correction factor based on validated third party CFD
- Use Type 219 sleeves during validation
- For adeno credit, use low wavelength sensor systems

**Future Work**

- Measure response of pathogens and validation microbes from 200 to 300 nm
  - No data on Giardia, T1UV and T7 phage
- Continue work quantifying issue using CFD-based UV dose models
  - Need a protocol for 3rd party CFD-based calculations
- Develop UV sensor systems for low wavelength UV light
- Evaluate impact of WTP waters on correction factors
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