A Review of the Ultraviolet Disinfection of Wastewater for Discharge and Reuse

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Advantages of Ultraviolet Disinfection

- Physical process not a chemical process
- Does not create toxic compounds which may affect the aquatic biota or a source of drinking water
- Inactivates viruses and vegetative and spore forming bacteria
- Inactivates *Cryptosporidium* and *Giardia*
- Is cost competitive with chlorination, ozonation and chlorination/dechlorination
- Eliminates handling and storing of dangerous toxic chemicals
- Uniform Fire Code is not applicable (USA)
- Minimizes building requirements
- Very few moving parts
What is Ultraviolet Light?

<table>
<thead>
<tr>
<th>Cosmic Rays</th>
<th>Gamma Rays</th>
<th>X-Rays</th>
<th>Ultraviolet</th>
<th>Infrared</th>
<th>Micro Waves</th>
<th>Radio Waves</th>
</tr>
</thead>
<tbody>
<tr>
<td>10^{-13} m</td>
<td>10^{-9} m</td>
<td>10^{-7} m</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Vacuum UV (UV-C) 100 - 185 nm
Short Wave UV (UV-B) 200 - 254 nm
Middle Wave UV (UV-A) 300 - 315 nm
Long Wave UV (UV-A) 400 nm

1 X 10^{-9} m = 1 nm (nanometer)

Making Water and Air Safer and Cleaner
Disruption of the DNA by the Action of UV Light

Hypothetical DNA Double Strand:

Replicating DNA:

Dimerization of Thymine Nucleotides:
Open Channel UV Disinfection of Wastewater for Discharge or Reuse

Calgon C3 Series UV Systems

Making Water and Air Safer and Cleaner
Pressurized UV Disinfection of Water or Wastewater

Calgon Sentinel UV Systems

Making Water and Air Safer and Cleaner
Factors Affecting UV Disinfection

- UV Transmission (Minimum) Examples
- Turbidity, Total Suspended Solids (Maximum) Examples
- Alkalinity (Cleaning System)
- Hardness (Cleaning System)
- Dissolved Ions (Cleaning System) Example: Iron
- Flow Rate (Maximum, Average, and Minimum)
- Permit Limit (Number of Lamps) Examples
- Temperature (Wastewater and Air) Examples
- Redundancy
- Space
- Power Consumption (Type of Lamp)
- Equipment Design Factors Examples
UV Transmittance

UV Lamp 254 nm

Aperture

Lens

Quartz Sample Cell

1 cm water layer

Transmitted UV Light

Detector (Photometer)

Making Water and Air Safer and Cleaner
## Typical UV Transmittances

<table>
<thead>
<tr>
<th>Water</th>
<th>UVT&lt;sub&gt;254&lt;/sub&gt;, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtered potable</td>
<td>85 - 99</td>
</tr>
<tr>
<td>Raw potable</td>
<td>20 - 99</td>
</tr>
<tr>
<td>Filtered secondary effluent</td>
<td>65 - 80</td>
</tr>
<tr>
<td>Secondary effluent</td>
<td>40 - 75</td>
</tr>
<tr>
<td>Primary effluent</td>
<td>5 - 35</td>
</tr>
<tr>
<td>Raw wastewater</td>
<td>5 - 10</td>
</tr>
</tbody>
</table>
Effect Of Varying % Transmittance On Disinfection

The UV System Must Be Designed for a Minimum UV Transmittance Level.
Effect of UV Transmission on UV Dose and the Number of Lamps

SUNTEC Flow Test Results

- **Equation 1:**
  \[ y = 4064.9x^{-0.7957} \]
  \[ R^2 = 0.9627 \]

- **Equation 2:**
  \[ y = 569.85x^{-0.5872} \]
  \[ R^2 = 0.8405 \]

Graph showing the relationship between flow (gpm) and estimated dose (mJ/cm²) with data points indicating days and percentages for different scenarios.
Effect of Particle Numbers and Size

- The most important factor in achieving disinfection for water reuse and discharge is shielding of the microorganisms from the UV light.
- The second most important factor is UV transmission.
Effect of Particle Numbers and Size

Impact of Disinfection following Activated sludge for UV

Hunter & Salveson
WEFTEC 06

making Water and Air Safer and Cleaner
Effect of Particle Numbers and Size

Impacts to Disinfection following Fixed Film for UV

Hunter & Salveson
WEFTEC 06

Making Water and Air Safer and Cleaner
Effect of Particle Numbers and Size

- Particle and particle size negatively affect UV disinfection system performance
- The type of upstream biological treatment process impacts the effect of particles

Filtration with coagulation enhances UV disinfection
Flow Rate

Maximum Flow Rate
Average Flow Rate
Minimum Flow Rate
UV Dose or Fluence
(mW·sec/cm² or mJ/cm² or J/m²)

Quantity of UV Light That Does the Work

Dose = I x T
I = Intensity (mW/cm² or W/m²)
T = Time (seconds)

1. As the flow rate increases, the number or output of the UV lamps must be increased proportionally to maintain the same disinfection requirements.
2. Therefore, the UV system must be designed for the maximum flow rate at the end of the lamp life.
Dose of the LPHO and LPLO UV Systems Using Fecal Coliforms versus Flow Rate

Secondary Effluent
% UVT 54 to 70
TSS 4 to 7.2 mg/L
6 Replicates
Permit Limits
Examples of Surface Discharge Regulations in the USA

- Typical Surface Waters: 200 fecal coliforms or 126 *E. coli* per 100 mL
- Discharge to Seawater: 35 Enterococci per 100 mL
Examples of Water Reuse Regulations in the USA

<table>
<thead>
<tr>
<th>State</th>
<th>Bacteria</th>
<th>Virus/Protozoa</th>
</tr>
</thead>
<tbody>
<tr>
<td>California “Tertiary Recycled”</td>
<td>2.2 MPN/100 mL Total Coliforms</td>
<td>5-log inactivation/kill of viruses expected, pathogen free water</td>
</tr>
<tr>
<td>Arizona Class A and Class A+ Water</td>
<td>ND Fecal Coliforms per 100 mL, 7-day median</td>
<td>Pathogen free water expected</td>
</tr>
<tr>
<td>Texas “Type 1 Reclaimed”</td>
<td>20 CFU/100 mL Fecal Coliforms</td>
<td>No Standard</td>
</tr>
<tr>
<td>Florida “High Level Disinfection”</td>
<td>ND Fecal Coliforms per 100 mL, 75% of the time</td>
<td>Pathogen free water expected</td>
</tr>
<tr>
<td>Nevada “Class A Water”</td>
<td>2.2 MPN/100 mL Total Coliforms</td>
<td>None Listed</td>
</tr>
</tbody>
</table>
California Title 22 UV Disinfection Guidelines

- Media Filtration 100 mJ/cm²
  - 55 % UVT at 254 nm
  - Less than 5 NTU 95 % of the time
  - TSS less than 5 mg/L (Florida)
  - Confirmation of dose with collimated beam

- Membrane Filtration 80 mJ/cm²
  - 65 % UVT at 254 nm
  - Less than 0.2 NTU 95 % of the time

- Reverse Osmosis 50 mJ/cm²
  - 90 % UVT at 254 nm
  - Less than 0.2 NTU 95 % of the time
Design Conditions:

- End of lamp life 50% unless testing shows different
- 80 percent UVT for quartz sleeves unless cleaning system shows different
- If transmittance data (a minimum of three samples per day spaced equally over the operating period) have been collected for a minimum period of 6 months, including wet weather periods, the 10-percentile UVT value can be used at a wavelength of 254 nm.
- One extra UV reactor (bank) per channel
- Power cabinets will have independent power supplies
- UV channels without crevices with UV resistant coating
- The cover over, in front of, and behind the UV system must be water and light tight
- Each reactor train must be capable of being isolated.
- There must be adequate online monitoring and alarms.
- The UV dose must be confirmed with a bioassay using MS2 coliphage according to a strict set of rules.
Thank you