Treatment Techniques for Cyanobacteria and their Toxins and Public Water Systems

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Wayne State University
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Understanding microorganism and chemical removal/inactivation

• Living organisms
  – Nonviable/Removal

• Chemical Contaminants
  – Adsorption/nano-RO Filtration/oxidation/
    Biodegradation
Overview Drinking Water Treatment

- Treatment to remove intracellular algal toxins
  - Conventional treatment
    - Filtration
    - Membrane technologies
- Treatment to remove extracellular algal toxins
  - Oxidation
  - Physical removal
  - Biologically active filters
Source Water

- Intracellular Toxin
  - Flushing
  - Harvesting
  - Diversion
  - Flocculants
  - Algaecides (low levels)
  - Ultrasound

- Extracellular Toxin
  - Awareness and get ready to treat
Cloud cover often interferes with MODIS images.
Early Warning Systems

Buoys: Fluorescence Probes

Remote sensing: MODIS
Intake

- **Intracellular Toxin**
  - Adjustable Intake
  - Night vs Day

- **Extracellular Toxin**
  - Oxidants
  - Inline Powdered Activated Carbon (PAC)

- A conventional treatment plant will want to keep the cells intact.

![Intake Microcystin Concentrations](image)
Powdered Activated Carbon

• Wood-based PAC is more effective than coconut-based and bituminous PACs in the removal of microcystins

• Jar Test

• Pre-chlorination is not recommended before the use of PAC
# Particulate Removal Treatment

## A Summary of Cyanobacteria Intact Cell Efficiency

<table>
<thead>
<tr>
<th>Treatment</th>
<th>% Optimized Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coagulation/sediment or dissolved air flotation/rapid sand filtration</td>
<td>&gt;99.5%</td>
</tr>
<tr>
<td>Lime precipitation/sedimentation/rapid sand filtration</td>
<td>&gt;99.5%</td>
</tr>
<tr>
<td>Ballasted Flocculation/filtration</td>
<td>&gt;95%</td>
</tr>
<tr>
<td>Coagulation/sedimentation microfiltration</td>
<td>&gt;90%</td>
</tr>
<tr>
<td>Coagulation/sedimentation ultrafiltration</td>
<td>&gt;90%</td>
</tr>
</tbody>
</table>
## Conventional Treatment

### Table 3.1. Utility Information.

<table>
<thead>
<tr>
<th>Site Identification Number</th>
<th>State</th>
<th>Source Water</th>
<th>PAC</th>
<th>Coagulation/ Flocculation</th>
<th>Clarification</th>
<th>Filtration</th>
<th>Disinfection</th>
</tr>
</thead>
<tbody>
<tr>
<td>123</td>
<td>VT</td>
<td>Lake</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Sand/Anthracite</td>
<td>Chlorine</td>
</tr>
<tr>
<td>485</td>
<td>FL</td>
<td>River/Reservoir</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Chloramines</td>
</tr>
<tr>
<td>619</td>
<td>OK</td>
<td>Reservoir</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Sand/Anthracite</td>
<td>Chlorine</td>
</tr>
<tr>
<td>762</td>
<td>CA</td>
<td>Reservoir</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Sand/Anthracite</td>
<td>Ozone/Chloramines</td>
</tr>
<tr>
<td>929</td>
<td>TX</td>
<td>Reservoir</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Sand/Anthracite</td>
<td>Chloramines</td>
</tr>
</tbody>
</table>

### Table 2.2.1. Range of cell removal by water treatment for total cyanobacteria and toxin-producers.

* log removal cannot be determined. Toxin producer numbers were very low in the raw water, and not detected in the finished water.

<table>
<thead>
<tr>
<th>Location</th>
<th>Total Cyanobacteria (Range of cell removal (log&lt;sub&gt;10&lt;/sub&gt;))</th>
<th>Toxin Producers (Range of cell removal (log&lt;sub&gt;10&lt;/sub&gt;))</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td>1.5 to &gt;5.5</td>
<td>1.5 to &gt;5.5</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>1.6 to &gt;3.4</td>
<td>0.2 to &gt;3.2</td>
</tr>
<tr>
<td>Vermont</td>
<td>&gt;2.5 to 3.1</td>
<td>* to &gt;2.2</td>
</tr>
<tr>
<td>Texas</td>
<td>&gt;2.8 to &gt;4.0</td>
<td>&gt;1.6 to &gt;4.0</td>
</tr>
<tr>
<td>Florida (both sources)</td>
<td>1.6 to 3.8</td>
<td>1.6 to 3.3</td>
</tr>
</tbody>
</table>

Szlag, et. al, Cyanobacteria and Cyanotoxins Occurrence and Removal from Five High-Risk Conventional Treatment Drinking Water Plants. Toxins 2015, 7, 2198-2220
Coagulation/Sedimentation

- **Intracellular Toxin**
  - Oxidants (not often used, afraid of lysing cell)
  - Flocculent aides
  - Settled water with less than 100 units algae/mL

- **Extracellular Toxin**
  - Activated Carbon
    - Powder (PAC)
    - Granular (GAC)
  - Filtration
    - Conventional
    - Biologically Active

- **Monitoring Techniques to determine treatment**
  - Turbidimeter
  - Streaming current detector
  - Particle Counter
  - Chlorophyll-a
  - Cell counts
  - ELISA
    - Saxitoxin, Anatoxin-a, Cylindrospermopsin, Microcystin
    - Plate, Test tube kit, Dip Stick

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**Diagram:**

- Raw Water → Rapid-Mix Basin → Flocculation Basin → Sedimentation Basin → Filters → Clearwell Backwash Pumps → To Distribution
- Disinfection Chemicals
- Coagulants and Coagulant Aids
- Sludge → Wash Water
Harboring/Culturing within the Treatment Process

<table>
<thead>
<tr>
<th>Location</th>
<th>Source Water</th>
<th>Plant Interior</th>
<th>After Filtration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cyr</td>
<td>sext</td>
<td>mcy</td>
</tr>
<tr>
<td>OHIO 1</td>
<td>BLD</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>OREGON 1</td>
<td>BLD</td>
<td>BLD</td>
<td>BLD</td>
</tr>
<tr>
<td>OHIO 2</td>
<td>BLD</td>
<td>BLD</td>
<td>YES</td>
</tr>
<tr>
<td>COLORADO 1</td>
<td>BLD</td>
<td>BLD</td>
<td>BLD</td>
</tr>
<tr>
<td>COLORADO PLANT 2</td>
<td>BLD</td>
<td>BLD</td>
<td>BLD</td>
</tr>
<tr>
<td>KENTUCKY</td>
<td>BLD</td>
<td>BLD</td>
<td>BLD</td>
</tr>
<tr>
<td>FLORIDA</td>
<td>BLD</td>
<td>BLD</td>
<td>BLD</td>
</tr>
<tr>
<td>OREGON</td>
<td>BLD</td>
<td>BLD</td>
<td>BLD</td>
</tr>
<tr>
<td>NEW YORK</td>
<td>BLD</td>
<td>BLD</td>
<td>YES</td>
</tr>
<tr>
<td>OKLAHOMA</td>
<td>BLD</td>
<td>BLD</td>
<td>YES</td>
</tr>
</tbody>
</table>

Ultrasonic Technology Treatment

Low power ultrasound
Tunable (79 frequencies)
Critical resonance (gas vesicles)
Cyanobacteria – Microcystis, Anabaena, Lyngba (Sonic Solutions)

George Hutchinson, Opflow April 2008
Breakthrough of cyanobacteria into the clarified water

WARNING: 9180 µg/L MC-LR

References:
1) Zamyadi et al. (2012) Water Research 46, 1511-1523
2) Zamyadi et al. (2013) Water Research 47, 1080-1090
Filtration

- Conventional
- Biologically Active
- GAC
- Low Pressure Membrane
Biologically active filters

- INTRACELLULAR TOXIN
- MCY-LR, MCY-LA, cylindrospermopsin, and anatoxin-a can be removed by biologically active sand and GAC filters
- Empty bed contact times--5 to 15 minutes.
  - Slow filtration
  - Rapid filtration
- Saxitoxin - not removed
GAC filtration

- Effectiveness of GAC filtration against cyanotoxins is source water dependent
- Significant differences in adsorption between LA and LR
- Saxitoxins and anatoxin-a are more readily adsorbed than microcystins
Pore Size

- **Equilibrium**
  - **Micropore**
    - Taste and odor
    - Industry spills, solvents
    - Anatoxin-a
  - **Mesopore**
    - Microcystins
      - RR > YR > LR > LA
    - Cylindrospermopsin
    - Saxitoxin

- **Kinetic <1 hour contact time**
- **Large pore volume seems to be more effective**
## Summary of Oxidation Treatment Processes Extracellular Toxins

<table>
<thead>
<tr>
<th></th>
<th>Microcystin</th>
<th>Saxitoxin</th>
<th>Chloramine</th>
<th>Chlorine dioxide</th>
<th>Hydroxyl radical</th>
<th>KMnO4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chlorine</strong></td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Ozone</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Chloramine</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td><strong>Chlorine dioxide</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td><strong>Hydroxyl radical</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td><strong>KMnO4</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Clearwell: Chlorination of Microcystin (1 log removal)

Acero et. al 2005

Extrapolation for pH above 9.0
Chloramination

Goal – To achieve additional removal of MC if pre-oxidation is not adequate

Summary
LW, LY, YR >> LR, RR> LA, LF, dmLR

Temperature Dependence
the warmer the better

pH Dependence
7 is better than 9
UV Treatment

- UV inactivation dose is about 40 mJ/cm$^2$ – inactivation of *Cryptosporidium parvum*.

- Photolytic destruction dose for microcystin, cylindrospermospin, anatoxin-a and saxitoxin is 1530 to 20,000 mJ/cm$^2$. 
- Intake
- Inline Chemical
- Coagulation/Flocculation/Sedimentation
- Storage Reservoir
- Filtration
- Carbon Adsorber
- Chlorine
Zamyadi et al. “Management of toxic cyanobacteria in full scale treatment plants. 4th National Cyanobacteria Workshop Adelaide, SA(9/23/114)

# Harboring/Seeding/Growing Cyanobacteria

<table>
<thead>
<tr>
<th>Location</th>
<th>Source Water</th>
<th>Interior Plant</th>
<th>After Filtration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CYL</td>
<td>SAX</td>
<td>MCY</td>
</tr>
<tr>
<td>NEW YORK</td>
<td>BLD</td>
<td>BLD</td>
<td>YES</td>
</tr>
<tr>
<td>OHIO 1</td>
<td>BLD</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>OHIO 2</td>
<td>BLD</td>
<td>BLD</td>
<td>BLD</td>
</tr>
<tr>
<td>KENTUCKY</td>
<td>BLD</td>
<td>BLD</td>
<td>BLD</td>
</tr>
<tr>
<td>FLORIDA</td>
<td>BLD</td>
<td>BLD</td>
<td>BLD</td>
</tr>
<tr>
<td>ARIZONA</td>
<td>BLD</td>
<td>BLD</td>
<td>YES</td>
</tr>
<tr>
<td>COLORADO 1</td>
<td>BLD</td>
<td>BLD</td>
<td>BLD</td>
</tr>
<tr>
<td>COLORADO PLANT 2</td>
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<tr>
<td>OREGON</td>
<td>BLD</td>
<td>BLD</td>
<td>BLD</td>
</tr>
</tbody>
</table>

Source Water
Interior Plant
After Filtration
Questions?