ATP Monitoring in Drinking Water Distribution Systems

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Overview

• Biofilms
• ATP (Adenosine Triphosphate) monitoring
• Examples of ATP Monitoring in drinking water distribution systems (DWDS’s)
• Future work
Water Treatment

• Disinfection does not mean sterilization
• Bacteria in the DWDS are inevitable
• Revised Total Coliform Rule:
  – Goal: Absence of Total Coliforms in 100% of samples
  – Maximum Contaminant Level: Absence of Total Coliforms in >95% of samples (for large systems)
Water Treatment

Juggling act
- Chlorine residual window (0.02-4.0 mg/L in DWDS)
- **Bacterial regrowth/biofilm formation**
- Organic content (DOC or TOC)
- DBP formation
- Corrosion control chemistry
- pH
- More...
Bacterial Regrowth

• Factors contributing to bacterial regrowth:
  • Temperature
  • pH
  • Pipe material
  • Contamination
  • Dissolved Organic Carbon (DOC): Bacteria food
Bacterial Regrowth

- Bacterial form biofilms in DWDS
- EPS Matrix: 75-90% of biomass of biofilm

Donlan, R. *Emerging Infectious Diseases* 2002, 8, 881-890.
99.9% of all bacteria on Earth are found in biofilms!
Bacterial Regrowth

• Biofilm formation in DWDS
  – In addition to pathogenic bacteria, biofilms can harbor:
    • Viruses
    • Parasites
    • Fungi

• Biofilms can release contents which may then react with free chlorine
Bacterial Regrowth

How can we detect biofilms?
Measuring ATP

- ATP is present in all living things
- Energy currency of biochemical reactions
Measuring ATP

- Results in minutes
- Surfaces, deposits, or liquid
- More ATP = more living cells
Measuring ATP

• “Firefly” ATP assay

  Luciferase (enzyme)  + Luciferin (substrate)  + ATP (energy source)

  1 UNIT OF LIGHT @ 560 nm (what we measure)
Measuring ATP

• LuminUltra System
  – Simple 4-step system
  – Portable luminometer
  – Operate with your phone
Measuring ATP

1. Filter sample

100 mL sample size
Filtration condenses any living cells onto filter
Measuring ATP

2. Lyse cells

Wash cells stuck on filter with solution that breaks cell open and allows ATP within the cells to pass through filter
Measuring ATP

3. Mix sample with reaction mix

\[
\text{ATP} + O_2 + \text{luciferin} \xrightarrow{\text{Mg}^{++} \text{luciferase}} \text{AMP} + PPi + \text{oxyluciferin} + \text{light}
\]

Can anyone guess what color?

A) Red
B) Orange
C) Yellow
D) Green
E) Blue
F) Violet

Image Credit: LuminUltra Technologies

\(~560 \text{ nm}\)
Measuring ATP

4. Measure immediately

Calibrate luminometer by first measuring a standard with a known concentration and then measuring samples.
Measuring ATP

- Results are given in RLU: Relative Light Units
- Compare your unknown against a standard to determine unknown concentration
- Calculations are performed in-app
- Results are time stamped, geo-coded
- Cloud server
Translating Results

• Intracellular ATP only (bulk water samples)
• Direct relation to an exact number of bacteria is difficult without proper equipment
• Best translation:
  – Low (< 10 pg/mL)
  – Continued monitoring (10 pg/mL <-> Raw Water)
  – High (>Raw water)
Bacterial Regrowth Areas of Concern

- Areas of high water age
- Finished water storage tanks
- Dead ends
- Interconnects with other DWDS’s
- Filter beds/Sides of filter bed walls
- More...
GAC ATP Monitoring

Granular Activated Carbon filters: DOC removal with help of biofilms

GAC Monitoring

Biofilm monitoring via ATP shows Biofilm stabilizes after 30 days...

GAC Monitoring

...and yields a stable ~15-40% Reduction in DOC over long term due to biofilm metabolism of DOC

GAC Monitoring

Without biofilm, DOC of effluent might look like this:

Filter Bed Spray Cleaners
Filter Bed Spray Cleaners
## Filter Bed Spray Cleaners

<table>
<thead>
<tr>
<th>Sample ID or QC Action</th>
<th>Result (RLU)</th>
<th>Result</th>
<th>Result Units</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coated Surface</td>
<td>102</td>
<td>10</td>
<td>pg/cm^2</td>
<td>73.5%</td>
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<tr>
<td>Coated: cleaned</td>
<td>27</td>
<td>2.6</td>
<td>pg/cm^2</td>
<td></td>
</tr>
<tr>
<td>Uncoated</td>
<td>1017</td>
<td>99</td>
<td>pg/cm^2</td>
<td>95.7%</td>
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<tr>
<td>Uncoated: cleaned</td>
<td>44</td>
<td>4.3</td>
<td>pg/cm^2</td>
<td></td>
</tr>
<tr>
<td>Trough</td>
<td>154</td>
<td>15</td>
<td>pg/cm^2</td>
<td>85.1%</td>
</tr>
<tr>
<td>Trough: Cleaned</td>
<td>23</td>
<td>2.2</td>
<td>pg/cm^2</td>
<td></td>
</tr>
<tr>
<td>Anthracite</td>
<td>11594</td>
<td>33500</td>
<td>pg/g</td>
<td>96.0%</td>
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<tr>
<td>Anthracite: Cleaned</td>
<td>468</td>
<td>1400</td>
<td>pg/g</td>
<td></td>
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<tr>
<td>Sand</td>
<td>1225</td>
<td>3500</td>
<td>pg/g</td>
<td>84.8%</td>
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<tr>
<td>Sand: Cleaned</td>
<td>186</td>
<td>540</td>
<td>pg/g</td>
<td></td>
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<tr>
<td>Biofilm</td>
<td>228959</td>
<td>660000</td>
<td>pg/g</td>
<td></td>
</tr>
</tbody>
</table>
Future Work

If we measure ATP....

We detect elevated biomass...

Does this correlate with anything else?
- DBPs
- Incidences of diseases
- More...
Thank you to:
Matt Seeker
CoB Filtration plant
Adam Barnett, LuminUltra