Methods for evaluating pathogen log removal in a water treatment plant

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Water Quality / Research Team

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N.McLellan

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Dr.M.Emelko.
Log removals – not a requirement

✓ Better understanding of plant performance
✓ Validate credits granted
✓ Learn how various pathogens are removed
✓ Weak points in your “multiple barriers”
✓ Fundamental to QMRA
✓ Best practice
✓ Public health
Tools & techniques to evaluate pathogen removal in a water treatment plant

1. Regulatory tables & guidance
2. Research Literature
3. Particle counts & turbidity
4. Native organisms
5. Pathogen challenge studies (pilot plant)
6. Microsphere & surrogate spiking (full-scale)
Method #1
Use of regulatory guidance values for pathogen removal
Regulatory tables state pathogen removal credits for various treatment processes

**Procedure for disinfection of drinking water in Ontario**  
*(Ministry of Environment, 2006)*

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Crypto log removal credit</th>
<th>Giardia log removal credit</th>
<th>Virus log removal credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional filtration</td>
<td>2.0</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Direct filtration</td>
<td>2.0</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Slow sand filtration</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Diatomaceous earth filtration</td>
<td>2.0</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Membrane filtration</td>
<td>2.0</td>
<td>3.0 +</td>
<td>0 – 2.0 +</td>
</tr>
<tr>
<td>Cartridge filtration</td>
<td>2.0</td>
<td>2.0 +</td>
<td>0</td>
</tr>
</tbody>
</table>
Method #2
Research literature values for various treatment processes
Method #2
Research literature values for various treatment processes

- KWR (2010) review of published literature values from various pilot & full-scale plant studies
- evaluated the *quality* of each study (level 1-5) and reported weighted-mean values for log-removal

<table>
<thead>
<tr>
<th>treatment processes:</th>
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<tbody>
<tr>
<td>coagulation &amp; sedimentation</td>
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<tr>
<td>conventional filtration</td>
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<tr>
<td>rapid granular filtration</td>
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<tr>
<td>slow-sand filtration</td>
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<tr>
<td>GAC filtration</td>
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<tr>
<td>direct filtration</td>
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</table>

<table>
<thead>
<tr>
<th>tables of reported log-removal values for</th>
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</thead>
<tbody>
<tr>
<td>cryptosporidium</td>
</tr>
<tr>
<td>giardia</td>
</tr>
<tr>
<td>bacteria</td>
</tr>
<tr>
<td>spores</td>
</tr>
<tr>
<td>Viruses</td>
</tr>
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</table>
### Method 2:
Example: literature reported values for log-removal by conventional treatment (KWR, 2010)

<table>
<thead>
<tr>
<th>Study #</th>
<th>Crypto</th>
<th>Giardia</th>
<th>Virus</th>
<th>Bacteria</th>
<th>B.spores</th>
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<tbody>
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<td>1.7</td>
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<td>23</td>
<td>1.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Wt. Avg (Std. dev) | 3.2 (1.3) | 3.4 (0.9) | 3.0 (1.4) | 2.1 (0.8) | 2.4 (0.9) |

**Ministry of Environment**

Log removal credit

**Health Canada**

Log removal credit
Method #3

Use of particle counts and turbidity data
Method #3
Use of particle counts and turbidity data

Coagulation transforms the entire particle matrix – therefore, not comparing the same particles!

average particle log removal = 3.6
Method #4
Use of “native” organisms to assess removal through treatment
Water Treatment Process
City of Ottawa – Britannia & Lemieux Island WPP’s

- Total coliforms
- E.Coli
- Aerobic spores

Raw water → Coagulation & Flocculation → Sedimentation → Dual-media Filtration → CT Disinfection (Clearwell) → pH Adjustment & Chemical Mixing

- log removal for coag + sed
- log removal for coag + sed + filtration
Water Treatment Process
City of Ottawa – Britannia & Lemieux Island WPP’s

Log removal
\[ = -\log_{10} \left( \frac{C_i}{C_o} \right) \]

log removal for coag + sed = 1 log
log removal for coag + sed + filtration = 4 log
COAG / FLOC / SEDIMENTATION

Ottawa Full-scale physical log-removal of “native” Total Coliform and 
E.coli microorganisms (2006 – 2011)

Total Coliform log removal
n=365, mean = 1.78, stdev = 0.51

E.coli log removal
n=258, mean = 1.40, stdev =0.34
Method #4
Use of “native” organisms to assess removal through treatment
Method #5
Pilot-scale seeding trials using microorganisms and surrogate particles

giardia

crypto

4.5 µm sphere

fluorescent e.coli
Pilot Plant Water Treatment Process

Raw water → Coagulation & Flocculation → Sedimentation → Dual-media Filtration

- Anthracite
- Sand
Feed locations for Pilot Plant experiments

Expt #4,5 & 8: raw water spiking (bio-colloids)

Expt #3,6 & 7: filter spiking (bio-colloids)

Have the flexibility to measure removals through both co-ag and filtration independently.
Pilot Plant experiments

Trial #3
Filter spiking cold water

Trial #4
Raw spiking warm water

Trial #5
Raw spiking cold water

Trial #6
Filter spiking warm water

Trial #7
variable seed concentrations

Trial #8
winter challenge trial

### Experimental methodology

<table>
<thead>
<tr>
<th>Pathogen surrogate</th>
<th>Size (µm)</th>
<th>Concentration (# per L)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>virus</strong> (PRD1 bacteriophage)</td>
<td>0.06</td>
<td>1.1 x 10^8</td>
</tr>
<tr>
<td><strong>bacteria</strong> (polystyrene microsphere)</td>
<td>1.0</td>
<td>2.6 x 10^7</td>
</tr>
<tr>
<td><strong>bacteria</strong> (fluorescent <em>E. Coli</em>)</td>
<td>1.35</td>
<td>1.7 x 10^6</td>
</tr>
<tr>
<td><strong>bacteria / protozoa</strong> (Aerobic Spores - <em>B. Atropheus</em>)</td>
<td>2.5</td>
<td>1.7 x 10^4</td>
</tr>
<tr>
<td><strong>cryptosporidium</strong> (polystyrene microsphere)</td>
<td>4.5</td>
<td>3.6 x 10^5</td>
</tr>
<tr>
<td><strong>cryptosporidium</strong> (<em>Cryptosporidium</em> oocysts)</td>
<td>4 – 6</td>
<td>2.6 x 10^6</td>
</tr>
</tbody>
</table>
Removal performance of coag/floc/sed vs. filtration

PRD1 1.0 µm E.coli Spores 4.5 µm Crypto
Removal performance of coag/floc/sed vs. filtration

- PRD1
- 1.0 µm
- E.coli
- Spores
- 4.5 µm
- Crypto

chart showing removal efficiency for different particles and treatment methods.
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**Question:**

Does spiking such high numbers bias the results?
Exp. #7 – Variable seed concentration

- Only crypto and 4.5 µm spheres used
- Optimal alum/pH/silicate
- High filter flow rate
- Cold water conditions
- Experiment conducted in duplicate over two days

Low
10 per L

Medium
$10^5$ per L

High
$10^8$ per L
Exp. #7 – Variable seed concentration

Log Removals - Day 1

<table>
<thead>
<tr>
<th></th>
<th>Low Seed Conc.</th>
<th>Mid Seed Conc.</th>
<th>High Seed Conc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crypto</td>
<td>5.5</td>
<td>5.5</td>
<td>n/a</td>
</tr>
<tr>
<td>4.5 µm Spheres</td>
<td>1.9</td>
<td>2.0</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Log Removals - Day 2

<table>
<thead>
<tr>
<th></th>
<th>Low Seed Conc.</th>
<th>Mid Seed Conc.</th>
<th>High Seed Conc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crypto</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>4.5 µm Spheres</td>
<td>4.9</td>
<td>4.6</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Answer: Apparently not
Method #5
Pilot-scale seeding trials using microorganisms and surrogate particles

giardia

crypto

fluorescent e.coli

4.5 µm sphere
Method #6
Full-scale seeding trials using surrogate particles
Full-Scale seeding trials using microspheres to estimate log-removal through filtration

2.5 x\(10^{10}\) 4.5 µm spheres
1.4 x\(10^{11}\) 1.5 µm spheres

Seeding time = 20-30 minutes
Method #6
Full-scale seeding trials using surrogate particles

- **Seeding Period**:
  - 4.5 µm spheres = 4.6-log removal
  - 1.5 µm spheres = 1.7-log removal

Graph showing:
- Red line: 4.5 micron Spheres per Litre
- Blue line: 1.5 micron Spheres per Litre

Y-axis: 1.5 µm sphere conc. (#/L)
X-axis: 4.5 µm sphere conc. (#/L)
Method #6
Full-scale seeding trials using surrogate particles
Next steps

1) Update our QMRA analysis (Quantitative Microbial Risk Assessment) to evaluate process risks, operational triggers, and evaluate need for UV

2) Process upsets & challenge conditions

3) Filter operations

4) Full-scale filter seeding trials (steady-state) with improved detection methods
Conclusion

1. Know your source water!
2. Know your treatment barriers!
3. Regulatory values/ literature values may not reflect pathogen removals at your treatment plant
4. Be careful using particle counts/turbidity to determine log-removal
5. Consider process variation & extreme events (upsets)
6. Be careful not to create other treatment risks in an effort to improve filter log removals
Thank you
&
Questions

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ian.douglas@ottawa.ca