Microbial quality of swimming pool water

Treatment without disinfection, with ultrafiltration, with UV-based treatment and chlorination

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Alternative disinfection

- **UV + H$_2$O$_2$** (Crandall ‘86, Dingman ‘90, Savino et al. ‘93)
- **UV in drinking water treatment** (Hijnen 2006)
- **Ultrafiltration** (van der Bruggen et al. 2003)
- **UV in pool water** (Caramello and Amisano 2001, Sobótka and Krysztofik 1984)
- **Ultrafiltration** (DIN 19643-4)
- **Natural waters** (Giampaoli eo al. 2014)
DIPool project

• Disinfection with ultrafiltration and UV-treatment every 30 minutes
• Reduction of nutrients with biological filtration

Goal: Investigate microbial water quality with UV-based treatment and influence of individual treatment steps
Experimental setup
Microbial water quality

- Intact cell count (iCC) with flow cytometry
- Intracellular ATP (cATP)
- 2x per week in duplo

- iCC + cATP → metabolic state
- Tendency for overestimated results
Main design specifications

- Turnover: 30 min
- (re)circulation: 1 m$^3$/h
- Setup volume: 500L
- Pool tank hydraulics:
  - Chlorination → well mixed
  - UV-based treatment → plug flow
Specific design specifications

- Biological sand filtration: 14-17 m/h
- Ultrafiltration:
  - 86 l/m²/h
  - 100-150 kD MWCO
- UV dose: 400 J/m²
- Sand filtration: 14 m/h
- Biological activated carbon filtration:
  - 10% side stream
  - 19 m/h
  - Norit PK1-3
Experiments

Without recirculation:
• Maximum concentration of nutrients
• Investigate influence treatment steps

With recirculation:
• Influence repetitive treatment and accumulation
Experiments without recirculation

- Biological sand filtration (BSF)
- BSF + ultrafiltration (UF)
- UV + BSF + UF
- UV + BSF + UF (25% BFA)
- Sand filtration (SF) + chlorination

<table>
<thead>
<tr>
<th></th>
<th>NPOC (mg/L)</th>
<th>TN (mg/L)</th>
<th>PO₄ (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological sand filtration (BSF)</td>
<td>2.0</td>
<td>4.0</td>
<td>0.5</td>
</tr>
<tr>
<td>BSF + ultrafiltration (UF)</td>
<td>2.0</td>
<td>4.0</td>
<td>0.5</td>
</tr>
<tr>
<td>UV + BSF + UF</td>
<td>2.0</td>
<td>4.0</td>
<td>0.5</td>
</tr>
<tr>
<td>UV + BSF + UF (25% BFA)</td>
<td>0.5</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Sand filtration (SF) + chlorination</td>
<td>2.0</td>
<td>4.0</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Experiments with recirculation

- BSF + UF + UV
- SF + chlorination
- 10 h/d (continual + accidental) → BFA

<table>
<thead>
<tr>
<th></th>
<th>NPOC (µg/L)</th>
<th>TN (µg/L)</th>
<th>PO₄ (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With PO₄</td>
<td>32</td>
<td>64</td>
<td>2.4</td>
</tr>
<tr>
<td>Without PO₄</td>
<td>32</td>
<td>64</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Body Fluid Analogue (BFA)

Components

• Urea (95% of all N)
• Creatine monohydrate (5% of all N)
• Sodium citrate (all remaining C)
• Potassium hydrogen phosphate

• Cold stored, refreshed weekly
Methods

Settings

- Water temperature: 30-32 °C
- pH: 7.4
- Free chlorine: 0.3-0.5 mg/L
- Duration of each experiment: 23 days
Equipment preparation

Before each experiment:
- Chemical cleaning sampling tubes
- Chemical cleaning UF
- Backwash filters (SF, BSF BACF)
Sampling + analysis

• Constantly running sampling points
• Sampling 2x per week

Analysis in duplo:
• iCC (BD Accuri C6® flow cytometer)
• cATP (Junior LB 9509 Luminometer, Aquatools)
Results (without recirculation)

- BSF
- BSF + UF
- UV + BSF + UF
- SF + Chlor

- cold tap water without additions
- results by Hammes (2010)
## Results (exp. without recirculation)

<table>
<thead>
<tr>
<th>Results after 16, 21 and 23 days min-max (average)</th>
<th>cATP ng/L</th>
<th>iCC Mcells/L</th>
<th>ATP/cell ag/cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV + BSF + UF 100% BFA</td>
<td>1.4-1.8 (1.6)</td>
<td>8.6-18 (12.5)</td>
<td>102-159 (133)</td>
</tr>
<tr>
<td>UV + BSF + UF 25% BFA</td>
<td>0.8-1.4 (1.1)</td>
<td>9.3-13 (11.1)</td>
<td>58-148 (102)</td>
</tr>
</tbody>
</table>
### Influence treatment steps (with recirculation)

<table>
<thead>
<tr>
<th></th>
<th>-log (C/C₀)</th>
<th>cATP</th>
<th>iCC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BSF (no disinfection)</strong></td>
<td>BSF</td>
<td>0.17</td>
<td>-0.21</td>
</tr>
<tr>
<td><strong>BSF + UF</strong></td>
<td>BSF</td>
<td>-0.03</td>
<td>-0.03</td>
</tr>
<tr>
<td></td>
<td>UF</td>
<td>0.16</td>
<td>-0.09</td>
</tr>
<tr>
<td><strong>UV + BSF + UF</strong></td>
<td>UV</td>
<td>0.19</td>
<td>-0.04</td>
</tr>
<tr>
<td></td>
<td>BSF</td>
<td>0.22</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>UF</td>
<td>1.40</td>
<td>1.47</td>
</tr>
<tr>
<td><strong>SF + Chlorination</strong></td>
<td>SF (without flocculation)</td>
<td>-0.28</td>
<td>0.27</td>
</tr>
</tbody>
</table>
Results (without recirculation)

![Graph showing intact cells (cells/mL) vs. intracellular ATP (ng/L) with different treatment conditions: BSF, BSF + UF, UV + BSF + UF, SF + Chlor, cold tap water without additions, and results by Hammes (2010).]
Results (with recirculation)

- BSF
- BSF + UF
- UV + BSF + UF
- SF + Chlor
- BSF + UF + UV, recirc, BFA + PO4
- BSF + UF + UV, recirc, BFA - PO4
- SF + Chlor, recirc, BFA + PO4
- SF + Chlor + BACF, recirc, BFA - PO4
- cold tap water without additions
- results by Hammes (2010)
## Results (exp. with recirculation)

<table>
<thead>
<tr>
<th>Results after 16, 21 and 23 days min – max (average)</th>
<th>cATP ng/L</th>
<th>iCC Mcells/L</th>
<th>ATP/cell ag/cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSF + UF + UV (BFA + PO₄)</td>
<td>9.3-13 (11)</td>
<td>54-66 (60)</td>
<td>151-223 (190)</td>
</tr>
<tr>
<td>BSF + UF + UV (BFA – PO₄)</td>
<td>1.4-2.7 (2.1)</td>
<td>17-24 (21)</td>
<td>58-161 (109)</td>
</tr>
<tr>
<td>SF + chlorination (BFA + PO₄)</td>
<td>2.8-5.9 (4.5)</td>
<td>18-30 (23)</td>
<td>159-273 (197)</td>
</tr>
<tr>
<td>SF + chlorination (BFA – PO₄)</td>
<td>0.5-5.1 (2.8)</td>
<td>13-38 (25)</td>
<td>38-137 (88)</td>
</tr>
<tr>
<td>Cold tap water</td>
<td>1.4-4.5 (2.4)</td>
<td>59-150 (98)</td>
<td>15-35 (21)</td>
</tr>
</tbody>
</table>
## Influence treatment steps (with recirculation)

<table>
<thead>
<tr>
<th>Treatment Step</th>
<th>-log (C/C₀)</th>
<th>cATP</th>
<th>iCC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UV-based treatment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pool tank residence</td>
<td>-0.93</td>
<td>-0.82</td>
<td></td>
</tr>
<tr>
<td>Chemical addition</td>
<td>0.20</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>BSF</td>
<td>0.10</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td>UF</td>
<td>0.50</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>UV</td>
<td>0.13</td>
<td>-0.12</td>
<td></td>
</tr>
<tr>
<td><strong>Chlorination-based treatment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pool tank residence</td>
<td>-0.31</td>
<td>-0.44</td>
<td></td>
</tr>
<tr>
<td>Chemical addition</td>
<td>0.33</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>SF (with flocculation)</td>
<td>0.21</td>
<td>0.39</td>
<td></td>
</tr>
</tbody>
</table>
Influence FAC concentration

Results
Conclusions to microbial water quality

- UV-based pool water similar to chlorinated pool water
- UF is important treatment step
- SF + flocculation improves water quality
- C-limitation is not likely in pool water
- P-limitation can be additional restrain
Acknowledgements

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Thanks for your attention

Questions ?

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