Impact of Bacteria and Pharmaceutically Active Compounds on Slow Sand Filtration

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Objectives

To investigate the ability of two Slow Sand Filtration (SSF) units to remove:

1. high levels of **bacteria** (> 10 E+6 MPN/100 mL),
2. broad range of **Pharmaceutical Active Compounds** (PhACs) – caffeine, carbamazepine, 17-β estradiol (E2), estrone (E1), gemfibrozil, and phenazone
Slow Sand Filtration

What is ... ?

- Low-cost water supply technology
- Oldest water treatment plant used * (1st Paisley, Scotland, 1809)
- Source of water *
  - Turbidity < 10-20NTU over long periods
  - Turbidity < 100NTU over a few hours period
- Filtering media:
  - Sand (0.15-0.35 mm)
  - Pea Gravel
- Flow rate * (0.1-0.3 m/h, 100-300 l/h per m² of filter)

Why...?

- Easy to assemble and to maintain
- Affordable
- Sustainable technology
- Can provide sufficient amounts of water for families or small communities

Experimental Setup

UNIT B1

Feed water - Unit B1: Stream water with 1% Primary Effluent

UNIT B2

Feed water - Unit B2: Stream water

SSF
55 gal barrels
Height: 88 cm,
Internal diameter: 57 cm
Filtering system: 40 mm SS filter @ bottom
Supporting system: 0.5 mm SS filter @ bottom
Packing material:
1. Pea gravel (10 cm)
2. Silica sand, 0.15 – 0.30 mm (57 cm)

Sampling ports
Locations: 5, 30 cm below the biolayer (sand/water interface)
# Experimental Conditions

<table>
<thead>
<tr>
<th>Experimental conditions</th>
<th>Duration [d]</th>
<th>Bacteria / PhACs used</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Spike</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Flush-out</td>
<td>30</td>
</tr>
<tr>
<td>1</td>
<td>Spike</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Flush-out</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>Spike</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Flush-out</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>Spike</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Flush-out</td>
<td>6</td>
</tr>
</tbody>
</table>

*Spike* = high bacteria levels or selected PhACs were added to the feed water; *Flush-out* = high bacteria levels and PhACs were removed from the feed water, and the two units were flushed using stream water with 1% of primary effluent or stream water alone.
Analysis

- **Total Coliform (TC) and E. coli**: Colilert 18 with Quanty-Tray 2000 from IDEXX industries

- **PhACs**: High Performance Liquid Chromatography (HPLC)

- **KCl**: Ion Chromatography (IC)

- **Microbial community DNA**: PowerSoil® DNA Isolation Kit (Mo Bio Laboratories, Inc., Carlsbad, CA, USA)

http://www.idexx.com
Removal of Total Coliforms in the presence of high bacterial levels

**Manoa stream with 1% primary effluent and Manoa stream alone were used to develop the biolayer in unit B1 and unit B2, respectively. Unit B1 was stressed for one day using Manoa stream with 20% primary effluent, while the second unit, B2, was used as control and no primary effluent was added.**
Key points

- High removal of total coliforms and *E. coli* was consistently achieved.

- Most of the bacterial removal occurred within the first few cm of the SSF. The removal efficiency of the SSF unit was mostly related to the quality of the biolayer.

- In the presence of > $10^6$ MPN/100 mL of total coliforms and *E. coli*, the SSF unit was able to achieve at least 85%. However, $10^5$ MPN/100 mL were still present in the effluent.

- A point of use device was needed to meet the WHO standards.
Bacteria Removal in the presence of selected PhACs
Key points

- Similar trend was observed in both SSF units,

- Removal of total coliforms decreased from 99% (during the first and second spike) to 84% (first day of flush-out after the first spike) and 39% (third day of flush-out after the second spike),

- No impact was observed during the third spike. 99% removal was achieved during the third spike as well as during the flush-out,

- Similar behavior in terms of *E. coli* removal was observed throughout the three spikes. However the impact of each spike was less severe compared to the trend observed in terms of total coliforms.
Fate of PhACs in presence of SSF...

No/Limited removal – carbamazepine, gemfibrozil, phenazone

Similar trend in both SSF units

<table>
<thead>
<tr>
<th>Removal (%)</th>
<th>Carbamazepine (%)</th>
<th>Gemfibrozil (%)</th>
<th>Phenazone (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top</td>
<td>Middle</td>
<td>After Sand</td>
</tr>
<tr>
<td>Unit B1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Unit B2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Unit B1 received stream water with 1% primary effluent; unit B2 received only stream water.
**Removal (%)**

<table>
<thead>
<tr>
<th></th>
<th>E2 (%)</th>
<th>E1 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top</td>
<td>Middle</td>
</tr>
<tr>
<td><strong>Unit B1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spike 1</td>
<td>42</td>
<td>56</td>
</tr>
<tr>
<td>Spike 2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td><strong>Unit B2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spike 1</td>
<td>85</td>
<td>86</td>
</tr>
<tr>
<td>Spike 2</td>
<td>61</td>
<td>87</td>
</tr>
</tbody>
</table>

*Top = 5 cm below the sand/water interface*

*Middle = 35 cm below the sand/water interface*
Similar trend in both SSF units
Dynamics of the biolayer

- Microbial communities in the *schmutzdecke*, sand, and water were significantly different ($R^2 = 0.860$, $P < 0.001$).

- Proteobacteria, predominantly *Gammaproteobacteria* (10–99%), and *Bacteroidetes* were the predominant phyla in the biolayer, while *Bacteroidetes* (13–25%), *Acidobacteria* (7–17%) and several classes of *Proteobacteria* (35–52%) (Alpha-, Beta-, Delta-, and Gammaproteobacteria) were the predominant phyla in the packing material (Fig. 1).

- *Actinobacteria* (16–22%), *Bacteroidetes* (3–15%), and *Proteobacteria* (52–56%) (Alpha-, Beta-, Delta-, and Gammaproteobacteria), were the predominant phyla detected in the clean sand used as packing material for the SSF units (approximately 1 year before the first spike).

- Changes in the microbial community compositions were significant over the time and less pronounced with the depth.
Conclusions

- SSF proved to be a valuable technology to enhance the quality of the feed water.

- Most of the bacterial removal occurred within the first few centimeters (biolayer) of the SSF.

- A point of use device is needed to meet the WHO standards.

- Complete removal of caffeine, partial removal (11–92%) of E1 and E2, and less than 10% removal of carbamazepine, gemfibrozil, and phenazone was achieved in the SSF units.

- Caffeine removal occurred within the *schmutzdecke* and was related to the occurrence of *Pseudomonas*. An increase in the number of *Pseudomonas* in the *schmutzdecke* enhanced the removal of caffeine.
Conclusions

- The presence of selected PhACs may have negatively impacted the bacterial removal in the SSF units.
  - Prior to the first spike of selected PhACs, 95% removal of total coliforms and *E. coli* was achieved within the *schmutzdecke*.
  - At the end of the study, only 20% bacterial removal was achieved within the *schmutzdecke*.

- We speculated that among the selected PhACs, *estrogen* compounds and *caffeine* may have negatively impact the bacterial removal.
  - During the first two spikes the bacterial removal achieved within the *schmutzdecke* dropped.

- In the presence of a “biologically mature” SSF unit, high removal (> 99%) of total coliforms and *E. coli* was achieved even in the presence of a *schmutzdecke* unable to remove bacteria.
Thank you!