Anaerobic biological treatment for removal of inorganic contaminants from drinking water

Workshop on Biological Drinking Water Treatment
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Nitrate risk factors

- Nitrate loading from agriculture, livestock operations
- Aquifer vulnerability: sandy formation, shallow wells

Affected communities

- Small town or rural
- Inland

Nolan et al., USGS, 1997 survey of 1400 wells
Objectives of drinking water denitrification studies

- Production of finished drinking water in field conditions and scale to meet regulatory and utility interests
- Demonstrate operability in small-utility settings
- Provide unit cost estimates of biological denitrification process
- Study nitrate-perchlorate competition for substrate
## Plant Characteristics

<table>
<thead>
<tr>
<th>Location</th>
<th>Purpose</th>
<th>Configuration</th>
<th>Flow (lpm)</th>
<th>Influent NO₃ (mg/L-N)</th>
<th>Duration (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wiggins</td>
<td>Demo.</td>
<td>Denitrify - SSF</td>
<td>38</td>
<td>15-25</td>
<td>365 (180 data)</td>
</tr>
<tr>
<td>Suff. Mt. Sinai</td>
<td>Demo.</td>
<td>Denitrify - SSF, MF</td>
<td>30 (DN)</td>
<td>9</td>
<td>243 (151 data)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8 (MF, SSF)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coyle</td>
<td>Drinking Water¹</td>
<td>Denitrify - SSF</td>
<td>106 (cap), 53 (DN)</td>
<td>10</td>
<td>758 (24 data)</td>
</tr>
</tbody>
</table>

¹ 290 residents, 400 schoolchildren
Wiggins, Colorado Well Pump House (left) and Demonstration Plant Building (right)
Wiggins demonstration plant: (right) anoxic denitrifying biotowers and aerobic prefilter; (left) slow sand filter.
Wiggins biotower influent and effluent nitrate (lines are 14-day moving averages)
Biotower Influent and Effluent Dissolved Oxygen at Wiggins Plant (lines are 14-day moving averages)
Influent (after corn syrup addition) and effluent TOC at Wiggins plant (lines are 14-day moving averages)
Individual Species and Total Trihalomethane Formation Potential in Wiggins Plant Influent and Effluent
Summary of Wiggins Demonstration

- Consistent denitrification achieved from average 19.6 to 4.3 mg/L N @ C:N = 1.3:1
- Influent dissolved oxygen 2 – 6 mg/L did not affect performance
- No significant change in DBP precursors
- Significant increase in Cl-demand from 0.6 to 4.5 ppm
- Corn syrup associated with high biomass growth, TOC, clogging, high effluent coliform and HPC bacteria, and NH$_4$ in effluent
Left: ceramic microfiltration system (BASX Systems). Right: hollow fiber membrane microfiltration system (Pall Corp.) used at Suffolk Demonstration Plant.
Biotower Influent and Effluent Nitrate at Suffolk Plant (acetate carbon addition to achieve 3 mg/L-N in effluent)
## Biotower Comparison

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Wiggins</th>
<th>Mt. Sinai</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon source</td>
<td>Corn Syrup</td>
<td>Acetate</td>
</tr>
<tr>
<td>Nitrate Removal Rate (kg-N/m³-media/d)</td>
<td>0.34</td>
<td>0.40</td>
</tr>
<tr>
<td>Effluent Nitrite (mg/L-N)</td>
<td>1.4</td>
<td>0.04</td>
</tr>
<tr>
<td>Effluent TOC (mg/L)</td>
<td>7.7</td>
<td>6</td>
</tr>
<tr>
<td>Effluent Turbidity (NTU)</td>
<td>2.52</td>
<td>0.9</td>
</tr>
<tr>
<td>Effluent Total Coliform (cfu/100 mL)</td>
<td>$5.1 \times 10^6$</td>
<td>65</td>
</tr>
<tr>
<td>HPC (cfu/100mL)</td>
<td>$6.6 \times 10^7$</td>
<td>$2.4 \times 10^5$</td>
</tr>
</tbody>
</table>
## Suffolk Filter Comparison

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Slow Sand Filter</th>
<th>Ceramic Microfilter</th>
<th>Hollow Fiber Memb. MF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effluent TOC (mg/L)</td>
<td>0.4</td>
<td>1.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Effluent Turbidity (NTU)</td>
<td>0.3</td>
<td>0.27</td>
<td>0.03</td>
</tr>
<tr>
<td>Effluent Total Coliform (cfu/100 mL)</td>
<td>1</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Effluent HPC (cfu/100 mL)</td>
<td>2,900</td>
<td>170</td>
<td>1</td>
</tr>
<tr>
<td>Chlorine Demand (mg/L)</td>
<td>0.55</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Suffolk Study Summary

- Use of acetate as carbon source reduces biotower effluent bacteria, turbidity and nitrite.
- Microfiltration produces bacteria-free low turbidity product water.
- 90% of DOC was removed in SSF and hollow fiber MF.
- Residuals from MF = 3% of product water.
- Chlorine injection to prevent fouling may account for rise in THMFP after MF treatment.
Coyle, Oklahoma Drinking Water Denitrification Plant
Power Cost at Coyle Denitrification Plant
Unit electric power cost: $0.0532/kwh
### Chemical Costs

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Before Blending (/1,000 gallons)</th>
<th>After Blending (/1,000 gallons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinegar (acetate)</td>
<td>$0.36</td>
<td>$0.18</td>
</tr>
<tr>
<td>Phosphate</td>
<td>$0.10</td>
<td>$0.05</td>
</tr>
<tr>
<td>Other (analytical)</td>
<td>$0.02</td>
<td>$0.01</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$0.48</strong></td>
<td><strong>$0.24</strong></td>
</tr>
</tbody>
</table>
Total Operating Costs at Coyle Plant

- BioDen Electrical: $0.14
- BioDen Chemical: $0.24
- Non-BioDen System: $0.18
- Total: $0.56
**TOTAL COSTS**

Usage: 15 million gallons per year (28 gpm)
Coyle plant: $130,000 capital (67% grant), 20 years, 5%
Future system: $130,000 capital, no grant, 20 years, 5%
Total unit cost (capital, O & M) for drinking water treatment (including well pumping) was $0.79/1,000 gallons (with 67% capital financing grant from State of Oklahoma).

Chemical costs are approximately 30% of total. Carbon (vinegar) is 75% of chemical cost.

Power costs are approximately 40% of treatment total.

Estimated unit cost with future system of equal capacity assuming pump replacement and plant configuration changes, and no grants is $0.65/1,000 gallons.
Acknowledgements

Nitrate Removal Technologies (NRT)  
National Water Research Institute  
EPRI/NRECA  
Colorado Dept. Local Affairs  
Town of Brighton, CO, Town of Wiggins, CO  
Suffolk County Water Authority (SCWA),  
Town of Mt. Sinai, New York, Town of Coyle, OK  
BASX  
Pall Corp.  
Colorado Dept. Public Health & Environment  
Oklahoma Dept. Environmental Quality
Biological reduction of mixed nitrate and perchlorate influent in biofilm reactor
Biofilm reactor profiles. $C: (N+\text{ClO}_4^-) = 1.8:1$

$\text{ClO}_4^-, \text{NO}_3^-, \text{CH}_3\text{COO}^-, \text{and Cl}^- \text{ concentration profiles in the biofilm reactor receiving 10 mg.L}^{-1} \text{ NO}_3^-\text{-N and 1,000 } \mu\text{g.L}^{-1} \text{ ClO}_4^-, \text{ and 42 mg.L}^{-1} \text{ CH}_3\text{COO}^-.$
Influent contained 1,000 μg.L⁻¹ ClO₄⁻, 16 mg.L⁻¹ NO₃-N and 52 mg.L⁻¹ acetate.
Effect of nitrate on chloride evolution in suspended cultures with excess acetate

Effect of 2 mM (28 mg/L) nitrate-N on reduction of 2 mM (200 mg/L) perchlorate in flasks inoculated with perchlorate-reducing culture, average MLSS in flasks was 5 g.L\(^{-1}\). 16.7 mM acetate was added to both flasks. C:(ClO\(_4\)+N)>1.8
Perchlorate and nitrate are reduced simultaneously along bioreactor flow path when sufficient acetate added C:(ClO$_4$+N)>1.8.

Low substrate conditions C:(ClO$_4$+N)<1.2 decreases perchlorate reduction more than denitrification

Perchlorate-reducing cultures reduced nitrate without acclimation

 Nitrate competed with perchlorate for substrate electrons even when mass ratio of ClO$_4$·N = 7 g/g