Understanding Membrane Fouling at High Organic Loading Rates in the Submerged Membrane Bioreactor Treating Municipal Wastewater

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Outline

• Introduction
• Rationale
• Materials and Methods
• Results
• Conclusions
• Acknowledgements
Introduction

• Membrane Bioreactor (MBR)
  – Modified activated sludge process
  – UF/MF membrane

• Two configurations
  – External (EMBR)
  – Submerged (SMBR)
Flow Schemes for the SMBR and Conventional Activated Sludge Process

**Conventional**

- Primary Treated Wastewater (Equivalent to a 3 mm screen)
- Aeration Basin
- Secondary Clarifier
- Microfiltration
  - Reverse Osmosis Feedwater
  - Backwash Water

**SMBR**

- Aeration Basin
- WASTE

(SMBR stands for Submerged Membrane Bioreactor)
Process Limitation

CAS
- Decline in effluent water quality
  - High effluent COD
  - High effluent SS
- Treatment capacity remains unaffected

MBR
- No decline in effluent water quality
- Membrane fouling
  - Loss of treatment capacity
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Rationale

\[ \frac{F}{M} = \frac{S_o}{\theta_H \cdot X_{MLVSS}} \]

- The SMBR process is currently limited to an MLSS concentration of approximately 10 g/L
- The F/M ratio is a key parameter to optimize reactor tank design
  - Small tank (low HRT)
  - Small tank (high F:M)
Effect of F/M on Steady-State Fouling Rate

\[ y = 1.661x^{2.1977} \]

\[ R^2 = 0.9517 \]

*Proceedings of WEFTEC 2004*
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Equipment and Apparatus

- Bench-scale SMBR
- Treating primary effluent from the City of San Francisco’s SEP
  - COD = 325 mg/L
  - TSS = 98 mg/L
Membrane Operation and Characteristics

- Mitsubishi Sterapore®
- Nominal pore size = 0.4 μm
- Hydrophilic
- Membrane flux = 18 L/m²·h
- Coarse bubble air = 0.4 L/s
- 9 min operating cycle followed by 30 sec relax
Experimental Methods

- Operating conditions:
  MCRT = 10 d (F/M = 0.50 gCOD/gVSS·d)
  MCRT = 2 d (F/M = 2.34 gCOD/gVSS·d)
- Dissolved oxygen > 2 mg/L
- Constant MLSS = 1.4 g/L
- Steady-state data collection began after 3 MCRTs
- 2 week steady-state data collection period
Tools Used to Understand Membrane Fouling

- Steady-state membrane fouling rate during operation
- Molecular weight distribution of influent, SMP and effluent
- FTIR of clean and fouled membranes
- Batch filtration experiments expressed as Modified Fouling Index (MFI)
  - Stir cell filtration of steady state mixed liquor with UF (NMWCO = 300 kDa, PES)
  - Data presented as MFI at 20°C and 210 kPa
- Fouled membrane resistances
Fouled Membrane Resistance Terms

- $R = R_M + R_F + R_C$
- $R = \text{Total resistance}$
- $R_M = \text{Membrane}$
- $R_C = \text{Cake Layer}$
- $R_F = \text{Foulants}$
  - Organics Adsorption
  - Inorganic Precipitation
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Membrane Performance at 10-d MCRT
(F/M=0.50 gCOD/gVSS·d)

- Flux
- Specific Flux

Start up
66 Days at 10-d MCRT
(F/M = 0.50 gCOD/gVSS·d)

Chemical Cleaning
Steady-state fouling rate
Membrane Performance at 2-d MCRT (F/M=2.34 gCOD/gVSS·d)

Flux, LMH

Specific Flux @ 20°C, LMH/bar

Days of Operation

Flux
Specific Flux

Chemical Cleaning
Chemical Cleaning
Chemical Cleaning

Steady-state
Improper Wasting Volumes

25 Days at 2-d MCRT (F/M = 2.34 gCOD/gVSS·d)
## Steady-State Membrane Fouling Rates

<table>
<thead>
<tr>
<th>F/M gCOD/gVSS·d</th>
<th>MCRT d</th>
<th>Steady-state Fouling Rate @ 20°C LMH/bar·d</th>
<th>SMP$_c$ mg/L</th>
<th>SMP$_p$ mg/L</th>
<th>Total SMP mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>10</td>
<td>2.60</td>
<td>24</td>
<td>14</td>
<td>38</td>
</tr>
<tr>
<td>2.34</td>
<td>2</td>
<td>59.0</td>
<td>10</td>
<td>49</td>
<td>59</td>
</tr>
</tbody>
</table>

- Membrane fouling rates increased with F/M
- Total SMP concentration increased with F/M
Carbohydrate Molecular Weight Increased at Low MCRT (High F/M)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Carbohydrate concentration, mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influent</td>
<td>&gt; 10 kDa</td>
</tr>
<tr>
<td>SMP - 10 d</td>
<td>10 kDa - 1 kDa</td>
</tr>
<tr>
<td>SMP - 2 d</td>
<td>&lt; 1 kDa</td>
</tr>
<tr>
<td>Effluent - 10 d</td>
<td>&gt; 10 kDa</td>
</tr>
<tr>
<td>Effluent - 2 d</td>
<td>10 kDa - 1 kDa</td>
</tr>
<tr>
<td></td>
<td>&lt; 1 kDa</td>
</tr>
</tbody>
</table>
Protein Molecular Weight Increased at Low MCRT (High F/M)

Influent SMP - 10 d SMP - 2 d EFF - 10 d EFF - 2 d

Protein Concentration, mg/L

Sample

Protein Concentration, mg/L

Influent SMP - 10 d SMP - 2 d EFF - 10 d EFF - 2 d

> 10 kDa 10 kDa - 1 kDa < 1 kDa

Sample
Fouled Membrane FTIR Results

- 3380 - indicates OH stretching
- 1660 and 1540 - indicates NH and COO\(^-\) (protein)
- 1060 - indicates CO stretching of polysaccharides
Fouled Membrane Resistance Terms

Fouled membrane R distribution for SMBR:
A) 10-d MCRT (0.5 gCOD/gVSS·d)
B) 2-d MCRT (2.34 gCOD/gVSS·d)
## Batch Filtration Results

<table>
<thead>
<tr>
<th>MCRT, d</th>
<th>Modified Fouling Index, $10^{-3}$ s/L²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mixed Liquor</td>
</tr>
<tr>
<td>2</td>
<td>47</td>
</tr>
<tr>
<td>10</td>
<td>17</td>
</tr>
</tbody>
</table>

- MFI was higher for all fractions at MCRT = 2 d
- SS represents the suspended solids alone (no soluble component) and increased 6 times with MCRT decrease
- Mixture effect was observed at both conditions
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Conclusions

• High organic loading rates (F/M) increased membrane fouling rates
• Increased steady-state membrane fouling rates correlated with total SMP
• MW of carbohydrate and protein SMP increased with F/M
• Membrane rejected higher MW SMP
• FTIR indicated protein and carbohydrate presence on fouled membranes with stronger adsorptions resulting from the 2-d MCRT condition
Conclusions

• Membrane fouling was primarily due to the adsorption of organics and $R_F$ was dominate resistance term of fouled membranes

• $R_C$ increased with F/M and this was attributed to changes in floc properties that result in a “sticky” cake

• Sludge filtration resistance (MFI) increased with F/M

• MFI of suspended solids increased 6 times, supporting the increasing importance of the cake layer with increasing F/M
Conclusions

Present Worth, $

\theta_H$, time

- Capital
- O&M
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