Dynamic Control of Membrane Fouling in MBR System

Chinh Hoang, Hong Zhao and Michael Sparks
Presentation Outline

- MBR Technology Overview
- Membrane Fouling – Number One Issue Facing MBR Operation
- Factors Influence MBR performance
- Pilot Study Results
- Dynamic Control of Membrane Fouling
- Summary
Membrane Bioreactor Process

Small Footprint (HRT 4-7 hrs)

- TANK VOLUME
  - Activated Sludge Process
- CONVENTIONAL AS
- MBR
Features and Advantages of MBR Systems

- No need for secondary clarifiers or tertiary filters
- Absolute Barrier
- Very compact footprint (MLSS 9 – 14,000 mg/L)
- Long SRT
  - Complete nitrification
  - Reduced sludge generation
- Exceptional effluent quality
  - Typical ND on TSS and BOD
  - < 0.1 NTU Turbidity
A Closer Look

Membrane Bioreactor

- Treated water
- Sludge
- Water/Air Flow
- Membrane
- Aeration
Over time membrane fouling is inevitable in MBR
Permeate flux decline (constant TMP operation) or TMP increase (constant flux rate operation)
Two types of fouling – Reversible and Irreversible
Reversible fouling caused by deposition of large particles and flocs on surface, can be managed with effective physical cleaning methods
Irreversible Fouling caused by small colloids and solute that plugging membrane pores, CIP cleaning may be required
Fouling usually lead to:
- Increase in high air scour flow rate – higher energy consumption
- Increase in CIP frequency – higher chemical consumption, shorter membrane life expectancy

Fouling must be managed to sustain operation of MBR system
Factors Influence Fouling of Membrane

**Sludge characteristics:**

- **MLSS level** – generally higher the level faster the formation of cake layer on membrane
- **The level of EPS in sludge** – high level of EPS will increase bio-fouling on membrane
- **Size of particles** – smaller particles combine with EPS can form a denser cake layer and will be harder to get rid of the membrane surface
Permeate Flux Rate

- Determine the rate of transport fouling components toward membrane
- The higher the flux rate the faster the formation of cake layer on membrane
- TMP rise more quickly when operate above critical flux
- Membrane “prefer” to operate at sub-critical flux rate, however fouling is inevitable in long term operation
Factors Influence Fouling of Membrane (con’t)

Air Scouring Flow Rate

- Provide shear forces that will help remove the solids on membrane surface
- Determine the rate of back-transport of foulants away from membrane surface
- Generally higher flux rate would require higher air scour rate
Factors Influence Fouling of Membrane (Con’t)

- **Relaxation**
  - Permeation is suspended, membrane sheets are loose
  - Air scour cleaning is more effective

![Filtration and Scour Aeration Diagram]

Filtration: 9 mins, 1 min, 9 mins, 1 min, 9 mins, 1 min
Scour Aeration: [Diagram showing alternating cycles of Filtration and Scour Aeration]
Pilot Study at Cary, NC
Pilot Study: Identifying Critical Flux

![Graph showing permeate discharge flow and transmembrane pressure over time with linear equations](image)

- **Permeate Discharge Flow, gpm**
  - Y = 0.0036X
  - Y = 0.0094X
  - Y = 0.029X

- **Transmembrane Pressure, PSI**
  - 0.0
  - 0.8
  - 1.6
  - 2.4
  - 3.2
  - 4.0
  - 4.8
  - 5.6
  - 6.4

**Date and Time Stamps:**
- 11/30/06 14:00
- 11/30/06 14:10
- 11/30/06 14:20
- 11/30/06 14:30
- 11/30/06 14:40
- 11/30/06 14:50
- 11/30/06 15:00
- 11/30/06 15:10
- 11/30/06 15:20
- 11/30/06 15:30
- 11/30/06 15:40
- 11/30/06 15:50
- 11/30/06 16:00
Pilot Study: Sludge property Affecting Membrane Performance

Graph showing the relationship between Permeate Flux Rate (GFD) and Rate of TMP Increase within One Cycle (PSI/min). Key points include:

- Biomass Killed & Temp < 12°C
- Alum addition at 30 mg/L & Temp < 15°C
- Alum addition at 75 mg/L & Temp > 15°C
- F/M > 0.2 Or Temp < 15°C
- F/M < 0.1 & Temp > 18°C
Pilot Study: Effect of Flux Rate on TMP (con’t)

![Graph showing permeate flow, scouring airflow, temperature, and transmembrane pressure versus flux rate with linear equations Y = 0.156X, Y = 0.061X, and Y = 0.020X.]

Permeate flow, GPM & Scouring Airflow, SCFM & Temperature, °C

Transmembrane Pressure, PSI

Pilot Study: Ineffective Fouling Control Lead to Rising in TMP

\[ Y = 0.15X \]
\[ Y = 0.19 \]
\[ Y = 0.25X \]
\[ Y = 0.32X \]
Pilot Study: Effect of Scour Air Flow Rates on TMP

<table>
<thead>
<tr>
<th>Permeate Flow, GPM</th>
<th>Scour Air Flow, SCFM</th>
<th>Temperature, °C</th>
<th>TMP, PSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.8</td>
<td>0</td>
<td>0</td>
<td>0.8</td>
</tr>
<tr>
<td>1.6</td>
<td>0</td>
<td>0</td>
<td>1.6</td>
</tr>
<tr>
<td>2.4</td>
<td>0</td>
<td>0</td>
<td>2.4</td>
</tr>
<tr>
<td>3.2</td>
<td>0</td>
<td>0</td>
<td>3.2</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>4.8</td>
<td>0</td>
<td>0</td>
<td>4.8</td>
</tr>
<tr>
<td>5.6</td>
<td>0</td>
<td>0</td>
<td>5.6</td>
</tr>
</tbody>
</table>

Timeline:
- 2/1/07 8:52
- 2/1/07 9:07
- 2/1/07 9:21
- 2/1/07 9:36
- 2/1/07 9:50
- 2/1/07 10:04
- 2/1/07 10:19
- 2/1/07 10:33
- 2/1/07 10:48
- 2/1/07 11:02
- 2/1/07 11:16
Effect of Relaxation Duration on TMP

The graph shows the effect of relaxation duration on TMP (Transmembrane Pressure). The graph includes data from 2/2/07, starting at 8:21 and ending at 9:25, with various relaxation periods indicated.

- **1 min Relaxation, TMP not stable**
- **2 min Relaxation, TMP stabilized**
Effect of Relaxation on TMP – No “True” Relaxation Leads to TMP Increase
A dynamic model can be employed to effectively control fouling.

Aim to control constant TMP.

By adjusting one or more of the following control variables:

- Scour Air Flow Rate, $V$
- Membrane Flux Rate, $F$
- Relaxation Phase, $TR$
- Permeate Phase, $TP$
Control Logic Scheme

- A hierarchal order logic scheme
- Priorities of process control variables are defined
- Control variables must satisfy set of pre-defined conditions in order to be adjusted
- Adjusting one or more process control variables will be made in the next cycle
Filtration Cycles: Permeation and Relaxation Phases

Diagram showing filtration cycles with phases labeled as follows:
- Nth cycle
- (N+1)th cycle
- Relaxation phase (TR)
- Permeation phase (TP)
- TMPs
- TMPe
- Scouring airflow, V
- Permeate flux, F
- Time, min.
Change in TMP within One or Two Filtration Cycles
Control Logic Scheme
Conclusions

- Fouling must be controlled in order to sustain operation of an MBR system.
- MBR fouling can be managed by different techniques such as air scour, relaxation, and reasonable flux (e.g. sub-critical) operation.
- A dynamic model can be employed to effectively control fouling and avoid unnecessary over-scouring.