SANITAS
Sustainable and Integrated Urban Water System Management

Towards Energy-Efficient MBR Systems: Challenges and Opportunities

SANITAS E-SEMINAR SERIES

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Outline

1. Introduction

2. Approaches to MBR Energy Optimization
   1. Understanding Fouling Occurrence
   2. Modeling Approaches
   3. Heuristical Approaches

3. Opportunities

4. Points for Discussion
What is a Membrane Bioreactor?

- Combination of a membrane process (micro/ultra filtration) with a suspended growth bioreactor
MBR Technology Drivers

- Water reuse
- Increasingly stringent legislation
- Footprint savings

(From Santos et al., 2011)
MBR Technology Challenges

• Higher operational and capital costs as compared to conventional activated sludge (CAS)

Cost Ratios (MBR/CAS)

<table>
<thead>
<tr>
<th></th>
<th>2350 PE</th>
<th>37350 PE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost</td>
<td>2</td>
<td>0.63</td>
</tr>
<tr>
<td>Operating Costs per Year</td>
<td>2,27</td>
<td>1.34</td>
</tr>
</tbody>
</table>
Operational Costs in MBR Systems

Operational Costs
- Energy: 84%
- Sludge Trtm/Dis: 12%
- Chemicals: 4%

Energy Consumption
- Membrane Aeration: 36%
- Biology Aeration: 21%
- Feed Pumps: 15%
- Permeate Pumps: 11%
- Rest: 17%

(Adapted from Judd, 2011)
(Adapted from Krzeminski, 2013)
Aeration in MBR Operation

AERATION CHARACTERISTICS
- Flow Rate
- Aerator Size
- Aerator Area
- Bubble Size
- Aeration Intensity

BULK BIOMASS CHARACTERISTICS
- Floc Size
- Viscosity
- MLSS
- O₂ Transfer
- Loading Rate

MEMBRANE OPERATION
- Permeability

(Adapted from Judd, 2011)
Approaches to MBR Energy Optimization

• Understanding fouling occurrence
  – What causes fouling? How does it cause fouling? What mitigation strategies can we draw from this knowledge?

• Modeling approaches
  – What is the optimal operation point?

• Heuristical approaches
  – What is experience with full-scale MBR systems teaching us? What energy-efficiency strategies are actually working?
Understanding Fouling Occurrence

- **Feed characteristics**
  - EPS: free, bound
  - Floc characteristics: size, structure
  - Bulk characteristics: viscosity, rheology, hydrophobicity

- **Biomass characteristics**
  - **Fouling**:
    - Reversible
    - Irreversible
  - **Clogging**:
    - Membrane channels
    - Aerator ports

- **OPERATION**
  - Retention time
    - Hydraulic
    - Solids
  - Hydraulics
    - Flux
    - TMP
  - Cleaning
    - Physical
    - Chemical

- **DESIGN**
  - Membrane module characteristics
    - Pore size, porosity, shape
    - Surface characteristics
    - Charge, hydrophobicity
    - Configuration
      - Geometry
      - Dimensions

- **Aeration**
  - Design (port size)
  - Mean flow rate
  - Pulse rate

(Adapted from Judd, 2011)
**Understanding Fouling Occurrence**

- Research has underlined the significance of several factors on fouling propensity:

<table>
<thead>
<tr>
<th>Environmental</th>
<th>Operational</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Feedwater composition and strength</td>
<td>• Solids retention time/MLSS concentration (+)</td>
</tr>
<tr>
<td>• Influent dynamics (-)</td>
<td>• Aeration</td>
</tr>
<tr>
<td>• Temperature (+)</td>
<td>• Unsteady-state operation (-)</td>
</tr>
</tbody>
</table>

- Not one single factor can predict fouling propensity, but rather a combination of various environmental and operational factors.
Fouling and Energy Efficiency

- **Appropriate feed pretreatment** (screening)
- **Feedback control systems** to optimize the use of anti-fouling strategies:
  - Control of biomass quality/properties through SRT adjustment, or chemical addition (coagulants, adsorbents)

### Control Variables
- Permeate pump (on/off or speed)
- Relaxation frequency, duration
- Membrane aeration rate, duration
- Backflush frequency, duration and flux

### Input Variables
- TMP, permeate flow rate, temperature (permeability)
- Filterability
- Growth of biofilm, concentration polarization phenomena

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**Less Commonly**
Modeling Approaches

- MBRs consist of several subprocesses with a high degree of coupling
- Energy optimization of full-scale systems can be approached through *integrated mathematical modeling of the subprocesses*
- Of especial importance is the inclusion of *appropriate process and membrane aeration models*
  - **Process aeration**: coarse/fine bubble; relationship between MLSS concentration and oxygen transfer efficiency
  - **Membrane aeration**: effect of membrane aeration on permeability (*less common*)
Modeling Approaches

- **Steady-state models**: general energetic costs of aeration requirements at different operational points

- **Dynamic models**: more accurate energy predictions of different operational points

- General strategies for energy reduction:
  - **Lower SRT operation**: need to consider sludge treatment/hauling costs!
  - **Lower membrane aeration**: need to consider effects on permeability!
Heuristical Approaches

- Operational parameters influencing MBR energy efficiency in full-scale plants:

- **Hydraulic utilization of membranes**
  
  (From Krzeminski, 2013)

  (From Palmowski et al., 2012)

- **Aeration strategy**
Heuristical Approaches

• **Energy optimization strategies:**
  
• **Increasing operational fluxes:**
  – Internal/external equalization
  – Match operating MBR lines to incoming flow
  – Temporary increases in operational fluxes when filter performance is good (e.g. high temperatures)

• **Decreasing membrane aeration**
  – Proportional/sequencing/intermittent aeration rather than continuous aeration
Opportunities

• New aeration systems
  – Spherical cap sparging

• New cleaning/fouling mitigation methods
  – Mechanical with granular medium
  – Ultrasound/membrane vibration

• Emerging technologies
  – Forward osmosis MBRs

(From Higgins, 2011)

(From Achilli et al., 2009)
Points for Discussion...

• Is really energy efficiency the sole limiting factor in widespread MBR implementation?

Results of Survey of MBR Practitioners

(From Santos et al., 2011)
Points for Discussion...

• What should be the focus of research moving forward?
  – Will further research in the mechanisms of fouling shed some light in the efficient operation of MBRs?
  – Or should research move to more macroscopic approaches such as mathematical modeling based on empirical relationships?
Thank you!

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Additional Slides

Comparative of Energy Consumption Between Treatment Technologies

<table>
<thead>
<tr>
<th>Treatment option</th>
<th>Energy use (kWh⁻¹ m⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAS</td>
<td>0.15</td>
</tr>
<tr>
<td>CAS-BAF</td>
<td>0.25</td>
</tr>
<tr>
<td>CAS-MF/UF</td>
<td>0.35–0.5</td>
</tr>
<tr>
<td>MBR</td>
<td>0.75–1.5ᵃ</td>
</tr>
</tbody>
</table>

ᵃPower consumption range for large- to smaller-scale plants.

(From Hai and Yamamoto, 2011)