OPTIMIZATION OF AN INTERMITTENTLY AERATED AND FED SUBMERGED MEMBRANE BIOREACTOR

P. MELIDIS, S. NTOUGIAS, V. VASILATOU, V. DIAMANTIS and A. ALEXANDRIDIS

Laboratory of Wastewater Management and Treatment Technologies, Department of Environmental Engineering, Democritus University of Thrace, Vas. Sofias 12, 67100 Xanthi, Greece, e-mail: pmelidis@env.duth.gr
Outline

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  – Membrane characteristics
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• Conclusions
Membrane bioreactors (MBRs)

- Today, much attention has been paid to environmental issues since legislation has become stricter.
- Membrane bioreactor (MBR) technology is becoming a promising option for wastewater treatment and reuse.
- MBR associates a suspended growth bioreactor and a filtration on porous membrane.
MBRs - The advantages

The advantages of MBR over conventional activated sludge (CAS):

• high pollutants loading capability
• superior organics removal,
• enhanced nutrient removal stability,
• lower sludge production,
• smaller footprint,
• effluent disinfection
Among the MBR systems, the submerged membrane bioreactor (SMBR) can assist in significantly reducing power consumption compared to external loop mode.
Introduction

MBRs - Conditions to improve pollutants removal and lower sludge production

SMBR could be operated over a broad range of solids retention time (SRT) due to the efficient biomass separation.

Operating a SMBR under total solid retention, MLVSS are increased continuously every day and could be associated directly with the sludge age (SRT).

→ This enhances the nitrification by preventing the nitrifying bacteria from being washed out.

→ This enhances cell metabolism and growth of the slow growers.

These conditions improve pollutants removal and lower the sludge production.
Biological nutrient removal using \textbf{IA} offers the opportunity:

- to treat wastewater within the same reactor
- to save energy by applying the half aeration time and omitting the internal recycling
- to control aeration providing the necessary aerobic and anoxic phases for nitrification and denitrification

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<td>2\textsuperscript{nd} cycle</td>
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Biological nutrient removal using **substrate feeding** within a short time period (PF) at the beginning of the anoxic phase offers the opportunity to:

- enhances the biological denitrification rate
- maximize the anoxic organic carbon removal
- minimize the anoxic phase duration

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The aim of this experimental work was to evaluate:

- the performance of a submerged membrane bioreactor
- operating with intermittent aeration and periodical feeding
- using real wastewater
- under complete sludge retention

in order to achieve:

- organic carbon and nitrogen removal
- minimize the required aeration and pumping energy
- to find the critical flux and the optimum working flow rate to prevent biofouling
The SMBR system

Fig. 1 Schematic diagram and foto of the SMBR system
The SMBR system consist of:

- tank with a volume 24 L
- air diffuser
- feeding and permeate pump
- feeding tank
- external carbon source equipment
- air compressor
- liquid and pressure level sensor (data sampling rate every 10 sec).
- immersed hollow fiber membrane (0.1 μm pore size)
The SMBR system – membrane characteristics

Table 1. Membrane characteristics

<table>
<thead>
<tr>
<th>Membrane type</th>
<th>Hollow fiber</th>
<th>Pore size</th>
<th>0.1 μm</th>
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</thead>
<tbody>
<tr>
<td>Construction material</td>
<td>Polyvinylidene difluoride (PVDF)</td>
<td>pH range</td>
<td>1-12</td>
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<tr>
<td>Clean water flux</td>
<td>500 L m⁻² h⁻¹</td>
<td>Maximum operating pressure</td>
<td>20-30 bar</td>
</tr>
<tr>
<td>operating temperature</td>
<td>5-45°C</td>
<td>The effective filtration area</td>
<td>1.5 m²</td>
</tr>
<tr>
<td>Fiber inner diameter</td>
<td>0.6 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fiber outer diameter</td>
<td>1.2 mm</td>
<td></td>
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</table>
The SMBR system - operation

operations which were controlled by PLC:

- time allocation between aerobic and anoxic phase
- feeding and permeate pump activation
- feeding time and duration
- permeate pumping time and duration
- influent and effluent flow rate settings
- mixed liquor level control
- pressure data logging and storing
The SMBR system – biological treatment operation

Intermittent aeration and periodical feeding:

- divided into one-hour cycles
- each cycle consisted of two phases
- anoxic (30 min) and aerobic (30 min)
- periodical feeding at the beginning of the anoxic phase within a short time period

(to ensure high substrate availability for denitrification)

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<tbody>
<tr>
<td>Feed</td>
<td></td>
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<tr>
<td>Denitrification</td>
<td>Nitrification</td>
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<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; Phase (30 min)</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Phase (30 min)</td>
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<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; cycle</td>
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The SMBR system – real wastewater characteristics

• Mean values of the sewage characteristics:
  – total COD, 406 (±78) mg/L
  – soluble COD, 188 (±54) mg/L
  – biochemical oxygen demand (BOD$_5$), 252 (±45) mg/L
  – total suspended solids (TSS), 166 (±41) mg/L
  – volatile suspended solids (VSS), 137 (±34) mg/L
  – NH$_4^+$-N, 58.3 (±6.2) mg N/L
  – total Kjeldahl nitrogen (TKN), 68.4 (±6.2) mg/L
  – PO$_4^{3-}$-P, 7.3 (±2.1) mg P/L
  – pH, 7.1 (±0.2)
  – electric conductivity, 1,265 (±106) μS/cm
The SMBR system – biological treatment characteristics

- duration of the study: 3 months
- inoculated with return activated sludge
- temperature: 25±0.4 °C
- dissolved oxygen was measured on-line and kept under 0.2 mg/L during the anoxic phase and between 2 and 6 mg/L in the aerobic phase
- SRT was always increased, i.e. 0-80 (Period I), 80-94 (Period II) and 94-100 (Period III) days
The SMBR system – biological treatment characteristics

- applied loading rates: 1, 2 and 3.4 L/L_{reactor} d
- corresponding HRTs: 1, 0.5 and 0.3 d
- volumetric organic loads: 0.31±0.06, 0.51±0.06 and 0.65±0.14 kg BOD$_5$/m$^3$d
- volumetric nitrogen loads: 0.08±0.01, 0.12±0.01 and 0.21±0.01 kg TKN/m$^3$d
Organic carbon removal

- average removal ratio of 98%, 97.7% and 97.3%
- BOD effluent conc. below 6 mg/L in any case

Fig. 2 IAF-SMBR system efficiency concerning BOD removal
Organic carbon removal

• average removal ratio of 95%, 98% and 93%

• greatest COD reduction in period II (MLSS from 7.8 to 10.4 g/L)

Fig. 2 IAF-SMBR system efficiency concerning COD removal

Lv= 0.31 kgBOD/m³d
Lv= 0.51 kgBOD/m³d
Lv= 0.65 kgBOD/m³d
Nitrogen removal

at 0.08 kg TKN/m\(^3\)\_d, the TKN removal efficiency was 87.6% and the respective effluent concentration was 10.3±2.52 mg TKN/L
Operational parameters – MLSS & MLVSS

Fig. 4 Mixed liquor Suspended Solids

The continuous increase in the suspended solids concentration was due to
• the gradual influent suspended solids transport,
• the biomass growth and
• the complete retention of solids in the reactor.
Operational parameters – MLSS & MLVSS

Fig. 4 Mixed liquor Suspended Solids

<table>
<thead>
<tr>
<th>Period</th>
<th>MLSS (g/L)</th>
<th>MLVSS (g/L)</th>
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<tbody>
<tr>
<td>I</td>
<td>9.6</td>
<td>7.8</td>
</tr>
<tr>
<td>II</td>
<td>12.8</td>
<td>10.4</td>
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<tr>
<td>III</td>
<td>15.1</td>
<td>12.3</td>
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The biomass productivity was accounted to $0.02 \pm 0.01 \text{ g VSS/g COD}$ (much lower than that determined in the conventional activated sludge systems).

The advantage of the high biomass concentration: Operation under low F/M conditions, high cleaning efficiency, production of small amounts of biosolids.

Period II MLSS = 12.8 g/L and MLVSS = 10.4 g/L
Period III MLSS = 15.1 g/L and MLVSS = 12.3 g/L
A key design parameter of MBR systems
It is defined as the flux below of which:
→ a biofouling of the membrane pores does not occur and
→ the permeability remains constant
Fig. 5. Determination of the critical flux

- TMP was maintained constant
- Monitoring of the variation of the flow rate

\[ \text{critical flux} = 6.5 \text{ L/m}^2\text{h} \]

\[ \text{optimum working flow rate to prevent biofouling} 3 \text{ and } 6 \text{ L/m}^2\text{h} \]
Membrane fouling and permeate flux lowering are associated with the deposition of biosolids onto membrane surface, thus it is expected that high MLVSS concentrations can lead to elevated TMP values.
Operational parameters – Impact of suspended solids concentration on TMP

Fig. 6. TMP vs MLVSS

Period I:
TMP=100 mbar
MLVSS rose up 8 g/L

Period II:
TMP=250 mbar
MLVSS rose up 10 g/L

Period III:
TMP=420 mbar
MLVSS rose up 12 g/L
Operational parameters – Impact of suspended solids concentration on TMP

Fig. 6. TMP vs MLVSS

TMP remained constant at the end of the 2nd and 3rd period although the MLVSS rose up

→ MLVSS slightly influence activated sludge filterability

**Results and Discussion**

Operational parameters – Impact of suspended solids concentration on TMP

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**Fig. 6. TMP vs MLVSS**

TMP remained constant at the end of the 2nd and 3rd period although the MLVSS rose up

→ MLVSS slightly influence activated sludge filterability
Conclusions

The intermittently aerated and fed SMBR system showed:
• high BOD (>97%), COD (>93%) and TKN (>87%) removal efficiencies
• the critical flux was estimated as 6.5 L/m²_h
• the optimum working flow rate to prevent biofouling ranged between 3 and 6 L/m²_h
• despite the fact that MLSS concentration rose up to 13 g/L, TMP was not affected

→ decrease the energy consumption due to the aeration time shortening and the absence of sludge return
→ the improved effluent quality enable the treated wastewater reuse
Thank you for your attention