EFFECT OF FLUX CONDITION ON POLLUTANTS REMOVAL OF SPONGE MEMBRANE BIOREACTOR TREATING HOSPITAL WASTEWATER

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ABSTRACT

Nowadays, membrane bioreactor (MBR) is an advanced available technology for wastewater treatment due to technical innovations and cost reduction. Especially, the high biomass concentration and long sludge retention time are favourable for the biodegradation of organic pollutants and nitrification. This research aims to study on the treatment performance of two lab-scale submerged membrane bioreactors treating hospital wastewater. One was operated at low fluxes (2, 4, 6 LMH) and the other at higher fluxes (10, 15, 20 LMH). Polyester-urethane cube sponge media (20 % v/v) was added into both reactors for fouling control and simultaneous nitrification denitrification (SND). The results showed that organic removal efficiencies were improved with an increase in flux. The removal efficiencies of COD and total nitrogen were 85-89 % and 26-42 % at low fluxes and 96-97 %, 53-65 % at higher fluxes, respectively. The treated water quality complied with Vietnam National Technical Regulation on health care wastewater, class A.

Keywords: membrane bioreactor, sponge, flux; fouling, hospital wastewater.

1. INTRODUCTION

There are about 750 health facilities, including central hospitals and private clinics in Ho Chi Minh City. Most of the hospitals do not have effective wastewater treatment system, so wastewater was discharged into the environment. Hospital wastewater may contain harmful pollutants such as pathogenic microorganisms (e.g., bacteria and viruses), heavy metals, biodegradable organic matters (e.g., protein, fat, carbohydrates) and pharmaceuticals (e.g., antibiotics, endocrine disrupting compounds (EDCs)), chemical residues (phenol, chloroform). The pollutants in hospital wastewater caused aquatic environment and human’s health problems [1]. Thus, hospital wastewater treatment has become essential in order to reduce environmental risks.
Membrane bioreactor (MBR) with benefits of space saving, high biomass retention, good treated water can operate flexibly for wastewater treatment [2]. In addition, MBR can eliminate antibiotics existing in wastewaters, especially hospital wastewater, which cannot be effectively eliminated by conventional activated sludge [3]. Sponge-MBR is advantageous in terms of functioning as an anti-fouling solution and removing pollutants. The cube sponges added in MBR could create microbial biodiversity and long attached biomass retention. Liu et al. [4] showed that the speed of trans-membrane pressure (TMP) increment in the Sponge-MBR was slowed down. When TMP reached 20 kPa, the Sponge-MBR could be operated more than 92 days while the conventional MBR operated only 57–65 days. The study also reported that in the Sponge-MBR, the average removals of COD, NH$_4^+$-N, TN, and TP were improved by 3.8 %, 4.2 %, 13.7 % and 1.7 %, respectively.

The aim of this study is a demonstration of the effect of flux condition on pollutants removal efficiency for hospital wastewater treatment by Sponge-MBRs. Flux ranges were varied of 2, 4, 6 LMH (low flux) and 10, 15, 20 LMH (higher flux).

2. MATERIALS AND METHODS

2.1. Experimental setup

Two lab-scale MBRs constructed by glass bioreactors were operated at different flux conditions. One MBR was operated at low fluxes (2, 4 and 6 LMH) had a working volume of 22 L (L × W × H = 0.28 m × 0.14 m × 0.55 m) and a hollow-fiber submerged membrane module (Motimo, China) with a surface area of 0.5 m$^2$ and pore size of 0.2 µm was installed. The other was operated at higher fluxes (10, 15 and 20 LMH) with a working volume of 8 L (L × W × H = 0.28 m × 0.08 m × 0.60 m) and a hollow-fiber membrane module (Mitsubishi, Japan) with a surface area of 0.1 m$^2$ and pore size of 0.4 µm was installed.

The polyester-urethane cubic sponges of 20 % reactor volume (porosity of 98 %, size of 1 cm × 1 cm × 1 cm) were added into MBRs. The systems were controlled automatically by timers, solenoid valves, and digital pressure gauges. Wastewater was fed directly into reactors by using a feeding pump in order to control the feeding rate while the effluent flow rate was controlled by a suction pump with cyclic mode (8 min on/2 min off). Air diffusers were installed at the bottom of the reactors to maintain dissolved oxygen value of higher than 4 mg/L. For each operated flux, membrane module was externally cleaned by NaOCl 5 % for 4 h. The digital pressure gauges were used to record the TMP to observe membrane fouling propensity.

The seed sludge was collected from an MBR treating domestic wastewater in Ho Chi Minh city. For both MBRs, the initially mixed liquor suspended solids (MLSS) was approximately 5,000 mg/L. The operating conditions of MBRs are presented in Table 1.

<table>
<thead>
<tr>
<th>Flux</th>
<th>2 LMH</th>
<th>4 LMH</th>
<th>6 LMH</th>
<th>10 LMH</th>
<th>15 LMH</th>
<th>20 LMH</th>
</tr>
</thead>
<tbody>
<tr>
<td>F/M (kgCOD/kgMLSS.d)</td>
<td>0.047 ± 0.01</td>
<td>0.072 ± 0.01</td>
<td>0.106 ± 0.03</td>
<td>0.18 ± 0.05</td>
<td>0.29 ± 0.04</td>
<td>0.34 ± 0.06</td>
</tr>
<tr>
<td>OLR (kgCOD/m$^3$.d)</td>
<td>0.15 ± 0.04</td>
<td>0.23 ± 0.07</td>
<td>0.39 ± 0.13</td>
<td>0.64 ± 0.16</td>
<td>1.07 ± 0.15</td>
<td>1.63 ± 0.29</td>
</tr>
</tbody>
</table>
2.2. Analytical methods

In this research, in order to evaluate the wastewater treatment efficiency, parameters such as pH, COD, TSS, NH\textsubscript{4}\textsuperscript{+}-N, NO\textsubscript{3}\textsuperscript{-}-N, NO\textsubscript{2}\textsuperscript{-}-N, TN, TKN, TP, MLSS, and MLVSS were determined using standard methods [5]. The biomass attached to sponges was converted into MLSS concentration. Five sponges were taken out from the reactor and squeezed sludge into a certain volume of distilled water. The MLSS in sponges was calculated based on the number of sponges in MBR and suspended solids concentration in squeezed solution. In addition, nitrogen balance was calculated using Eq.1. Nitrogen assimilated into the biomass was estimated based on the assimilated nitrogen of 12 % VSS [6].

\[
\text{TN}_{\text{in}} = \text{TN}_{\text{out}} + \text{TN}_{\text{assimilated}} + \text{TN}_{\text{denitrification}}
\]

where, \(\text{TN}_{\text{out}}\): total nitrogen in effluent; \(\text{TN}_{\text{in}}\): total nitrogen in influent & \(\text{TN}_{\text{denitrification}}\): total nitrogen was converted into nitrogen gas.

2.3. Wastewater characteristics

Hospital wastewater was collected from the equalization tank of Trung Vuong hospital wastewater treatment plant in Ho Chi Minh City. The wastewater contains 38 - 405 (222) mg COD/L, 27 - 125 (76) mg TSS/L, 3.0 - 38.4 (20.7) mg NH\textsubscript{4}\textsuperscript{+}-N/L, 19.6 - 57.1 (38.3) mg TKN/L, 1.3 - 5.5 (3.4) mg TP/L and pH of 6.8 - 8.2 (7.5). The number in the brackets are average values.

3. RESULTS AND DISCUSSION

3.1. COD removal

The average COD concentrations and removal efficiencies at various flux values were shown in Figure 1. COD of raw wastewater was varied of 38 - 404 mg/L; however, the average COD concentrations in the membrane permeate were as low as 8 - 16 mg/L. The COD effluent reached the Vietnam National Technical Regulation on health care wastewater - QCVN 28:2010/BTNMT (class A: 50 mg/L of COD). Wen et al. [7] studied hospital wastewater treatment using a submerged MBR and reported that it’s permeate was always less than 30 mg/L with a COD removal efficiency of 80 %.

![Figure 1. COD removal efficiencies at different flux values.](image-url)
The average COD removal efficiencies (n = 13) at low fluxes of 2, 4, 6 LMH were 89 ± 9 %, 88 ± 6 %, and 85 ± 10 %, respectively. While those were 97±3 %, 96±2 % and 96±2 % for higher fluxes of 10, 15, 20 LMH, respectively. This result indicates that COD removal of the sponge-MBR system can improve slightly with increasing flux conditions. The MBRs were operated at F/M ratio of fewer than 0.34 day⁻¹ for all fluxes. In addition, the influent concentrations of COD were lower at the lower flux rates (120 - 140 mg/L) while they were higher (250 - 340 mg/L) at higher fluxes.

3.2. Nitrogen removal

Average effluent concentrations of TKN, NH₄⁺-N, NO₂⁻-N, NO₃⁻-N and TN are summarized in Table 2. The concentrations of NH₄⁺-N and NO₃⁻-N in membrane permeate comply with the requirements of QCVN 28:2010/BTNMT (10 mg/L of NH₄⁺-N and 30 mg/L of NO₃⁻-N). The NH₄⁺-N removal efficiencies of higher 95% were observed in both Sponge-MBRs at different flux ranges, with the operating HRTs in range of 5-22 h. Besides, the average NO₃⁻-N concentrations in permeates were approximately 0.3 mg/L. Gender et al [8] reported that the nitrification of MBR is greater than the conventional activated sludge due to higher sludge retention time (SRT). High SRT also allows the enrichment of slow-growing microorganisms (e.g. nitrifying bacteria). At low SRT as conventional activated sludge there was caused a negative effect on nitrifier growth, which needs a long term for adaptation and development to support nitrogen removal [9]. In fact, MBRs can maintain both of fast and slow-growing bacteria. Therefore, consequently the establishment of a more diverse bacteria population, which favors the removal of pollutants.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Flux conditions</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>2 LMH</td>
</tr>
<tr>
<td>TKN (mg/L)</td>
<td>2.1 ± 2</td>
</tr>
<tr>
<td>NH₄⁺-N (mg/L)</td>
<td>0.5 ± 1</td>
</tr>
<tr>
<td>NO₂⁻-N (mg/L)</td>
<td>16.7± 6</td>
</tr>
<tr>
<td>NO₃⁻-N (mg/L)</td>
<td>0.2 ± 0</td>
</tr>
<tr>
<td>TN (mg/L)</td>
<td>18.5 ± 7</td>
</tr>
</tbody>
</table>

While nitrification takes place on the surface of the sponges, denitrification could occur inside the sponge pores where the oxygen concentration is limited. A simultaneous nitrification and denitrification (SND) occurring in the sponges makes a suitable environment for removing nitrogen completely [10]. The TN removal efficiencies at fluxes of 2, 4, 6 LMH were 42 ± 22 %, 36 ± 13 %, and 26 ± 12 %, respectively. However, fluxes were increased up to 10, 15 and 20 LMH, the removal efficiencies were higher 55 ± 14 %, 65 ± 20 %, and 53 ± 17 %, respectively. At a higher flux range (F/M ratio less than 0.34 day⁻¹) which give higher organic loading rate (OLR) lead to more biomass of microorganisms attached in the sponge in order to create effective biomass layer to increase the SND. Thus, the average removal efficiencies of TN were higher at high flux range.

Table 2. Average nitrogen concentrations in membrane permeate.
3.3. Phosphorus removal

Total phosphorus removal efficiencies were quite high of $49 \pm 25\%$, $53 \pm 22\%$ and $53 \pm 22\%$ for the fluxes of 10, 15 and 20 LMH, respectively, while those for the fluxes of 2, 4 and 6 LMH were $28 \pm 12\%$, $22 \pm 11\%$, and $26 \pm 11\%$. Khan et al. [11] reported that the TP removal of Sponge-MBR (15 % of sponge volume) was quite similar to this study, the removal efficiency was 58%.

TP removal mechanism was mainly through the accumulation of biomass and then removed from the system through excess sludge. Thus, TP removal efficiency depends on the amount of biomass produced and sludge elimination. When flux condition increased, the concentration of the biomass attached in sponges and the concentration of suspended biomass increased, so TP removal efficiency was high. In low flux range of 2 - 6 LMH, treatment efficiency was only about 22 - 28 % TP, while at high flux range of 10 - 20 LMH, the removal efficiencies were 49 - 53 %. (Figure 3).

In some other studies, TP removal efficiency of the Sponge-MBR system was quite high. Liu et al. [12] show the TP removal efficiency of Sponge-MBR was 80.5 % which 1.7 % higher than the conventional MBR. According to Khan et al. [11], TP removal efficiencies of Sponge-MBR and MBR were 58 % and 38 % at SRT of 30 days, respectively. Lower performance for TP removal can be explained by longer SRT in this study. The SRT was as short as 10 days in the study of Liu et al. [12].
3.4. Biomass characteristics

Microorganisms in Sponge-MBR includes both attached (in sponges) and suspended biomass. The results showed that the sponge MLSS concentrations (attached biomass) were between 2909 – 3425 mg/L for low fluxes of 2-6 LMH and between 2342 – 6060 mg/L for higher fluxes of 10-20 LMH. In general, the Sponge-MBR demonstrated superior biomass retention compared to the MBR. This was due to a large amount of biomass attached in sponges. In addition, the average MLVSS/MLSS ratio at low fluxes of 2 - 6 LMH was 0.61 while at higher fluxes of 10-20 LMH it was up to 0.78. Higher organic loading rate (OLR) allowed more biomass attached in the sponge. In addition, high applied OLR could raise the MLVSS/MLSS ratio in the MBR. In this study, by using only 20 % sponge of reactor volume, it contained up to 60 % of the total biomass of the Sponge-MBR. The high ratio of attached sponge biomass enhanced both COD removal and simultaneous nitrification and denitrification.

4. CONCLUSIONS

The results demonstrated that sponge membrane bioreactor technology was appropriate for pollutants removal in hospital wastewater. The removal efficiencies of COD, TN, and TP were high and improved with an increase in flux ranges. The treated wastewater complies with Vietnam National Technical Regulation on health care wastewater, class A.

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REFERENCES


