Preliminary Study of Hospital Wastewater Treatment with a Submerged Membrane Bioreactor (SMBR): Case Study of Songklanagarind Hospital -Thailand

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ABSTRACT

The objective of this research was to study hospital wastewater treatment using a submerged membrane bioreactor (SMBR). The lab scale unit of SMBR with a working volume of 20 liters was operated at a hydraulic retention time of 0.416 day and 0.208 day at F/M ratio of 0.18 day⁻¹ and 0.29 day⁻¹. The operating conditions were set up to provide good biological treatment without sludge extraction, and two different permeate flux values were studied. The performance of membrane was studied by monitoring the variation of transmembrane pressure (TMP) during filtration runs. The efficiency of SMBR was investigated according to the daily measurements of pH, dissolved oxygen and temperature. The COD, BOD₅, NH₄⁺-N, TKN, color, turbidity, SS and Escherichia coli (E. coli) in influent and effluent were analyzed. Membrane fouling intensity occurred slowly when the system operated with flux at 10 L/h/m² and 20 L/h/m², which induced high TMP at the initial period of filtration. The fouling rate was at about 0.3022 mbar/day for the permeation of flux at 10 L/h/m². The fouling rate still remained at 0.2774 mbar/day for 20 L/h/m². The results showed the great effect of membrane use for total biomass retention and the removal rate of COD, BOD₅ and E. coli were over 90%. The characteristics of sludge in SMBR showed healthy floc formations with good settling. Although the ratio of MLVSS/MLSS was lower than the normal range (about 0.2), it was found that the average values of COD and NH₄⁺-N in permeate were lower than 2-80 mg/L and 0.05-6.75 mg/L while the value of turbidity was also less than 3 NTU.

Keyword: Submerged membrane bioreactor; hospital wastewater treatment, efficiency, MLSS/MLVSS

1.0 INTRODUCTION

The hospital is the point source of infectious wastewater because of its activities. It generates wastewater different from domestic wastewater due to contamination by hazardous chemicals, hormones and infected microorganisms from patients [1]. In addition, most of the hospital is facing unsafe water due to contamination in natural water resources from elsewhere. Therefore, water reuse and recycling program/concept is becoming attractive. A variety of the wastewater treatment processes have been used for treating hospital wastewater. In Thailand aerobic treatment systems are widely used and recommended such as Aerated Lagoon (AL) and Activated Sludge (AS) found in hospitals in the central or urban areas [2]. It is considered an issue if these conventional systems still have some limitation such as requiring a large space for the system, or if the AS needs attention and specialists for
monitoring the system, and also if the quality of
effluent still does not pass the Thai Standard for
effluent due to the limitation of each selected
process. The SMBR process has become
increasingly popular in the field of wastewater
treatment; it is used as a modification of AS, where
the traditional secondary clarifier is replaced by a
membrane unit for the separation of treated water
from the mixed solution in the bioreactor [3].
SMBR technology has many advantages: high
treated water quality, retention of all suspended
solids and microorganisms, and absolute control
of biomass and long hydraulic retention time. This
system can operate in various conditions and its
application has been widely accepted and
recommended for the treatment of domestic and
also industrial wastewaters. This system including
the bioreactor system and membrane system, was
integrated and developed from the AS wastewater
treatment system. The SMBR system is mostly
characterized by immersing the membrane
modules as separation units directly in the bio­
reactor. The SMBR wastewater treatment received
increasing attention because of its advantages such
as complete solid removal from effluent, effluent
disinfection, low/zero sludge, its compact size, low
energy consumption and acceptable effluent for
recycling purposes [4-6].

However, membrane fouling is a major problem
affecting performance. The characteristics of
fouling appear as follows: the membrane's surface
is clogged by a deposited layer of particles
(reversible fouling), and the soluble substances of
macromolecules are adsorbed in membrane
material. The latter induces membrane fouling in
long periods of filtration as defined in irreversible
fouling for example. To overcome the membrane
performance the operating conditions in SMBR
should be of concern. Aeration at different degrees
promotes and induces the local shear stress close
to membrane surface. This technique also produces
the circulation of flow inside, favoring the
movement of the membrane if membrane fiber is
used. Moreover, the permeation of flux is recom­
mented in the sub-critical region. Besides, the
formation of biomass cake layer on the membrane
surface can be observed playing a key factor in the
efficiency and performance of SMBR [6-9].

The objective of this work was to study the
effect of sub-critical permeation flux on the
efficiency and performance of the submerged
membrane bioreactor for the hospital's wastewater
treatment.

2.0 EXPERIMENTAL SET-UP AND
OPERATION

Experiments were carried out in laboratory scale
SMBR units. The working volume of the reactor
was about 20 L. A detailed schematic of the pilot­
scale SMBR system is presented in Figure 1. The
membrane module used was a hollow fiber
membrane module, made from Polyethylene-
Hydrophilic Polymer Membrane, with a pore size
of 0.22 mm and a filtration area of 0.2 m²/module.
The hollow fiber membrane module was directly
submerged in the reactor, in which the aeration

![Figure 1 Schematic diagram of SMBR](image)

(1) Influent tank, (2) Bioreactor with air bubbling system and
membrane module, (3) Permeate tank
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To avoid over-fouling of the membrane, the limitation of TMP was controlled and the cleaning processes were performed when the TMP increased to 0.5 bars. The specific cleaning steps were different in the hydrodynamic and chemical methods: rinsing with water, backwashing with water at 10 L/h/m² for 1 hour, backwashing with 1% w/v citric acid at flux 10 L/h/m² for 1 hour and immersed in 1% w/v citric acid for 1 hour, backwashing with 1% w/v caustic at flux 10 L/h/m² for 1 hour and immersed in sodium hypochlorite 1% w/v cleaning for 1 hour. The permeability of water was measured after each cleaning step. The origin and potential of membrane fouling can be identified if the causes are present.

3.0 CHARACTERISTICS OF STUDIED HOSPITAL WASTEWATER AND SEEDING SLUDGE

The SMBR used real wastewater from Songkanagarind's hospital. The characteristics of the wastewater used are summarized in Table 2. The SMBR operated without sludge extraction excepting when the samples of sludge were taken for mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS) and biomass compositions analysis. The experimental conditions are summarized in Table 1.

Table 1 Operating conditions

| Conditions         | Values |
|--------------------|--------|
| Permeation flux    | L/h/m² |
| Hydraulic retention time (day) | 0.416 / 0.208 |
| pH                 | 6.8-8.2 / 6.8-8.2 |
| Temperature (°C)   | 25-30 / 25-30 |
| F/M ratio, day⁻¹  | 0.18 / 0.29 |
| Air flow rate (L/min) | 5 / 5 |
| TMP limitation (bar) | 0.5 / 0.5 |

Table 2 Wastewater characteristics of Songkanagarind Hospital

| Parameters | Values(mean±SD) |
|------------|----------------|
| Turbidity, NTU | 84±45 |
| Color, SU    | 1.07±0.34 |
| SS, mg/L     | 114.78±70.6 |
| COD, mg/L    | 433.4±153.5 |
| SCOD, mg/L   | 145.81±50.3 |
| BOD₅, mg/L   | 162±56.56 |
| TKN, mg/L    | 37.05±11.55 |
| NH₄⁺-N, mg/L | 30.42±5.87 |
| E.coli/MPN   | 2.1*10⁸ - 7*10¹⁰ |
the removal efficiency was stable at about 80% with the concentration of biomass at about 2,000 mg/L, which was transferred to the SMBR and this biomass concentration was in the normal range value of criteria design for AS.

4.0 ANALYTICAL METHODS

The efficiency of MBR were investigated according to the daily measurements of pH, dissolved oxygen and temperature. The COD, BOD$_5$, NH$_4$+N, TKN, color, turbidity, SS and Escherichia coli in influent and effluent were analyzed three times a week while the biodegradable organic content in the BOD$_5$ was done once/twice a week. The permeate and effluent were analyzed for the nitrogen compounds in terms of NO$_3$- N. All parameters followed standard methods [10]. The particle size distribution, using a Laser Particle Size Analyzer (COULTER LS230), was also studied. The structure of biomass and its population in the SMBR was analyzed using an optical microscope. The sampling of sludge for its characteristic determination, once per each experimental run, may not reduce the SRT of the system significantly.

5.0 RESULTS AND DISCUSSION

5.1 COD and BOD$_5$ Removals

The BOD$_5$/COD ratio of influent was moderate with values between 0.23 to 0.65. The concentration of COD and BOD$_5$ was in the range of 200 to 750 mg/L and 130 to 220 mg/L during the course of operation. The fraction of soluble COD in the influent was an average 143.81±50.31 mg/L and the SCOD/TCOD ratio was at about 0.33 implying that the influent solids rarely contributed to the TCOD of influent while the concentration of soluble COD was comparable to the BOD$_5$ of the influent. The removal efficiencies of the organics observed in this study are summarized in Table 3.

After steady state condition of the treatment the results showed that the SMBR had a high removal rate of COD, BOD$_5$ and Turbidity. The removal rate of COD and BOD$_5$ are shown in Figures 2-3. It was found that the removal efficiency of COD and BOD$_5$ of MBR was between 80-98% and over 98% whatever the permeation of flux tested. The SMBR showed an increase of removal efficiency of COD with time while the constant of BOD$_5$ removal was observed. The soluble COD fraction could be removed by the biological

### Table 3 Performance summary of SMBR

| Parameter* | Wastewater Supernatant of sludge in reactor | SMBR permeate | Removal efficiency (%) in SMBR |
|------------|---------------------------------------------|---------------|-------------------------------|
|            | 10 (L/h/m$^2$) | 20 (L/h/m$^2$) | 10 (L/h/m$^2$) | 20 (L/h/m$^2$) |
| Turbidity, NTU | 84±45 | - | 1.06±0.85 | 0.86±0.23 | 98.60 | 98.12 |
| Color, SU | 1.07±0.54 | - | 0.46±0.08 | 0.51±0.02 | 54.59 | 56.92 |
| SS, mg/L | 114.7±70.6 | - | - | - | - | - |
| COD, mg/L | 435.4±153.5 | - | 35.59±24.67 | 17.33±10.93 | 90 | 95 |
| SCOD, mg/L | 143.81±50.31 | 89.03±29.85 | 35.59±24.67 | 17.33±10.93 | 90 | 95 |
| BOD$_5$, mg/L | 162±36.56 | - | 1.88±0.94 | 1.56±1.19 | 98.89 | 99.04 |
| TKN, mg/L | 37.05±11.55 | - | 6.52±2 | 6.49±2.48 | 86.34 | 79.5 |
| NH$_4$+N, mg/L | 30.42±5.87 | - | 3.05±1.59 | 4.47±0.41 | 90.06 | 9.89 |
| NO$_3$- N, mg/L | N.D | - | 20.4±7.76 | 27.3±3.98 | - | - |
| E. coli, MPN/100 ml | $2.1*10^5$ - $7*10^{10}$ | - | $4*10^5$ - $4.6*10^5$ | $4*10^2$ - $4*10^7$ | 99 | 99 |

*All analyses were performed at steady-state period
ND: non detectable (lower than detection limit value)
reaction with efficiency between 20-75%. The BOD$_5$ concentration of effluent was less than 2.5 mg/L. The effectiveness of membrane separation can remove some fraction of soluble COD and colloids in a wide range of 20-90%. However, the quality of permeate from the MBR still remained non-biodegradable in organics in terms of COD concentration, which was not completely eliminated by biological reaction and membrane separation using the pore size studied. The residual of COD in effluent remained in the wide range of 2 to 80 mg/L. However, it is supposed that the removal efficiency of soluble COD fraction will gain in the long run of operations.

Figure 4 shows the physical quality removal by this MBR studied in terms of turbidity. The results showed that the variation of turbidity in the influent was between 21 to 205 NTU. However, the turbidity of permeate was always below 3 NTU with the removal efficiency over 98 % respectively, while the effectiveness of membrane retaining E.Coli was over 99%.
5.2 TKN and NH$_4^+$-N Removals

The amount of nitrogen compound in terms of TKN and NH$_4^+$-N concentration were in the same range (TKN = 37.05±11.35 mg/L and NH$_4^+$-N = 30.42±5.87 mg/L). This indicated that most of organic nitrogen was mostly transformed to NH$_4^+$-N concentration in the influent. The overall removal rate of TKN, NH$_4^+$-N of MBR was observed and it was over 90% in the two conditions tested. The nitrogen compounds were mostly transformations and eliminated by the process of nitrification due to effective nitrifying bacteria growing in SMBR, which was operated in long sludge retention time. It can be seen from Figure 5 that despite the fluctuation of TKN and NH$_4^+$-N concentration in the influent, only 0.05 to 6.755 mg/L of NH$_4^+$-N was detected in the permeate. The concentrations of NO$_2^-$-N still remained in the range of 12.67-31.68 mg/L. To eliminate and avoid the accumulation of NO$_2^-$-N and NO$_3^-$-N in studied SMBR, the step of denitrification will be recommended and implemented in order to process the intermittent aeration to transform NO$_3^-$-N concentration in permeate to nitrogen gas.
5.3 Sludge Characteristics

The characteristics of sludge or biomass in the SMBR were analyzed and their development was also surveyed. Figure 6 shows the evolution of biomass during the course of operations. The biomass concentration (MLSS and MLVSS) was determined. It was observed that the constant or slow increase of biomass at the beginning until the day 6 of the phase in the start up period with a concentration of 1,500 mg/L. After that MLSS concentration was slowly increased in a range from 1,600 to 2,500 mg/L from day 7 to day 9. The steady state condition was reached after 12 days. The concentration of MLSS and MLVSS still increased slowly with time and stabilized at 2,000 mg/L with MLVSS/MLSS < 0.3 in SMBR. This calculated ratio was lower than the ratio values in conventional activated sludge and MBR which is known to be 0.5-0.8 in most cases [11]. The relatively stable and low ratio of MLVSS to MLSS in this SMBR indicated that the amount of inorganic remainders constituted in the biomass [12] due to the nature of hospital wastewater contained a high composition of chemical substances [1]. However the efficiencies of treatment in SMBR were satisfied: the COD treatment efficiencies reached to 80-90% without any problem from sludge. The formation of a biomass layer on the membrane surface was also slightly observed and it plays a secondary layer as a membrane.

![Figure 6](image)

**Figure 6** Sludge or biomass concentration during operation courses

![Figure 7](image)

**Figure 7** An example of protozoa indicating the stability of SMBR
At a certain SRT (without sludge extraction) in this study, the excess sludge might be oxidized in the bioreactor, which will keep sludge concentrations constant during the course of operation. The SVI value was measured and its values reported to be about 103-108 ml/g. This range of SVI values showed the good settling characteristic of sludge that may be expected in the SMBR, even if the system was not operating for a long enough period of time [8-9]. This result clearly showed that the sludge characteristics obtained from a short term operation of 30-35 days can represent that of a long term operation as in general AS.

The morphology of sludge and floc size determination was observed to identify the microbial community found in the SMBR (Figure 7). The mean floc size was at 54.82 μm with a high variation of large and small floc sizes observed (24.01 and 82.26 μm). In this SMBR stalked ciliates were found higher than free swimming ones and only a few Suctoria or Rotifer. These microbials indicated and confirmed that the stability of studied SMBR was well performed whatever the permeation of flux values tested [8-9].

5.4 Membrane Performance

The performance of the SMBR system was investigated by monitoring the values of TMP with time. Figure 8 shows that the values of TMP increased slowly and fouling rate was an average of 0.5022 mbar/day for the permeation of flux at 10 L/h/m². When the SMBR operated at 20 L/h/m² the fouling rate still increased with a constant remaining rate of 0.3224 mbar/day. This fouling increased slowly due to the accumulation of sludge on the membrane surface, in which some of the cake layer was removed by air scouring. However, it was still found as the biofilm or gel layer. The gel layer could function as a dynamic membrane to enhance the elimination of soluble organic matters. In addition, the adsorption of soluble organic matters in the membrane plays a key factor in irreversible fouling [7, 13].

The intensity of aeration considers improving and controlling biomass layer formation thus reducing reversible fouling. Moreover, it is very difficult to avoid fouling in SMBR in long runs, even if the system was set up under good operating conditions.

6.0 CONCLUSIONS

A Lab-scale submerged membrane bioreactor was used effectively for hospital wastewater treatment. The results showed the great effect of membrane used for total biomass retention and the removal rate of COD, BOD₃ and *Escherichia coli* were over 90%. The removal efficiency of COD and BOD₃ of MBR were between 80-98% and over 98% whatever the permeation of flux tested. It was found that the average values of COD and NH₄⁺-N in permeate were lower than 2-80 mg/L and 0.05-6.755 mg/L while the value of turbidity was also less than 4 NTU. The soluble COD fraction could be removed by the biological reaction with efficiency between 20-75%. The BOD₃ concen-
The effectiveness of membrane separation can remove some fraction of soluble COD and colloids in a wide range of 20-90%. The performance of the membrane was studied by monitoring the variation of TMP during filtration runs. The fouling rate was at about 0.324 and 0.2774 mbar/day for the permeation of flux at 10 and 20 L/h/m². The major fouling in this SMB is of an irreversible type according to the adsorption of soluble organic matters and also the biofilm layer or gel layer on the membrane surface.

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