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Evaluation of using membrane bioreactor for treating municipal wastewater at different operating conditions

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Abstract

Membrane bioreactors (MBRs) can replace the activated sludge process and the final clarification step in municipal wastewater treatment. The combination of biological degradation with membrane filtration allows for high reduction of chemical oxygen demand (COD), biochemical oxygen demand (BOD), and ammonia nitrogen (NH_3-N). In this paper, a laboratory-scale membrane bioreactor was fed with synthetic wastewater to investigate the possibility of simultaneous removal of organics and nitrogen. The degradation of synthetic wastewater at a hydraulic retention (HRT) time of 8 h has been studied. Three different concentrations of COD of the influent were investigated and the averages of these concentrations are 606, 1440 and 2500 mg/L. The initial range of BOD and NH_3-N were, 471.6 to 1888.6 mg/L and 19.455 to 53.609 mg/L respectively. Sludge retention time (SRT) was varied between 30 and 35 days. Mixed liquor suspended solids (MLSS) was ranged between 9980 and 26,720 mg/L. Results showed that removal efficiencies for the MBR varied from 97.8 to 99.9% for COD, 98.9 to 99.9% for BOD and 91.0 to 99.9% for NH_3-N. pH of the effluent was increased compared with pH of the influent but it was not exceeded the effluent discharge standards to Malaysian inland waters (pH range from 6.0 to 9.0).

Keywords: Membrane bioreactor (MBR); Synthetic wastewater; COD removal; BOD removal; NH_3-N removal

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1. Introduction

Membrane bioreactors (MBRs) can be defined as integrating biological degradation system of waste products with membrane filtration [1]. The two basic MBR process configurations are external and submerged [2]. In the external MBR (EMBR), the mixed liquor is pumped from the aeration tank to the membrane at flow rates that are 20–30 times the product water flow to provide adequate shear for controlling solids accumulation at the membrane surface. The high cost of pumping makes EMBR system impractical for full-scale municipal wastewater treatment plants [3]. In the submerged MBR (SMBR) process, the membrane is submerged directly in the aeration tank. By applying low vacuum or by using the static head of the mixed liquor, effluent is driven through the membrane leaving the solids behind. In SMBRs, the shear required to control solids accumulation at the membrane surface is provided by coarse bubble aeration. MBRs have been used to treat various type of wastewaters with a chemical oxygen demand (COD) ranging from about 100 to more than 40,000 mg/L and hydraulic retention time (HRT) varying from 4 h to several days [4].

There are several advantages associated with the MBR, which make it a valuable alternative over other treatment techniques. First, the retention of all suspended matter and most soluble compounds within the bioreactor leads to excellent effluent quality capable of meeting stringent discharge requirements and opening the door to direct water reuse [5]. The possibility of retaining all bacteria and viruses results in a sterile effluent, eliminating extensive disinfection and the corresponding hazards related to disinfection by products [6]. Since suspended solids are not lost in the clarification step, total separation and control of solids retention time (SRT) and hydraulic retention time (HRT) are possible. Thus, optimum control of the microbial population and flexibility in operation are possible. The absence of a clarifier enables sensitive, slow-growing species (nitrifying bacteria, bacteria capable of degrading complex compounds) to develop and persist in the system even under short SRTs [7]. The potential for operating the MBR at very high solid retention times without having the obstacle of settling, allows high biomass concentrations in the bioreactor. Consequently, higher strength wastewater can be treated and lower biomass yields are realized [8]. This also results in more compact systems than conventional processes significantly reducing plant footprint making it desirable for water recycling application.

The disadvantages associated with the MBR are mainly cost related. High capital cost due to expensive membrane units and high-energy costs due to the need for a pressure gradient have characterized the system. Membrane fouling problems can lead to frequent cleaning of the membranes, which stop operation and require clean water and chemicals. Another drawback is that waste-activated-sludge may exhibit poor filterability properties [9]. Additionally, when operated at high SRTs, inorganic compounds accumulating in the bioreactor can reach concentration levels that can be harmful to the microbial population or membrane structure [10].

Some researches have been done on the effect of operating parameter such as organic loading rate (OLR), solids retention time and food to microorganism ratio (F/M) on the performance of MBR. Trussell et al. [11] reported that the membrane fouling was increased with increasing F/M whereas, How and Salwomir [12] found that an excellent organics removal efficiencies were achieved in the MBR operated at different SRT however, nitrification ceased when SRT was lesser than 2.5 d.

The goal of this study is to evaluate the performance of MBR on the simultaneous removal of organics and nitrogen under different operating conditions (VLR and SRT) as well as to monitor the variation of pH of the wastewater.

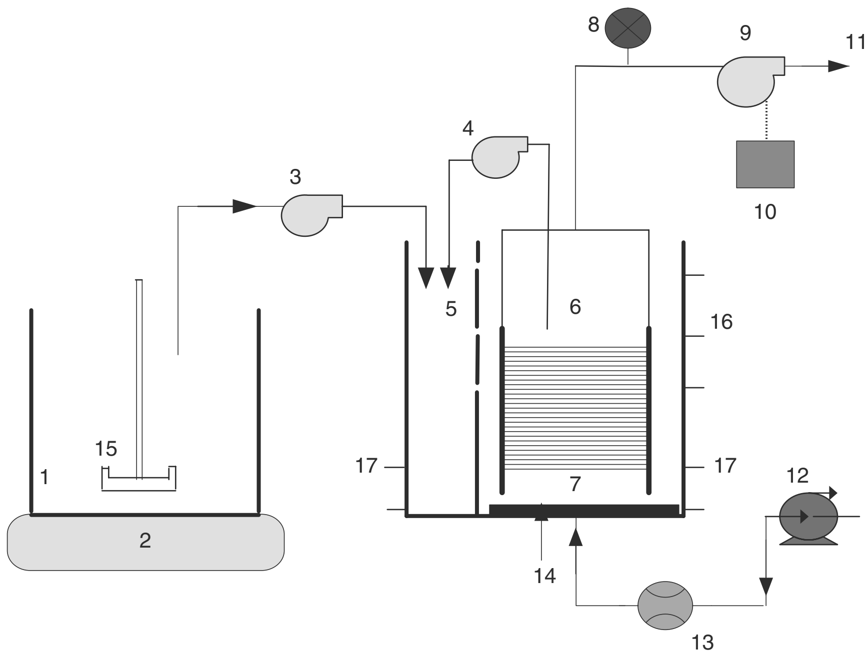

Fig. 1. The schematic diagram of the membrane bioreactor.

2. Materials and methods

2.1. Bench-scale submerged membrane bioreactor

A laboratory-scale bench-scale submerged membrane bioreactor (SMBR) was constructed and installed at the Public Health Engineering Laboratory, Department of Civil Engineering, University Putra Malaysia. The schematic flow diagram of the system is shown in Fig. 1. The bioreactor consists of two compartments; aerated and non-aerated with working volume of 20.4 L (15.3 L for aerated compartment and 5.1 L for non-aerated compartment). A microfiltration membrane module (Table 1 and Fig. 1) was immersed in the aerated compartment for filtration. The MBR was aerated from beneath the microfiltration module through a diffuser to provide the cross flow effect, the oxygen requirement for the biological process, and to mix the mixed liquor in the reactor.

2.2. Feed wastewater

Synthetic wastewater was used in this study instead of actual wastewater to control variable nature of nutrient concentration in raw wastewater. The composition of wastewater is shown in Table 2. The concentrations of the chemicals were taken from Jin et al. [13] as shown in Table 2. A concentrated solution was prepared by increasing proportions of Jin et al. [13] five times

Table 1
Specification of the membrane

Module specification	Value
Membrane material	Polyethylene
Outer diameter	540 μm
Inner diameter	350 μm
Pore size	0.4 μm
Surface area	0.2 m^2
Manufacture	Mitsubishi Rayon (Japan)

Table 2
Composition of synthetic wastewater (mg/L)

Composition	Concentration (mg/L) — Jin et al. [13]	Concentration — used in the study
Glucose	670–1080	5400
Glutamic acid	285–460	2300
CH_3COONH_4	220–350	660
$NaHCO_3$	750–3000	5000
NH_4Cl	33–53	165
KH_2PO_4	60	300
K_2HPO_4	80	400
$MgSO_4 \cdot 7H_2O$	33	165
$FeCl_3 \cdot 6H_2O$	2	10
$CaCl_2 \cdot 2HO$	20	100
NaCl	25	125

(Table 2) and the solution kept in refrigerator at 4°C. The stock solution was diluted with distilled water to a desired COD concentration and a portion of clay suspension was added before being fed to the reactor. In this synthetic wastewater, glucose and glutamic acid were used as carbon sources, CH_3COONH_4 and NH_4Cl were used as nitrogen sources, and KH_2PO_4 and K_2HPO_4 were used to provide orthophosphate phosphorus (PO_4^{3-}-P) in the synthetic wastewater. Sodium bicarbonate ($NaHCO_3$) was used for alkalinity to keep pH at around natural [14]. Laguna clay suspension was added at a rate of 165 mL per one liter of the synthetic wastewater to increase the suspended solids.

2.3. Preparation of Laguna clay suspension

Seventy-five grams of Laguna clay was added to 5 L of distilled water. The suspension was stirred slowly at 50 rpm for 1 h in a 5-L beaker for uniform dispersion of clay particles. The suspension was then allowed to stand for 24 h to allow for complete hydration of the clay. The supernatant was decanted into a plastic container and kept in a room temperature. This suspension was used as a stock solution for the preparation of synthetic wastewater.

2.4. Reactor operation

The reactor was operated for different, sludge retention time (SRT) and organic loading rate. Initial HRT was fixed at 8 h. The feeding tank was placed in a water bath/low temperature bath circulator to control the feeding temperature. The feed water was pumped to the MBR module through a peristaltic pump. Permeate was extracted by a peristaltic pump with an intermittent suction in a 10-min cycle; 8-min on and 2-min off. The excess sludge was removed from the reactor daily according to the desired sludge retention time (SRT). The mixed liquor suspended solids (MLSS) and dissolved oxygen (DO) concentration were measured regularly and when the DO dropped lower than 1 mg/L, the aeration rate was increased. Samples were taken for analysis every 2 days. Flux and suction pressure were measured during each run.

The COD, BOD, NH_3-N, MLSS and MLVSS were analyzed as described in ABHA [15]. Dissolved oxygen was measured by using the DO meter (Radiometer analytical, model IONcheck 20). A pH meter (Mettler Toledo, model Delta 320) was used for measuring the pH.

3. Results and discussion

3.1. Removal of COD and BOD

Synthetic wastewater was prepared from the dilution of the stock solution that prepared according to Table 2. Three runs were carried out with three kinds of synthetic wastewater. The characteristics of the wastewater sample for each run as well as the VLRs are shown in Table 3.

The variation of COD vs. time for each run is illustrated in Fig. 2. During run 1, the lowest and highest removal of COD was 98.9% on the first 3 days and 99.9% on day 4 until the end of the experiment. The COD concentration of effluent was ranged between 8 and 16 mg/L. For run 2, the lowest COD removal was 98.8% whilst the highest removal was 99.7% and the COD

Table 3
Characteristics of the synthetic wastewater and the operational performance of the membrane bioreactor

Run	Influent			VLR		
	COD (mg/L)	BOD (mg/L)	NH_3-N (mg/L)	COD (g L^{-1} d^{-1})	BOD (g L^{-1} d^{-1})	NH_3-N (g L^{-1} d^{-1})
1	1440	971.0	32.554	3.93	2.65	0.11
2	2500	1888.6	53.609	6.97	5.27	0.19
3	606	471.6	19.455	1.73	1.36	0.07

concentration of effluent was maintained at 8 mg/L however on day 10 it was increased to 32 mg/L due to the sudden increase of the influent COD to 2760 mg/L. With regard to run 3, COD removal varied from 97.8 to 98.7%. The effluent COD concentration was 16 mg/L at the first day because of the relatively higher COD (720 mg/L) in the influent however, it maintained at 8 mg/L during the other days.

Fig. 3 shows the variation of BOD during the running period of the three experiments. It is observed that the highest and lowest BOD removal for run 1 was 99.9 and 99.2% respectively. The corresponding BOD concentration of influent and the VLR were 971 mg/L and 2.65 kg BOD m^{-3} d^{-1} respectively (Table 3). The BOD concentration of effluent was in the range of 1–2 mg/L. With regard to run 2, the BOD removal varied between 99.4 and 99.8%. The BOD concentration of effluent was in the range of 2.6 to 3.7 mg/L however; on day 9 it was raised up to 13.1 mg/L and this may be attributed to the high BOD in the influent (2140 mg/L). Results of run 3 have shown that the BOD removal varied between 98.9 and 99.6% whereas the BOD concentration in the effluent varied between 2 and 5 mg/L.

All the results of the three experiments were complied with standard A of the effluent discharge standards to Malaysian inland waters (maximum permitted values for BOD_5 and COD are 20 and 50 mg/L respectively).

From the results presented above it can concluded that the anoxic–aerobic MBR has great potential in biodegrading organic pollutants from municipal wastewater. It can also be seen that under different operating conditions; VLR, SRT, and temperature of the feeding wastewater (Tables 3 and 4), the MBR performance has proved to be sound and stable. This fact is in agreement with Xing et al. [16] as well as with Stefan and Walter [17]. The former reported that

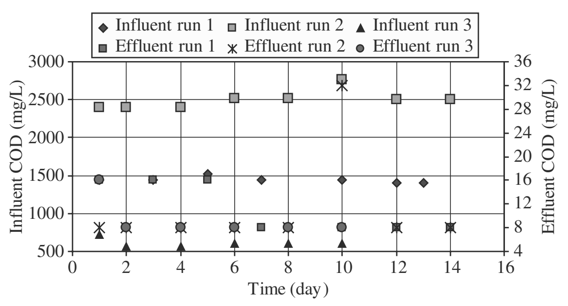

Fig. 2. Evolution of COD for run 1, run 2 and run 3 vs. running time.

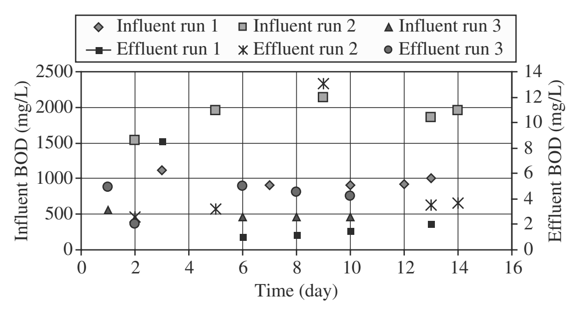

Fig. 3. Evolution of BOD for run 1, run 2 and run 3 vs. running time.

Table 4
Operational parameters and characteristics of the wastewater samples

Run	Sludge retention time (d)	Initial HRT (h)	Influent — average pH	Effluent — average pH	MLSS range (mg/L)
1	30	8	5.95	8.27	9980–12,420
2	35	8	6.82	8.46	16,480–26,720
3	35	8	6.79	8.15	17,160–20,760

the biological performance of a tangential-flow MBR under different operational parameters has proved to be stable. The later used MBR in treating urban wastewater and he found that the COD of the filtrate did not exceed 30 mg/L although; COD in the influent was varying between 400 and 900 mg/L. This refer to the fact that, as a large organic load of the wastewater result in a high biomass production, the system can react immediately to alternating substrate concentrations in the feed stream [17].

Ujang et al. [18] conducted a study using an intermittent aeration in MBR with volumetric loading rate range between 0.62 and 0.7 kg COD m^{-3} d^{-1} and the removal efficiencies obtained were from 97 to 98%. Zhang and Verstraete [19] have carried out a study using staged anaerobic and aerobic MBR with the volumetric loading rate of 1.25 kg COD m^{-3} d^{-1} and he reported that the removal efficiency was 97%. Comparing the present results with the published ones, the efficiency of COD removal for this study is slightly higher than the published studies.

3.2. Ammonia removal

Fig. 4 shows the evolution of ammonia for the three previous experiments whereas the influent ammonia concentration and the VLR, are shown in Table 3. the average ammonia removal for run 1, run 2 and run 3 was 99.5, 95.7 and 99.8% respectively and the corresponding effluent ammonia concentration was between 0.04–0.6 mg/L, 0.022–4.706 mg/L and 0.007–0.09 mg/L respectively. The results revealed that the potential of this system to remove NH_3-N is very high. This implies that high nitrification had occurred during the period of operation. The high nitrification may arise for two reasons. First, membrane separation entirely confined the nitrifying bacteria within the bioreactor independent of sludge concentration. In the presence of nutrients, the autotrophic nitrifying bacteria that would normally have a long generation time were ‘forced’ to reproduce quickly instead of being washed out of the system. In contrast, the nitrifying bacteria were inevitably washed out in CASP especially when SRT was kept too low [8]. Thus, the concentration of nitrifying bacteria in MBR was relatively high comparing with that in CASP. Secondly, since sludge production is low in MBR process [20], nitrifying bacteria met less competition from other heterotrophic microorganisms that were also active consumers of ammonia nitrogen [20]. Thus a high nitrifying rate could be achieved in this study even though the system was operated under

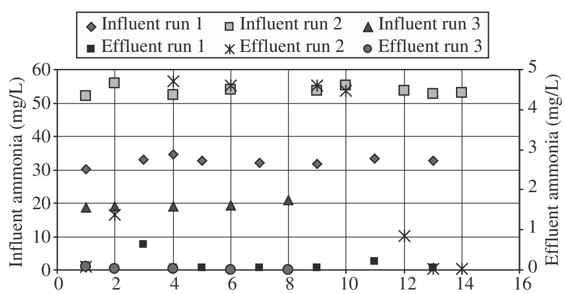

Fig. 4. Evolution of ammonia for run 1, run 2 and run 3 vs. running time.

the different operating parameters that mentioned previously. It is noted that the efficiency of ammonia removal increases with decreasing of the influent ammonia concentration. During experiment 2, it is observed that the concentration of effluent NH_3-N was fluctuated. Thus, for the day 2, the concentration was 1.3 mg/L and it raised to 4.468–4.706 mg/L from day 4 to day 10 however, it decreased a gain to 0.856–0.022 mg/L form day 12 to day 14. The factors that have a significant influence in nitrification process are temperature, dissolved oxygen and pH. The optimum temperature for the growth of nitrifying bacteria is between 28 and 36°C whereas the pH value varies between 8 and 9 [21]. Since both of the temperature and the pH of the reactor are slightly varied during the run, the fluctuation in the effluent NH_3-N concentration is refer to the variation of the dissolved oxygen (DO) in the reactor as it shown by Fig. 5. At a DO concentration of 1 mg/L and below, the effluent NH_3-N was in the range of 4.468 mg/L whereas it decreased below 0.1 mg/L after the DO reached 1.8 mg/L and above. In contrast, for the same DO concentration (1.0 mg/L) in experiment 1 (influent ammonia 32.554 mg/L), the effluent NH_3-N was below 1.0 mg/L. This implies that oxygen consumption to oxidize ammonia to nitrate and nitrite depends on the concentration of the influent ammonia (the higher ammonia concentration the higher oxygen consumption).

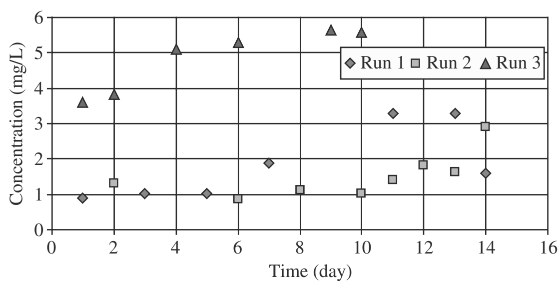

Fig. 5. Evolution of dissolved oxygen vs. running time.

3.3. pH variation

The pH values of influent, aeration tank and effluent samples for run 1, run 2 and run 3 were measured throughout the experiment's duration and results are shown in Fig. 6.

The pH values of the influent for run 1, run 2 and run 3 ranged between 5.50–6.30, 6.34–7.98 and 6.45–7.14 respectively. The pH values in the aeration tank for the same runs varied between 7.60–8.19, 8.10–8.72 and 7.69–8.02 respectively, and the pH values of the effluent ranged between 7.69–8.58, 8.36–8.60 and 8.01–8.38. A significant increase in pH values of wastewater was observed at the aeration tank and

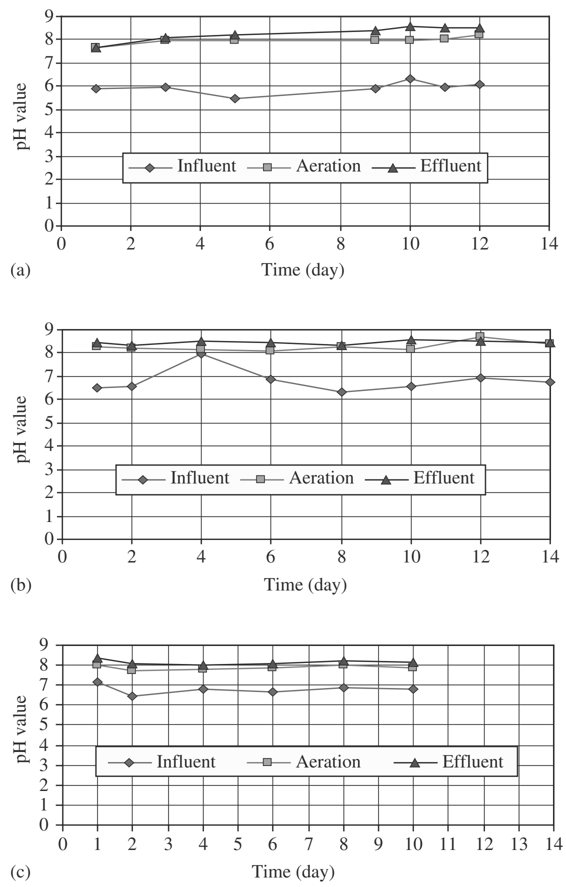

Fig. 6. Evolution of pH vs. running time (a) run 1 and (b) run 2.

effluent tank. The average increment of pH values of the effluent were 39.2, 27.2 and 20.1% for run 1, run 2 and run 3 respectively. pH values of the effluent were complied with the effluent discharge standards to Malaysian inland waters for pH (6.0–9.0). An increase in pH values of wastewater in the reactor was probably due to bioprocess such as degradation of volatile fatty acids which results in the pH increase.

4. Conclusions

In this study, a submerged anoxic–aerobic membrane bioreactor was operated at different conditions namely; VLR and SRT and its performance was evaluated. Results have shown a high removal of BOD, COD and NH_3-N under the studied operation conditions. The removal efficiencies of BOD, COD and NH_3-N were ranged between 98.9–99.9%, 97.8–99.9% and 91.0–100% respectively.

The pH of the effluent was increased by 20.1–39.2% of influent pH however; all the values were complied with effluent discharge standards to Malaysian inland waters for pH (6.0–9.0).

The anoxic–aerobic MBR is recommended for application in high strength municipal wastewater treatment plants that subjected to a variable concentration of COD, BOD and NH_3-N.

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