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Treatment of Septic Tank Effluent by Membrane Bioreactor: A Laboratory-scale Feasibility Study

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ABSTRACT

A laboratory scale membrane bioreactor (MBR) fed on real septic tank effluent was studied at different levels of alkalinity (0, 250 and 500 mg $NaHCO_3$/L addition) and sludge retention time (SRT, complete sludge retention, 10 and 20 days). A long-term operation of 267 days was divided into 5 stages to examine the SRT and alkalinity influences on parameters related to nitrification, chemical oxygen demand (COD) removal, extracellular polymeric substances (EPS) production and membrane cleaning. The results of the study showed that the removals of TCOD, SCOD and NH_4^+-N varied between 86-94%, 71-86%, and 70-94%, respectively. Appropriate alkalinity supplement and SRT control can enhance the COD removal and nitrification. Irreversible membrane fouling occurred fast and water cleaning for the improvement of filtration capacity was ineffective. The results also revealed that the rejection of EPS played a major role both in the enhancement of removal efficiency as well as the increase of filtration resistance during the operation.

Keywords: Septic tank effluent, membrane bioreactor (MBR), nitrification, extracellular polymeric substances (EPS)

1.0 INTRODUCTION

On-site sewerage treatments, such as septic tank (ST) – soil absorption systems (SAS), are used in non-sewered areas to treat and disperse domestic wastewater. For example, more than 68 percent of Taiwan's population relies on on-site ST systems. However, detailed studies conducted in urban area of Taiwan indicated that the septic tanks employed did not conform to the required effluent standard, mostly caused by nitrogen compounds. The septic tanks just converted the suspended pollutants into dissolved form and released them to the environment due to inadequate design and maintenance. Community level septic tanks should be encouraged in order to facilitate post septic tank hybrid treatment systems to be installed in the future upgrades.

The membrane bioreactor (MBR) has been receiving a lot of attention in wastewater treatment and water reuse, as membrane filtration promises a complete solid-liquid separation which can prevent the failure of biological systems due to biomass loss and/or bulking and consequently maintains a high number of mixed liquor suspended solids (MLSS) in the reactor [1]. With a large number of MLSS, hydraulic retention time (HRT) and sludge production are minimized and nitrification is enhanced.

Nitrification can only be successfully operated under low chemical oxygen demand (COD), sufficient dissolved oxygen (DO) and long sludge retention time (SRT) in bio-treatment system. In

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principle, membrane bioreactors have no theoretical limitation to the operational biomass concentration, and some researchers reported that bacterial growth could be minimized by operating these systems under long SRT with limiting sludge withdrawal which could lead to the high solid concentrations (15–25 g SS L^{-1}) [2, 3]. The possibility of operating membrane bioreactors without sludge withdrawal was also explored and reported [1, 2, 4-9]. However, some possible disadvantages were often indicated under these operating conditions, such as oxygen transfer limitations and increased membrane cleaning requirements [3, 4, 9]. Furthermore, although the linkage of alkalinity and nitrification has been known for decades on a scientific basis for municipal sewage treatment, very limited information is available about the nitrification of MBR for the polishing of septic tank effluent.

This paper attempts to explore the feasibility of septic tank effluent polishing using a laboratory scale membrane bioreactor. In particular, this paper focuses on those parameters directly related to nitrification performance and how they are influenced by SRT and alkalinity.

2.0 METHODS

Figure 1 shows the experimental setup for a flat-type submerged membrane bioreactor system. A Kubota flat-sheet type membrane was used (chlorinate polyethylene material, 0.4 μm pore size and 0.124 m^2 area) in the system. In continuous operation the suction pump was stopped for 1 minute to allow membrane relaxation after each 5 minutes of filtration to give an average flux of 13.5 L $m^{-2}h^{-1}$ and a hydraulic retention time (HRT) of 6.5 hours. The flow rate was examined and adjusted for every 12 hours to obtain the desired condition of flux. Air bubbles provided both aeration for biological reactions and reduction of fouling of membranes. In this study, the DO concentration was maintained in the range of 3 mg L^{-1} to 4 mg L^{-1}.

A long-term operation of 267 days was divided into 5 stages according to changes in the levels of alkalinity and SRT, as shown by Table 1. The wastewater used for this study was collected from the outlet of a septic tank which was located in Chia Nan campus. Its composition is shown in Table 2. Having undergone solid-liquid separation and anaerobic treatment, it had very low rates of organic matter and a considerably high concentration of nitrogen contributed mainly by NH_4^+-N.

The influent wastewater and permeate were analyzed for total and volatile suspended solids (TSS and VSS), total and soluble COD, TKN, NH_4^+-N, NO_2^--N and NO_3^--N. Ammonia and TKN were determined by the TKN Analyzer (KJELTEC 1035 Analyzers). Nitrite and nitrate

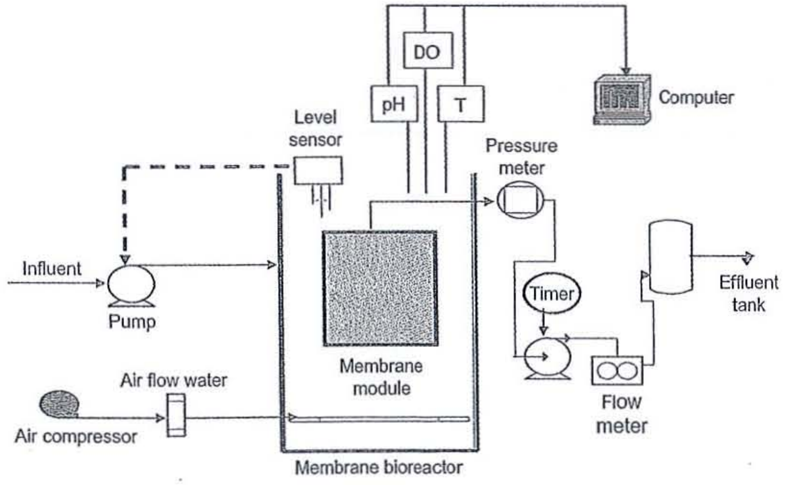

Figure 1 Schematic of an experimental MBR unit

Table 1 Experimental scheme of MBR operation

Process condition	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
SRT, days	a	a	a	10	20
$NaHCO_3$ addition, mgL^{-1}	b	250	500	500	500
Operation time, days	73	82	34	33	45

a Without sludge withdrawal b Without $NaHCO_3$ addition

Table 2 Characteristics of septic tank effluent

Parameters[a]	Mean	Minimum	Maximum
DO (mgL^{-1})	0.75	0.04	1.77
pH (mgL^{-1})	7.85	7	8.5
Alkalinity (mg $CaCO_3$ L^{-1})	15	12.8	16.5
SS (mgL^{-1})	190	60	535
TCOD (mgL^{-1})	326	99	738
SCOD (mgL^{-1})	106	43	192
TOC (mgL^{-1})	38	11	70
TKN (mgL^{-1})	131	50	254
NH_4^+-N (mgL^{-1})	118	42	198
NO_2^--N (mgL^{-1})	0.03	Not detected	0.5
NO_3^--N (mgL^{-1})	1.0	Not detected	4.9
EPS, protein (mgL^{-1} VSS^{-1})	150	59	473
EPS, polysaccharide (mgL^{-1} VSS^{-1})	101	44	362

were determined using an ion-chromatography system (DX-120, Dionex Inc.). Extraction of extracellular polymeric substances (EPS) including protein and polysaccharide were extracted using the procedures reported by Liu and Fang [10]. The extractant used in this study was EDTA (2%; at 4°C for 3 h). Polysaccharide was determined according to Dubois *et al.* [11]. Glucose was used as a standard for calibration and samples were measured at 490 nm in triplicate. Protein was determined according to the method described by Froelund *et al.* [12]. Calibration was done with BSA and samples measured at 750 nm in duplicate. Dissolved oxygen was determined using a WTW Multi pH/Oxi 340i Dissolved Oxygen Meter. Bioactivities, expressed in terms of specific oxygen uptake rates (SOUR), were calculated from oxygen uptake rates (OUR) using the Winkler bottle method.

3.0 RESULTS AND DISCUSSIONS

The variation of COD with the operation period is presented in Figure 2. As shown in Figure 2, during the initial 11 days of acclimatization period, the effluent concentration in terms of the soluble COD (SCOD) gradually decreased and varied between 41-80 mgL^{-1}. The effluent SCOD remained remarkably stable all the time and the concentrations lower than 30 mgL^{-1} were obtained except the initial effluent of stage 2. In the initial period of stage 2, obviously, the higher effluent SCOD was observed. In the meanwhile the influents of TCOD in stage 2 were much higher than that of other stages. It is noted that the system was stopped on day 75 due to sludge washout caused by a broken water level controller and restarted on day 79. The seed sludge used for restart was a mixture of the first stage's sludge (20%, v/v) and the fresh sludge (80%, v/v) obtained from the source mentioned as method

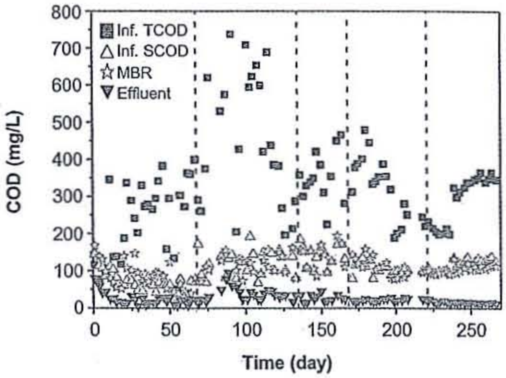

Figure 2 Variation of COD

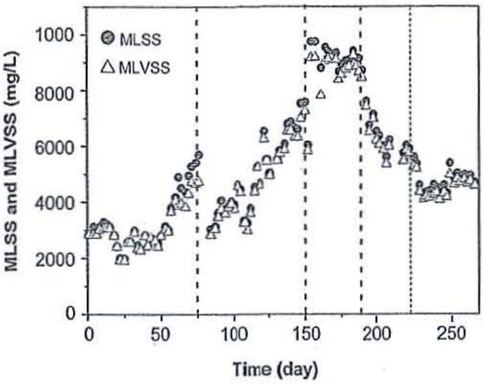

Figure 3 Variation of MLSS and MLVSS

section. Apparently, the effluent SCOD dropped back quickly within one week and kept stable subsequently as shown in Figure 2. This shows good adaptability and tolerance of the microbes in this system to shock loading and disadvantageous circumstance. Comparing the SCOD concentration profiles of MBR tank with that of effluent, it seems that SCOD may be removed by the filtering of membrane.

The MBR was operated initially with a MLSS concentration of 2800 mgL^{-1} by seeding the activated sludge obtained from a municipal wastewater treatment plant. For complete sludge retention (CSR) operation (stage 1 to 3), MLSS increased to a maximum of 5700 mgL^{-1} at the end of stage 1, then restarted from 3300 mgL^{-1} at stage 2, and again continuously increased at stage 3 to the range of 8600 mgL^{-1} to 9700 mgL^{-1}, changing no more; and MLVSS increased to a maximum of 4750 mgL^{-1} at stage 1, restarted from 2950 mgL^{-1} at stage 2, showing stable values in the range of 8300 mgL^{-1} to 9200 mgL^{-1} without any further great change at stage 3. From day 190 to day 222 (stage 4), sludge wastage from the MBR was carried out to keep a SRT of 10 days. One can see that the biomass reduced rapidly and kept decreasing at this stage and finally led to the range of 5300 mgL^{-1} to 6200 mgL^{-1}. For stage 5, the SRT was controlled at 20 days and a quite stable MLSS range of 4200 mgL^{-1} to 4960 mgL^{-1} was obtained. The VSS/TSS ratio of the biological sludge was always quite high, ranging between 92-96% for all stages. The average specific oxygen uptake rate (SOUR) was 28, 41, 46 and 58 mgO_2/g VSS h for stages 2 and 3, 4 and 5, respectively. The lowest SOUR value was found at stage 2, which could be attributed to the lag phase of the microorganisms. The negative growth was observed at the third stage, the microorganisms in reactor were in endogenesis respiration for the scarceness of food due to the CSR operation.

Theoretically, the heterotrophs were not expected to be dominant in this system since the septic tank effluent was with a characteristic of low organic carbon concentration as shown in Table 2. However, low C/N ratios of the influent and high DO operation indicated accordingly that autotrophic nitrifiers would be the dominant species in this system even though at the different conditions of SRT. Table 3 shows the influent, effluent and removal efficiencies of COD and nitrogenous compounds. As shown in Table 3, the influent had such a low rate of carbon to nitrogen and most of the nitrogen components turned out to be NH_4^+-N, which might have resulted from the anoxic treatment in septic tank. The influent COD and nitrogen concentration from the campus septic tank was not constant, but fluctuated widely depending on the water usage of campus. In fact, stage 2 was during the beginning of semester and accordingly resulted in a higher strength influent than that of other stages. A good performance of TCOD removal was observed from Table 3, the highest removal efficiency of 96% could be found at stages 3 and

Table 3 Performances of COD removal and nitrogen conversation

Parameters	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**
Influent					
TCOD (mgL^{-1})	99-620	197-738	281-479	189-387	138-365
	(260)	(483)	(269)	(266)	(293)
SCOD (mgL^{-1})	43-172	58-192	75-172	68-111	78-138
	(74)	(130)	(122)	(102)	(116)
TN (mgL^{-1})	50-115	137-254	152-204	94-165	76-129
	(88)	(196)	(192)	(132)	(107)
NH_4^+-N (mgL^{-1})	42-113	101-195	146-198	85-160	63-110
	(72.5)	(156)	(165)	(123)	(93)
Effluent					
SCOD (mgL^{-1})	15-44	14-48	15-30	17-28	12-23
	(21)	(32)	(21)	(24)	(15)
NH_4^+-N (mgL^{-1})	19-39	16-70	6-39	7-28	6-16
	(20)	(46)	(21)	(21)	(5)
NO_3^--N (mgL^{-1})	39-81	61-135	118-165	71-126	70-121
	(53)	(93)	(139)	(103)	(95)
Removal					
TCOD removal (%)	23-97	81-98	91-96	89-95	90-96
	(86)	(91)	(94)	(92)	(94)
SCOD removal (%)	43-91	22-88	75-88	68-82	78-90
	(71)	(75)	(82)	(77)	(86)
NH_4^+-N conversation (%)	25-88	60-84	80-96	77-95	78-98
	(70)	(71)	(87)	(82)	(94)

The values in parentheses represent the averaged data

5 and both were with the same average removal of 94%. At stage 5, the highest removal of SCOD was slightly lower than that of TCOD. The slightly lower SCOD removal efficiencies (71-86%) than TCOD in all stages were mainly due to the residual of NH_4^+-N in the effluent, although phenomena such as EPS production and cell lysis might also have a role in this study. According to Table 3, the average NH_4^+-N removals varied between 70% and 94% and the nitrogen compounds in the effluent appeared mostly nitrate nitrogen at stage 5, indicating that nitrification occurred almost completely. The results also showed that NO_2^- concentration in the effluent remained below 0.5 $mgNL^{-1}$.

Figure 4 presents the variations of ammonium nitrogen in influent and effluent during the five

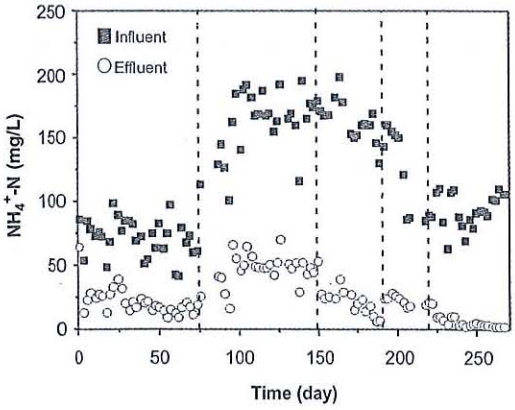

Figure 4 Variation of NH_4^+-N

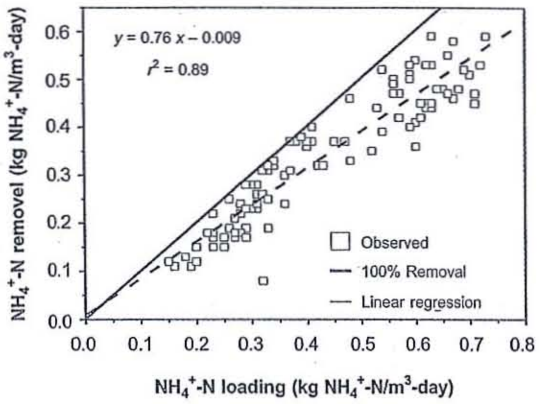

Figure 5 NH_4^+-N loading rate vs. NH_4^+-N removal rate

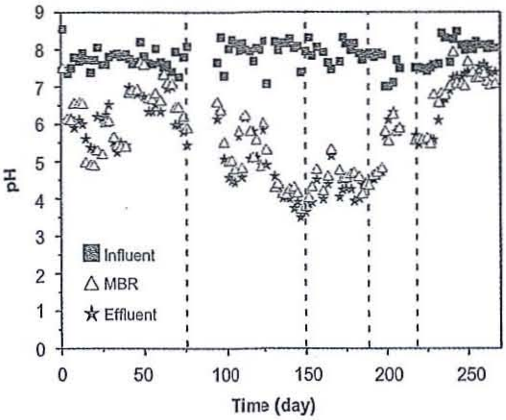

Figure 6 Variation of pH

experimental stages. When compared stage 5 with other stages, stage 5 showed stable levels of effluent NH_4^+-N with a relatively small range of fluctuation. Figure 5 illustrates NH_4^+-N removal performance in MBR system. As shown in Figure 5, the overall removal efficiency of TN was 76% with r^2 of 0.89 in the linear regression and the highest ammonia removal efficiency reached 98% when the nitrogen loading rate (NLR) was 0.41 kg NH_4^+-Nm^{-3} day. Other researches of NLR were reported to 0.3 kg NH_4^+-Nm^{-3} day using biofilm reactor by Abeling [13] and 0.3-0.48 kg NH_4^+-Nm^{-3} day using modified Ludzack-Ettinger process [14]. Comparing the NLR value with other researches, the NLR value of 0.41 kg NH_4^+-Nm^{-3} day can be shown some high since such a NLR value was attained by low biomass concentration about 4700 mg $MLSSL^{-1}$ at the 5th stage of this study.

Microbial nitrification is known to be highly sensitive to pH, and optimal conditions have been found to be within the narrow pH range of 7-8 [15]. In fact, pH acts on the NH_4^+/NH_3 equilibrium: alkaline pHs shift the chemical equilibrium to free ammonia, inhibiting nitrite-oxidizing bacteria (NOB). In addition, alkalinity is consumed theoretically at 7.14 g as $CaCO_3$ per gram of NH_4^+ oxidized to NO_2^-. There is no further alkalinity consumption at the oxidation of NO_2^- to NO_3^-. In this study, pH underwent a big drop from 8.5 in influent to 3.5 in effluent as shown in Figure 6. It meant that the total ammonia nitrogen (TAN) in MBR tank existed in the form of NH_4^+ which would not inhibit the growth of NOB. Meanwhile, excess alkalinity with a range of 3-7 mg $CaCO_3$ L^{-1} in the effluent was measured at stages 3, 4 and 5, whereas no residual alkalinity in the effluent was detected at stage 2. It indicated that the addition of 500 mg $NaHCO_3$ L^{-1} could provide the alkalinity supplement to ammonia-oxidizing bacteria (AOB) for nitrification.

The variations of permeate flux and transmembrane pressure (TMP) are presented in Figure 7. A series of screening tests were carried out to estimate the suction on-off operation mode and eventually the on-off mode of 5-1 min was adopted. An important finding was that the water cleaning operation could not recover the filtration

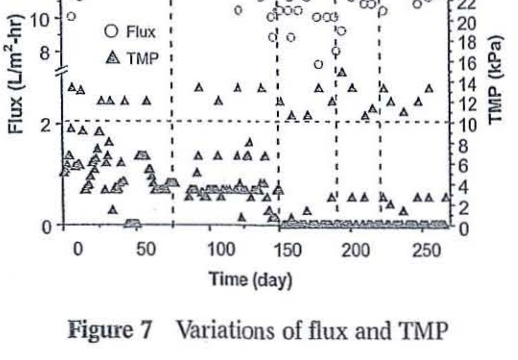

Figure 7 Variations of flux and TMP

Table 4 The frequency of membrane cleaning

Stage	Run (d)	MLSS* (mg/L)	Chemical cleaning frequency (d)	Numbers of wash during the experiment
1	73	3320	12.2	6
2	82	5150	20.5	4
3	34	9010	6.8	5
4	33	6610	8.25	4
5	45	4820	9.0	5

* The mean value of MLSS concentration

capacity of the membrane fully, which indicated the occurrence of irreversible membrane fouling even after physical cleaning in this study. The membrane cleaning frequency is shown in Table 4. As shown in Table 4, the cleaning cycle of stage 3 was 6.8 days, shorter than that of other stages. Figures 8 and 9 showed the concentration variations of soluble EPS. Both protein and polysaccharide concentrations in the MBR were much higher than the original contents and similar to the trend of biomass variation. Moreover, the results obtained from Figures 8 and 9 apparently showed that MBR rejected mostly of EPS in this study.

In this study, the fouling phenomena happened during the experimental period showed the irreversible membrane fouling occurred fast during the filtration and about 20-130 mg SCODL^{-1} in the MBR tank was removed by membrane, not attributed to the microorganisms. The results of this study confirmed that the rejection of EPS played a major role both in the enhancement of removal efficiency as well as the increase of filtration resistance during the operation.

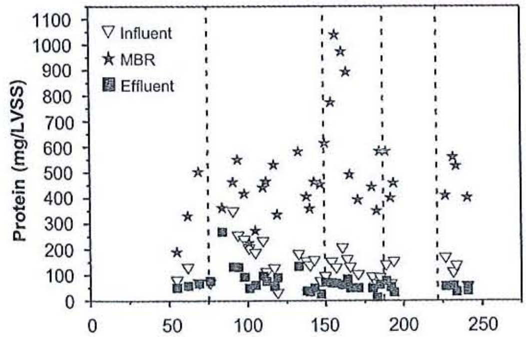

Figure 8 Variation of protein

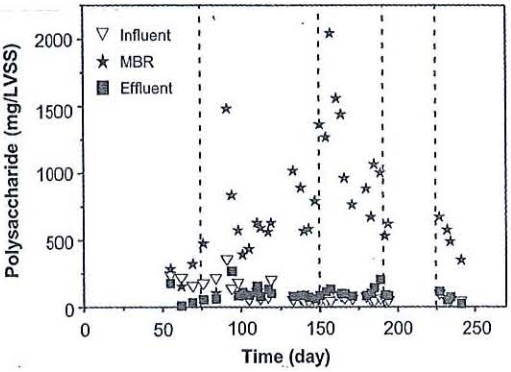

Figure 9 Variation of polysaccharide

4.0 CONCLUSIONS

Septic tank effluent was treated by a laboratory-scale submerged membrane bioreactor (MBR) for more than 260 days. The results indicated that the appropriate alkalinity supplement and SRT control can enhance the COD removal and nitrification. The operation of complete sludge retention could increase the levels of EPS, whereas it could decrease the frequency of membrane cleaning. Irreversible membrane fouling occurred fast and water cleaning for the improvement of filtration capacity was ineffective. The results also showed that the rejection of EPS played a major role both in the enhancement of removal efficiency as well as the increase of filtration resistance during the operation.

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