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The BNR-MBR(Biological Nutrient Removal-Membrane Bioreactor) for nutrient removal from high-rise building in hot climate region

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Abstract. The overall performance of BNR-MBR, so-called Anoxic-Anaerobic-Aerobic Membrane Bioreactor (A^3-MBR), developed for nutrient removal was studied to determine the efficiencies and mechanisms under different solid retention time (SRT). The reactor was fed by synthetic high-rise building wastewater with a COD:N:P ratio of 100:10:2.5. The results showed that TKN, TN and phosphorus removal by the system was higher than 95%, 93% and 80%, respectively. Nitrogen removal in the system was related to the simultaneous nitrification-denitrification (SND) reaction which removed all nitrogen forms in aerobic condition. SND reaction in the system occurred because of the large floc size formation. Phosphorus removal in the system related to the high phosphorus content in bacterial cells and the little effects of nitrate nitrogen on phosphorus release in the anaerobic condition. Therefore, high quality of treated effluent could be achieved with the A^3-MBR system for various water reuse purposes.

Keywords: anoxic-anaerobic-aerobic membrane bioreactor (A^3-MBR); biological nutrient removal (BNR); simultaneous nitrification-denitrification (SND); enhanced biological phosphorus removal (EBPR), high-rise buiding wastewater recycling

1.Introduction

Nowadays, impact of nutrients especially nitrogen and phosphorus from high-rise building wastewater on deterioration in water quality of water resource has been recognized to be a significant problem. Moreover, overgrowth of aquatic plants has been commonly found, for closed water system. Many techniques have been proposed and aimed at the modification of the conventional activated sludge process to improve nutrient removal. Activated sludge system has become more complex as its function is expanded from carbonaceous removal alone to include nitrification, denitrification and biological phosphorus removal. This is because nitrification, denitrification and biological phosphorus removal system involves three separated groups of microorganism and operates on three distinct environmental regimes. Temperature is considered to be a significant parameter that affects the performance of biological nutrient removal. It was found that phosphorus removal efficiency decreased when operating temperature changed from psychrophilic range (15-20°C) to mesophilic range (20-45°C).

The objective of the present work is to develop a new biological nutrient removal system especially for phosphorus reduction in a mesophilic temperature range application. At high solid retention time

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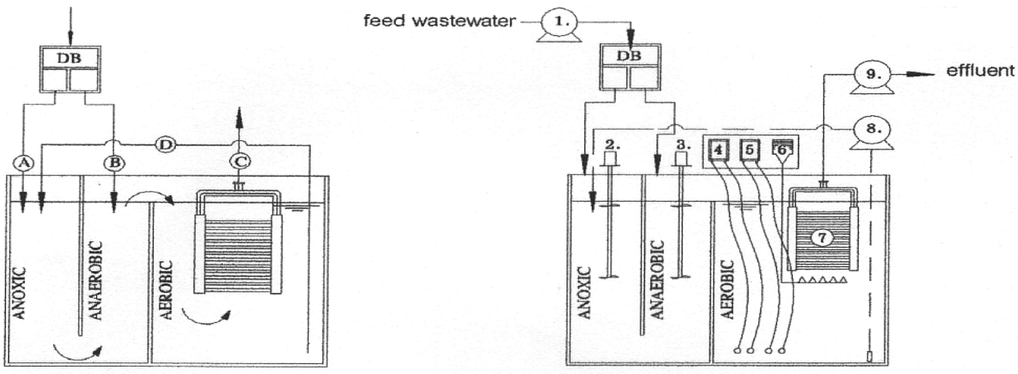
(SRT), a number of microorganisms can be kept in the system to solve the problem of low specific activity of phosphorus accumulating organisms (PAOs) at higher temperature. This developed system of A^3-MBR aims to improve performance of biological nutrient removal process especially nitrogen and phosphorus for high-rise building wastewater recycling purposes via simultaneous nitrification-denitrification (nitrogen removal) and enhanced biological phosphorus removal or EBPR (phosphorus removal) in order to improve effluent quality for further water reuse application.

2. Materials and methods

2.1 Description of the A^3-MBR system

The A^3-MBR system with a total working volume of 90 L (0.4 × 0.45 × 0.5 cm) was arranged by dividing into three subsequent compartments of anoxic, anaerobic and aerobic zones as shown in Fig. 1. The wastewater flowrate of 80 L/d was divided by the distribution box into two parts, one was fed to the anoxic compartment and the other was fed to the anaerobic compartment by different flowrate distribution ratio as described in Table1. Both anaerobic and anoxic tanks were agitated at 100 rpm. The hydraulic retention time(HRT) for each compartment was 6, 6 and 15 h, resulting in working volume of 20, 20 and 50 L for anoxic, anaerobic and aerobic compartments, respectively. A hollow-fiber microfiltration membrane module used in this study had surface area of 0.3 m^2 and pore size of 0.4 µm. The membrane was submerged inside the aerobic compartment. The crossflow filtration for the submerged membrane was achieved by providing air flowrate capacity of 60 L/min. The permeate suction mode was set at 10 min.(suction) and 10 min.(without suction) in order to reduce membrane fouling. The return sludge from the aerobic compartment was recirculated to the anoxic compartment at the rate 1.5 Q_{inf} or at 5.0 L/hr.



(a) Direction of flow (b) Instruments diagram

(a) direction of flow ; A = Influent to Anoxic , B = Influent to Anaerobic , C = Effluent from Aerobic , D = return sludge from Aerobic to Anoxic , DB = distribution box.

(b) Instruments diagram; 1 = Influent pump , 2 = anoxic mixer , 3 = anaerobic mixer , 4 = aerator 1 , 5 = aerator 2 , 6 = air compressor , 7 = microfiltration membrane , 8 = return sludge pump , 9 = effluent pump.

Fig. 1 Schematic diagram of the A^3-MBR system

Table 1 Operating condition for three experimental runs

Experimental run no.	Running time (Day)	SRT (Days)	Flowrate distribution ratio (anoxic:anaerobic)
1	1 - 46	40	25% : 75%
2	47 - 106	40	75% : 25%
3	107 - 149	80	75% : 25%

2.2 Operating conditions

The research consisted of three experimental runs in order to know the effects of flowrate distribution ratio together with solid retention time(SRT) on performance of the A^3-MBR system in treating COD, total nitrogen and phosphorus as shown in Table 1.

2.3 Synthetic wastewater

The wastewater used in this study was synthetic wastewater, having COD of 320 mg/L., TKN of 37 mg/L. and TP of 8.0 mg/L. The COD : N : P ratio was kept at approximately 100:10:2.5. The synthetic wastewater was prepared as shown in Table 2.

2.4 Analytical methods

The parameters concerned in this research were COD, SS, TKN, NO_2^-, NO_3^- and phosphorus which were analysed in accordance with Standard Methods (1995). The reactor effluent and feed wastewater were sampled at least three times a week for the measurement of COD, TKN, NO_3-N, NO_2-N and

Table 2 Chemical agents used for synthetic wastewater

Chemical agents	Dosage (mg/L)
Sugar	355
CH_3COOH acid	0.01 ml/L
NH_4Cl	150
KH_2PO_4	36.6
$CaCl_2.2H_2O$	6.9
$MgSO_4.7H_2O$	15.4
$NaHCO_3$	305

Table 3 Specific probes employed in FISH analysis

Probe	Specificity
PAO(mix)	PAO-cluster
GAM42	gamma Proteobacteria
BET42	beta Proteobacteria
ALF968	alpha Proteobacteria
PAE997	Pseudomonas spp.
NIT3	Nitrobacter spp.
NSO190	ammonia-oxidizing bacteria

TP. Bacterial communities inside the system were identified using FISH (Fluorescent *in situ* Hybridization) technique with different probes shown in Table 3.

3. Results and discussion

3.1 Operating temperature of the system

Temperature in the reactor was in room temperature range of hot climate condition. The minimum temperature of the system was 27.7°C and the maximum temperature was 31.6°C. The average temperature range was 29-30°C, which is in a mesophilic temperature range as shown in Fig. 2. The A^3-MBR showed a high phosphorus removal performance in the mesophilic temperature range which is contrasted to a previous study by Laorujinda, 1998. Since the A^3-MBR could maintain high sludge biomass in the system.

3.2 Performance of A^3-MBR system

3.2.1 COD removal

The average effluent COD concentrations of both SRT 40 and 80 days were approximately 6.0 mg/L, and COD removal efficiencies for both SRT 40 and 80 days were 98.2%. The average influent COD concentration was 320 mg/L which is equivalent to COD loading rate of 0.33 $Kg.COD/m^3$-d, as shown in Fig. 3. There was no significant effect of SRT on COD removal efficiency because of sufficiently high SRTs of the system. Influent COD concentration was rapidly decreased in the anoxic and anaerobic compartments since the unbalance conditions occurred due to intermittently-fed and the sequence of anaerobic /aerobic condition in the system which accelerated microorganisms to store the substrate from feed wastewater into cells. The average MLSS concentrations in anoxic, anaerobic and aerobic compartments of SRT 40 days were 3,314, 3,066 and 4,084 mg/L, respectively. The average MLSS concentrations in anoxic, anaerobic and aerobic compartment of SRT 80 days were 4,037, 3,675 and 4,582 mg/L, respectively. As shown in Fig. 4, MLSS concentration of the aerobic compartment seemed to be higher than those of anoxic and anaerobic compartments. There might be an effect of the substrate storage mechanism which the substrate was taken up into

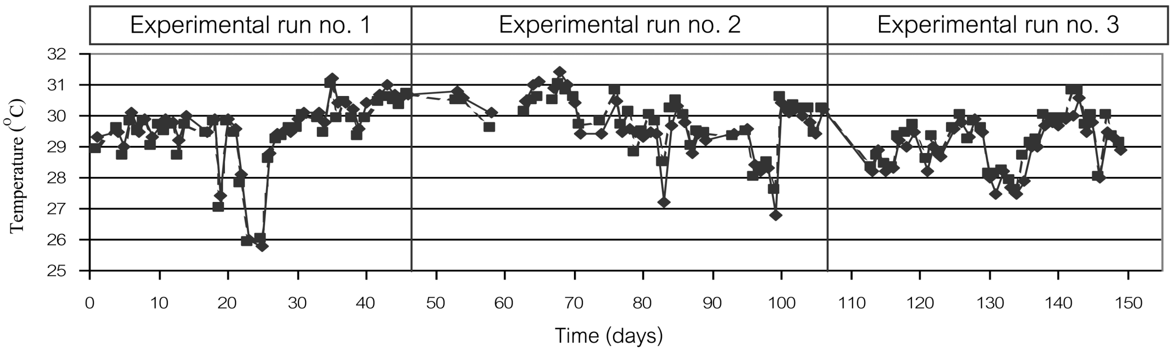


Fig. 2 Temperature condition inside A^3-MBR system

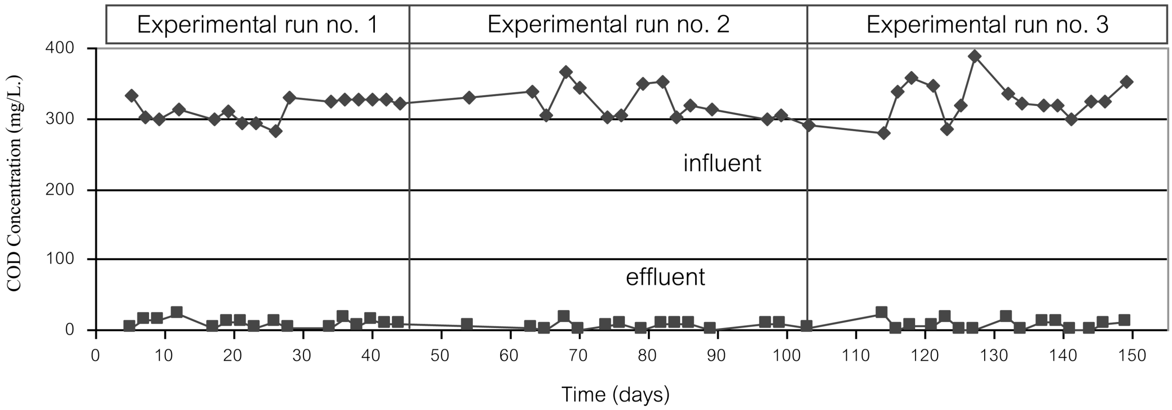


Fig. 3 COD removal performance of A^3-MBR system

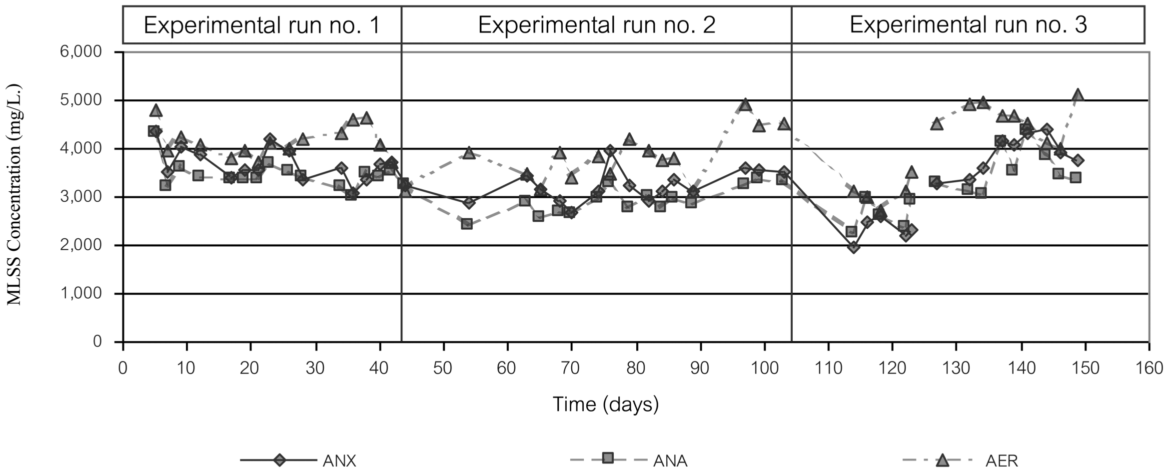


Fig. 4 MLSS concentration inside A3-MBR system

bacterial cells in the stress condition, liked anoxic and anaerobic condition, and utilized this storage substrate for cell synthesis and growth in optimum condition, liked aerobic condition. Thus the MLSS concentration in the aerobic state was higher than other states. VSS:SS ratio of the sludge in both experiments were 0.75-0.79, which is similar to other studies in MBR process (Fan *et al*. 2000, Ueda and Hata 1999, Wagner and Rosenwinkel 2000, Xia *et al*. 2008) and the higher SRT, the higher MLSS concentration in the system could be obtained.

3.2.2 Nitrogen removal

TKN was rapidly removed since the anoxic and anaerobic compartment of the system because of the dilution of the return sludge from the aerobic compartment together with cell synthesis utilization. TKN outflow from the anaerobic compartment was further oxidized by nitrification in the aerobic compartment, transformed ammonia nitrogen to nitrite and nitrate nitrogen. Effluent TKN concentrations of SRT 40 and 80 days were 0.7 and 1.2 mg/L., respectively as shown in Fig. 5 and TKN removal

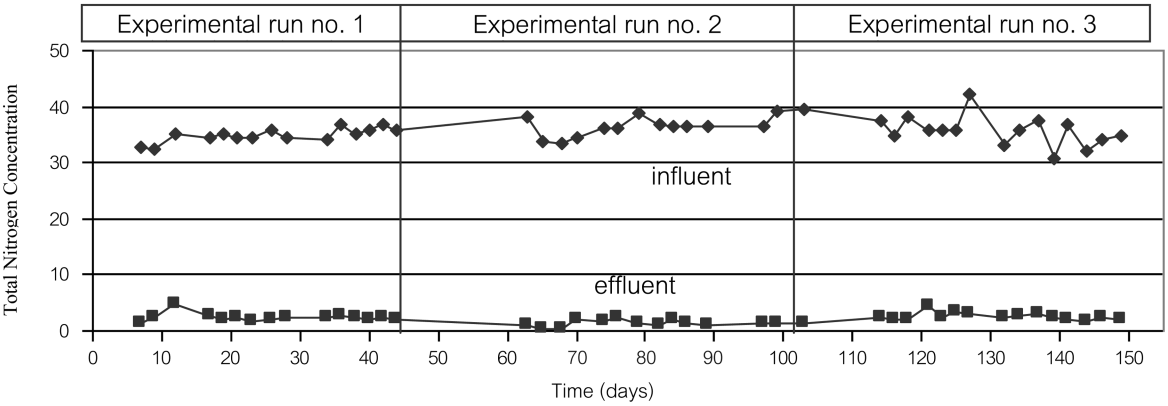


Fig. 5 Total nitrogen removal performance of A^3-MBR system

efficiencies of SRT 40 and 80 days were 98.2% and 96.7%, respectively. Therefore, SRT 40 days was already sufficient for TKN removal by A^3-MBR system. However, in the both experiments, there found that product nitrate nitrogen which was transformed from ammonia nitrogen by nitrification in aerobic state was less than a calculated value from a stoichiometric of nitrification (Halling-Sorensen and Jorgensen 1993).

$$48.6\ NH_4^+ + 96\ HCO_3^- + 90\ O_2 \rightarrow C_5H_7NO_2 + 47.6\ NO_3^- + 50.6\ H_2O + 91\ H_2CO_3$$

Effluent nitrates of SRT 40 days and 80 days were 0.60 and 1.20 mg/L., respectively, resulted in high total nitrogen (TN) removal efficiency. TN removal efficiencies of SRT 40 and 80 days were 96.5% and 93.3%, respectively.

3.2.3 Phosphorus removal

Effluent phosphorus concentrations of SRT 40 and 80 days were 0.7 and 1.4 mg/L, respectively as shown in Fig. 6. Phosphorus removal efficiencies of SRT 40 and 80 days were 90.2% and 83.3%, respectively. SRT 40 days gave a slight higher phosphorus removal efficiency. Because SRT 40 days experimental had higher sludge wastage, then higher phosphorus was removed from the system.

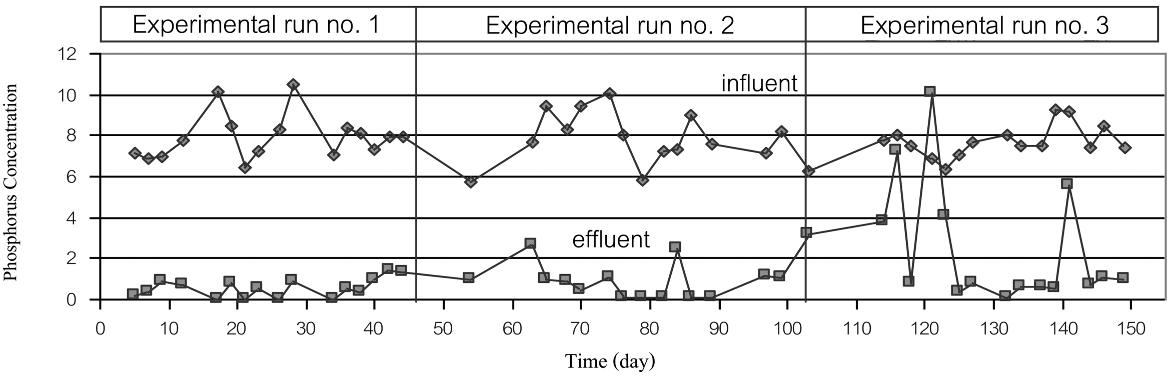


Fig 6 Phosphorus removal performance of A^3-MBR system

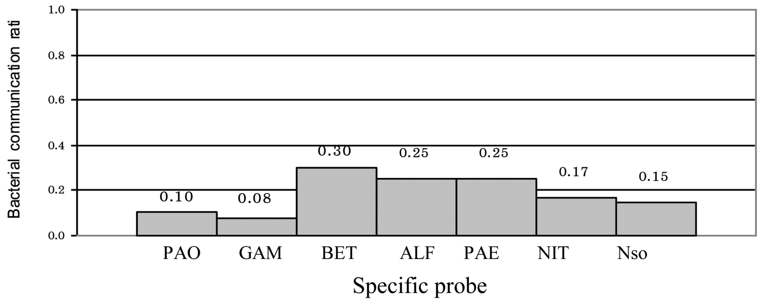


Fig. 7 Bacterial communities of A^3-MBR system

According to FISH technique investigation by mix-PAO probe (Crocetti *et al*. 2000), It was found that the amount of PAOs occupied at ten percents apparently inside A^3-MBR system, as shown in Fig. 7. Moreover, SND reaction in the aerobic compartment auxiliary reduced the effects of nitrate interference on the phosphorus release mechanisms in the anoxic and anaerobic compartments.

3.2.4 Membrane performance

Before the experimental run no.1, start-up period was run to provide the optimum condition for microorganisms in the system. After 150 days of start-up period, it was found that the transmembrane pressure increased to 32 kPa. The membrane cleaning was performed four times on Day 70,100, 130 and 148 using mixed cleaning agent (NaOH 2% and NaOHCl 1.2%). As a result, transmembrane pressure could be reduced not to be more than 30 kPa as the target pressure. An increase in transmembrane pressure of membrane filtration is recognized to be caused by membrane resistance, concentration polarization resistance and external fouling resistance (Choo and Lee 1996). The average flux membrane along the experimental run was kept at approximately 13.5 L./m^2-hr. and operating transmembrane pressure was maintained below 30 kPa. In experimental run no. 1 and 2, transmembrane

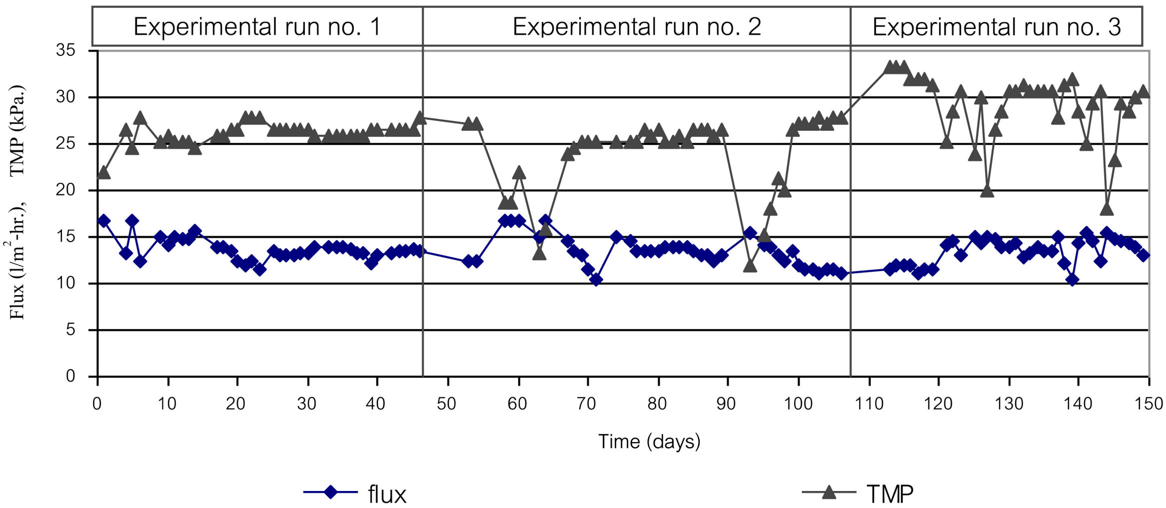


Fig. 8 Transmembrane pressure and flux performance of A3-MBR system

pressure could be maintained below 30 kPa through 100 days operation with two-time membrane cleaning in the experimental run. In experimental run no. 3, because of a long time of membrane operation and higher amount of MLSS in the system then membrane was necessary to be cleaned more often until the run completed in order to keep the stable membrane flux.

4. Conclusions

1) The developed A^3-MBR system could overcome the low efficiency of enhanced biological phosphorus removal efficiency in mesophilic temperature range as a very high phosphorus removal efficiency of more than 93% could be achieved by the system.

2) Due to an advantage of high SRT, the A^3-MBR system is a promising system to achieve simultaneous nitrification-denitrification which reduced the effects of nitrate from return sludge on the phosphorus release mechanism.

3) The developed A^3-MBR system can be a promising alternative for high-rise building wastewater recycling.

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