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Treatment efficiency and membrane fouling of a lab-scale Anaerobic Membrane Bioreactor treating dilute municipal wastewater

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The study aims to investigate the application of anaerobic processes coupled with membrane filtration for treating dilute municipal wastewater in Hanoi city (COD:100-300mg/l, BOD_5: 60-180 mg/L, NH_4-N:14-35 mg/L). A lab-scale Anaerobic Membrane Bioreactor (AnMBR) with flat sheet, polyvinylidene fluoride membranes (nominal pore size=0.4µm; total filtration area=0.09 m^2) was operated at different HRTs (48 hours, 36 hours, 24 hours, 12 hours, 8 hours and 6 hours) for 560 days with COD loading rates up to 1.58 kg/m^3.d at room temperatures (from 10-39°C). The biomass accumulated reached 8gMLVSS/L by the end of the operation period. No noticeable volatile fatty acids (VFAs) were detected regardless of HRT variations. The AnMBR system maintained relatively constant TransMembrane Pressure (TMP). The results showed that physical retention of organics by the MF membrane played a significant role in achieving good and stable performance (removal rate for TSS: 98-100%, COD:70-90%, and BOD: 72-88%) at wide range of temperatures.

Introduction

The anaerobic treatment of low strength or dilute wastewaters, such as domestic sewage, has started to attract much attention, which at present is largely treated by aerobic processes. Two major factors are of concern with the activated sludge process, high sludge production and high operating cost associated with aeration. Anaerobic treatment offers many benefits compared to aerobic treatment such as low energy consumption, low sludge production, and useful methane production (Baek et al., 2006). However, high biomass inventory and long hydraulic and solids retention times (SRT) are needed to achieve efficient treatment, particularly for dilute wastewater due to low biomass yield. In addition, the effluent quality of anaerobic system is poorer than the aerobic one. These limitations have prevented a wide application of anaerobic technology for treating such wastewater. Therefore, different strategies have been developed to achieve long SRT in the reactor such as anaerobic contact process, anaerobic filter, up-flow anaerobic sludge blanket (UASB) reactor, expanded granular sludge bed (EGSB), anaerobic fluidized bed reactor and anaerobic sequencing batch reactor. Such reactor configurations maintain significantly longer SRT irrespective of HRT. The UASB and EGSB processes have been widely adopted among all these reactor configurations due to their superior performance (Munariatis and Grigoropoulos, 2002). However, those systems require meticulous process control to achieve and maintain sludge granulation.

Membrane–coupled anaerobic bioreactors have been applied as one alternative to cope with treatment challenges. It could produce excellent effluent quality in terms of suspended solids, chemical oxygen demand (COD) and pathogen count, and there is a possibility of reuse and recycling of the treated effluent for non-potable purposes. A typical anaerobic membrane bioreactor include: a anaerobic reactor which play a role as a digester and membrane modules which can either submerge or place outside of the reactor. The membrane modules work as a barrier to retain all of the biomass in the reactor effectively and help to maintain a long sludge retention time (SRT) irrespective of short HRT. Therefore, the key advantage of AnMBR system is to decouple hydraulic retention time (HRT) and SRT in order not only to achieve high sludge concentration in the system but also to decrease reactor size. This high-rate anaerobic technology therefore may also work with low strength wastewater which have a limitation with conventional anaerobic treatment due to a slow growth rate of anaerobic microorganisms. Previous studies elucidated the potential of AnMBR for the treatment of low strength wastewater at ambient temperature (Ho et al., 2007).

Hanoi's sewerage network is a combined system which was initially developed for urban flooding prevention, and then gradually receive municipal wastewater. Most urban residents of Hanoi have a flush toilet with a connection to the septic tank from which the effluent (septic) is discharged into sewers and semi-open drainage canals (e.g To Lich River, Kim Nguu River and Set River) before flow into the Red River. As the collection system have no Combined Sewage Overflows (CSOs) and with a large proportion of open canals in the network, wet weather conditions are expected to have big impact on the delivered wastewater composition and flow. A recent study by World Bank (2013) revealed that BOD concentration of wastewater in collection network in Hanoi City varies largely from less than 50 mg/L to above 250 mg/L with the lower range was observed in the rainy season (from July to September).

The objective of this study is to investigate the application of an anaerobic membrane bio-reactor for the treatment of dilute wastewater like municipal wastewater in Hanoi. The focus was to investigate the optimum operation parameters to achieve good removal efficiency while minimize backwashing or chemical cleaning of the membrane modules.

Methodology

Laboratory experimental setup

A laboratory-scale anaerobic membrane bioreactor (AnMBR) with 5L of working volume were run at ambient temperature (see Figure 1). The anaerobic reactor was equipped with biogas collection system and a blower for keeping the sludge in the suspension and membrane scouring effect using gas generated from the system. Other equipments are the TransMembrane Pressure (TMP) sensor and a data logger, and level sensors to control permeate flow rate. A flat sheet, polyvinylidene fluoride (PVDF) with nominal pore size of 0.4µm and total filtration surface area of 0.09 m^2 (supplied by KUBOTA Cooperation, Japan) was placed submerged inside the reactor tank.

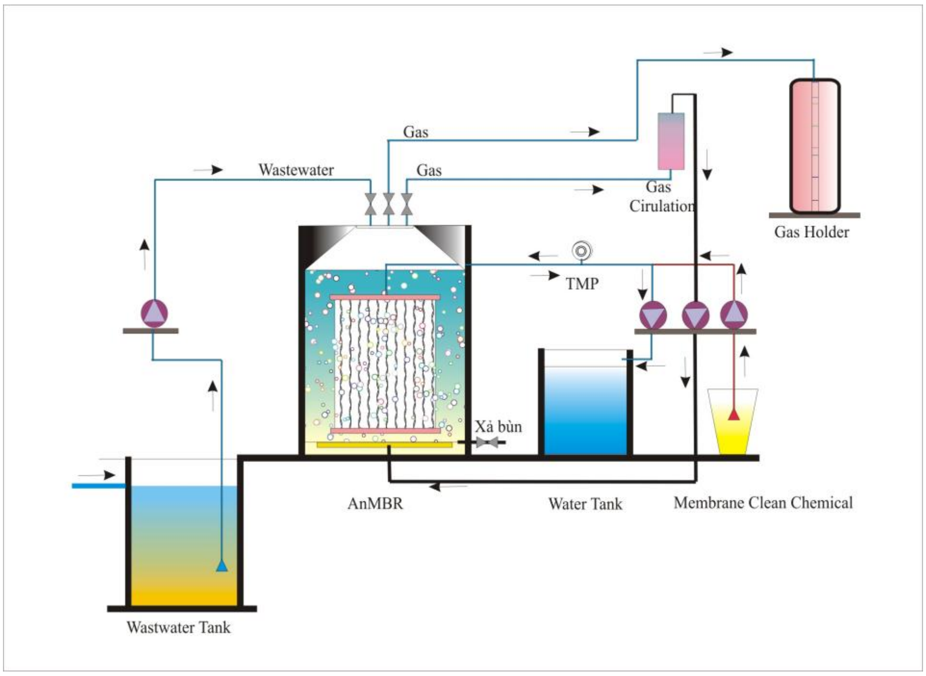

Figure 1. Schematic of the lab-scale AnMBR

Feed water was taken from an equalization tank in Kim Lien Wastewater Treatment Plant (WwTP). The raw wastewater quality is shown in Table 1. Seeding sludge (1.5 g/L) was obtained from the mesophilic anaerobic digester in Yen So municipal wastewater treatment plant. The AnMBR system has been operated for about 560 days at different hydraulic retention times. The average HRTs for the entire system were 48 hours, 36 hours, 25 hours, 12 hours, 8 hours and 6 hours. The membrane flux was maintained at 0.03, 0.08, 0.12, 0.24 and 0.36 m^3/m^2.day; and organic loading rate was therefore 0.31, 0.54, 0.95, and 1.58 $kgCOD/m^3$.day respectively. There was no sludge withdrawal except for the sludge analysis. No chemical cleaning was attempted during the entire experiment.

Table 1. Influent wastewater quality in Kim Lien Wastewater Treatment Plant

Water parameters	Range (mg/L)	Average (mg/L)
BOD_5 (mg/L)	39-220	85
COD (mg/L)	47-470	172
TSS (mg/L)	30-345	105
NH_4-N (mg N/L)	5-30	15
TKN (mg N/L)	5-35	20
T-P (mg/L)	2-10	4
Fat and Grease (mg/L)	<30	-
Alkalinity (mg $CaCO_3$/L)	>100	-
pH	6-9	-

Sample analysis

DO, pH, temperature of feed, feed and permeate flowrate in anaerobic tank were measured daily by portable meters. Wastewaters and mixed liquor were also sampled on times per week and analyzed for chemical oxygen demand (COD), Biological Oxygen Demand (BOD) total nitrogen (T-N), ammonia nitrogen (NH_4-N), dissolved oxygen (DO), Mixed Liquor Suspended Solid (MLSS) and Mixed Liquor Volatile Suspended Solid (MLVSS), Volatile Fatty Acids (VFA). The concentrations of COD, T-N, NH_4-N, MLSS and MLVSS were analysed following Standard Method (APHA 2003) and HACH methods with the appropriate kits and a DR 2800 Spectrophotometer (HACH Company, USA). A wet-test gas meter was used to measure biogas. Gas composition and methane gas was analyzed using test kit GAC25 (Japan).

Results and discussions

AnMBR performance and treatment efficiency at ambient temperature

The reactor has been operated at different hydraulic retention times (48 hours, 36 hours, 24 hours, 12 hours, 8 hours, and 6 hours) for a period of about 560 days (from June 2012 to December 2013) at ambient room temperatures from 10-39°C. Seeding sludge was obtained from the anaerobic digester in Yen So municipal wastewater treatment plant. Since the digester has just been put in operation, MLSS concentration of the sludge was still low, ranging from 1200-1500 mg/L. The results showed that sludge concentration have been increased steadily when increasing of feed flow rate over experimental period and reached 8000 mg/L at the end of the Phase 6 with the HRT is of 6 hours accordingly. It also indicates no sludge washout in the system.

Although pH in the AnMBR system was not controlled, the pH levels in the reactor did not affect anaerobic degradation of organics. VFAs profiles indicated that acetic acid was the predominant VFA in the reactor. Propionic and butyric acid were not detected.

Biological removal rate was calculated by the difference between influent COD and mixed liquor COD divided by the influent COD, while physical removal rate was the difference between the total COD removal rate and the biological removal rate. The concentration of COD in feed and permeate, removal efficiency are shown in Figure 2 and Table 2. The COD level in the feed water varied from less than 50 mg/L to 470 mg/L, with average value of 172mg/L. With this range of COD values, the feed water could be classified as low strength or dilute wastewater.

As shown in the Figure 2, the removal rate for COD was not good in the first 111 days (R1, HRT 48 hours) with COD level in permeate ranged up to 100 mg/L. This start-up period could be considered an acclimatization stage for the microbial communities. In the next 180 days (R2 and R3), the COD removal rate remain unstable, ranging from 40% to 97%. During these periods, the MLSS concentration in the reactor was increased but still low of less than 4000 mg/L. When HRT changed to 12 hours (R4), the removal rate become more stable, ranging from 70% to 90%. The COD removal rates remained quite stable and high in the next 85 days with HRT of 8 hours. The MLSS concentration reached nearly 6100 mg/L at the end of Run 5. During these periods, COD in the permeate varied but always less than 100 mg/L with an average of 39.2 mg/L. This value was lower than the discharge limit of 50 mg/L (National Technical Regulation for Domestic Wastewater Discharge, QCVN14:2008/BTNMT, applied for category A - water bodies using for domestic water supply). The BOD concentration in the permeate was also stable and less than 30 mg/L, indicating AnMBR system was effective in the treatment of organic matter. After day 420th, when the HRT changed to 6 hours (R6), COD removal rate was getting fluctuated and COD in the permeate was higher than the previous run, ranging up to 90 mg/L.

Throughout the operation at different hydraulic retention times, COD removal rates from a low value of 31.8% to a high of 98.4 % could be obtained by the reactor, with COD in the permeate fluctuated but mainly less than 100 mg/L, which meet the discharge standard QCVN14:2008/BTNMT, Category B (water bodies using for other water usage purposes than domestic water supply). The system achieved the best and stable removal efficiency for COD and BOD at HRT of 8 hours, with COD in the permeate satisfied the consent applied for Category A.

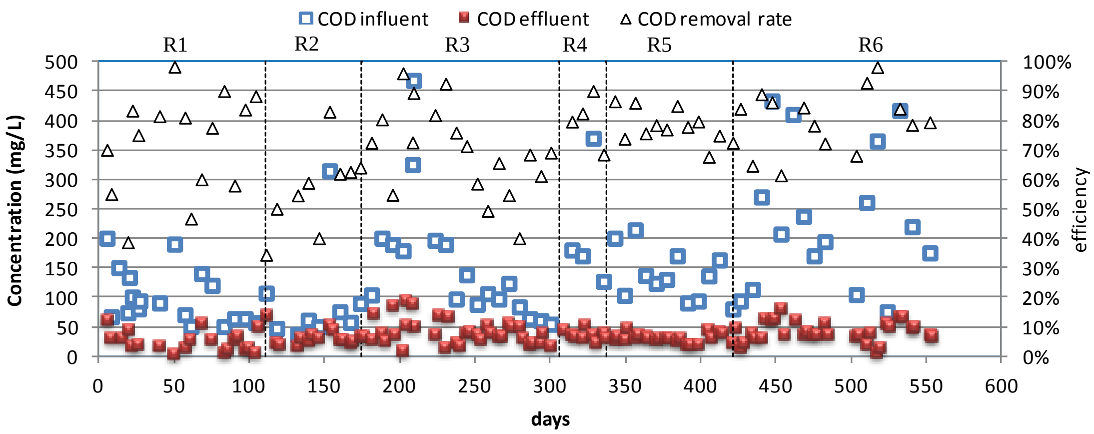

Figure 2. COD profiles in feed and permeate and removal efficiency in AnMBR system

The change in the ammonium concentration in feed and permeate during operation is shown in Table 2. Raw wastewater have ammonium concentrations of about 3-30 mgN/L. Ammonium concentration in permeate showed a higher range of about 4-67 mgN/L, which account for 80-95% of TKN level. The results indicated that ammonium is the main nitrogen component and exists stably in the anaerobic environment. It also showed that AnMBR system is ineffective in treating nitrogen compounds in wastewater to achieve the current discharge requirements, highlighting the need of further processes to reduce its residual nitrogen levels to meet stringent Vietnamese wastewater discharge standards (QCVN14:2008/BTNMT).

Table 2. Style: Summary of AnMBR operation and treatment efficiency						
	Run					
	R1	R2	R3	R4	R5	R6
Operating conditions						
HRT (hours)	48	36	25	12	8	6
Operation time (days)	111	64	131	31	85	155
ORL (kgCOD/m^3.d)	0.02-0.09	0.03-0.2	0.05-0.42	0.29-0.78	0.19-0.65	0.22-1.58
Flux (m^3/m^2.d)	0.04-0.18	0.05-0.13	0.03-0.08	0.06-0.17	0.12-0.25	0.13-0.36
Ambient temp (°C).	28-31	18-28.5	11-26	24-30	25-29.5	14-29
Effluent						
COD (mg/L)	24.3[a] (3.3-63.3)[b]	32.3[a] (16.7-70.0)[b]	40.8[a] (7.14-92.9)[b]	40.4[a] (23.4-66.7)[b]	33.7[a] (19.0-63.3)[b]	42.1[a] (6.89-80.0)[b]
NH_4-N (mgN/L)	19.7 (4-27)	30.5 (11.4-53.6)	38.3 (30.9-51.5)	39.3 (24.9-66.79)	37.8 (23.2-58.4)	49.0 (3.4-64.6)
TKN (mg/L)	-	52.9 (33.5-69.4)	-	-	-	62.0 (49.0-68.0)
T-P (mg/L)	4.7 (2.5-11.4)	3.9 (2.47-5.8)	4.0 (1.8-5.4)	4.5 (4.0-4.9)	4.2 (2.6-6.1)	5.2 (3.0-7.0)
pH	7.2-8.3	7.6-8.2	8.1-8.4	8.0-8.3	6.9-8.6	7.2-8.2
Biogas						
CH_4 content (%)	-	-	-	-	-	28-30
Total gas yield (L/d)	-	0.39[a] (0.16-0.61)[b]	0.21[a] (0.03-0.87)[b]	0.11[a] (0.04-0.25)[b]	0.22[a] (0.01-0.70)[b]	0.37[a] (0.01-1.29)[b]
Note: a: average value b: (min-max) value - : n/a						

Biogas generation

Biogas volume is collected and measured daily. Experimental results showed that very limited amount of gas could be collected at different hydraulic residence time (from 48 to 6 hours HRT). Therefore we could not estimate the CH_4 yield from system although the COD removal rate was good and stable. Experimental results also show that average methane content in some period of operation time could achieved up to 30 % (Table 2). The results showing a majority of biogas and methane is lost from the system. The gas leakage control activities have been tightly controlled in the system so the reasons could be possibly: i) COD is utilized for sulphate reduction; and/or ii) the gas dissolved in the water and have been washed out of the reactor with permeate through the membrane. This observation also coincides with findings from the previous studies (Ho and Sung, 2010). The loss of methane from the system, especially when large-scale implementation, not only to loss of biogas resources, but also bring negative effects to the climate since the global warming potential of methane is around 21 times higher than for CO_2 (Jaeho and Shihwu, 2010) .

TransMembrane pressure and membrane fouling

Throughout the experiment, the change in TransMembrane Pressure (TMP) across the submerged membrane in the reactor was monitored by a digital vacuum gauge. If the TMP value greater than 20 kPa, the membrane was considered in the fouling mode and the filtration of membrane was stopped temporary for membrane cleaning. For the first 420 days, the TMP was always less than 2 kPa, and no membrane cleaning was required. But after the HRT changed to 6 hours, significant jumps in the TMP values were observed several times (see Figure 3) and membrane cleaning with citric acid was needed. It is noted that membrane fouling occurred when the feeding tube was clogged (on Day 445th, 480th, 492th); the membrane then become exposed since the permeate pump continued to operate. The increase of flowrate could be a reason for these unstable conditions. After the system was restarted with the cleaned membrane, the TMP returned to low value of less than 2kPa, indicating the cleaning process is effective. Over the course of 550 days of operation, the sludge concentration was gradually increased but still remained low (MLVSS was less than 8000 mg/L at the end of experiment period). One advantage of an AnMBR system treating dilute municipal wastewater is it could maintain a low suspended mixed liquor sludge concentration in the reactor which help prevent membrane fouling. The results suggested that HRT of 8 hours would be good since the system showed stable performance with a high removal rate of organic matter while minimize membrane clogging .

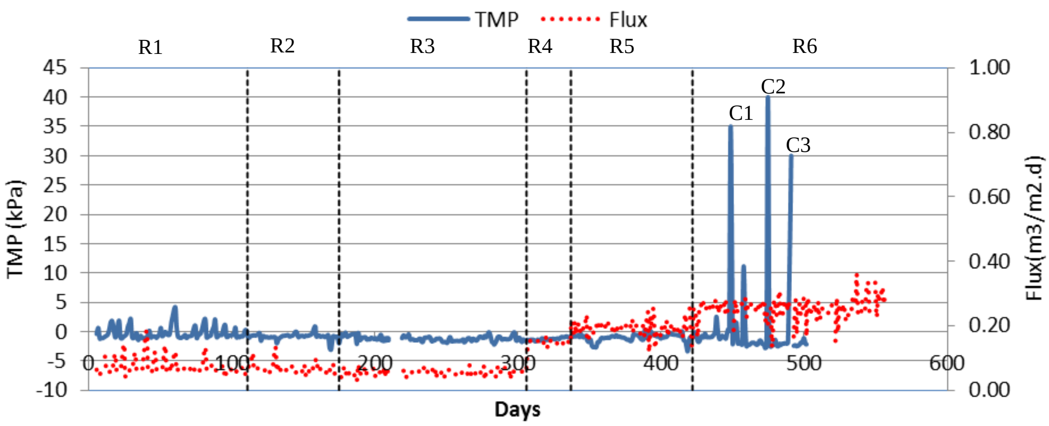

Figure 3. Flux and TMP variations during the entire experimental phase

Note: C1, C2, C3 indicate membrane was taken out for cleaning by citric solution (8-10%).

Conclusions

A laboratory-scale anaerobic membrane bioreactor (AnMBR) was run over for about 560 days to investigate the efficiency and membrane fouling in treating low strength domestic wastewater in Hanoi. Results showed that at different hydraulic retention time and organic loading, high and stable removal efficiency of organic matter COD (70-90%) and suspended solid TSS (95-98%) were achieved. Nitrogen content (TN, NH_4-N) in the treated water was almost familiar with untreated sewage, suggesting anaerobic processed coupled with membrane filtration does not remove nitrogen. In order to meet the current discharge consent for domestic wastewater (QCVN14:2008/ BTNMT), the permeate from AnMBR system needs to be undergone a nitrification processes for ammonia removal. The results show that AnMBR technology is suitable for treating domestic wastewater in Vietnam conditions. Treated wastewaters were of good quality and fit with WHO guidelines for agricultural reuse (WHO, 2006). In addition, AnMBR bring small footprint advantage which is very applicable in small urban areas and having difficulties in sludge treatment.

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