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Research Article

Application of the single-stage anaerobic membrane bioreactor (1S-AnMBR) for the co-digestion of organic kitchen waste and sewage

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ABSTRACT

In the scenario of sustainable technology application, the minimization of waste and resource consumption are more fundamental compared to effluent quality. In recent years, many kinds of researches related to green technology in wastewater treatment have been conducted, such as constructed wetland, membrane bioreactor, etc. With the same perception, the co-digestion of kitchen waste and sewage study was carried out. The principle of this environmentally friendly technology is to create a low-cost pretreatment for domestic wastewater, by taking advantage of the organic carbon available in the leftovers to remove contaminants in the wastewater, improve water quality, reduce excess sludge and save money. The study is aimed to evaluate the carbon and nutrient recovery of a laboratory single-stage anaerobic membrane bioreactor (1S-AnMBR), which included an Up-flow Anaerobic Sludge Blanket (UASB) continuous with an UF membrane bioreactor. The result shown that the obtained COD removals were above 80% at all organic loading rates (OLRs). The effluent COD concentrations were 160±21, 227±45, 340±78, 563±104 and 886±96 mg.L^{-1} at OLRs of 0.9 to 1.5; 2.0; 3.5; 5.0 and 7.0 kg COD.m^{-3}.day^{-1}, respectively. The biogas yields collected were 1119±76, 1550±68, 2155±80, 3610±86 and 5989±88 mL.day^{-1} at OLRs of 0.9; 1.5; 2.0; 3.5; 5.0 and 7.0 kg COD.m^{-3}.day^{-1}. High performance of ammonia conversion from organic nitrogen was obtained in the AnMBR. Total nitrogen and phosphorus losses were 12% and 15%, respectively. Transmembrane pressure (TMP) increased to the pressure limit of 45kPa after 11 days of operation at OLR of 5 kg COD.m^{-3}.d^{-1}. Thus membrane fouling is a big challenge for AnMBR. Besides these promising research outcomes, the technology is expected to bring convincing results into practice in the co-digestion of solid wastes and sewage that may be suitable for rural or remote areas, in which solid waste and sewage collection systems are not available.

Key words: co-digestion, 1S-AnMBR, sewage, kitchen waste, membrane bioreactor

INTRODUCTION

In recent years, many previous studies have developed innovative approaches to effectively recycling biowaste to produce bioenergy to offset the fossil fuel demand and reduce the burden of landfills [1,2]. Anaerobic biological treatment for low-strength wastewater such as sewage was an attractive option due to reducing sludge regeneration, operation costs, and promoting carbon and nutrient recovery through biogas production [1]. Furthermore, the use of biogas generated from anaerobic digestion can significantly mitigates greenhouse gas emissions [3–5]. Indeed, biogas can produce electricity and heat or use as a vehicle fuel or inject into the natural gas grid. Anaerobic co-digestion (AcoD) is the simultaneous AD of two or more different substrates. Compared to single digestion, AcoD is more susceptible to process instability, as it operates at a higher organic loading and significant variation in substrate composition [6].

An anaerobic reactor coupled with a membrane can overcome sludge wash-out and troubles of biomass retainment, which are the critical challenge of the conventional anaerobic processes [7,8]. To date, AnMBR has been widely applied for high organic-strength industrial wastewater treatment [9]. Operation temperature, sludge retention time, pH, and accumulation of volatile fatty acids and MLVSS are factors that significantly affect AnMBR performance [10]. Higher temperatures resulted in better COD removal. The fact that Ho and Sung [11] claimed that total COD removals of AnMBRs achieved were over 95% at temperature 25^{o}C and by 85% at 15^{o}C. AnMBRs run at longer SRTs can achieve greater biogas yield [12], whereas short SRTs are insufficient for stable digestion [13]. AnMBR operating at high MLVSS concentrations achieved removal

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efficiency of around 98–99%. However, fast fouling development became trouble for AnMBR [14]. Volatile fatty acids (VFAs) are important mid-products in the production of methane, and their concentrations affect the efficiency of fermentation of AnMBR. Yeole et al. [15] observed that the pH of 7 and the propionic acid concentration of 5000 mg.L^{-1} decreased the methane yield to 22–38%, and this research also indicated that the inhibition of the anaerobic reactor significantly strengthened when pH was decreased.

The application of AnMBRs for the treatment of municipal wastewater, diluted wastewater has been proven as a sufficiently sustainable approach in practice. AnMBRs can effectively remove biodegradable organic matter from wastewater for water reuse, methane-rich biogas production, and up-concentration of nutrients for subsequent recovery for fertilizer production [16].

In this study, a mixture of sewage and biodegradable kitchen solid waste was used. In some countries, residential food waste grinders, as electrical devices, are fixed under a kitchen sink. The grinder cuts food waste into small pieces less than 2 mm to pass through internal household plumbing. These small pieces are then combined with enough water to make a slurry, sending the debris from the kitchen sink into the municipal wastewater system. However, the FWDs are improper for combined sewer systems because of increasing pollutant loads to the centralized wastewater treatment plants (WWTPs), receiving waters at outlets of overflow structures, and increasing clogging by grease and food solids for the operation and maintenance of the combined sewers [17]. However, the disposal of food waste into the sewer, named as domestic in-sink food waste disposers (FWDs), for the decentralized wastewater management system, can be an alternative to overcome the limitations of conventional waste disposal methods such as sanitary landfill and incineration and the co-treatment with sewage can increase energy recovery potential [18].

AnMBR is used to treat low-strength wastewater as sewage coupled with high solid contents as kitchen waste, which is considered as FWDs for the decentralized wastewater system, has not much focused. Therefore, the study aimed to evaluate the performance of a laboratory single-stage anaerobic membrane bioreactor (1S-AnMBR) for co-digestion of sewage and kitchen waste. The performance of 1S-AnMBR was characterized in terms of COD removal, biogas yield, nutrient losses, and membrane fouling.

METHOD

AnMBR reactor

An AnMBR used in the study consisted of an Up-flow Anaerobic Sludge Blanket Reactor (UASB) followed by a UF membrane tank. The UASB was the key reactor, which played a role in the anaerobic degradation of organic matter in the mixture of sewage and biowaste, whereas the UF membrane was responsible for the solid separation and up-concentration of the diluted sewage. UASB with gas-solid-liquid separator fixed in the upper part can mitigate the effluent suspended solids concentration that helped to reduce fast development of membrane fouling for UF membrane placed subsequently.

The Up-flow Anaerobic Sludge Blanket (UASB) reactor was made of an acrylic tube with a diameter of 100 mm and a working volume of 12.5 L. Biogas was collected by a gas-solid-liquid separator and measured by a gas flip-box. A membrane tank with a working volume of 4 L followed the UASB reactor. An internal circulation pump with a flow rate of 70 L.d^{-1} was used to create an up-flow velocity of 0.4 m.h^{-1} in the UASB reactor (Figure 1).

The Mitshubishi UF hollow membrane module, which had a pore size of 0.03 μm, a fiber diameter of 1.65 mm, and a total area of 0.1 m^2 was submerged in the membrane tank. To control membrane fouling, a vibrating device, which was fixed on the membrane module, has a vibration speed of 12,000 rpm and oscillations of 1-3 mm. Furthermore, a suction pump was run at the ON : OFF mode of 08 minutes:2 minutes.

MATERIALS

Domestic wastewater

The feed wastewater used in the study was domestic wastewater generated from an apartment building in District 11, Ho Chi Minh City. The feed wastewater was characterized by the mean pH value of 6.3 $\pm$ 0.5, tCOD concentration of 352 $\pm$ 83 mg.L^{-1}, TKN of 116 $\pm$ 13 mg.L^{-1}, NH_4^+-N of 77 $\pm$ 7 mg.L^{-1}, TP of 6 $\pm$ 0.4 mg.L^{-1}.

Kitchen solid waste

The kitchen waste fed into the UASB reactor was taken at a canteen of the university campus. The waste consisted mainly of rice, noodle, and vegetables. The hard solids like bones, shells were sorted out, and then the waste was ground into the 2-mm particulates. The composition of the feed biowaste is presented in Table 1.

The seed anaerobic granular sludge was collected from a UASB tank of a slaughterhouse wastewater

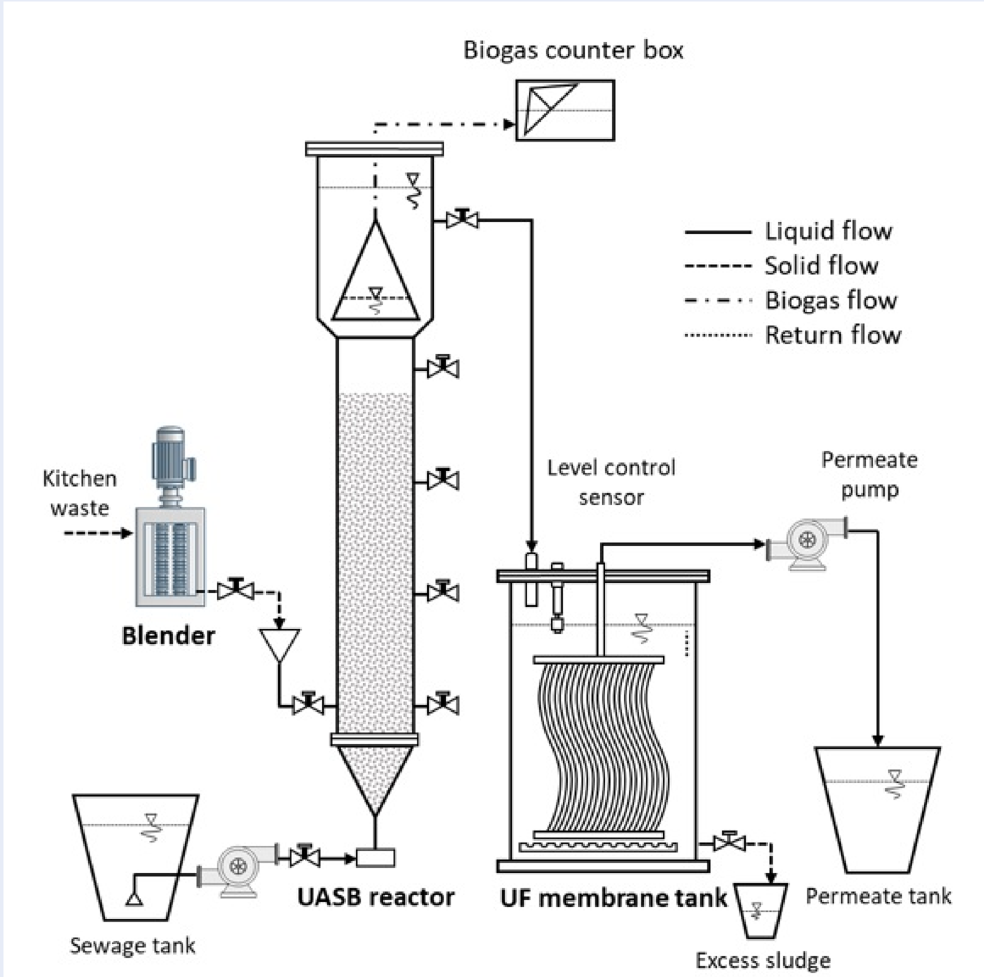

Figure 1: Schematic diagram of the experimental setup

Table 2: The composition of the feed mixture of sewage and bio-waste into the 1S-AnMBR reactor

Parameter	Unit	Organic Loading Rate (ORL kg COD.m^{-3}.day^{-1})			
		2.0	3.5	5.0	7.0
pH		6.94 ± 0.17	6.87 ± 0.1	6.88 ± 0.1	6.9 ± 0.05
TSS	mg.L^{-1}	1996 ± 332	2507 ± 451	-	-
tCOD	mg.L^{-1}	3008 ± 129	3462 ± 191	5012 ± 91	7017 ± 99
sCOD	mg.L^{-1}	1120 ± 105	1364 ± 110	1841 ± 42	2600 ± 76
TKN	mg.L^{-1}	135 ± 15	137 ± 13	77 ± 4	-
NH_4^+-N	mg.L^{-1}	86 ± 8	84 ± 6	43 ± 1.4	-
TP	mg.L^{-1}	8.8 ± 0.5	9.0 ± 0.8	7.4 ± 0.5	8.1 ± 0.2

Table 1: Composition of the feed biowaste

Parameter	Unit	Value
pH		5.7 ± 0.3
TS	$g.L^{-1}$	235 ± 25
VS	$g.L^{-1}$	203 ± 21
COD	$g.L^{-1}$	100 ± 31
TKN	$mg.L^{-1}$	10 ± 3
TP	$mg.L^{-1}$	2.4 ± 0.38

treatment plant in District 6, Ho Chi Minh City. The sludge, which contained TS of 21 $g.L^{-1}$, VS of 9 $g.L^{-1}$, and COD of 29 $g.L^{-1}$ was seeded into the UASB reactor to obtain a TSS concentration of mix liquor of 7.5 $g.L^{-1}$. The composition of the feed mixture of sewage and kitchen waste into the 1S-AnMBR reactor at the various OLRs shows in Table 2.

OPERATING CONDITION

The 1S-AnMBR was operated for 90 days at the ambient temperature of 28 – 40°C, and sludge retention time (SRT) of 50 days. The pH value of the mixture of biowaste and wastewater was adjusted to 6.8 – 7.2 using 5% $NaHCO_3$ solution. The reactor was started up at OLR of 1.0 – 2.0 kg COD. $m^{-3}.d^{-1}$ for 45 days. Then, the OLR decreased step-wise hydraulic retention time (from 36 h to 24 h) and increased the amount of daily feed solid from 62, 85, 250, and 350 g wet weight/d, with the respective OLRs from 2.0, 3.5 5.0, and 7.0 kg COD.$m^{-3}.d^{-1}$ (Table 3). The membrane flux was adjusted according to Table 3.

ANALYTICAL METHOD

Soluble and total COD concentrations, TS, VS contents, NH_4^+-N, total phosphorous (TP), and total nitrogen (TN) were analyzed according to the water and wastewater examination standard methods (APHA, AWWA, 1998).

RESULTS AND DISCUSSION

COD

Figure 2 shows the variation of tCOD concentration at different OLRs. The COD removal efficiency of the AnMBR at HRT of 48 hours and OLR of 0.9 kg COD.$m^{-3}.day^{-1}$ was very high (91%) at the start-up phase. As reducing HRT to 36 hours, the efficiency decreased to 89.1% and 88.7% at OLRs of 1,5 and 2.0 kg COD.$m^{-3}.day^{-1}$, respectively. At higher OLRs (3.5 and 5.0 kgCOD.$m^{-3}.day^{-1}$), the efficiency decreased significantly to 83.8 and 82.3%, respectively. Figures 3 shows that the AnMBR was under overloaded at HRT of 7.0 kg COD.$m^{-3}.day^{-1}$. The fact that COD removal efficiency was sharply decreased to 58%. Thus, the proper OLRs of AnMBR for this study ranged from 3- 5 kg COD.$m^{-3}.d^{-1}$, at which a high performance of above 80% can be obtained. This is similar to the previous study of Chen Weng (1999), in conventional anaerobic process, the COD removal was in the range of 60 to 95% [19].

Nitrogen

Figure 3 shows that the total loss of TKN at all OLRs was not significant. The TKN losses were 14 ± 3; 9 ± 9; 9 ± 5; 6 ± 3 and 25 ± 4 %, at OLRs of 0.9; 1.5; 2.0; 3.5 and 5.0 kg COD.$m^{-3}.day^{-1}$, respectively. Generally, TKN removal in the anaerobic treatment processes was low due to converting organic nitrogen in solids or complex compounds to soluble ammonia that can easily pass through the membrane [20]. Some studies claimed the ineffectiveness of soluble nitrogen and phosphorus removal by using membrane filtration [21].

Figure 4 presents that the permeate NH_4^+-N concentrations (93 ± 8, 96 ± 8 and 47 ± 2 $mg.l^{-1}$ at OLRs of 2.0; 3.5 and 5.0 kg COD.$m^{-3}.d^{-1}$, respectively) were higher than the influent concentrations. The previous research by Wang reported that the NH_4^+-N in the bioreactor effluent increased slightly because of the ammonolysis reaction and was barely rejected by the membrane filtration [22]. In addition, the NH_4^+-N molecule size was too small to be removed by the physical rejection of the membrane [23].

Biogas

Figure 5 shows that at OLR of 0.9 kg COD.$m^{-3}.day^{-1}$, the average biogas production was 1.11 $L.day^{-1}$, which corresponds to a yield of 0.109 $m^3.kg\ COD^{-1}$ removed. At OLR of 1.5 and 2.0 kg COD.$m^{-3}.day^{-1}$, biogas yields obtained were 0.095 and 0.098 $m^3.kg\ COD^{-1}$, respectively. Biogas yields at higher OLRs were not significantly different from those at low OLRs. They are 0.1, 0.12, and 0.08 $m^3.kg\ COD^{-1}$ removed at OLR to 3.5, 5.0 and 7.0 kg COD.$m^{-3}.day^{-1}$, respectively.

The biogas yields obtained from this study were stable at the various OLRs. However, the obtained results were lower than those of some previous studies in the range of 0.23 - 0.33 $m^3.kg\ COD^{-1}$ removed and lower than 0.382 $m^3.kg\ COD^{-1}$ of theoretical methane yield. The loss of biogas may be due to membrane adsorption and the high solubility of methane.

Table 3: Conditions of operation of the 1S-AnMBR

Organic loading rate	OLR	kgCOD.m^{-3}.d^{-1}	2	3.5	5	7
Hydraulic retention time	HRT	hour	36	24	24	24
Sludge retention time	SRT	day			50 – 60	
Sewage flow rate	QN	L.d^{-1}	8.33	12.5	12.5	12.5
Amount of feed biowaste	QR	g WW.d^{-1}	62	85	250	350
Membrane flux	J	L.m^{-2}.h^{-1}	6.9	10.4	8.3	8.3

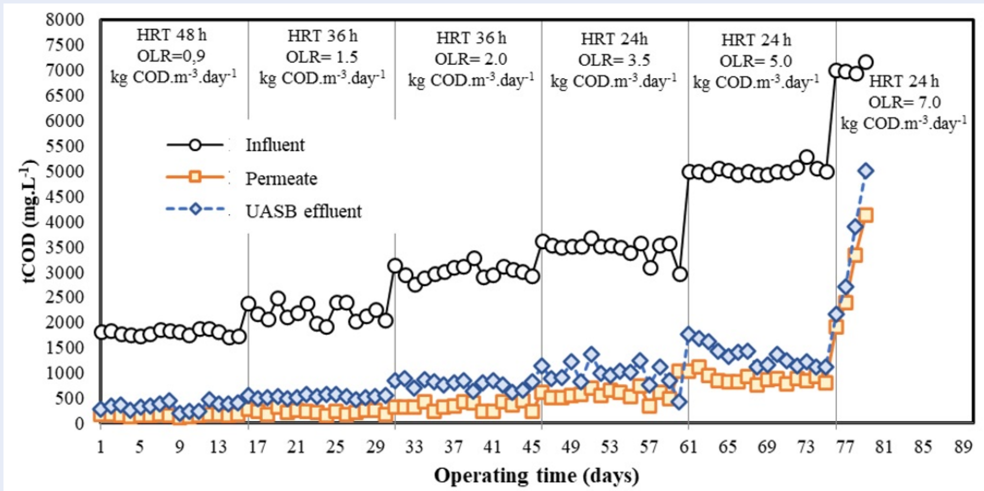

Figure 2: Variation of tCOD concentration at different OLRs

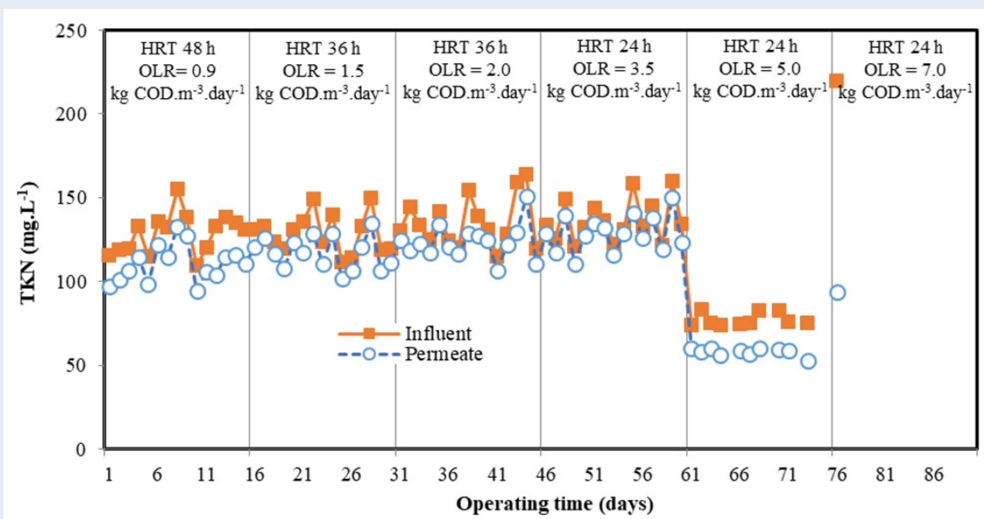

Figure 3: Variation of TKN concentration at different OLRs

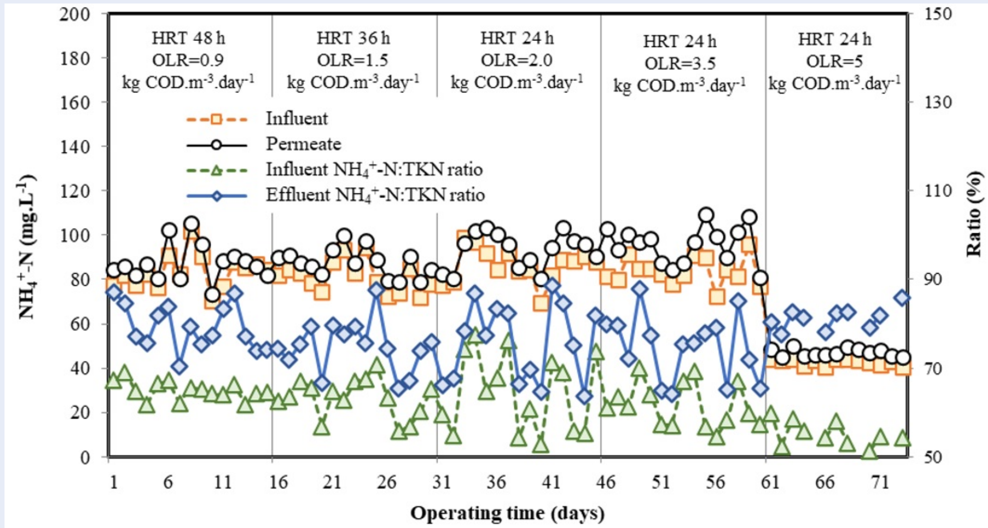

Figure 4: Variation of N-NH_4 concentration at different OLRs

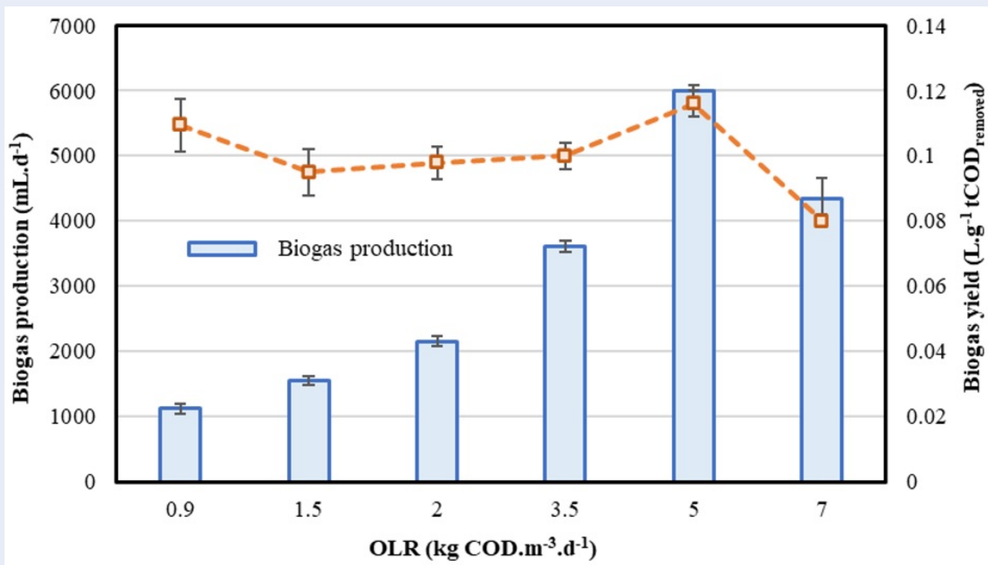

Figure 5: Variation of biogas production at different OLRs

In addition, it was suggested that the continuous effluent flow could result in a loss of more than 50% of the generated biogas [24].

Moreover, none of the collection of biogas generated from the membrane tank may be attributed to significant biogas loss. Floating materials/sludge, which clogs the solid/air/liquid separator frequently, may lead to an increase in methane solubility and biogas loss. Methane solubility in water was 15 mL/1,000 mL at 1 atm and 35 °C, resulting in low biogas production rates [20]. The solubility of methane was about 1.5 times lower at 15 °C than the solubility of methane at 35°C [21].

Volatile Fatty Acid (VFA)

VFA was an important intermediate product of methane which was transformed to acetic acid before being converted to CH_4 [7]. Figure 6 shows that the average VFA concentration in the UASB reactor increased from 122 ± 8 $mg.L^{-1}$ at OLR of 0.9 kg $COD.m^{-3}.d^{-1}$ to 236 ± 14 $mg.L^{-1}$ at OLR of 0.9 to 7.0 kg $COD.m^{-3}.day^{-1}$. This result was similar

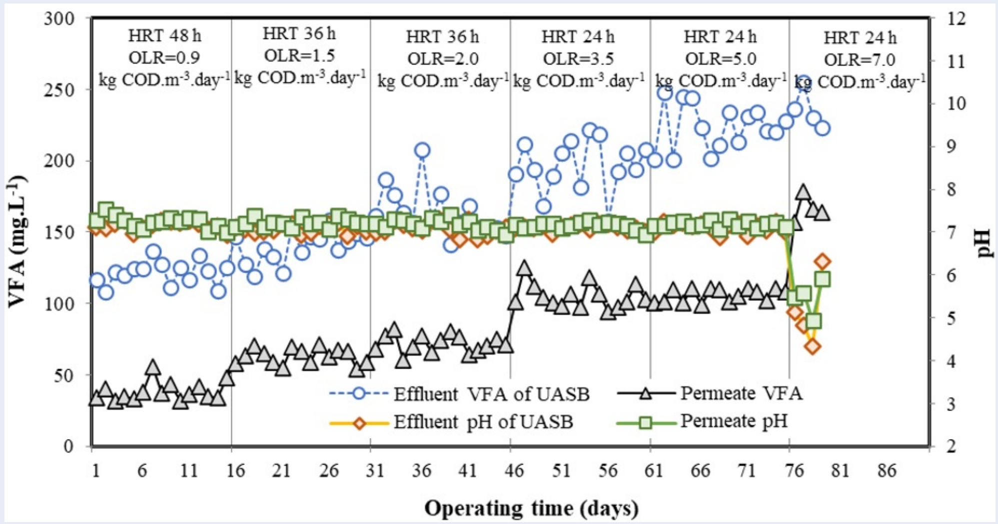

Figure 6: Variation of VFA concentration at different OLR

to Akanyeti's research, which reported the accumulation of VFA in the AnMBR happened at high OLR. Short HRT resulted in incomplete hydrolysis of solids and decomposition of methanogenesis bacteria in the methane phase. It is observed that the permeate VFA concentration was lower than that of UASB effluent. Thus, the amount of VFA might be used by bacteria present in the membrane tank. This may be why the permeate pH value increased compared to that of the UASB effluent. The influent pH was ranged from 6.8 to 7.2, whereas pH in permeate is stable (7.0 and 7.5), which similar to [22].

Total phosphorus

Similar to nitrogen losses, Figure 7 shows TP loss was low. Indeed, TP losses at OLRs of 0.9; 1.5; 2.0; 3.5; 5.0 kg COD.m^{-3}.day^{-1} was 13.1±5.9%; 7.15±4%; 6.52±4.9%; 4.86±4.6%, respectively. This illustrated that nutrients were preserved during the anaerobic process. The fact that the phosphorous and nitrogen losses may be attributed to adsorption in the excess sludge that was daily withdrawn according to SRT of 50 – 60 days. Besides, the loss of TP was caused by its presence as a precipitate in the sludge biomass and also served as a nutrient for microbial life. TP loss could be induced by the precipitation of metal phosphates such as calcium phosphate and iron phosphate in the fermenter under high alkalinity conditions, in addition to struvite precipitation [25]. The sludge and the permeate containing high inorganic nutrients can be used for agriculture or irrigation purposes, respectively.

Transmembrane Pressure (TMP)

At the HRT of 36 hours, the AnMBR was run at the flux of 5.2 L.m^{-2}. Figure 8 and Figure 9 shown that TMP increased slightly from day 1st to day 3rd. Due to the vibration system, membrane fouling was significantly improved. During operation time from day 3rd to day 12th, TMP tends to increase to 10kPa. After 16 days of operation at OLR of 2 kg COD.m^{-3}.d^{-1}, TMP exceeds 45 kPa. Therefore, the membrane CIP using 0.5% NaOCl was carried. When the AnMBR operated at HRT of 24 hours (OLR of 3.5 kg COD.m^{-3}.d^{-1}), TMP increased slowly in the first five days. Then, TMP increased rapidly then achieved 45 kPa on day 11th. TMP sharply increased and achieved 45 kPa at OLR of 5 kg COD.m^{-3}.d^{-1}. The rapid increase in TMP was due to the large amount of dissolved organic matter accumulated in the membrane. In an AnMBR, operating factors including organic loading rate, sludge retention time, hydraulic retention time, and operating temperature can have a major effect on TMP and permeate flux. Thus, instead of optimizing the TMP and permeate flux, these factors were commonly adjusted to enhance the biological component of the system [26].

CONCLUSION

The result presented the suitable OLRs of the 1S-AnMBR for co-digestion of kitchen waste and sewage had a high COD removal of above 80% at OLR of 3- 5 kg COD.m^{-3}.d^{-1}. The TKN and TP losses were not significant. Use of UASB coupled with UF filtration fixed with the membrane vibration improved membrane fouling for the 1S-AnMBR. The application

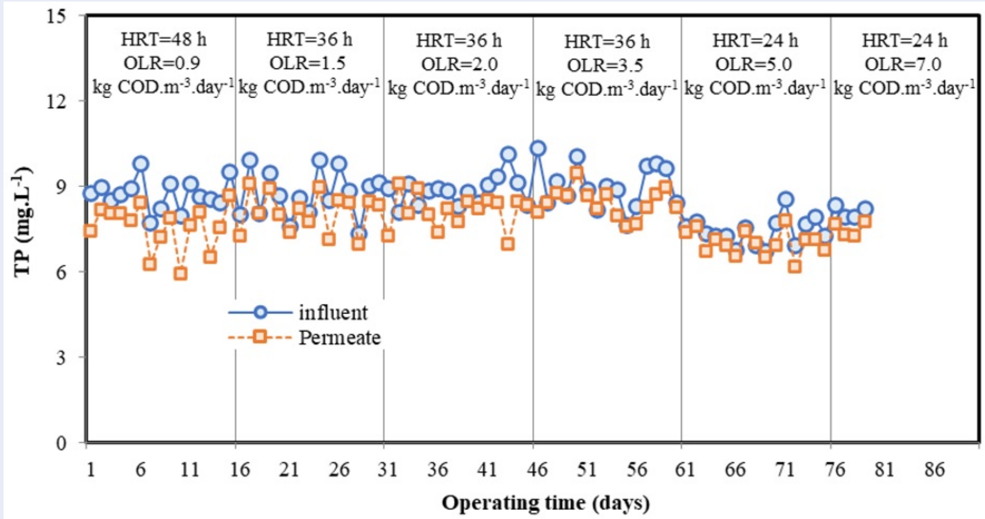

Figure 7: Variation of TP concentration at different OLRs

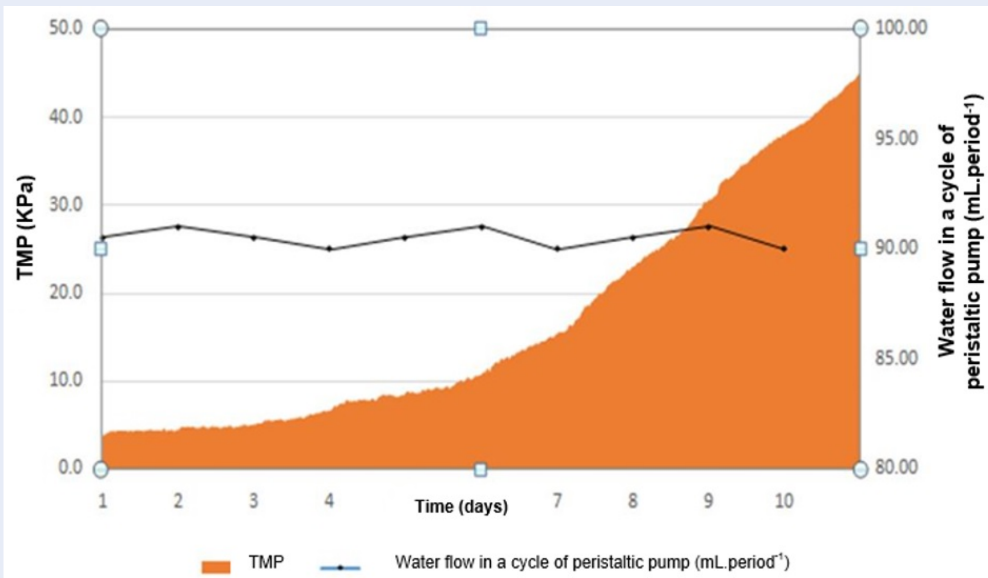

Figure 8: Variation of TMP at 24h of HRT, OLR = 3.5 kgCOD.m^{-3}.d^{-1}

of an anaerobic membrane bioreactor (AnMBR) for the co-digestion of organic kitchen waste and sewage brought several good outcomes related to waste disposal and sustainable development.

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LIST OF ABBREVIATIONS

UASB Up-flow anaerobic sludge blanket
UF Ultrafiltration
OLR Organic loading rate
AnMBRs Anaerobic membrane bioreactors
COD Chemical oxygen demand

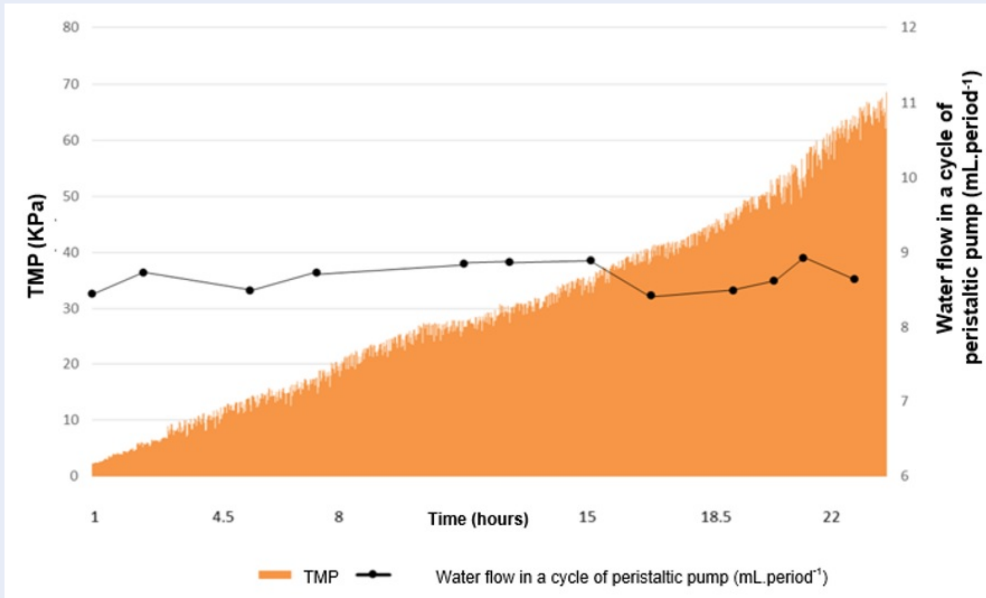

Figure 9: Variation of TMP at 36h of HRT, OLR = 2 kgCOD.m^{-3}.d^{-1}

WWTPs Wastewater treatment plants
SRT Sludge retention time
HRT Hydraulic retention time
TN Total nitrogen
TP Total phosphorus
TMP Transmembrane pressure
MLSS Mixed liquor suspended solids
MLVSS Mixed liquor volatile suspended solids

CONFLICT OF INTEREST STATEMENT

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AUTHORS CONTRIBUTION

Bui Hong Ha: Writing review & edit and resources;
Huynh Tran Uy Lam and Nguyen Xuan Hung: Data curation and formal analysis;
Nguyen Phuoc Dan: Supervion and conceptualization;
Nguyen Quang Loc: writing - original draft;
Bui Xuan Thanh: Validation and visualization;
Le Quang Do Thanh: Project administration.

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Bài nghiên cứu

Ứng dụng phản ứng sinh học màng kỵ khí một giai đoạn (1S-AnMBR) để đồng phân hủy chất thải hữu cơ nhà bếp và nước thải

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TÓM TẮT
Trong kịch nghiên cứu ứng dụng công nghệ bền vững, việc giảm thiểu chất thải và tiêu thụ tài nguyên là cơ bản hơn so với chất lượng dòng ra. Trong những năm gần đây, nhiều nghiên cứu liên quan đến công nghệ xanh trong xử lý nước thải đã được thực hiện như đất ngập nước kiến tạo, bể phản ứng sinh học màng, ... Với nhận thức tương tự, nghiên cứu đồng phân hủy rác thải nhà bếp và nước thải sinh hoạt đã được thực hiện. Nguyên lý của công nghệ thân thiện với môi trường này là tạo ra một phương pháp tiền xử lý nước thải sinh hoạt với chi phí thấp, bằng cách tận dụng nguồn cacbon hữu cơ có sẵn trong thức ăn thừa để loại bỏ các chất ô nhiễm trong nước thải, cải thiện chất lượng nước, giảm lượng bùn dư thải phát sinh và tiết kiệm chi phí. Nghiên cứu nhằm đánh giá khả năng thu hồi cacbon và dinh dưỡng của bể sinh học màng kỵ khí một giai đoạn quy mô phòng thí nghiệm (1S-AnMBR), mô hình bao gồm Bể kỵ khí dòng chảy ngược (UASB) nối tiếp với bể sinh học màng UF. Kết quả cho thấy rằng việc loại bỏ COD đạt trên 80% ở tất cả các tải trọng hữu cơ (OLR). Nồng độ COD trong nước thải sau xử lý đạt 160 $\pm$ 21, 227 $\pm$ 45, 340 $\pm$ 78, 563 $\pm$ 104 và 886 $\pm$ 96 mg.L^{-1} tương ứng với OLR là 0.9; 1.5; 2.0; 3.5; 5.0 và 7.0 kg COD.m^{-3}.ngày^{-1}. Sản lượng khí sinh học đạt 1119 $\pm$ 76, 1550 $\pm$ 68, 2155 $\pm$ 80, 3610 $\pm$ 86 và 5989 $\pm$ 88 mL.d^{-1}. Ngày 1 ở OLR là 0.9; 1.5; 2.0; 3.5; 5.0 và 7.0 kg COD.m^{-3}.ngày^{-1}. Kết quả nghiên cứu cho thấy hiệu quả chuyển hóa cao từ nitơ hữu cơ sang nitơ ammonia. Áp suất chuyển màng (TMP) gia tăng nhanh và đạt đến giá trị giới hạn 45kP sau 11 ngày vận hành ở tải trọng OLR 5 kg COD.m^{-3}.ngày^{-1}. Điều này cho thấy bẩn màng là một thách thức lớn đối với AnMBR. Tổng nitơ và phốt pho bị khử lần lượt là 12% và 15%. Công nghệ 1S-AnMBR còn được kỳ vọng sẽ mang lại kết quả khả quan khi ứng dụng vào thực tiễn cho việc đồng phân hủy chất thải rắn và nước thải. Phù hợp với các vùng nông thôn hoặc vùng sâu vùng xa, nơi mà hệ thống thu gom chất thải rắn và nước thải chưa hoàn thiện.
Từ khoá: đồng phân hủy, 1S-AnMBR, nước thải sinh hoạt, chất thải nhà bếp, bể phản ứng sinh học màng

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