DOI: 10.31276/VJSTE.63(1).71-76

Co-digestion of domestic wastewater and organic fraction of food waste using anaerobic membrane bioreactor: a pilot scale study

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Received 24 February 2020; accepted 20 July 2020

Abstract:

In this study, a co-digestion pilot scale study of a mixture of domestic wastewater and the organic fraction of food waste using an anaerobic membrane bioreactor was developed. The results show that the removal efficiencies of the chemical oxygen demand (COD) and total suspended solids (TSS) were high and reached more than 90%. However, the removal of nitrogen and phosphate was not remarkable. The daily biogas yield reached 2.12 m^3/d. The obtained biogas per COD removed was 0.22 $m^3/kgCOD_{removed}$. The average generated methane yield was 1.33 m^3/d, which is equivalent to 0.14 $m^3/kgCOD_{removed}$. A high efficiency of organic compound removal combined with a large amount of retained nutrients and high biogas yield suggests the results of this pilot scale study can be practically applied to the recovery of nutrients for agricultural use along with biogas for cooking. These benefits remarkably reduce environmental pollution, especially for decentralized residential areas and independent-stationed military units located far from concentrated wastewater treatment plants.

Keywords: **anaerobic, AnMBR, biogas yield, co-digestion, domestic wastewater, food waste, pilot scale.**

Classification number: **3.5**

Introduction

Municipal wastewater and solid waste from decentralized residential areas and independent-stationed military units are rapidly increasing because of remarkable population growth. Almost all of this wastewater has not yet been treated to meet to allowable standards due to its distance away from wastewater treatment plants. Besides, municipal solid waste is also difficult to treat because of high cost and the generation of secondary pollution from landfills. Generally, these wastes are usually collected and treated separately by aerobic biological technologies, which leads to high cost, high energy consumption, and is ineffective for decentralized discharge sources. Meanwhile, anaerobic biological degradation is a technology that poses many advantages, such as low waste sludge and low energy consumption, while offering superb energy recovery potential from biogas, which reduces greenhouse gas emission and increases the energy recovery from waste treatment effluent [1, 2] However, the application of anaerobic technology has been limited by its long biomass retention time and poor biomass settling, leading to washout of biomass from the effluent [1, 3]. In order to overcome these disadvantages, recent research has developed membrane technologies; specifically, a submerged membrane technology that permits retaining complete microbial biomass in the reactor while also maintaining low reactor volume [4]. With regard to the recovery of biogas, a fraction of organic food waste can increase the biogas yield thanks to the growth of influent organic loading. Theoretically, the obtained CH_4 yield from anaerobic digestion is about 0.35 $m^3/kgCOD_{removed}$. Research results achieved by some scholars have shown a similar or lesser CH_4 yield when conducting experiments with a mixture of wastewater and the organic fraction of solid waste in anaerobic digestion. For instance, in Gouveia's research that uses a pilot scale anaerobic membrane bioreactor

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(AnMBR) for the treatment of municipal wastewater, the methane yield achieved 0.18-0.23 Nm^3 CH_4/kg $COD_{removed}$ [5]. An AnMBR combined with activated carbon (GAC) was studied by Gao, et al. (2014) [6] to treat urban wastewater and obtained a methane yield of 140, 180, and 190 l CH_4/kg$COD_{removed}$ corresponding to a hydraulic retention time (HRT) of 8, 6, and 4 h, respectively. Galib, et al. (2016) [7] studied the treatment of food wastewater by anaerobic membrane (AnMBR) with a retention time of 5 d, 2 d, and 1 d and the biogas production generated ranged from 0.13 to 0.18 l CH_4/g$COD_{removed}$.

Anaerobic membrane technology has been widely applied to the treatment of various biodegradable wastewater on both the lab and pilot scale, such as a pilot AnMBR for the treatment of urban wastewater [8] and the decolonization of dye wastewater [9]. Anaerobic co-digestion of wastewater and solid waste have also been investigated by scholars over recent decades, for example, Lim (2011) [10] conducted a study on the co-digestion of a mixture of brown wastewater and food waste and the co-digestion of food waste and domestic wastewater by an upflow anaerobic sludge blanket (UASB) [11]. The mechanism of anaerobic digestion is the conversion of organic matter into valuable biogas without energy consumption. However, rarely has a study of the co-digestion of a mixture of wastewater and food waste submerged in an anaerobic membrane bioreactor (AnMBR) been conducted, especially a pilot scale study.

Therefore, in this work, a pilot scale study using the anaerobic co-digestion of a mixture of wastewater and organic fraction of food waste in a constantly-stirred, submerged anaerobic membrane bioreactor set up at an independent-stationed military unit far from residential areas. Based on the practical data collected of the discharge amount of domestic wastewater and organic fraction of food waste at various independent-stationed military units, together with inherited lab scale study results, the study found a suitable mixture ratio between these wastes to conduct the pilot scale study. Hence, the aim of this study is to evaluate the removal efficiency of organic compounds (COD), nutrients (N, P), total suspended solid, and pathogens and to estimate the biogas yield produced from the pilot scale co-digestion process.

Materials and methods

Domestic wastewater (DWW) and organic fraction of food waste (OFFW)

Domestic wastewater was directly taken from the septic tank at Radar Station 33 of the independent-stationed military unit in Ba Ria-Vung Tau province, Vietnam. The characteristics of this wastewater are presented in Table 1.

Table 1. Properties of domestic wastewater.

No.	Parameter	Unit	Value (n=10)
1	pH	-	7.1±0.5
2	COD	mg/l	152.0±51.0
3	TN	mg/l	113.05±18.5
4	$N\text{-}NH_4^+$	mg/l	103.08±11.8
5	TP	mg/l	8.95±1.25
6	TSS	mg/l	82.0±23.0

Food solid waste was collected from the residue of the kitchen at Radar Station 33, which included rice, fruit, and vegetable remains as well as meat and fish residues. The collected solid waste was then removed of its inorganic components (i.e. grit and plastic). In the next step, the residues were cut into small pieces and blended by blender to a size less than 0.5 mm. Finally, blended OFFW (BOFFW) samples were stored in plastic containers and kept in the refrigerator at 4°C. The characteristics of blended organic fraction of food waste are shown in table 2.

Table 2. Characteristics of blended organic fraction of food waste (BOFFW).

No.	Parameter	Unit	Value (n=3)
1	pH	-	6.8±0.5
2	Moisture	%	86.0±2.0
3	C/N	-	32.0±1.03
4	TS	g/kg wet	235.0±13.0
5	VS	g/kg wet	213.0±12.0

Based on the data collected of the discharge of domestic wastewater and solid waste at ten independent-stationed military units and some decentralized residential areas (data not shown), the ratio of BOFFW to DWW was at 5:1 (5 kg of BOFFW:1 m^3 of DWW). After mixing, the characteristics of the influent of the AnMBR-CSTR system are presented in table 3.

Table 3. Characteristic of influent wastewater after a mixture.

No.	Parameter	Unit	Value (n=3)
1	pH	-	7.3±0.3
2	COD	mg/l	2093.0±126.0
3	TN	mg/l	188.4±17.3
4	$N\text{-}NH_4^+$	mg/l	130.2±7.9
5	$P\text{-}PO_4^{3-}$	mg/l	6.0±0.3
6	TSS	mg/l	844.0±52.0

Set up treatment model

Because anaerobic sludge was not available, the sludge for this model was cultivated from probiotics, cow dung, and mud (500 l). The microbial culture process was carried out over 35 d. Firstly, the cow dung was finely ground then mixed with probiotic and molasses according to the ratio presented in Table 4. The mixture was then pumped into anaerobic tanks that contained the available wastewater. In the following step, the wastewater was stirred completely such that microorganisms make thorough contact with the cow dung, molasses, and sewage contained in the wastewater. The supplemented substrates were calculated as follows.

The initial culture sludge volume required to add into the tank:

V_s = (V×C)/MLSS = (5000×6000)/11200 ≈ 2678.6 (l) (choose 2.7 m^3)

where V_s is the volume (l) of sludge to be added to the tank, V is the volume (l) of the mixing anaerobic tank, C is the optimal anaerobic sludge concentration in the mixing tank with a range of 4000≤C≤6000 mg/l and C=6000 mg/l was chosen for this study, and MLSS is the concentration of anaerobic sludge added to the original tank, where MLSS=11200 mg/l.

The amount of probiotics, molasses, cow dung, clean water, and sewage added is presented in Table 4.

Table 4. The supplemented substrates used to cultivate microbials in the setup stage of the model.

Stage	Time (d)	Supplemented substrates					
		Wastewater (m^3)	*Fresh water (m^3)*	*Organic fraction of food waste (kg)*	*Probiotic (g)*	*Cow dung (kg)*	*Molasses (g)*
1	1-5	1	3	5	100	5	200
2	6-13	2	3	10	200	10	400
3	14-20	3.5	1.5	17.5	200	10	300
4	21-35	5	0	25	100	0	200

During the sludge culture process, the sludge volume must be checked and compared with the volume of sludge needed for the treatment process by turning off the agitator, letting the sludge settle for 30 min, and then measuring the volume of sludge. If the amount of obtained sludge was less than that of above-calculated sludge amount, the cultivating process needs to continue. If the amount of obtained sludge was enough or more than 10% in comparison with the calculated amount, the cultivating process was stopped.

The pilot model description

The pilot AnMBR-CSTR model is shown in Fig. 1. The model consists of an anaerobic continuous stirred reactor (AnCSTR) of 5 m^3 total volume with a diameter of 1.42 m, a height of 3.44 m, and a membrane tank that has the same total volume as the AnCSTR. One ultrafiltration membrane module (0.05 µm pore size) with a total membrane surface area of 10 m^2 was placed in this membrane tank. The model was operated with a flux of 10-50 l/m^2h.

Fig. 1. The pilot scale AnMBR-CSTR model.

Operation of the model

Figure 2 shows the flow diagram of the pilot model. The system's treatment medium flowrate was 210 l/h. The pilot system consisted of one continuous-stirred anaerobic tank with a volume of 10 m^3 and one submerged membrane tank with the same volume. Both tanks were connected each other to ensure that the sludge concentration in the two modules were the same and a circulating pump was continuously operated to circulate sludge from the membrane tank into the anaerobic continuously-stirred tank. The pilot model was fed with wastewater pre-treated as above description. The wastewater was first pumped into the anaerobic continuously-stirred tank. The AnCSTR was completely mixed using a paddle to increase the contact between the anaerobic sludge and the wastewater. After a certain retention time period, the wastewater was continuously pumped into the membrane tank. Both modules were equipped with biogas, temperature, and pressure meters. In order to control membrane fouling and maintain of the trans-membrane pressure (TMP), the membrane was cleaned with an operating cycle of 3 min of backwash, 5 sec of relaxation time, and 10 min filtration followed by 5 sec of relaxation time.

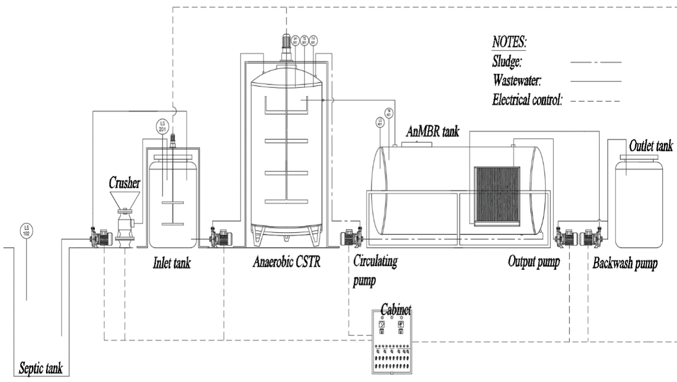


Fig. 2. Process flow diagram of the pilot scale AnMBR.

The operation conditions of AnMBR-CSTR were summarized in Table 5.

Table 5. AnMBR system operation parameters.

Parameter	Symbol	Unit	Value
pH	pH	-	7-8
Temperature	-	^oC	32.4-34.7
Hydraulic retention time	HRT	d	2
Sludge retention time	SRT	d	60
Organic load	OLR	kg COD/m^3.d	<1.3
Effective volume of the system	V	m^3	10
Flow input	Q	m^3/d	5

Analysis

The pH, COD of the influent, effluent, and membrane tank, and biogas yield in the effluent were analysed on a daily basis. TSS, N-NH_4^+, and P-PO_4^{3-} were measured at every other day. The operation time (total time of model) was 60 d.

The pH was measured by an online pH meter system that was directly installed into the treatment system. The COD, TSS, N-NH_4^+, and P-PO_4^{3-} were determined according to the standard methods for the examination of water and wastewater (APHA, 2012). The biogas yield was regularly monitored by an airflow measurement system and the obtained data were analysed using computer software.

Results and discussion

During 60 operation days, the pH of the influent and effluent of the AnMBR-CSTR at a SRT of 48 h ranged between 6.8-7.9±0.3 and 6.7-7.8±0.3, respectively. The pH was quite stable during the anaerobic degradation process of the mixture of BOFFW and DWW and suitable for the growth of anaerobic microorganisms. The pH of the effluent was slightly higher than that of the influent due to the accumulation of volatile fatty acids (VFAs) during acidification stage. However, the fluctuation of the pH was not significant, which showed there was a good balance between the metabolism of acidification and methane groups.

Total suspended solids (TSS) removal

The data in Fig. 3 shows the TSS of the influent and effluent and TSS removal efficiency of the pilot scale AnMBR-CSTR over a 60-d period of operation. It can be seen from Fig. 3 that despite the very high TSS in the influent, the effluent's TSS was low. The highest TSS removal efficiency reached greater than 95%.

The average TSS concentration in the influent was 844 mg/l and the TSS in the effluent was 52 mg/l. This result can be explained due to the presence of the ultrafiltration module in the AnMBR-CSTR system. The results were similar to the results obtained by a lab scale co-digestion model [12] and other studies [4, 5, 8, 9].

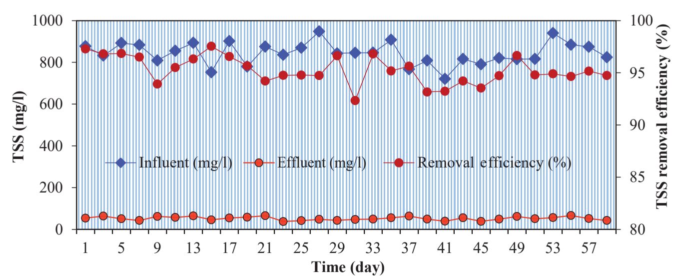


Fig. 3. The TSS removal efficiency.

The removal efficiency of COD

The influent and effluent COD and COD removal efficiency are presented in Fig. 4. A total removal efficiency higher than 90% was achieved with total COD values in the effluent ranging from 103 to 182 mg/l during the 60-d operation period despite an excellent COD in the influent (1807-2300 mg/l). The COD in the effluent was fairly stable during the treatment process. With the same HRT of 48 h, the pilot scale AnMBR-CSTR gave a similar removal efficiency of COD to the lab scale AnMBR-CSTR [12].

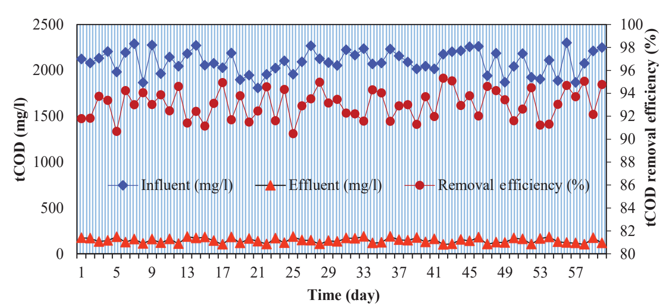
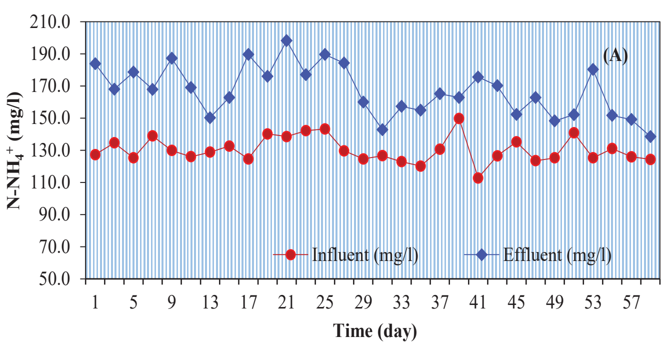


Fig. 4. The COD removal efficiency.

Nitrogen and phosphorus removal

The data in Figs. 5A and 5B show the concentrations of $N\text{-}NH_4^+$ and TKN, respectively, in the influent and effluent of the pilot scale AnMBR-CSTR. As can be seen from Fig. 5A, the $N\text{-}NH_4^+$ in the influent and effluent of was high and reached 112-149 and 139-198 mg/l, respectively. There was an increase in $N\text{-}NH_4^+$ in the effluent, which can be explained by the anaerobic degradation process where organic nitrogen derived from urine and some food wastes were converted into ammonium nitrogen by anaerobic microbial. Additionally, a part of $N\text{-}NH_4^+$ is used for cell synthesis of microorganisms. The results in Fig. 5B indicate that the TKN in the influent and effluent was significantly changed. From Fig. 5A and 5B, it can be seen that most of the N-TKN in the wastewater existed in the form of $N\text{-}NH_4^+$. These results agree with the work of Gouveia, et al. (2015) [5].



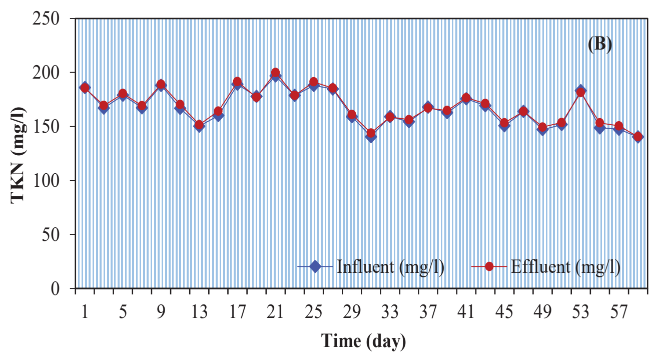


Fig. 5. Nitrogen removal (A) $N\text{-}NH_4^+$, (B) TKN.

The $P\text{-}PO_4^{3-}$ concentration also significantly changed. The results in Fig. 6 indicate that there was a slight decline in $P\text{-}PO_4^{3-}$ in the effluent, ranging from 6.0 mg/l to 3.9 mg/l. This decline in phosphorus is due to its use for the synthesis of microorganism cells.

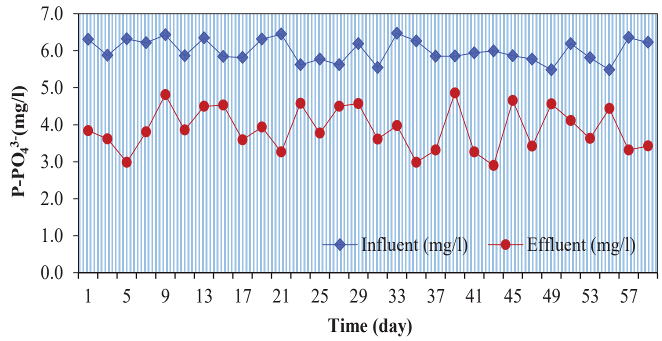


Fig. 6. Phosphate removal.

Biogas yield

The measured daily biogas yield had an average value of 2.12 m^3/d (the highest was 2.56 m^3/d and the lowest was 1.76 m^3/d). The amount of obtained biogas per removed COD was 0.22 $m^3/kgCOD_{removed}$ (the highest was 0.24 $m^3/kgCOD_{removed}$ and the lowest was 0.19 $m^3/kgCOD_{removed}$). The biogas yield data is presented in Fig. 7.

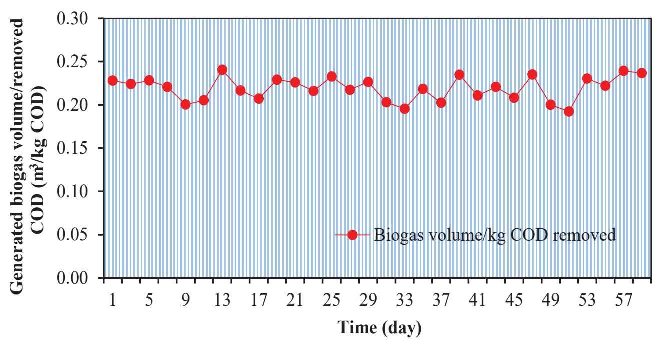


Fig. 7. The biogas yield generated per COD removed.

Conclusions

The co-digestion of domestic wastewater and food waste by a pilot scale anaerobic membrane bioreactor can solve both issues of wastewater treatment and food waste management for decentralized residential areas and independent-stationed military units. The removal efficiency of COD and TSS was quite high, especially with the presence of the membrane, from which TSS was completely removed. Moreover, supplementing with the organic fraction of food waste improved biogas generation. In summary, the pilot scale co-digestion technology performed in this study can be applied to a wider scale to resolve both wastewater and solid waste for decentralized areas that are far from concentrated treatment plants.

COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

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