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Performance of Single-phase Complete-mix Anaerobic Digestion of Organic Fraction of Municipal Solid Waste

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Abstract: The single–phase anaerobic digestion (AD) of organic fraction of municipal solid waste (OFMSW) had been investigated under organic loading rates (OLRs) of 3.9, 5.1 and 7.3 kg TVS/ (m^3· d), consecutively. The complete-mix, pilot-scale digester with working volume of 250 l was used. The hand-sorted OFMSW were shredded before batch- feeding into reactor. The anaerobically digested sludge was used as seed. The experiments had been conducted at ambient temperature of mesophilic range. The OFMSW input was found to be partially fermented with average pH of 3.73-4.88 and volatile fatty acid (VFA) of 2,898 – 3,819 mg/l as acetic acid. During digestion, $NaHCO_3$ was periodically added to maintain neutral pH in reactor. The average total volatile solids (TVS) of OFMSW input were 11.0 -15.0% while concentrations in effluent were 3.1-4.0%, indicating high rate of digestion. The TVS reductions were not significantly different with increasing OLRs, i.e. 79.5, 79.2 and 84.5 % in run 1, 2 and 3 respectively. The average effluents VFA from 3 runs were not related to OLR, i.e. 419- 819 mg/l as acetic acid. The biogas produced had methane composition of 56.3 –64.2 % and biogas production rates of 0.39-0.52 m^3/ kg TVS input, which slightly decreased with increasing OLRs. The application of single–phase AD for OFMSW disposal was found to be technically feasible and the OLR of 7.3 kg TVS/ (m^3· d), is suggested as design criterion.

Keywords: Anaerobic Digestion, Biogas, Organic Fraction of Municipal Solid Waste, Total Volatile Solids

Introduction

Municipal solid waste (MSW) disposal is considered as a big burden for public health and municipality officials. However, the OFMSW can become an endless resource for community provided that appropriate management is taken. The application of AD technology is among the promising alternatives. This technique is employed during the last 10 years in Europe[1] where source separation of MSW is commonly practiced. The co-digestion of OFMSW with night soil and animal waste are also feasible [2][3]. The major advantage of AD is methane production, which can be used as fuel while digested organics can be utilized as compost. In Thailand, about 65% of collected MSW are mainly disposed by open dumping[4]. There are currently 96 open dumpsites, 27 landfills, 9 sanitary landfills and 2 incinerators [4] while full-scale MSW separation does not exist. There are currently 3 full-scale AD sytems under operation with loading rates much lower than the designed values due to source-separation limitation. The site selection of MSW disposal is the most controversial issue due to public protest, mainly based on smell problem. Since AD system normally operates in enclosed reactor with biogas collection, the smell can be eventually eliminated. In terms of energy consumption, AD is more superior to conventional aerobic composting and can result in lower operation and maintenance cost. The reactor can be designed as single–phase or two-phase, where acidogenesis is separated from methanogenesis. Since OFMSW characteristics vary from country to country as well as other operating conditions, laboratory or pilot- scale experiments are required to obtain suitable design criteria. The objective of this study is to investigate the system performances of single- phase AD under different organic loading rates (OLRs) and to find suitable design criteria for full-scale application.

Methodology

The pilot–scale reactor made from mild steel plate, diameter 0.7 m x height 0.75 m and working volume of 250 l, had been used in this study. The complete-mix condition was maintained by paddle mixers, diameter 0.36 m and speed 26.2 rpm. The OFMSW was hand-sorted from Chiang Mai municipality transfer station every 2 weeks. It was shredded to 2.5 cm, weighed to the required daily feeding and packed in plastic bags before storing in 0-4 °C room. The OFMSW was daily shredded by meat shredder into sludge form and put in feeding tank before batch-fed to anaerobic digester. There was no liquid addition to incoming OFMSW. The effluent slurry was stored in 75-l plastic tank for solids-liquid separation, in which suspended solids floated up due to biogas. The biogas produced was measured by revolving- box gas counter. The anaerobically digested sludge from Chiang Mai University wastewater treatment plant was added as seed at the initial concentration around 1 %VSS. There were 3 experimental runs with OFMSW feeding rate of 6.7, 12 and 16.7 kg wet wt./d. It was initially expected that OFMSW had TVS of 15% and the feeding rates would be corresponding to organic loading rates (OLRs) of 4, 7.2 and 10 kg.TVS/ ($m^3 \cdot d$), respectively. However, actual analysis had different TVS values resulting in actual OLRs of 3.9, 5.1 and 7.3 kg.TVS/ ($m^3 \cdot d$), respectively. The sampling points included influent, effluent, sludge and supernatant in receiving tank. For the influent sludge, some parameters such as VFA, total alkalinity, etc. were analyzed from liquid portion after centrifuged. The water quality analysis was conducted according to Standard Methods[5] while biogas composition was analyzed by Gas Chromatography (Shimadzu model GC-8A). All experiments had been conducted at ambient temperature of mesophilic range in the Department of Environmental Engineering, Chiang Mai University, Thailand during March 2003 to June 2004. The diagram and photographs of experimental set up are shown in Fig.1 and 2, respectively.

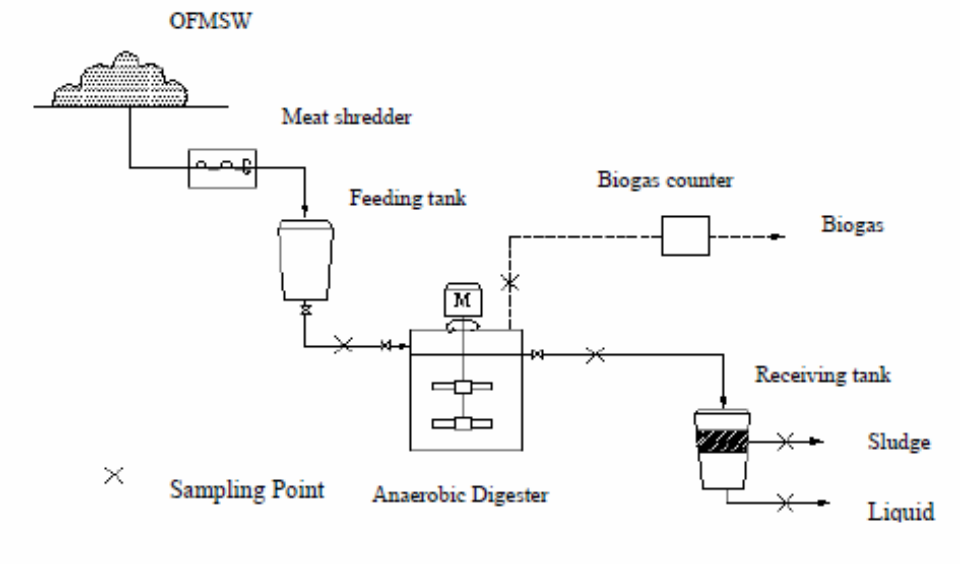
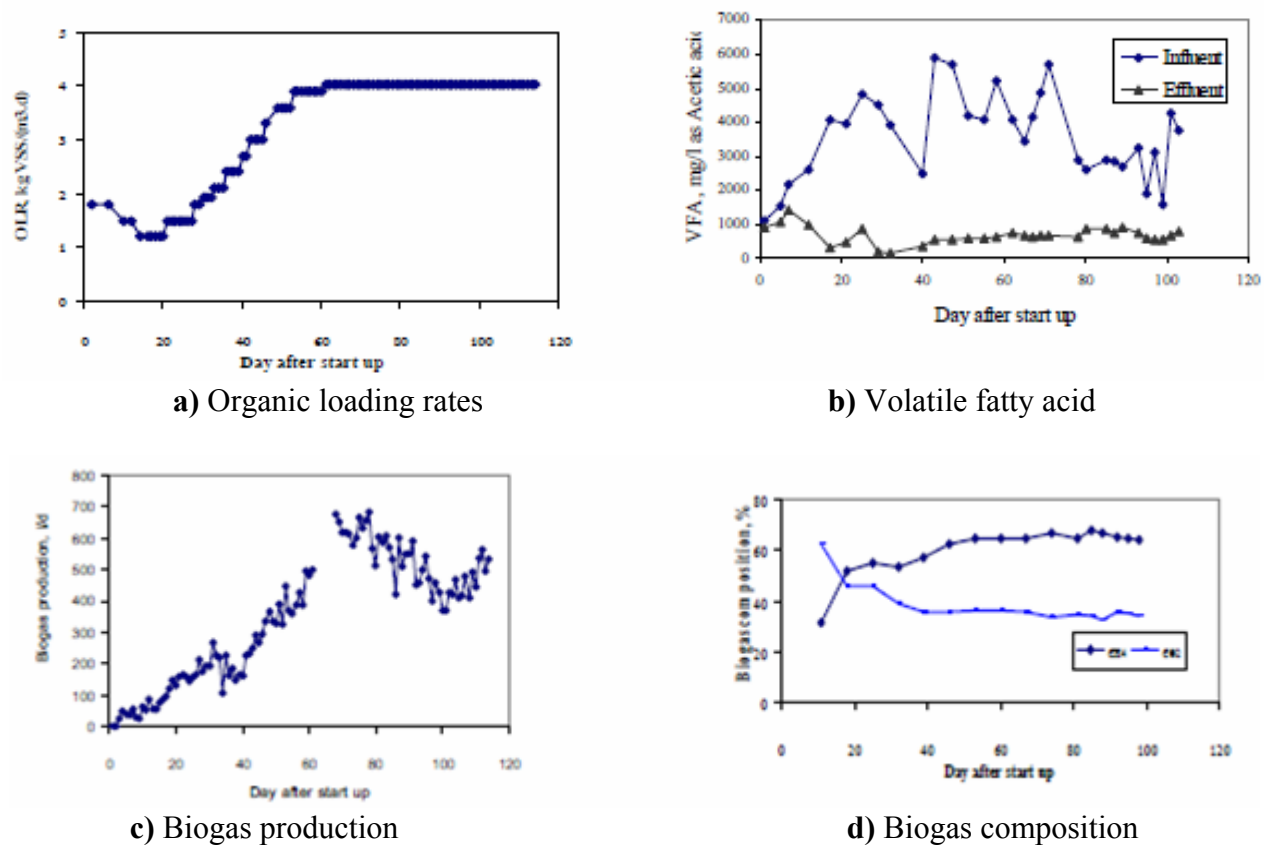


Fig.1 Diagram of experimental units

Fig. 2 Photographs of experimental units

Results and Discussion

The OFMSW was stepwise fed from 2 kg wet wt./d, resulting in stepwise increase of OLRs until reaching the targeted value of 6.7 kg/d, corresponding to 3.9 kgVS/ (m^3·d) VFA in the effluent and biogas composition were used as major indicators of steadystate condition and the system performances during start up are shown in Fig. 3.

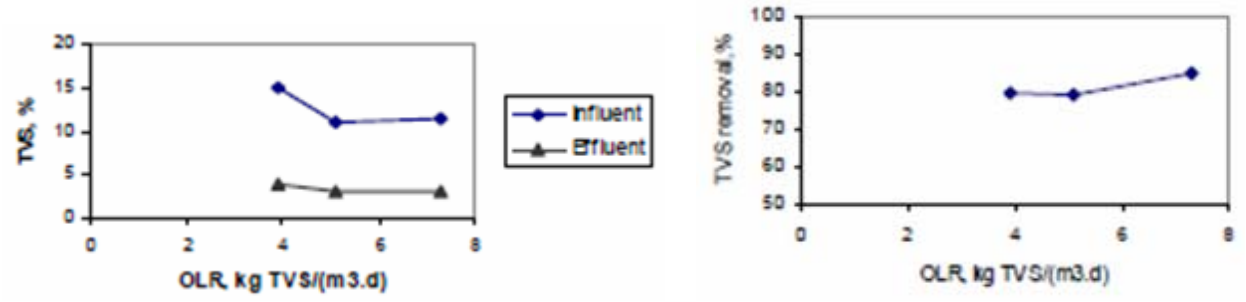


a) Organic loading rates **b)** Volatile fatty acid

c) Biogas production **d)** Biogas composition

Fig. 3 System performances during start up and Run 1

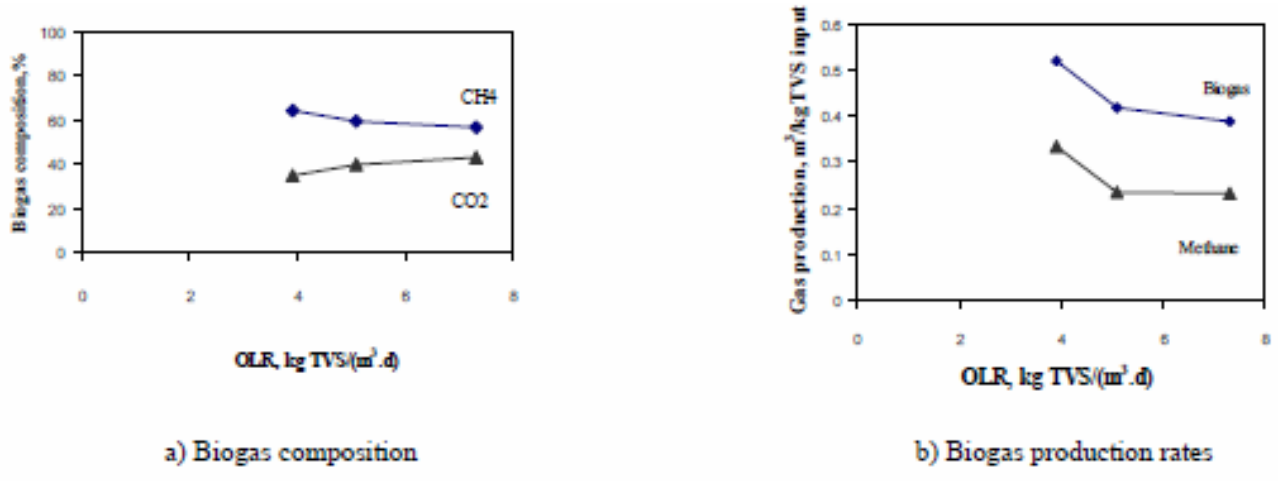
It took 61 d to step up the OLR to 3.9 kg TVS/ (m^3·d). The influent OFMSW had very low pH, average value 3.73, with high VFA concentrations, average value 2,898 mg/l as acetic acid, indicating partial fermentation of waste. The influent VFA concentrations were highly fluctuated while the effluent concentrations were relatively uniform. The VFA concentrations in the effluent were found to be not much different during OLR increased, with average value during steady state-condition of 819 mg/l as acetic acid. During the start up period, biogas production proportionally increased with increasing OLRs and reached the peak value of 680 l/d. The biogas production then slightly decreased with some fluctuations, having average value of 519.7 l/d while OFMSW feeding was kept constant at 6.7 kg wet wt./d. Biogas composition is one of the important indicator of system performance. It was found that methane composition steadily increased to the average value of 64.2 % while carbon dioxide proportionally decreased as shown in Fig.3 (d). It also demonstrated the shift of microbial consortia towards higher number of methane producers and indicated the balanced anaerobic digestion. The system reached pseudo steady- state condition within 78 days after start up. During the study, VFA accumulation and unbalanced methanogenesis sometimes caused pH drop in the reactor. To maintain reactor's pH not lower than 7 as suggested by Diaz (6), $NaHCO_3$ was periodically added throughout the study. There were totally 800, 860 and 640 g of commercial $NaHCO_3$ used in run 1, 2 and 3, respectively. The pH drop in single-phase AD system was found to be more obvious than two–phase AD system under similar condition (7) . After run 1, OFMSW was stepwise increased. Due to too rapid increase of OLRs, pH significantly dropped resulting in poor performances. The reactor was therefore seeded again and similar stepwise increases of OLRs were performed until reaching the targeted load in Run 2 and 3, consecutively. The relationship between TVS and OLRs in this study is summarized in Fig. 4.



a) TVS concentrations **b)** TVS removal

Fig. 4 Relationship between TVS and OlRs

Although the OFMSW input was not diluted with water, the system was operated under "wet digestion", i.e.TS <15% [8]. The OFMSW mainly consisted of food wastes and vegetable which were easily hydrolyzed. The average influent TVS in run 1, 2 and 3 were 15.0, 11.0 and 11.4 %, respectively. The TVS: TS ratios were rather high, i.e. 0.85-0.93, indicating easily biodegradability. The biodegradable portions of OFMSW were first hydrolyzed by acid-forming bacteria, resulting in relatively lower TVS in the effluent, i.e. 3.1- 4.0 %. The effluent wet weight was daily recorded and weight losses were found to be 23.9, 28.3 and 43.1 % in run 1, 2 and 3, respectively. The biogas and associated moisture are expected to cause weight loss. During the study, reactor's temperature were around 27 -29 °C. The TVS removal, based on mass, were found to be rather high, 79.2- 84.5% as shown in Fig. 4. The effluent slurry was stored in plastic tank for solids- liquid separation. It was found that TVS mass in the effluent were mainly in floated sludge, i.e. >90%. During the study, the average influent pH in Run 1, 2 and 3 were 3.73, 4.88 and 4.24, respectively. The low pH resulted from partial fermentation of OFMSW before treatment, with VFA concentrations in 3 runs of 2898, 3819 and 3642 mg/l as acetic acid, respectively. The average total alkalinity of influent in run 1, 2 and 3 were 887, 1614 and 958 mg/l as $CaCO_3$, respectively. Under anaerobic condition, the organic matter, including VFA, were converted to biogas, leaving VFA in the effluent in 3 runs at 819, 419 and 770 mg/l as acetic acid, respectively. This indicated the relatively high carbon oxidation. The pH was maintained at neutral range with average values of 7.03-7.15. The alkalinity in reactor was periodically adjusted by $NaHCO_3$ as previously mentioned, having average effluent concentrations of 4956-5732 mg/l as $CaCO_3$. The VFA: alkalinity ratios in reactor were 0.07-0.14 which indicated the sufficient buffering capacity. The biogas productions at steady-state condition were found to be 519.7, 553.7 and 741.5 l/d in run 1, 2 and 3, respectively. The biogas composition consisted of methane (56.3-64.2 % by vol.), carbon dioxide (34.8-42.7% by vol.), nitrogen (1.0-1.2% by vol.) and trace amount of hydrogen (0.01-0.02% by vol.). The biogas production rates, including dissolved gas in the effluent, in 3 run were found to be 0.52, 0.42 and 0.39 m3 /kg TVS input, respectively. The relationship between biogas composition and production rate with OLRs are shown in Fig. 5.



a) Biogas composition b) Biogas production rates

Fig. 5 Relationship between biogas composition and production rates with and OLRs

It was found that higher OLRs gave slightly lower methane composition and higher carbon dioxide. At OLR of 3.9 kg TVS/ (m^3·d), the highest biogas production rate was observed. The relationship between higher OLR, from the observed range, with biogas production rates is uncertain and higher OLR should be studied. The overall performances of this study are compared with other experiments as presented in Table 1.

Table 1 Comparison of system performances with other studies

Item	Reference					
	Kubler [9]	Ghosh [10]	de Laclos [1]	Groppelli[11]	Meta-Alvarez [12]	This study
Type of reactor	CSTR	CSTR	PF	CSTR	CSTR	CSTR
Temperature , °C	Mesophilic	35	40	35	55	27-29
TS in reactor,%	29	4-6.9	37-55	19.6	25.3	4.7-5.2
OLR, kg TVS/(m^3·d)	3.7-6.1	7.5	(HRT 20-60 d)	3.5-4.0	9.0-18.0	3.9-7.3
Methane composition, %	61-64	53	72	60	55-56	56-64
Biogas production, l/kg wet wt. input	65-100	49.1		76-100	35-38	44-78
Biogas production rate, m^3/ kg TVS input	0.36-0.55	0.22	0.29	0.49-0.65	0.32-0.35	0.39-0.52
Volumetric biogas production, m^3/ (m^3 tank vol·d)	2.0-1.8	0.83			3.1-6.1	2.1-3.0
TVS removal,%	41-64	26.0			37.3-40.1	79.2-84.5

According to table 1, this study had TS contents in the "wet digestion" range although there was no liquid addition to the OFMSW input. This may be the characteristic of OFMSW in Thailand which is different from developed country. The liquid temperatures were on mesophilic range and lower than the optimum value of 35 °C [13] . However, tropical climate facilitates the AD process without digester heating requirement as compared to temperate climate. The OLRs employed were comparable to most studies as well as the methane composition found in biogas which was in combustible range. The biogas production per OFMSW wet weight input was rather fluctuated in each study, possibly due to different waste composition. This study gave relatively high biogas production rates, based on TVS input. For TVS removal, the efficiencies from this study were much higher than other study. Karnchanawong[7] investigated the two-phase AD under the same reactor and operating condition and found 15.7-30.8% TVS removal. Authors suggest that higher OLR should be investigated in

further study. Based on data from this study, OLR of 7.3 kg TVS/(m^3·d) is suggested as design criteria with biogas production rate of 0.39 m 3/ kg TVS input. There was not dewatering study of the effluent slurry. However, previous study[7] employed sand drying beds and confirmed that dry sludge had better N ,P, K than normal compost from agricultural products. It may be assumed the effluent slurry is also suitable for crop fertilization. The singlephase AD system is another alternative for OFMSW disposal where renewable resources, i.e. biogas and compost, can be recovered

Conclusion

The single-phase, complete-mix reactor is found to be technically feasible for OFMSW disposal. The OLR of 7.3 kg TVS/(m^3·d) is suggested as design criterion with biogas production rate of 0.39 m 3/ kg TVS input. The pH adjustment is required to ensure smooth operation.

Acknowledgment

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