Methane Production from Co-digestion of Food Wastes and Septage in Two-Phase System Involving Upflow Anaerobic Sludge Blanket Reactors

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Abstract. With rapidly increasing population in large cities in the Philippines, there is need for compact treatment systems for large amounts of generated solid wastes, ca. 40% of which is biodegradable food wastes. In this study anaerobic codigestion of food wastes and septage in two-phase system is explored. The first phase of the system was a set of four intermittently fed hydrolysis-acidogenesis reactors while the second phase was a set of three upflow anaerobic sludge bed (UASB) reactors. Prior to the two phase codigestion experiment, the best ratio of the co-substrates was determined among 0:100, 30:70, 50:50, 70:30 and 100:0 food waste-to-septage ratios (v/v) in batch runs. The 70:30 digestion run had the highest methane production (92.0 $mL.g^{-1}$ VS), highest VS removal (44%), best TCOD removal (24.7%) and best hydrolysis rate (first-order kinetic constant, k = 0.1462 day^{-1}). With 50% higher amount of seed sludge, the methane production increased to 137.8 mL g^{-1} VS. The VS and TCOD removals were also increased to 56.1% and 36.6%, respectively. The hydrolysis rate also increased (k = 0.1542 day^{-1}). When fed into the two-phase system, a higher methane yield of 295.8 mL g^{-1} VS was obtained from 70:30 food waste – septage mixture at 16 days solid retention time.

Keywords: biogas, biosolids, hydrolysis, septage

1. Introduction

With rapidly increasing population in many urban centers in the Philippines comes huge amounts of restaurants and household solid waste generated daily. These cities lack space where these waste can be treated or disposed. Transporting them to disposal site far from the urban centers entails high costs. About 40% (NSWMC-DENR, 2015) of the solid waste generated are food waste. At present they are brought to centralized controlled dump sites together with other wastes that are not deemed recyclable. Some communities treat their food waste via composting (NSWMC-DENR, 2015). Meanwhile, most densely populated cities in the country do not have sewer systems through which domestic wastewater can be brought to a centralized treatment facility. Most household (40% in the country, ca. 85% in Metro Manila according to USAID 2010) dispose waste through septic tanks, which have to be regularly desludged, i.e. every ca. 2 years. Large amounts of septage, i.e., sludge from these septic tanks, are transported daily to sludge treatment facilities, where they are dewatered and dried.

Considering the high organic matter content of food waste and the favorable tropical climate in the country, anaerobic digestion where these organic matter is converted to methane is an attractive option. However, digesting food waste alone may result in high levels of volatile fatty acids (VFAs) that come from hydrolysis of the solids. VFAs or the resulting low pH may inhibit both further hydrolysis and methanogenesis (Chen *et al*. 2008). Thus, this study explores codigestion of food waste and septage. The latter generally contains high amount of nitrogen (Lin and Lee, 2002), which can enhance the degradation of food waste.

The digestion system must be compact as urban areas generally have limited space. In this study, co-digestion of food waste and septage in two-phase anaerobic digestion system is explored. Hydrolysis and acid formation in the first phase is expected. Thus, the system involves sprinkling the system with recycled leachate. This recycling of dilute leachate at the top of the first phase reactors is expected to wash down accumulated volatile fatty acids that can slow down digestion and correct the pH and moisture level of the waste, thereby enhancing overall waste degradation efficiency and methane generation of the system. Upflow anaerobic sludge blanket reactors, where a high popoulation of active methanogenic microorganisms can be maintained, was used to convert the hydrolysed organic matter in the leachate to methane. In view of the above concerns and potential solution, this study aimed (1) to determine a good food waste and septage mixture that allows high methane production and yield and (2) to determine the feasibility of the two-phase system for the co-digestion of food waste (FW) and septage (S).

2. Materials and Methods

A batch co-digestion experiment was done at varying food waste to septage ratio (table 1) to determine the effect of the latter on digestion performance. The food waste was obtained from university cafeteria and the septage was obtained from a screened raw septage treatment plant. Methane was measured via liquid displacement in Mariotte flasks containing 6% NaOH solution. After the batch experiment the feasibility of a two-phase anaerobic co-digestion system (fig. 1) was evaluated. The first phase (P1) consisted of four fed-batch 1-L reactor, which were connected in parallel and fed in rotation. Every 4 days one reactor was emptied and fed with new FW+S mixture. Each P1 reactor was emptied after 16 days that it was fed with new waste. Leachate from these reactors were brought to a reservoir, from which influent to three parallel UASB reactors (phase 2) came from. Part of the contents of the reservoir was recycled to the P1 reactors at 10 mL/min each reactor. Part of the UASB effluent was brought back to this reservoir in order to dilute the influent to UASB and the recycle to P1 reactors. The FW:S ratio used in this two-phase experiment was based on the prior batch co-digestion experiment. The UASB reactors were acclimatized for 16 days by feeding them with 3,000 mg/L COD food wastewater containing macronutrients and micronutrients (in µ/L): 6.00 $FeCl_3.4H_2O$, 6.00 $CoCl_2.6H_2O$, 1.50 $MnCl_2.4H_2O$, 1.09 $CuCl_2.2H_2O$, 0.15 $ZnCl_2$, 0.15 H_3BO_3, 0.27 $(NH_4)_6Mo_7O_{24}.4H_2O$, 0.30 $NiCl_2.6H_2O$; and, in mg/L: 0.84 NH_4Cl, 0.75 KH_2PO_4, 0.30 $MgSO_4.7H_2O$, 0.03 $CaCl_2.2H_2O$, 0.30 yeast extract (Le and Rollon 2012). They were later run at 4.2 hours hydraulic residence time (HRT) per pass. The whole system was run at 2.8 kg COD/m^3/d organic loading rate (OLR).

Total COD (TCOD), dissolved (DCOD), total solids (TS), volatile solids (VS) and N were measured according to standard methods (APHA 2005). Hydrolysis of solids in anaerobic conditions is commonly described as first order with respect to hydrolyzable solids (Bolzonella *et al.* 2005). The fraction hydrolyzed was defined as the TCOD part converted to methane and the part remaining as DCOD. The first-order rate constant was obtained by linear regression of ln (1-fraction hydrolyzed) against time. All experiments were done under ambient conditions (30 – 32°C).

Table 1.Initial characteristics of the food waste (FW) – septage (S) mixtures

Characteristics	Feedstock Mixture (Food Waste : Septage)				
	0:100 (Septage)	30:70	50:50	70:30	100:0 (Food Waste)
$gVS_{FW} : gVS_S$	0:100	94.3:5.7	97.5:2.5	98.9:1.1	100:0
%MC	98.37	95.48	91.75	90.31	88.56
pH	8.2	5.8	5.5	5.2	4.9
VS/TS (mg/L)	3,410 /6,566	35,647 /43,880	67,927 /78,007	85,173 /95,143	131,300 /141,594
VS/TS	0.52	0.81	0.87	0.90	0.93
TCOD:N	2.6	19.2	57	86	194
DCOD/TCOD (mg/L)	2,855/8,353	35,400/58,722	56,867/94,778	60,466/120,167	79,533/176,333
DCOD/TCOD	0.342	0.603	0.600	0.503	0.451

Each digestion mixture had 16 L (ca. 16 kg) total volume and contained 45% weight of FW+S, 50% added water and 5% cow rumen (as inoculum). FW:S = 30:70 means the mass ratio FW to S in 7.2 kg FW+S.

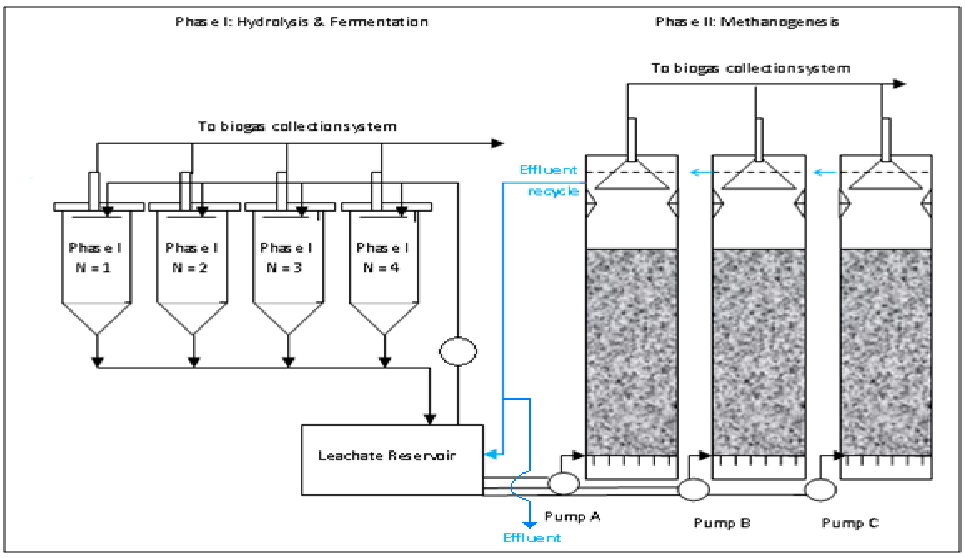

Figure 1. Experimental setup of the two-phase anaerobic co-digestion system

3. Results and Discussion

3.1. Batch co-digestion at various FW:S ratio

The septage had much lower water content (ca. 98%) than FW (ca. 89%) water content. Thus, as the proportion of FW increased, the VS, TS and TCOD levels increased (table 1). The pH values of the mixtures with food waste are all below 7.0, with increasing acidity as the fraction of food waste increases. This must be due to high levels of hydrolyzed organic materials, which increase as the FW fraction increases. Among the feedstock only the septage with inoculum had basic pH. The initial pH levels of the digester contents were adjusted to pH 7 by adding NaOH. The methane produced and yield based on VS removed were higher at the FW:S of 30:70, 50:50 and 70:30 compared with septage nor FW only (fig. 2, table 2). This trend must be due to higher organic matter content in these feedstock. However, for 100:0, the one without septage (FW and inoculum only), methane production was lower than those with septage. Probably, this must be due volatile fatty acids, which may have reached inhibitory levels from high initial TCOD and VS levels. As the FW fraction increased (from 30:70 to 70:30) the lag period before active methane production also became longer. Probably, VFA and LCFA from the food wastes initially inhibited methanogenesis (Chen *et al*., 2008). For the 0:100 feed mixture (septage alone), although it had the lowest organic content among the different feed mixtures, it had the longest lag period before methane production. Apart from LCFA and VFA, ammonia-N can also inhibit the digestion process (Kroeker *et al.*, 1979), and it is highly possible that it has been the main inhibitory agent in the mixture.

The extent and rate of hydrolysis was best in the 70:30 FW:S mixture, where ca. 18% of TCOD was hydrolyzed in 24 days and the first-order hydrolysis rate constant (k_h) was 0.143 (table 2). In all feed mixtures, production of methane slowed down after the region of active methane production even when not all the initial TCOD have been converted to methane. As the anaerobic digestion process progressed, VFA and LCFA might have accumulated and this inhibited the methanogenic bacteria from producing methane. If such was the case, then there were not enough methanogens present in the system to consume the fatty acids being produced from hydrolysis. Hence, in this case, methanogenesis and not hydrolysis was the rate-limiting process. More methanogenic seed microorganisms should have been added.

After 24 days run, the final VS/TS of the mixtures were 0.60 – 0.65 for the mixture containing FW (from initial values of 0.81 – 0.93. A large amount of organic solids still remain in the digested mixture. The time to reach 90% highest methane yield were 19, 15, 10, 14 and 13 d in the mixtures from 0:100 to 100:0 FW:S. Thus, 16 days SRT would be enough for mixture of 70:30 in next experiment, i.e., on two-phase system.

In another batch co-digestion experiment, the amount of inoculum was increased by 50%. This resulted in 55% increase in methane production and an increase in rate of hydrolysis, i.e., increase in k_h value from 0.143 to 0.154. Thus, a system containing higher population of active hydrolytic and methanogenic microorganisms may give better extent of stabilization of solids and higher methane production and yield.

3.2. Co-digestion in Two-phase system

The startup performance of the two-phase co-digestion system is shown in fig. 3. While the contents of the first phase reactor was increasing, the TCOD of the earlier fed part was decreasing and the TCOD level in the reservoir that received the leachate from the first phase digesters was increasing. The daily methane production in the UASB reactors were increasing and the overall remaining TCOD was decreasing.

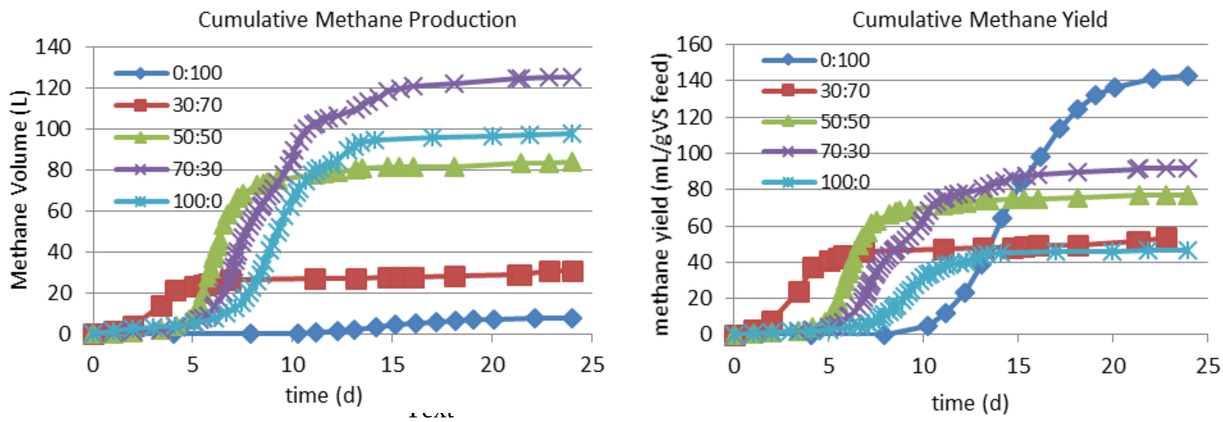

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Figure 2. Cumulative methane produced and yield vs. time

Table 2.Digestion performance of various food waste (FW) + septage (S) mixtures

Performance	Feedstock Mixture (Food Waste : Septage)				
	0:100 (Septage)	30:70	50:50	70:30	100:0 (Food Waste)
%VS Removal (16 & 24 d)	20.4; 30.5	19.3; 22.8	43.4; 43.6	41.9; 44.1	20.5; 23.9
%TCOD removal (16 & 24 d)	14.4; 18.7	16.3; 17.0	22.8; 24.0	22.0; 24.7	12.8; 13.3
Methane yield (L) in 24 d	7.8	30.9	83.8	125.35	97.5
Methane yield (mL/gVS)	142.96	54.18	77.07	91.98	46.41
Methane/TCOD removed	0.94	0.58	0.69	0.79	0.78
1st-order hydrolysis constant	0.0455	0.0645	0.1053	0.1434	0.0914

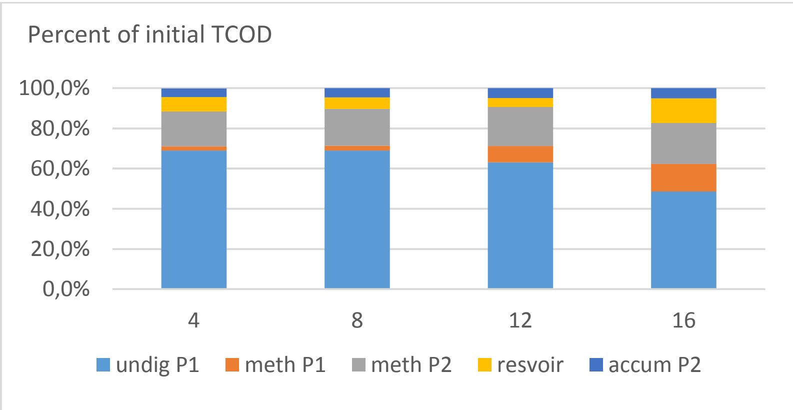

Figure 3. TCOD fractions (vs. feed TCOD) in phase 1 and 2 of two-phase anaerobic co-digestion system against time (days). The fractions were based on the total TCOD fed into the system. “Undig” means remaining TCOD in first phase reactors; “meth P1” and “met P2” are COD equivalent of methane from first and second phase reactors, respectively. “resvoir” is the TCOD remaining in the leachate reservoir. “accum P2” is the TCOD associated with the growth of microorganisms in UASB reator.

An inventory of the TCOD fed into the whole system as solids of the 70:30 FW:S mixture is shown in fig. 3. Within 16 days, the methane yield increased to more than 30% (fig. 3), which is much greater than that achieved in the batch digestion experiment in 24 days (ca. 18%). This yield is expected to increase as the methanogenic activity in the UASB reactor is also expected to increase in time as the reactor continues to feed on the leachate coming from the firs phase reactors. In a previous study on two-phase anaerobic digestion of organic fraction of municipal waste, about 47% TCOD conversion to methane was achieved after 40 days but at longer SRT (21 days) and similar OLR rate (2.87 kg COD/m^3/d). The startup performance of the present system is very promising as it achieved about 30% conversion to methane in 16 days operation. The portion of the whole system that contains active methanogenic microorganisms, i.e., UASB, may be increased in order to enhance the methane generation of the system.

4. Conclusions

This study shows a promising option for enhancing methane production from organic waste such as food waste and septage. Co-digestion of the two waste produces higher amounts and yield of methane.

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