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Methane Production and Waste Stabilization in Anaerobic Co-Digestion of Food Waste, Biosolids and used Cooking Oil

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Abstract

Restaurants, food processing industries and café kitchen generate significant amounts of food waste (FW) and waste cooking oil. Septage treatment also generates large amount of biosolids. This study explores the application of anaerobic process, which generates methane, a renewable energy resource, to these wastes. The performance of batch anaerobic co-digestion of food waste, biosolids and waste cooking oil at varying waste ratio, namely 0, 30, 50 and 70 mass percent volatile solids (VS) was determined. The seed sludge used was a combination of cow rumen obtained from a slaughterhouse and pig manure. The waste mixture that did not contain waste oil yielded the highest amount of methane (61.5 mL g^{-1} VS), showed the highest VS destruction (48.51%) and rate of hydrolysis (first-order rate constant of 0.187 d^{-1}). Rates of hydrolysis and methane production, methane yield and methane content of the biogas produced were lower at higher amounts of oil added but constant amount of seed sludge. Nevertheless, the mixture containing 70% waste oil produced 9.54 mL g^{-1} VS. Compared with other simple means of disposal, this method of the three kinds of wastes is a promising energy-generating option for treating food waste.

Keywords: biogas, COD, fats, hydrolysis, septage

1. Introduction

The generation of both solid waste and septage collected from septic tanks in Metro Manila have been increasing alongside growing urban population. Food waste is about 45% of solid waste generated. Meanwhile, the number of restaurants is also rapidly increasing with urban population. The disposal of a large amount of food waste and waste cooking oil is also a problem that the growing food service industry is facing. These wastes, i.e., food waste, used cooking oil and biosolids (i.e., dewatered septage) contain high amounts of organic matter, thus, converting them to biogas through anaerobic co-digestion may be a sustainable disposal option. The biosolids are expected to contribute nitrogen and phosphorus, and suitable microorganisms to the mixture, while used oil and food wastes contain higher amounts of carbon.

In anaerobic digestion, complex organic polymeric substances in wastes such as lipids or oil, carbohydrates and proteins are first broken down via hydrolysis to their monomers, long-chain fatty acids, sugars and amino acids, respectively. In the next step, the products of hydrolysis are converted to volatile fatty acids, which are further converted to simpler molecules such as formic and acetic acids, H_2 and CO_2. Lastly, these intermediates are converted to methane. Studies have shown that lipid-rich wastes improve anaerobic digestion by increasing methane yields (Zhu *et al*., 2010; Long *et al.* 2011). On the other hand, lipids at very high levels may also inhibit the methane production step. Thus, the effects of oil addition on the anaerobic digestion of food waste and biosolids on methane (CH_4) yield, VS removal and rate of hydrolysis, k_H, were determined in this study.

2. Materials and Methods

With a working volume of 3 L, four composite feed samples were made by varying the amount of waste oil added. Oil addition was done based on the total initial VS loading, giving 0, 30, 50, and 70% VS_{oil}/VS_{total} hereon referred to as R-0, R-30, R-50, and R-70, respectively. Each feed sample contained 25% cow rumen, 25% pig manure and 50% distilled water (v/v).

Table 1. Characteristics of initial digestion mixtures (R0, R-30, R-50, R70, numbers are % oil in the mixture); septage (S), food waste (FW), waste cooking oil (WCO), inoculum (I)

	R-0	R-30	R-50	R-70
%MC	96.79	95.75	95.63	93.27
VS/TS	0.84	0.88	0.91	0.94
pH	5.7	5.8	5.7	5.8
TCOD ($g.L^{-1}$)	29.72	66.90	100	138.45
DCOD ($g.L^{-1}$)	10.02	12.30	11.10	14.00
NH_4-N ($mg.L^{-1}$)	247.6	116.4	141.2	189.2
TKN ($mg.L^{-1}$)	619	801	764	510
TCOD:TKN	48.02	67.98	162.7	294.4
	S	FW	WCO	I
%MC	97.93	78.93	0.38	86.89
VS/TS	0.60	0.88	1.00	0.86

Gases from digesters were brought to Mariotte containers filled with tap water. The volume of water displaced in the containers corresponded to the volume of biogas produced. Biogas and CH_4 yields were calculated in milliliters of biogas/methane produced per gram of VS initially added. Digestion was done at ambient temperature and in duplicates that were dedicated to provide samples for total and dissolved chemical oxygen demand (TCOD and DCOD), total solids (TS), VS, ammonium-nitrogen (NH4-N) and total Kjeldahl nitrogen (TKN) concentrations analyses. The levels of these were determined using standard methods (APHA, 1998). Biogas samples were analyzed for methane content through a Shimadzu Gas Chromatograph-14B equipped with a flame ionization detector set at 150°C and having argon and nitrogen as carrier gases.

The rate of hydrolysis of solid organic matter is considered first order with respect to the level of the remaining solids. The corresponding rate constant was calculated by plotting the negative natural logarithm of the unhydrolyzed fraction of organics versus time and taking the slope. The extent and rate of hydrolysis was based on COD where hydrolyzed COD (HCOD) is the sum of the amount of DCOD in the digestion mixture and the amount of COD converted to methane.

3. Results and Discussions

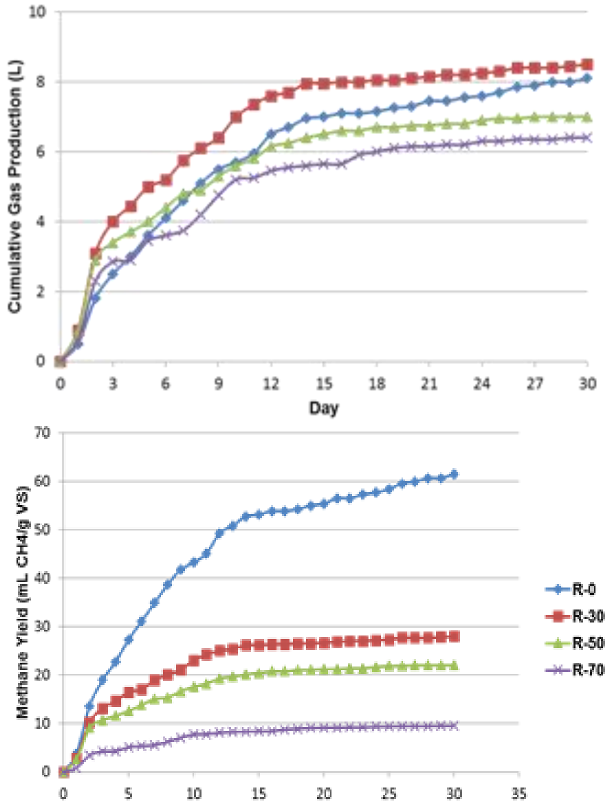

Figure 1. Cumulative gas production and corresponding CH_4 yield from different digestion mixtures

R-30 produced more methane while R-50 and R-70 produced less methane than R-0 (fig. 1). This suggest that at low level, addition of oil increases methane production but higher amounts may lead to inhibition of methanogenesis, liley by long-chain fatty acids (LCFA) and volatile-fatty acids (VFA) accumulation. At high concentrations, LCFA molecules adhere on bacterial cell walls thereby disrupting cell functions (Chen *et al.*, 2007). High levels of VFA can impede hydrolysis (Siegert & Banks, 2005). At the beginning of digestion, R-0 had the slowest biogas production, but outperformed R-70 at day 4 and R-50 at day 8. Slowing down of biogas production occurred first at R-70, next at R-50 and then R-30. In terms of methane yield as equivalent COD to initial total COD, R-0 had a very high methane yield compared to the three systems added with oil. It also yielded the highest methane content in the biogas (62.5%). This may be due to the TCOD/TKN ratio (48.02), which is nearest the value favorable for microbial growth, or the lower initial VS content in R-0.

Table 2 Biogas Composition & Volatile Solids (VS) Removal

Digestion Mixture	CH_4 content, %	% VS Removal
R-0	62.5	48.51
R-30	37.9	47.20
R-50	40.5	37.66
R-70	28.7	32,08

The hydrolysis rate constant gives an indication of the speed of the process as a function of the solids level. R-0 gave the highest value at 0.187 d^{-1}, and this value decreased through R-70 with 0.043 d^{-1}. The high lipid concentration at R-70 has inhibited both hydrolysis and methanogenesis, directly or indirectly through the intermediates LCFA and VFA. This inhibition has also decreased the methane yield.

4. Conclusions

Co-digestion of food waste with biosolids is a promising option for recovering energy resource from waste, giving 61.48 mL CH_4 g^{-1} VS and 48.51% VS destruction. Addition of used cooking oil into the digesting mixture (e.g., 30%) may increase gross methane production but not the methane yield per g VS. At higher levels, WCO inhibits hydrolysis and methane production. It is recommended to explore improvements in biogas production through higher initial seed sludge concentration, thus, lower sludge oil loading rate.

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