High Solid Anaerobic Co-digestion of Household Organic Waste with Cow Manure

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Latifah Abd Manaf
Universiti Putra Malaysia

Normala Halimoon
Universiti Putra Malaysia

Wan Azlina Wan Ab Karim Ghani
Universiti Putra Malaysia

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High solid anaerobic co-digestion of household organic waste with cow manure

Nuruljannah Khairuddin[a,*], Latifah Abd Manaf[a], Normala Halimoon[a], Wan Azlina Wan Abdul Karim Ghani[b], Mohd Ali Hassan[c],

[a] *Department of Environmental Sciences, Faculty of Environmental Studies, Universiti Putra Malaysia, 43400 UPM Serdang, Malaysia*
[b]*Department of Environmental Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Malalysia*
[c]*Department of Bioprocess Technology and Bimolecular Sciences, Universiti Putra Malaysia, 43400 UPM Serdang, Malaysia*

Abstract

Different mixture ratio of household organic waste (HOW) and cow manure (CM) were investigated for biogas production. The objective was to explore possible significant synergistic effect obtained from the combination of these different substrates in Reactor 1 – 4 (R_{1-4}) batch experiment. The highest methane yield, 247 mL/g VS was obtained from R_3 and 243 mL/g VS in R_4. Co-digestion in R_4 increased to 9% for CM and 78% for HOW in methane production. The results clearly demonstrate synergistic effect from nutrient balanced that improves the stability of anaerobic process.

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Keywords: Biomethane potential; biodegradability; anaerobic co-digestion; high solid

1. Introduction

Anaerobic digestion is one of the promising technologies in order to ensure betterment in landfill management. In fact, anaerobic digestion produce biogas which is can be potential renewable energy source, energy recovery and nutrient soil replacement through digestate composting. However, the process is sensitive and prone to failure [1]. The degradation of macromolecules in organic fraction of substrate resulting accumulation of volatile fatty acid (VFA) reduced the pH value. This limiting step in anaerobic digestion is known as hydrolysis step. Anaerobic

* Corresponding author. Tel.:+6011-10720301
E-mail address: jannah.env@gmail.com

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digestion (AD) was found to be unstable when the household organic waste and cow manure were used as sole-substrate due to low C/N ratio [2]. Co-digestion of organic fraction with other organic waste has been proposed as a solution to these problems. Co-digestion promoting a better nutritional supply and reducing the limiting element in anaerobic digestion such as ammonia and lipid. Another advantage is that, the residue from co-digestion may enhance the performance of the anaerobic digestion. However, co-digestion substrates should be selected to prevent adverse effects during the digestion process such as lowering the pH value and accumulation of toxic substance such as ammonia [3]. On the other hand, high solid anaerobic digestion also known as dry anaerobic digestion; is preferable due it minimal pre-treatment and added water [4]. High anaerobic co-digestion enhances the stability of the digestion process and produced more stable biogas production [4]. However more information is required to understand the mechanism involved in the process and to maintain to the optimal value for the maximum production. Hence, this present work was designed to evaluate the significant synergistic effects from high solid anaerobic co-digestion of household organic waste and cow manure. This paper also seeks to measure the performance of designed batch experiment of present work.

2. Materials and methods

2.1. Preparation of Substrate

Samples were collected from household organic waste (HOW) mainly food wastes, manually sorted and shredded using laboratory blender. Water was added to desire total solid content (TS = 15%) and keep frozen (4^{o}C). Cow manure (CM) was sampled from Universiti Putra Malaysia (UPM) agricultural park. The sample was stored in 4^{o}C to prevent organic decomposition until required prior to experiment. Due to high TS content (15.2%) water was added to 5% of TS content. Anaerobic inoculum used in this study was supplied by SP Multitech (SP Multitech Renewable Energy Sdn Bhd). The inoculum were thermophilic (55^{o}C) treated in air-tight reactor before introduced to the feedstock. The compositions of the feed for household organic waste, cow manure and inoculum are summarised in Table 1.

Table 1 Characteristics of feedstock and inoculums

Parameter	HOW	CM	Inoculum
pH	5.3	7.5	8.3
TS (%)	40.4	15.2	26.3
VS (%)	30.6	13.8	22.5
Moisture Content (%)	84.5	50.4	44.0
C:N	11.0	11.2	25.3
Ammonia (g/L)	4.3	26.88	14.8

2.2. Experimental Design and Operation

Batch experiments were constructed to evaluate the performance of high solid anaerobic co-digestion on household organic waste and cow manure. The assay was operated in four different mixture ratio (HOW/CM) on w/w basis in 1 L Schott bottles with total working volume of 800 mL in cooperated with 3 separated ports (pH adjustment, biogas measurement and biogas collection). All bottles were sealed with Teflon hermetic caps, flushed with a N_2 atmosphere and incubated in thermophilic condition (55 ± 1^{o}C). The experimental design and scheme is explained as in Table 2.

Table 2 Batch Experimental Design and Scheme of Feedstock and Inoculum

Reactor	Feedstock		Inoculum (mL)
	HOW (mL,15% TS)	CM (mL, 5%TS)	
R_1	-	760	40
R_2	760	-	40
R_3	380	380	40
R_4	506	254	40

The biogas was measured according to standard temperature and pressure (STP) by water displacement method. Qualitative characterisation of biogas; methane (CH_4) and carbon dioxide (CO_2) analyses was carried out by gas chromatography separation (6890N Agilent Technologies, CA, USA) with thermal conductivity detector (GC-TCD), equipped with a Hay sep N 80/100, a molecular sieve column (5A 60/100). Argon (Ar) was used as carrier gas at a flow rate of 12mL/min. The injector, oven and detector temperatures were 105^{o}C, 60^{o}C and 150^{o}C. CH_4 generation yield were normalised by correcting the gas volume to normal conditions (0^{o}C, 101.325 kPa). The samples were measured daily during first until third weeks of the experiment and weekly for the following weeks.

2.3. Analytical Procedures

Analytical characterisation were analysed to monitor total solids (TS), volatile solids (VS), alkalinity, total nitrogen (TKN), chemical oxygen demand (COD) and ammonium nitrogen (N_4^+-N) according to Standard Methods [5]. Additionally, to estimate theoretical biogas yield high solid anaerobic co-digestion of HOW and CM, an elemental analysis was conducted using LECO-CHNS-932 analyser.

2.4. Theoretical Methane Yield (TMY), Biodegradability (BD) and Relative Error (E)

The theoretical methane yield (TMY) was calculated by taking into account the elements of C, H, O and N of the waste composition considering total degradation. The assessments are basically is estimated using stoichiometric equation as expressed as in equation (1), based on Buswell formula [6, 7, 8].

$$TMY\left(\frac{mL\ CH_4}{g\ VS}\right) = \frac{\left(\frac{a}{2}+\frac{b}{8}-\frac{c}{4}-\frac{3d}{8}-\frac{e}{4}\right)\times 22400}{(12a+b+16c+14d+32e)} \tag{1}$$

Where *a,* is the number of atoms of carbon; *b* is the number of atoms of hydrogen; *c* is the number of atoms of oxygen; *d* is the number of atoms of nitrogen; *e* is the number of atoms of sulphur.

Once the digestion had finished the biodegradability of the substrates where analysed in order to evaluate the level of anaerobic biodegradability. Experimental biodegradability (BD_{exp}) was measured using initial and final volatile solids (VS_i and VS_f) as presented in equation (2) [9, 10].

$$BD_{exp}(\%) = \left(\frac{VS_i - VS_f}{VS_i}\right) \times 100 \tag{2}$$

Relative error (RE) were calculated (equation 4) [10] to evaluate the stability of the CH_4 production based on EMY and TMY measurement with the adjustment of the experimental TMY_{BD} (equation 3) [10].

$$TMY_{BD}\left(\frac{mL\ CH_4}{g\ VS}\right) = BD_{exp} \times TMY \tag{3}$$

$$RE\ (\%) = \frac{EMY - TMY_{BD}}{EMY} \tag{4}$$

2.5. Synergistic Effects

Theoretical methane yield may predict the methane production from experimental process. Concurrently the presence of different types of residues in anaerobic co-digestion, enhance the process to produce higher methane yield compare to sole digestion methane production [11]. This is due to the significant of synergistic interactions on co-digestion. The heterogeneity in substrate composition provides essential nutrients to stimulate anaerobic degradation. The synergistic effect during the co-digestion was investigated according to equation 5 [10, 12].

$$\alpha = \frac{Co-digestion\ methane\ yield}{sole-digestion\ methane\ yield} \tag{5}$$

The co-digestion experiment is the value from experimental methane yield for each co-digestion while sole digestion is the experimental methane yield from sole-digestion (HOW). The interactions can be interprets as follow:

$\alpha > 1$; the mixture has synergistic effect in the final products, $\alpha = 1$; the substrate work independently from the mixture,
$\alpha < 1$; the mixture has the competitive effect in the final products.

3. Results

3.1. Stability of High Solid Anaerobic Co-digestion

The main properties of individual reactors (R_1, R_2, R_3 and R_4) that describe psycho-chemical characteristics are summarised as in Table 3. The degradation of VS in organic substrate promotes significant contribution on methane yield in anaerobic digestion. In addition, higher organic elimination ($TS_{initial} - TS_{final}$) indicates the treatment efficiency of the treatment process. The current study agreed that more than 70% of organic elimination meets almost 70 – 80% of treatment effectiveness. From elemental analyses, anaerobic digestion influence to several improvements in digested composition which is essential for field application [13]. The information on psycho-chemical properties of feedstock of each functioning reactor is substantial to determine methane yields and describing the performance of anaerobic digestion. The measurement of essential elements such as macromolecules (N, P and K) is important as added value of the digestate. Almost 5 – 30% of nitrogen content increase from each reactor. However, there are no significant of AD on phosphorus (P) availability in digestate (0.01 – 1.00%). The mineralisation stage during AD accumulates with suspended solid lead to precipitation of P [14]. Moreover, the highest increment of potassium (K) content in digestate was observed in R_2 (33%) followed by R_3 (4.34%), R_1 (2.36%) and R_4 (2.1%).

Table 3 Average Value Psycho-chemical characteristics of Initial and Final Substrate

Parameter	Initial Substrate				Final Substrate			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
pH	7.8	5.5	6.8	7.1	7.2	4.5	6.5	6.9
TS (mg/kg)	20	20	20	20	8.1	13	7.5	8
VS (mg/kg)	50.4	73.5	48.3	44.1	10.1	24	11.0	12.7
Moisture Content (%)	64.3	70	70.1	75.2	43	44	47.2	53.0
COD (mg/L)	6879	10587	7380	6541	5000	2500	3500	3500
C:N	11.2	24.5	14.3	18.2	5.4	8.1	9.6	13.0
Total C (%)	35.4	59.2	47.3	46.4	-	-	-	-
Total N (%)	14	5.4	8.9	6.3	18	5	10.2	7.4
Total H (%)	6.3	9.4	7.8	8.3	-	-	-	-
Total O (%)	33.7	17.7	20.1	25.7	-	-	-	-
Total S (%)	-	-	0.7	0.5	-	-	-	-
Total P (%)	0.18	0.52	0.27	0.41	0.18	0.52	0.3	0.4
Total K (%)	1.27	0.9	2.3	1.4	1.30	0.61	2.2	1.7

3.2. Experimental and Theoretical Methane Yield

The experimental results were obtained after a period of 40 days when the batch assays ended with a methane production less than 1%. Fig. 1 shows the daily production during experiments for the sole substrates (HOW and CM) and each of the co-digestion mixtures. Methane production in R_4 is the highest (247 mL CH_4/g VS) followed by R_3 (243.75 mL/g VS). All these mixtures obtained higher values than the sole substrate in R_1 (CM) and R_2 (HOW) with 223 mL/g VS, 54 mL/g VS respectively. Co-digestion in R_4 increased 9% for CM and 78% for HOW in methane production. The CH_4 content is varied between 50 – 75 % for R_1, R_3 and R_4. From Fig.1 R_1 produce high methane production within 10 days operation. However, R_2 was completely halt and the process fault at day- 14 with CH_4 content <10%. Anaerobic co-digestion may enhance the stability of the anaerobic process because of a better carbon to nitrogen (C/N) balance [15]. The variation in the CH_4 production in the reactors was likely due to changing composition of the substrate [16].

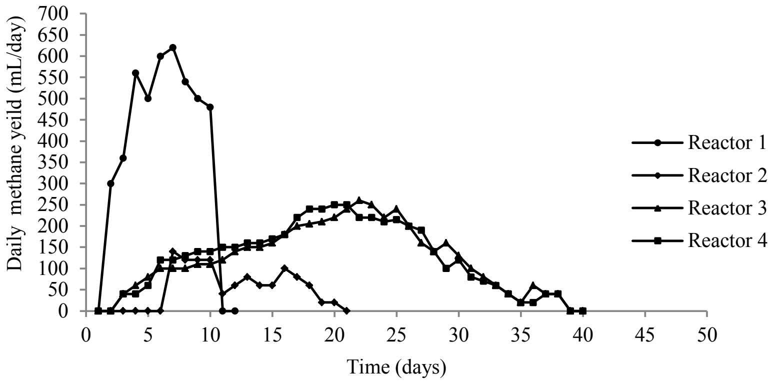

Fig. 1 Daily Methane Production of High Solid Anaerobic Co-digestion of HOW and CM

The potential of theoretical methodology to precisely estimate methane yield of anaerobic co-digestion was evaluated by comparing the EMY with TMY. Table 4 represent the experimental production (EMY), Biodegradability (BD_{exp}) and the theoretical estimation was corrected using the experimental biodegradability (TMY_{BD}). Relative error (RE) is measured from equation 4 by comparing EMY and TMY_{BD}. The methane yield from experimental process gets agreement more than 90% to the theoretical methane yield estimation for R_3 and R_4. Adopting the biodegradability of the experimental, preventing the methane production from co-digestion exceed the production from sole-digestion. The results showed different behaviour for R_1 and R_2 (sole-digestion) indicates that the synergistic effects is significant on anaerobic co-digestion. Overall, it is ascertainable that theoretical estimation methods based on stoichiometric composition with biodegradability values are potentials to evaluate specific methane yield with lower error (R_3 and R_4).

Table 4 Methane Yield from Experimental and Theoretical Measurement and biodegradability

Reactor	Experimental Measurement		Theoretical Measurement		
	EMY (mL/g VS)	BD_{exp} (%)	TMY (mL/g VS)	TMY_{BD} (mL/g VS)	RE (%)
R1	223	59.5	232.3	137.5	38.3
R2	54	67.3	505.2	340.3	-530.2
R3	247	77.2	345.2	266.5	7.9
R4	243	71.2	317.7	226.2	6.9

3.3. Synergistic Effects on High Solid Anaerobic Co-digestion

Anaerobic co-digestion in several combination of waste influences the biogas yield, process stability and the degradation. Anaerobic co-digestion can induced synergistic or antagonistic effect along the degradation process. The synergism can be explained as the increase in methane yield for co-digestion samples over sole-digestion. Whereas antagonism is understood as affect that caused decreases in methane yield in the co-digestion. The synergistic and antagonistic effect from this study where calculate according to equation 5. From the result, the optimum ratio for higher methane yield was 1:1 in R_3 (α = 4.6) followed by R_4 (α = 4.5). Hence, it is agreed that anaerobic co-digestion promote enhancement in treating organic waste fraction.

4. Conclusion

The experimental results indicate that all the co-digestion reactors (R_3 and R_4) have higher methane production from the sole digestion (R_1 and R_2). These finding support the synergism effect on high solid anaerobic co-digestion.

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