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Mesophilic Anaerobic Co-Digestion of Fruit and Vegetable Waste and Domestic Primary Sewage Sludge: Performance and Kinetic

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Abstract: Wastes such as fruit and vegetable waste and sewage sludge are not easy to be manage because of their chemical and physical properties. These waste also high putrescible. Recent years, landfill disposal is no longer a sustainable way for waste management as the area of landfill has become more limited. Therefore, new approach such anaerobic digestion should be considered for these wastes. However, the mono-digestion has a drawback, including lesser methane yield due to the substrate characteristics. To overcome this problem, the co-digestion is introduced, in which two or more substrate feed to the digester concurrently. This study aims to evaluate the performance and the kinetics from the co-digestion of fruit and vegetable waste with domestic primary sewage sludge. In this study, the bio-methane potential assay (BMP) at batch mode is conducted. The BMP assay is carried out at the inoculum to substrate (I/S) ratio of 2.0 at 37ºC. The kinetics analysis was included using Modified Gompertz Modelling. The characteristics study showed that the complex organic compounds existed in form of particulate mostly. The methane production was stopped at day 12 resulted in the ultimate methane yield of 1149.50 mLCH_4/gVS. In addition, the methane kinetics parameter observed from laboratory work slightly different from what was observed from the modelling.

Keywords: anaerobic, fruit, landfill, sludge

1. Introduction

The solid waste management system in Malaysia suffers from problem such as insufficient areas for landfill disposal, however there are approximately 95%-97% of collected waste was sent to the landfill [1]. Food waste composed about 40% to 64% of the municipal solid waste generated in Malaysia. With the increase of Malaysia's population and living standards, in the year 2014 the generation of food waste in Malaysia has reached a worrying number of 8000 tons of food waste per day. Food waste is categorized under the organic fraction of municipal solid waste (OFMSW) [2]. Fruit and vegetable waste account for a large composition of food waste as they are produced in a large scale in all the wholesale markets and in many activities around the world [3].

Malaysia is estimated to generate a volume of 2.97 billion cubic meters of wastewater per year [4]. Taking this into consideration, it is expected that the sewage sludge production is also high. In Malaysia, it is a practice to dump the food waste and sewage sludge in landfill. Unfortunately, landfill is no longer an effective waste management solution as the landfill have reached their capacity in Malaysia [5]. Moreover, fruit and vegetable waste (a components of food waste) creates more problems for landfill disposal because of their very high deteriorate rate. The waste management of

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fruit and vegetable waste is always a problem for community because of their high perishability. Fruits and vegetable waste degraded quickly and causes high environmental complications when disposed in the landfill [3], [6].

In recent years, anaerobic digestion is chosen as the most suitable technologies to handle fruit and vegetable waste because of the high moisture content of the waste [7]. Anaerobic digestion is a waste-to-energy technology; able to transform organic waste into biogas which consist of mainly methane and carbon dioxide. The transformation of organic waste to biogas was done by bacteria under no oxygen condition through several stages such as hydrolysis, acidogenesis, acetogenesis and methanogenesis [6], [8], [9]. Currently, anaerobic digestion is widely studied for the production of biogas from sewage sludge, and fruit and vegetable waste [6], [8].

To date, most of the experiment on pilot or industrial scale of anaerobic digestion for biogas production uses anaerobic co-digestion [3] which is the simultaneous anaerobic digestion of two or more substrate [11]. The motivation on using the co-digestion is due to the drawback of lesser methane production from the mono-digestion (using only a single substrate in anaerobic digestion). The lesser methane yield from mono-digestion is due to the chemical composition of the substrate itself [3], [11]. Mono-digestion of sewage sludge shows lower methane yield because of the low organic content of the sewage sludge [12]. Besides that, fruit and vegetable waste have high simple sugars content which will leads to fast acidification of the biomass and hence causing inhibition of the methanogenic bacteria activity [3].

The efficiency and feasibility of a material to be used as a substrate in an anaerobic digestion process is measured by the biochemical methane potential (BMP) test. The BMP test is able to provide information and data on the decomposition rate of a material during the biogas production process. The BMP is expressed as the volume of dry methane gas under standard conditions (273.15K and 101.33kPa) per mass of volatile solids (VS) of the substrate added, the units for BMP is LCH_4kgVS^{-1} [13].

The co-digestion of fruit and vegetable waste with primary sewage sludge was studied previously. All of the experiment shows positive result where there is a significant increase in biogas and methane generation when anaerobic co-digestion is adapted [14], [15]. However, the study on methane yield from the co-digestion fruit and vegetable waste with primary domestic sewage sludge in less reported. Therefore, this study was initiated to investigate the methane yield from the co-digestion of fruit and vegetable waste (FVW) with domestic primary sewage sludge (DPSS).

2. Material and Methods

2.1 Sample Collection and Storage

Three (3) types of sample were collected in this study. They are domestic primary sewage sludge, fruit and vegetable waste, and anaerobically digested sludge. The domestic primary sewage sludge was collected at the primary clarifier of the sewage treatment plant in Universiti Tun Hussein Onn Malaysia. The fruit and vegetable wastes were collected at the local shop at Parit Raja, Batu Pahat. The fruit and vegetable waste consisted of orange, lettuce, tomatoes and cucumber as described by Gómez, [15]. The fruit and vegetable were roughly chopped and blended around 2-3 minutes using household blender into a thick consistency [14]. The anaerobically digested sludge was collected from the existing anaerobic digester treating palm oil mill effluent (POME). All sample were stored at 4℃ until the anaerobic digestion assay [16].

2.2 Anaerobic Digestibility Assay

The biochemical methane potential (BMP) test was carried out using the Automatic Methane Potential Test System (AMPTS II) [16-17]. Duran bottle of 500ml is used as the batch reactor contained the substrate and the inoculum. The co-digestion substrate was the mixture of food and vegetable waste (FVW) and domestic primary sewage sludge (DPSS). The mixture had an FVW:DPSS ratio of 2.09 on VS basis [18].

The inoculum to substrate ratio used in this test is 2.0 on the basis of VS [18]. A 100 ml headspace volume and 400 ml working volume were prepared [17]. The pH value of the mixture and blank was recorded before the test; no pH adjustment was made because of high buffer capacity [17]. The anaerobic digestion typically take place at the pH range of 6.0 to 8.3 [16]. The reactors were flushed with pure nitrogen gas for 2 minutes in order to create an anaerobic environment in the headspace of the reactors [16]. The reactors were incubated in water bath of mesophilic temperature of 37°C and the mixing speed is set at 80 rpm [14].

A duplicate sample reactors (co-digestion) were prepared, contained of substrate and inoculum (anaerobically digested sludge), while duplicate blank reactors which contained the inoculum only were also prepared. In order to avoid early reaction of the substrate and inoculum, the sample were prepared one after another. Table 1 shows the mass of substrate and inoculum filled into the reactors. Fig. 1 shows the BMP assay set up used in this study. The pH of the blank reactors ranges from 7.4 to 7.6 while the pH of the sample reactors were all at 7.2. No pH adjustment has to be made as the pH of the reactors lies between the optimum pH value for anaerobic digestion process which ranged between 5.5 to 8.5 [19].

Table 1 - Mass of inoculum and substrate filled into the reactors.

Reactor	Mass of inoculum (g)	Mass of Substrate (g)	pH
Blank	272.53	0	7.6
Co-digestion	272.53	127.47	7.3

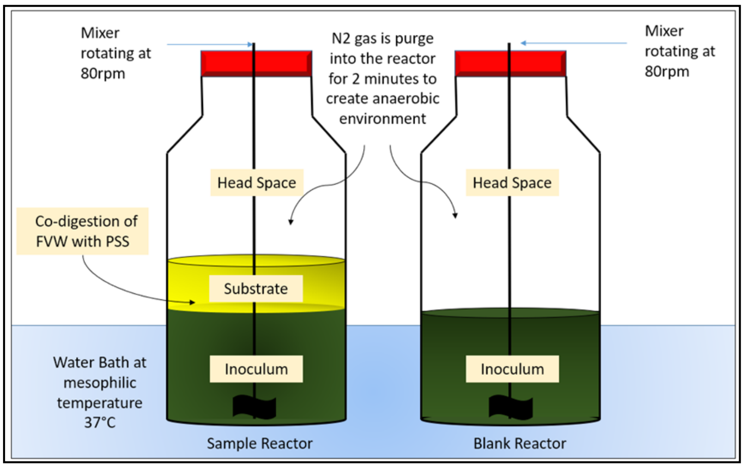

Fig. 1 - BMP assay set-up.

2.3 Analytical Method

Table 2 tabulates the established method used for the characteristic study of the substrate and the inoculum. The calibrated pH meter was used for measuring pH. The soluble form each for substrate and inoculum were prepared by centrifuging the sample and followed by filtration through a 0.45 µm cellulose acetate filter [20].

Table 2 - Mass of inoculum and substrate filled into the reactors.

Parameter	Analytical Method	Reference
COD (mg/L)	HACH method 8000	[14]
TS (mg/L)	APHA: Method 2540G	[14]
VS (mg/L)	APHA:Method 2540G	[14]
Protein (mg/L)	Lowry Method	[16]
Carbohydrate (mg/L)	Dubois Method	[17]
Alkalinity(g$CaCO_3$/L)	APHA: Method 2320B	[17]

3. Results and Discussion

3.1 Characteristic of Substrate

Table 3 presents the characteristics of substrate particularly for solids and organic. The pH of substrate is 6.7. However, pH acidic was also reported [22]. TS and VS relatively lower as compared to what was observed by Rizk [22]. It was observed that the concentration of chemical oxygen demand, protein and carbohydrate in form of particulate are higher than the concentration of soluble form. This was similar to the study conducted by [17]. This indicated that the readily degradable organic is less available in the substrate. In the substrate, the complex organic compound was dominated by carbohydrate.

Table 3 - Susbtrate characteristics (N=3).

Parameter	Concentration	Parameter	Concentration
Total solids (TS) (mg/L)	26330.00 ± 580.00	Protein total (mg/L)	3973.00 ± 10.03
Volatile solids (VS) (mg/L)	11000.00 ± 580.00	Protein soluble (mg/L)	245.76 ± 1.28
COD total (mg/L)	34375.00 ± 478.00	Carbohydrate total (mg/L)	6334.00 ± 16.13
COD soluble (mg/L)	6337.50 ± 179.00	Carbohydrate soluble (mg/L)	837.70 ± 3.29

3.2 Characteristic of Inoculum

The characteristics of the inoculum are tabulated in Table 4. It was observed that VS/TS ratio obtained from the analysis was 54% which was almost similar to what was obtained by Xie, [23]. Besides that, the pH of the inoculum used in this study is 8.7. Xie [23] observed that the pH for the inoculum was at 7.5. On the other hand, the total chemical oxygen demand obtained from this study was 20375 mg/L which was almost double from what observed by Xie [23]. However, the protein was much higher as compared to the carbohydrate. This is similar to the data observed by Cabbai [17].

Table 4 - Inoculum characteristics (N=3).

Parameter	Concentration
pH	8.7
Total Solid (g/L)	19.56 ± 0.51
Volatile Solid (g/L)	10.66 ± 0.58
COD total (mg/L)	20375.00 ± 250.00
COD soluble (mg/L)	7575.00 ± 125.80
Protein total (mg/L)	4830.00 ± 31.51
Protein soluble (mg/L)	1596.00 ± 12.59
Carbohydrate total (mg/L)	1304.00 ± 0.52
Carbohydrate soluble	212.50 ± 0.45

3.3 Stability of Anaerobic Process for BMP Test

At the last day of the BMP assay, the pH value of sample in each reactor was taken. The sample from each reactor was also taken for the alkalinity test. The pH value of the blank reactors at last day were all at 8.4, while the pH value of the sample reactor ranged from 8.1 to 8.2. The pH values of blank and sample reactors were remained in the suitable pH range of 5.5 to 8.5, indicating that there is no inhibition take places. The intermediate alkalinity to partial alkalinity ratio (IA/PA) values for each sample were calculated and they were less than 0.3. IA/PA lesser than 0.3 is indicating a stable anaerobic process [18].

3.4 Methane Accumulation

The total digestion time of the BMP assay was 18 days. However, the methane production in the batch reactors has stopped at the 12th day, 18 days digestion time was taken in order to confirm that the reactor no longer produce methane anymore. Park [14] observed the digestion time to remain constant at 10 days. The net accumulated methane was 459.8 mL after subtracting the methane accumulation from the blank reactor (Table 5).

Table 5 - Methane accumulation for the 18 days BMP assay.

Volume (mL)	Blank	Sample
Average accumulated	76.6	533.4
Net accumulated methane	459.8	

3.5 Methane Yield

The methane yield from the co-digestion study was presented in the unit of $mLCH_4/gVS$ and was tabulated in Table 6. The ultimate methane yield was 1149.50 $mLCH_4/gVS$ and observed starting from day 12. The ultimate yield observed from this study was higher than what was observed from the previous research [14], [15]. This is possible due to the different setup of the BMP test, and the substrate characteristic.

Table 6 - Methane yield for BMP assay.

Day	Methane Yield	Day	Methane Yield
0	0.0	9	1100.6
1	331.3	10	1137.3
2	509.6	11	1148.4
3	669.3	12	1149.5
4	810.4	13	1149.5
5	860.9	14	1149.5
6	907.4	15	1149.5
7	964.5	16	1149.5
8	1033.5	17	1149.5

3.6. VS Removal

The BMP also used to evaluate the matter removal (in term of TS, VS or COD) [24]. The co-digestion in this study recorded the VS removal of 75 %. Maria [25] observed the VS removal of 43% in the co-digestion test. Meanwhile, the similar substrate from different origin also resulted in the different VS removal [24].

3.7. Methane Production Kinetic Modelling

The Gompertz Kinetic Modelling was used to predict the final productivity of anaerobic digestion process within the 7 days of the experiment to comprehend with the major drawback of BMP assay which is long duration of testing [26]. Table 7 summarized the results of fitting the modified Gompertz model to the anaerobic digestion data obtained from the laboratory. The short lag phase time of 0.04 days were shown in the actual laboratory test while the Gompertz modelling showed there was no lag time in the digestion process. The ultimate methane yield obtained in the laboratory was 1149.50 $mLCH_4/gVS$. However, in the modelling analysis, the ultimate methane yield is lesser, which was reduced by almost 100 $mLCH_4/gVS$. Meanwhile, the methane production rate for laboratory data and modelling are well fitted. Nielfa, [26] also observed the kinetics from the modelling were slightly different from what was observed from laboratory.

Table 7 - Kinetic parameters.

Kinetic Parameter	Laboratory Data	Gompertz Data
Ultimate methane yield, M_o ($mLCH_4/gVS$)	1149.50	1052.64
Methane production rate, R_m ($mL\ CH_4/gVS/day$)	254.81	254.68
Lag phase λ (day)	0.04	0.00

4. Conclusion

The co-digestion of fruit and vegetable waste (FVW) with domestic primary sewage sludge (DPSS) was done in this study. The ultimate methane yield from the batch co–digestion conducted at I/S ratio of 2 under mesophilic temperature was 1149.50 $mLCH_4/gVS$. This value is relatively higher from other observations. This could be due to the addition of the domestic primary sewage sludge. Furthermore, chemical compositions of the substrate used, and the inoculum origin also effected the BMP results. No lag phase was observed in this study, suggesting that the mixture of the FVW and PSS is suitable for anaerobic digestion. In addition, the COD, protein and the carbohydrate of the mixture of FVW and PSS mostly existed in the form of particulate. The methane yield observed from this study could be uses as a preliminary reference for obtaining the suitable condition in order to generate the optimal methane yield from the co-digestion of FVW and PSS. In future, the co-digestion at bigger scale of similar substrate can be done at a shorter retention time

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