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INFLUENCE OF ORGANIC FRACTION OF MUNICIPAL SOLID WASTE PARTICLE SIZE ON BIOGAS PRODUCTION

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ABSTRACT

The performance of anaerobic digestion (AD) to process organic fraction of municipal solid waste (OFMSW) can be improved with various pre-treatments. Mechanical pre-treatments, mainly chopping, have shown to be the most economical and relatively effective method to increase contact between the substrate and microorganisms. The purpose of this research was to analyze the effect of OFMSW particle size on CH_4 gas formation in a laboratory-scale Biochemical Methane Potential (BMP) assay. The research was conducted for 35 days at a temperature of 35°C with three sizes of OFMSW co-digested with cow manure. OFMSW with particle sizes of 10–13 mm, 4.76–10 mm, and 2–4.76 mm produce CH_4 gas with an average of 114.7+14.7 ml, 101.7+0.5 ml, and 110.9+10.8 ml, respectively, while methane yield was 0.277 L CH_4/g VS, 0.208 L CH_4/g VS, and 0.229 L CH_4/g VS, respectively. Particle size is more likely to have an influence on the hydrolysis and acidogenesis processes, as demonstrated by the significant difference of VFA value, but not on the biogas potential. Particle sizes of 13–15 mm produce 19.25 mg VFA/L, while the size range of 2–4.76 mm produces 118.1 mg VFA/L.

Keywords: BMP; CH_4 gas; Organic waste; Particle size; VFA

1. INTRODUCTION

The issue of municipal solid waste in Indonesia is becoming an increasing concern. It is estimated that up to 200 thousand tons/day is generated (Bappenas, 2011), with an organic waste fraction of 60% (KNLH, 2008). Anaerobic Digestion (AD) can be a viable technology solution for treating the organic fraction of municipal solid waste (OFMSW). AD can reduce cost and increase renewable energy since it produces CH_4 gas, known as methane (Izumi et al., 2010), through hydrolysis, acetogenesis, asidogenesis, and methanogenesis (Shah et al., 2014).

Solid contents in municipal solid waste can be relatively high, ranging from 23–27% (Tassakka, 2016), when compared to other substrates used for AD in Indonesia, such as cow manure. This high solids concentration can reduce the effectiveness of anaerobic digestion since there will be less contact between microorganisms and the substrate. Various pre-treatment methods can be applied to increase the degradation rate of OFMSW, including mechanical, thermal, and biological methods(Ariunbaatar et al., 2014). From these available methods, mechanical pre-treatments have demonstrated to be the easiest method to implement with a relatively low energy demand (Ariunbaatar et al., 2014). Previous studies have also shown that there are

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various mechanical treatments that have different effects on the physical characteristics of the substrates (Izumi et al., 2010). The common action is that mechanical pre-treatments reduce particle size, thus increasing contact between the substrate and microorganisms and increasing the hydrolisis rate, which will in turn decrease COD and increase methane production (Mata-Alvarez et al., 2014; Esposito et al., 2012; Jain et al., 2015). From all the possible options, mechanical methods using chopping to reduce particle size appear to be the most readily available method for developing countries such as Indonesia, as it is also used as pre-treatment for composting. For example, Silvestre et al. (2015) demonstrated that the reduction of organic waste particle size from 20 mm to 8 mm increased methane formation from 0.31 to 0.42 L CH_4/g VS. Agyeman and Tao (2014) performed a study with leftover waste as a substrate that showed reducing particle size from 8 mm to 2.15 mm resulted in a 10–29% increase in CH_4 gas production and a 9–34% increase in methane gas potential (Agyeman & Tao, 2014).

However, OFMSW in Indonesia contains different compositions, and the impact of particle size reduction on biogas potential might differ from previous research. Furthermore, mechanical pre-treatment effects are shown to be complex and dependent on substrate characteristics (Carlsson et al., 2012). Therefore, the purpose of this research is to analyze the effect of Indonesian OFMSW particle size reduction, using chopping, on potential methane gas formation.

2. EXPERIMENTAL SETUP

A Biochemical Methane Potential (BMP) assay was performed based on Angelidaki et al. (2009) and Cresson et al. (2014). The OFMSW used in this study originated from Waste4Change (a treatment center for municipal solid waste in Bekasi) and was sampled using the quartering method. Cow dung was chosen as a co-substrate and detailed in another study. The microorganism inoculum originated from an anaerobic digester of market waste in Petamburan, Jakarta. The acclimatization of the inoculum was performed over two weeks. Afterward, the degasification of the inoculum was performed in an incubator at a temperature of 35˚C for two to five days (Angelidaki et al., 2009).

Based on the availability of different manual chopping and sieving equipment, and with a reference particle size of less than 20 mm, three particle-size ranges were chosen: 10–13 mm, 4.76–10 mm, and 2–4.76 mm (Figure 1). The OFMSW and cow dung were mixed with a volatile solid (VS) ratio of 3:1. This mixture was then combined with the inoculum in a 1:1 VS ratio. The final VS created a mixture of 10.8 gr VS/L. This mixture was then poured into airtight vial bottles of 125 mL. Each particle size was prepared in triplicate. Blank samples using only the inoculum were also prepared in triplicate. Headspace was determined to be 60% of the bottle's volume, which is equivalent to 75 mL; thus, the remaining 40% for substrates, co-substrates, and inoculum would be equivalent to 50 mL. Purging was performed using a mixture of 80% nitrogen gas (N_2) and 20% carbon dioxide (CO_2; Edward et al., 2015).

The BMP bottles were stored for five weeks in the incubator with a temperature of 35°C, while the gas volume and concentration were measured on days 7, 14, 21, 28, and 35. An airflow meter (Keyence) measured gas volume, while a gas chromatograph measured gas concentration (Bruker 400-GC Series #1). During the experiment, the BMP bottles were manually shaken every one to two days to ensure the sample in the bottle was well mixed. The final methane production was obtained from the triplicate samples by substracting the methane production due to the inoculum, as derived from the blank samples. The theoritical methane yield was calculated based on VS (Silvestre et al., 2015) and compared with the real methane yield after five weeks of the experiment.

To complete the data, several physical and chemical parameters were measured at the beginning and at the end of the BMP experiment (TS and VS using the gravimetry method, COD and C/N using the spectrophotometric method, and VFA and alkalinity using the titrimetric method).

(a) (b) (c)

Figure 1 Resulting substrate after chopping and sieving: (a) 10-13 mm; (b) 4.76-10 mm; and (c) 2-4.76 mm

3. RESULTS AND DISCUSSION

3.1. Results

Characterization was performed separately for the substrate, co-substrate, and inoculum. The TS, VS, and C/N values are shown in Table 1.

Table 1 Parameter of single substrates used in the BMP assay

No.	Subject	TS (%)	VS/TS (%)	C/N
1	Range of 10-13 mm	16.03	90.04	16.2
2	Range of 4.76-10 mm	22.94	89.94	12.5
3	Range of 2-4.76 mm	22.32	100.00	14.7
4	Cow dung	19.02	62.03	14.4
5	Inoculum	2.19	57.97	-

The prepared sample mixtures of OFMSW, cow dung, and inoculum were again characterized in triplicate at the beginning and at the end of the BMP assay. The results of the comparison parameters are shown in Table 2. Furthermore, the value of TS, VS, and COD are measured at the beginning and at the end of BMP assay.

Table 2 Parameter of substrate mixtures for each BMP assay

No.	Mixed Sample Range	C/N	Initial TS (%)	Final TS (%)	Initial VS (%)	Final VS (%)	Initial COD (mg/L)	Final COD (mg/L)
1	10-13 mm	1.18	1.39 ± 0.01	1.19 ± 0.16	59.86 ± 1.20	49.78 ± 10.13	20,540	4,723
2	4.76-10 mm	0.54	1.46 ± 0.02	1.11 ± 0.11	67.32 ± 5.31	50.01 ± 16.57	12,064	5,417
3	2-4.76 mm	2.33	1.34 ± 0.18	1.14 ± 0.03	73.47 ± 15.99	50.03 ± 7.04	73,320	3,623

After five weeks, the BMP assays were analyzed to compare the cumulative CH_4 and CO_2 production with the weekly CH_4 production, as shown in Figure 2.

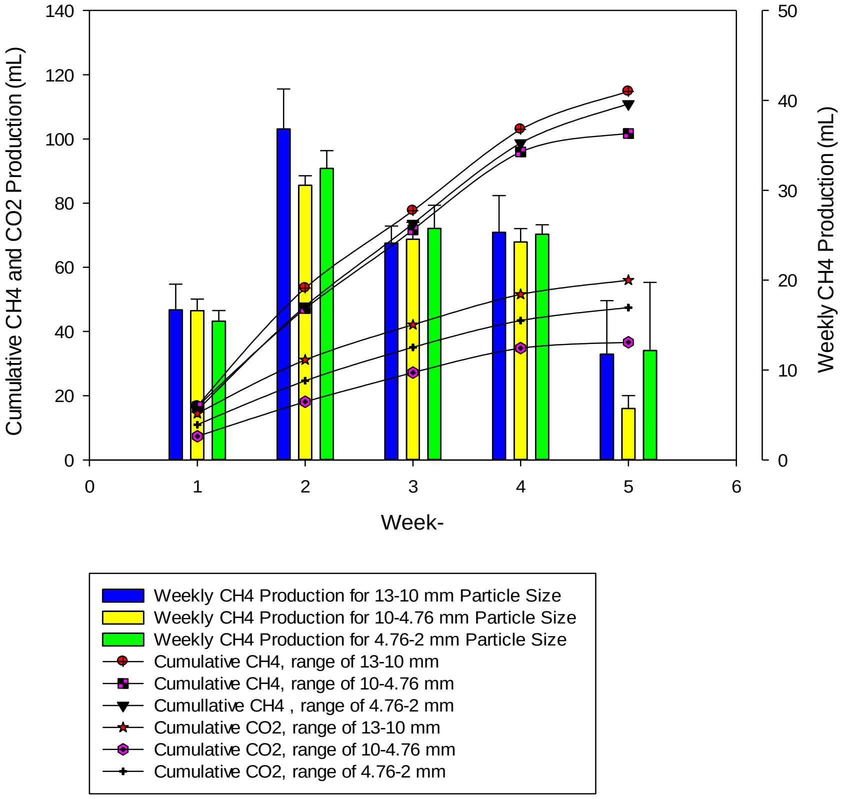

Figure 2 Comparison chart for the cumulative volume of CH_4 and CO_2 with weekly CH_4 production

The percentage of CH_4 gas between the theoretical yield and the real yield is demonstrated in Table 3 to observe the level of substrate degradation achieved at the end of five weeks.

Table 3 Theoretical and real methane yield

No.	Sample	Methane Yield		
		Theoretical ($L CH_4$/grVS)	Real ($L CH_4$/grVS)	Percentage
1	Range of 10-13 mm	0.977	0.277	28%
2	Range of 4.76-10 mm	0.486	0.208	43%
3	Range of 2-4.76 mm	2.983	0.229	8%

Furthermore, process indicators, such as VFA, alkalinity, and pH, were measured, as shown in Table 4.

Table 4 Sample VFA, alkalinity, and pH

No.	Particles Size	VFA (mg/L)	Alkalinity (mg/L $CaCO_3$)	VFA/Alkalinity	pH
1	Range of 10-13 mm	19.25	5,807	0.0033	6.87
2	Range of 4.76-10 mm	65.25	6,017	0.0108	7.40
3	Range of 2-4.76 mm	118.10	5,890	0.0201	7.00

3.2. Discussion

Based on the literature, the TS values of OFMSW are generally between 7.94–22.1% (Wang et al., 2014), which is similar to the TS measured in this study (Table 1). Cow dung measured in this study had a TS value of 19.0%, comparable to previously reported values between 15–19%

(Salam et al., 2015). The mixture's C/N ratio was approximately 12−16, somehow lower than the optimum ratio, which ranges between 20−30 (Metcalf & Eddy, 2004). Overall, the chopping and sieving process demonstrates an impact on the initial characteristics of OFMSW, producing higher TS and VS for smaller particle sizes. Pre-treatment has also been shown to affect COD, demonstrating a significantly high value of initial COD in waste samples with a size range of 2−4.76 mm. While preprocessing should not change the COD value (Government of Canada, 2013), this effect may be due to the sieving process, which was performed after the chopping process.

Of the three samples, the smallest size range of 2−4.76 mm seemed to demonstrate the highest VS and COD reduction (Table 2). This finding is in line with other studies that have shown chopping can increase COD reduction by increasing contact between the substrate and microorganisms (Esposito et al., 2012). However, this difference in VS and COD reduction does not seem to have an impact on methane production (Figure 2). The OFMSW with particle sizes of 10-13 mm, 4.76-10 mm, and 2-4.76 mm produces CH_4 gas with an average of 114.7$\pm$14.7 mL, 101.7$\pm$0.5 mL, and 110.9$\pm$10.8 mL, respectively (Figure 2), while methane yield was 0.277 L CH_4/g VS, 0.208 L CH_4/g VS, and 0.229 L CH_4/g VS, respectively (Table 3). Compared with the literature, the CH_4 gas potential in this experiment is higher than the capable potential range for CH_4 gas produced from organic wastes, which is generally between 0.11−0.16 L of CH_4/gr VS (Gunaseelan, 1997).

With a confidence level of 95%, there is not a significant difference in methane production between one particle-size range and the others. However, the methane yield of the 2−4.76 mm range is only 8% of the theoritical methane yield based on VS values. This indicates that, although VS reduction is the highest in the smaller particle-size range, the process does not necessarily lead to methanogenesis. The results displayed in Table 4 further demonstrate this, where particle size seems to impact Volatile Fatty Acid (VFA) production. With a confidence level of 95%, the smallest particle-size range produced the highest VFA. The largest particle size, which is a range of 10−13 mm, produced as much VFA as 19.25 mg/L, while the smallest particles in the range of 2−4.76 mm produced as much VFA as 118.1 mg/L, approximately six times higher than the particle-size range of 10−13 mm. This indicates that different particle sizes between 2−13 mm would not have a significant influence on methane production; however, it has an influence more specifically on the hydrolysis and acidogenesis phases. The smaller particle size would promote a higher hydrolisis rate. However, the methanogenesis rate would limit methane production, thus accumulating VFA in the AD of OFMSW. Based on this study's results, the 10−13 mm particle size has the potential for further study. This particle size is chosen because there is no significant difference in the biogas production between the different particle sizes, and larger sizes would require less chopping energy.

This experiment's VFA values are in the range of 19−118 mg/L. Based on the literature, the value of a good VFA should be below 100 mg/L (Silvestre et al., 2015). This high VFA would indicate inhibitor potential in the decomposition process (Bouallagui et al., 2009). A VFA amount that is too high will cause the pH to decrease, resulting in the reduction of methane gas formation. However, with a good buffer system, the VFA will not significantly alter the samples' pH. In Table 4, the sample's alkalinity value has a similar range of 5,800-6,000 mg/L. In general, the alkalinity value should be in the range of 1,300−7,000 mg/L (Bouallagui et al., 2009). The sample's ratio of VFA and alkalinity is in the range of 0.003−0.02, which is relatively small compared to the maximum VFA/alkalinity being generally less than 1.0 (Lohri, 2008). Therefore, although VFA is relatively high, the process remains stable due to the sufficient alkalinity. An adequate co-substrate, such as the cow manure used in this study, can maintain the high alkalinity. However, the VFA increase must be further studied in a pilot-scale reactor to observe the long-term impact of VFA accumulation.

Beside VFA accumulation, biogas and renewable energy potential must also be further investigated. Biogas from AD can be a benefit to the waste treatment facility and its surroundings. If the waste that is available from the Waste4Change treatment facility used in this study is considered, there is potential to generate up to 3 m^3/day of OFMSW. There are 287 kg VS/day of OFMSW that can be converted into CH_4 gas. Based on the results of the potential formation of CH_4 gas particles of 10–13 mm of 0.277 L CH_4/gr VS, the total CH_4 gas generated per day would be 80 Nm^3 CH_4/day with an energy equivalent of 31.3 Kilowatts. This potential should be harnessed in waste treatment sites to increase the value of municipal solid waste management in Indonesia.

4. CONCLUSION

Based on the results of the BMP assay conducted over 35 days, it can be concluded that particle size has no significant influence on the process of CH_4 gas formation, where methane yield was 0.277 L CH_4/g VS, 0.208 L CH_4/g VS, and 0.229 L CH_4/g VS, respectively. However, significant difference is observed on the process of hydrolysis and acidogenesis, which is seen from the significant difference of VFA. Looking at the volume of CH_4 gas generated and the CH_4 gas potential that can be created from VS, there is no optimum particle size in the formation of CH_4 gas. However, considering the cost and energy needed for chopping, the particle range of 10–13 mm should be adopted.

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