Biogas production from modification of food waste anaerobic digestion process

Chantika Fathia Khairunnisa[1], *IDAA* Warmadewanthi[1*], and *Dang* Vu Bich Hanh[2]

[1]Department of Environmental Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

[2]Department of Environmental Engineering, Faculty of Environment and Resources, Ho Chi Minh city University of Technology, Ho Chi Minh City, Vietnam

Abstract. Food waste is Indonesia's largest solid waste composition, and most of it is disposed of directly into landfills. Food waste is a suitable substrate for anaerobic digestion. This study was conducted to examine the effect of adding mixed cultures of methanogen bacteria (MCB) on food waste anaerobic digestion. Variables used in this study were the percentage of MCB added and its addition frequency. The quantity of MCB added is calculated based on the percentage of MCB to the solid waste weight, which is 10%, 30%, and 50%. The frequency of MCB added is every 10 and 15 days. The addition was carried out starting on day 0. Results of this study showed that the variation of 50% MCB added every 15 days had the highest biogas cumulative production, up to 201.5 liters. The result showed that the anaerobic process was under mesophilic conditions, varying from 28-30°C. Moisture content was increased with the addition of MCB. Temperature, pH, moisture content, and C/N ratio testing were also examined at the end of the study to determine the result product quality. It was shown that moisture content and C/N value were still high, which explains that the anaerobic degradation has not been done yet.

1 Introduction

The increase of population growth has resulted in the increasing of solid waste generation. World Bank sources mentioned that the increase of solid waste is even greater than the increase in population [1]. In many developing countries, food waste management practices are often inadequate, with a significant portion of the waste ending up in landfills or open dumpsites [2]. This leads to the loss of valuable resources and contributes to greenhouse gas emissions, groundwater contamination, and the spread of diseases [3].

According to a study report by [4], as much as 44% of Indonesia's total solid waste generation is food waste. The Food Sustainability Index 2021 study results stated that Indonesia produces 121 kg/capita/year of food waste. Around 63% of the food waste comes from household waste. According to [3], more than 40% of food waste in developing countries is generated at the retail and consumer stages. This type of food waste is more difficult to recycle due to the high variety and contamination.

* Corresponding author: warma@its.ac.id

With its high organic content and energy potential, food waste is a suitable substrate for anaerobic digestion (AD) [5]. Compared to other solid waste treatment methods, such as composting, incineration, and black soldier fly technologies, AD offers several advantages, including energy generation, nutrient recovery, and reduced environmental impact [3], [5], [6]. An increasing number of countries have implemented AD as a treatment option for food waste, including China and several Southeast Asian countries [7].

AD is a biological process that involves the processing and stabilization of organic materials without the presence of oxygen carried out by a consortium of microorganisms [8]. This oxygen-free condition allows microorganisms to degrade organic matter, producing stable sludge (digestate) and biogas [9]. Several factors that affect the AD process include pH, temperature, particle size, C/N ratio, and total solids. pH indicates the stability of the AD process. Some studies have shown that the pH range of 6.5 – 8.5 is suitable for the AD process [10]. According to research by [11], the degradation of food waste has a higher temperature due to the higher moisture content, so bacterial activity increases. Most AD studies choose mesophilic processes (~35◦C) because degradation can run more steadily [12]. According to [13], the smaller the particle size, the better the biogas production. This is because methanogenic bacteria have a wider contact with the degradable organic material of the substrate. The initial concentration of the substrate in the anaerobic process also has an important role in the decomposition of waste and the formation of methane gas [14].

The efficiency of AD can be significantly influenced by the microbial community present, particularly by introducing mixed cultures containing methanogenic bacteria. These communities enhance the degradation process by facilitating a more effective conversion of volatile fatty acids into methane, thus optimizing biogas production [9]. Based on previous field observations, several landfills in Indonesia have begun to use methanogenic bacteria from industrial wastewater treatment of dairy factories to accelerate the anaerobic decomposition of waste. This can certainly extend the service life of the landfill, considering that the land used for the landfill is also increasingly limited. Various studies have developed on using microbes to increase waste decomposition and biogas production.

Therefore, further studies are needed on the effect of the addition of mixed culture bacteria (MCB) of methanogens on the decomposition of food waste through the AD process. The quality of products, the quantity of biogas, and process parameters are assessed in this study. Variables used in this study were the percentage of MCB added and its addition frequency. The quantity of MCB added is calculated based on the percentage of MCB to the solid waste weight, which is 10%, 30%, and 50%. The frequency of MCB added is every 10 and 15 days. The results of this study can be useful for further application of MCB to accelerate the waste degradation process in landfills as well as potential sources of biogas.

2 Material and Methods

2.1 Sampling Location

The food waste samples were obtained from two distinct sources in Surabaya: restaurants and traditional markets. The waste samples in this study were categorized into four types to reflect the typical compositions of food waste and food loss in Indonesia: carbohydrates, proteins, vegetables, and fruits. Carbohydrate and proteins were gathered from restaurants, while vegetables and fruits were collected from traditional market. The proportions of each composition are presented in Table 1.

Table 1. Food waste composition.

Composition	Percentage (%)
Vegetables	75
Proteins	1106
Carbohydrates	10
Fruits	5

2.2 Sampling method

Food waste sampling began by providing plastic bags to each restaurant selected near the Institut Teknologi Sepuluh Nopember (ITS) campus area. Every plastic bag was picked up the following day. Scraps from the wet market were gathered directly from the traditional market. Both samples were then moved to a shredding facility for size reduction. Particle size considerably impacts the AD process, particularly in the hydrolysis step. Smaller particle sizes enhance microbial access to nutrients, facilitating more efficient degradation and biogas production [15]. Food waste was mechanically shredded to a 5 mm particle size in accordance with the method adopted by [16]. After being shredded, the sample was blended to obtain a homogenous sample and weighed for each reactor.

2.3 Initial characteristics

The initial characteristics of food waste as substrate and MCB as inoculum were tested, as presented in Table 2 and Table 3. The initial characteristics enabled us to assess the transformations in substrate properties throughout the AD process.

Table 2. Initial characteristics of food waste.

Parameter	Samples						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Temperature (°C)	32	34,3	34,5	34,8	32,1	35,3	35,5
pH	4	5	5	4,5	4,5	5	4,5
Moisture content (%)	70,1	71,2	72,3	71,9	73,7	72,4	73,5
C/N	43,68	44,07	47,52	50,02	48,22	49,95	52,40

Table 3. Characteristics of MCB

Parameters	Measured value
TS (mg/L)	29,624
VS (mg/L)	17,336
Density (kg/m^3)	1,006.6
pH	7.5
Chemical Oxygen Demand (COD) (mg/L)	11,000
Biochemical Oxygen Demand (BOD) (mg/L)	5,880
C/N	11.85
Microorganisms abundance (CFU/mL)	210 x 10^8
Dominant genus	*Methanosaeta, propioniclava, brooklawnia*

2.4 Reactors and variables set up

Plastic reactors with dimensions 30 × 30 × 40 cm were utilized as laboratory-scale vessels to examine biogas production and the effectiveness of the waste degradation process. The reactors were integrated with a gas collection system and a leachate drainage system and designed as a fully enclosed anaerobic system.

Food waste from restaurants and traditional markets was mixed with the composition shown in Table 1 and added as much as 15 kg for each reactor. MCB was added on day 0, followed by every 10 or 15 days. The proportions of MCB added varied, with proportions of 10%, 30%, and 50% corresponding to the mass of solid waste in the reactor. MCB was injected through the port and thereafter mixed with the substrate inside the reactor. This study was carried out for 30 days of degradation.

The quantity of biogas produced, and its temperature and moisture content were measured daily. Biogas volume was measured by applying the water displacement method using a 1-Liter measuring cylinder. Temperature was measured using a thermometer, and moisture content using a moisture meter. In this research, 14 reactors were utilized, with each variation and control reactor duplicated. The reactor variation and experimental setup are detailed in Table 4.

Table 4. Experimental set up.

Reactor name	Percentage MCB added (%)	Frequency MCB added (days)
MW0	-	-
MW11	10%	10
MW31	30%	
MW51	50%	
MW15	10%	15
MW35	30%	
MW55	50%	

3 Results

3.1 Cumulative biogas production during anaerobic digestion process

The measurement of cumulative biogas production was carried out to determine the rate of gas production [17]. From Figure 1, it was shown that the biogas accumulation was increased with the increasing percentage and frequency of MCB added. The highest cumulative biogas production occurred in MW51, in which MCB was added 50% for every 10 days. The cumulative biogas production reached 198,3 liters for 30 days of degradation. At the same time, the lowest production occurred at MW0 or the control reactor with 30,8 liters of biogas. This concludes that the addition of MCB as much as 50% every 10 days could improve biogas production up to 6,43 times than its control.

Alongside the breakdown of organic materials that promote biogas production, there was a significant amount of biogas resulting from the MCB itself. The MCB as inoculum used in this study was obtained from wastewater treatment sludge in the dairy factory industry. Most of the dairy waste contains milk or milk products, resulting in a high concentration of protein, fats, and carbohydrates within the waste. The substantial presence of lipids, characterized by high-fat content, has the potential to significantly enhance the generation of biogas, as illustrated in Figure 1 [18].

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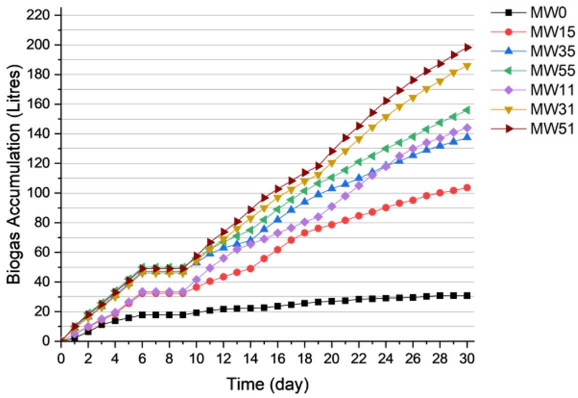
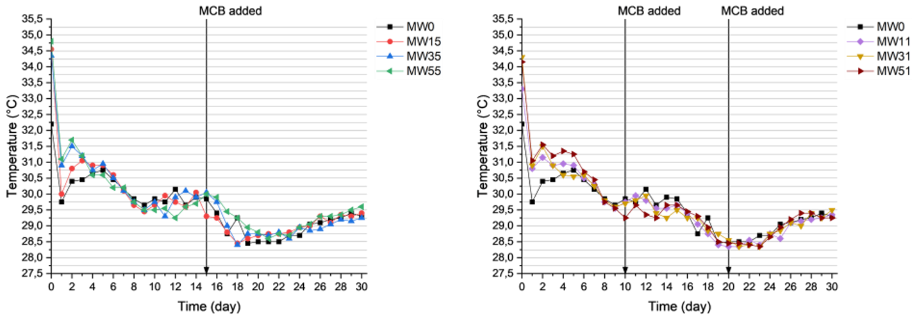


Fig. 1. Cumulative biogas production during AD process

3.2 Temperature during anaerobic digestion process

Temperature is a key factor that reflects microbial activity throughout the degradation process, while it also has a role in biogas production [11]. Temperature was measured every day for 30 days of study, shown in Figure 2. On the initial day, the temperature was around 32 – 35,5 °C for all variations. However, this condition did not last long; starting on day 1, the temperature decreased, fluctuating from 28 to 30 °C. The previous studies stated that for the first two weeks of anaerobic degradation, the temperature ranged around 28 – 28,9 °C [19]. This is in line with the temperature process in this study, which undergoes mesophilic conditions. Most anaerobic digesters work in mesophilic conditions (25 – 40°C) compared to thermophilic (>45°C). This is because, in mesophilic conditions, the AD process is more stable and less susceptible to the accumulation of volatile fatty acids (VFA), which can inhibit methanogenesis. Therefore, mesophilic conditions also generate more biogas than thermophilic [20]. One of the drawbacks of mesophilic is that its requires a longer start-up and degradation time [10].

Another study has indicated that the optimal temperature for biogas production is 35 °C [14]. As illustrated in Figure 2, that temperature never reached 35 °C, except in the initial days. The biogas production depicted in Fig 1 implies that even with the lack of optimal temperature conditions, the generation of biogas remained high, particularly in reactors with an increased addition of inoculum. The MCB as inoculum plays a crucial role in optimizing biogas production while also mitigating the accumulation of VFA. The MCB possesses an alkaline pH, which may influence the reactor performance. Even though it has been claimed that mesophilic conditions enhance biogas generation compared to thermophilic conditions, the inoculum plays an important factor in maximizing biogas output. Additionally, another study mentioned that temperature has less influence on substrate degradation during the AD process than moisture content [21].



(a) (b)

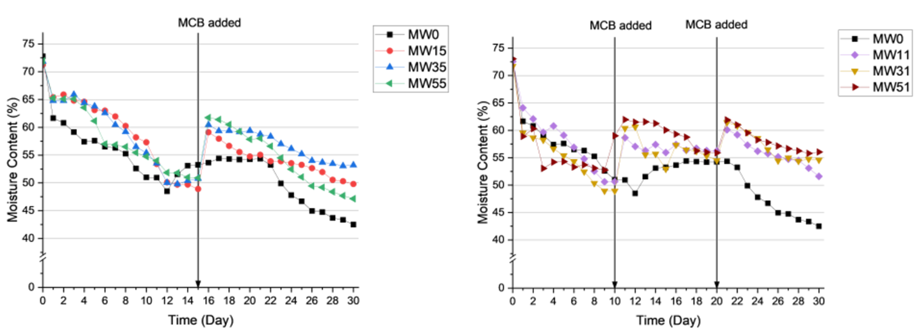
Fig. 2 Temperature during AD process from

(a) mixed waste with 10%, 30%, and 50% MCB added every 15 days
(b) mixed waste with 10%, 30%, and 50% MCB added every 10 days

3.3 Moisture content during anaerobic digestion process

The optimal moisture content for the waste degradation process is found within the range of 40 to 60%. Microorganisms engaged in various stages of waste degradation can easily break down organic materials when the moisture content is suitably regulated [21]. Moisture content measurements were carried out daily during the study, and the results are shown in Figure 3. Based on Figure 3, the initial moisture content of the waste is above 70%. This phenomenon can be explained by the fact that the substrate composition is sourced from traditional markets and restaurants. Market waste and food waste, identified by their significant moisture and organic materials content, are more favorable for biological processing rather than incineration or direct landfill disposal [22].

From Figure 3(a), the moisture content demonstrates an increasing trend after day 15. This is due to the addition of MCB in a slurry form. This finding is also supported by Figure 3(b), where the addition of MCB occurs on days 10 and 20. In the control reactor, the moisture content consistently remains lower than in others. In reactors where MCB is added at a frequency of once every 10 days (MW11, MW31, MW51), the moisture content generally shows an increase. The increasing quantity of mixed cultures of methanogenic bacteria added increased the moisture content in the waste.



(a) (b)

Fig. 3. Moisture content during AD process from

(a) mixed waste with 10%, 30%, and 50% MCB added every 15 days

(b) mixed waste with 10%, 30%, and 50% MCB added every 10 days

3.4 Final Characteristics of Substrate

At the end of the study, temperature, pH, moisture content, and carbon-to-nitrogen (C/N) ratio testing were carried out to assess the final quality of the product. These parameters were compared with the Indonesia national standard for mature compost as specified by SNI 19-7030-2004. The comparative analysis of the product is presented in Table 5.

The results presented in Table 5 demonstrate that the product's quality at the end of the study did not meet the national standard for compost criteria, particularly for moisture content and the C/N ratio parameter. The final quality assessment of the product following a 30-day AD indicates that this study primarily prioritizes biogas generation over the quality of the compost product. The high C/N ratio and the physical characteristics of the waste imply that the degradation process is currently ongoing.

Table 5. Final characteristics of substrate.

Parameter	National Standard	Measured value						
		MW0	MW15	MW35	MW55	MW11	MW31	MW51
Temperature (°C)	≤ 30°C	28.9	29.5	29.4	29.7	29.3	29.5	29.1
pH	6.8 – 7.49	5	7.5	7.5	7.5	7	7.5	7.5
Moisture content (%)	≤ 50%	42.5	53.3	59.6	49.1	53.2	57.8	53.8
C/N	10 – 20:1	53.01	37.6	44.67	35.05	36.06	37.74	35.64

4 Conclusion

Within 30 days degradation of waste, process parameters showed that the addition of inoculum resulted in enhanced cumulative biogas production. Anaerobic process was under mesophilic condition, while moisture content was increased with more addition of MCB. Temperature, pH, moisture content, and C/N ratio testing were also examined at the end of study to determine the result product quality. It was shown that moisture content and C/N ratio was still high, indicating that the degradation still occurs.

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