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Biogas Production from Various Vegetable Waste Using the Mesophilic Batch Process

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Abstract. *Vegetable waste is a significant component of both household and food industry waste. If not properly managed, the accumulation of this waste can harm the environment, primarily due to the unpleasant odor it generates. One effective way to utilize vegetable waste is through anaerobic digestion process. This method not only enhances the quality of waste but also has the added benefit of producing biogas, a form of renewable energy. Therefore, this research aimed to examine the potential of vegetable waste in producing biogas. Anaerobic digestion process was performed on three different types of vegetables, namely cabbage, kale, and long beans, with co-digestion as cow dung. This process was performed in mesophilic batch anaerobic reactor with a fermentation time of 30 days. The highest biogas yield for 30 days was obtained from long bean waste, 1853.76 ml biogas/g COD. Observations were made on waste at the beginning and end of the process to determine the value of removing chemical oxygen demand (COD). Reducing COD value was necessary to examine whether the quality of waste has improved and ready to be used in the environment. The results showed that long beans have the lowest COD removal efficiency value, 31.54%. Due to the high lignin content in these vegetables, there is a need for further research regarding the pretreatment of vegetable waste before anaerobic decomposition process begins. Meanwhile, the highest COD removal efficiency was achieved by kale vegetable waste at 45.35%.*
Keywords: *anaerobic; biogas; vegetable; waste; COD.*

Type of the Paper: Regular Article.

1. Introduction

As the population grows, the amount of food waste generated per individual is also expected to rise. The magnitude of household food waste is almost incalculable, considering that edible food may not simply be thrown away in the trash but served to pets, composted in the trash, or even thrown into the environment [1]. In recent years, food waste has become increasingly attractive to various parties from various scientific disciplines. This growing interest results from concerns over food security, environmental impacts, and greenhouse gas emissions [2]. One significant type of food waste is vegetable waste. As a major vegetable-producing country, Indonesia generates a substantial amount of produce annually. With the rise in production, there is also a growing potential for an increase in vegetable waste [3].

There are various ways in which vegetable waste can be processed, such as anaerobic

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digestion process. Subsequently, anaerobic digestion process is used to process organic materials using microorganisms in conditions without the presence of oxygen [4,5]. This method has two benefits, including improving the quality of waste by reducing the value of chemical oxygen demand (COD) and producing biogas, in the form of renewable energy. Organic material measured as COD can be converted into an intermediate product of Volatile Fatty Acid (VFA) by acidogenic microorganisms, which will then be converted back into methane gas by methanogenic microorganisms. This process also does not produce an unpleasant odor using closed equipment [6].

Biogas is a type of renewable energy produced through anaerobic digestion of organic materials. This process occurs when microorganisms break down organic matter, such as food waste, animal manure, and plant material, in the absence of oxygen. The main components of biogas include methane (CH_4) and carbon dioxide (CO_2), with trace amounts of other gases. Co-digestion is often used to increase biomass conversion [7]. Subsequently, cow dung is often used as the easiest co-digestion, containing microorganisms that can convert organic material into biogas [8]. Animal waste has been widely used as compost, but this method still releases a lot of gases into the atmosphere such as N_2O, NH_3, CO_2, and CH_4 [9]. Therefore, using cow dung in anaerobic digestion will help the environment.

The substrate in anaerobic digestion process usually uses organic waste and other biodegradable sources, as well as the help of bacterial starters, to speed up the process. Vegetable waste is organic, hence, it is suitable as a substrate in anaerobic process. The process required for waste is a process that can reduce pollutants in waste in order to avoid causing harm to the environment. Processing vegetable waste using anaerobic digestion process is easily implemented by various sectors in processing community waste independently. Using vegetable and fruit waste as a single substrate in anaerobic process is quite challenging because of the high sugar content which can cause the methanogenesis process to be hampered due to the accumulation of VFA [10,11]. The purposes of this research focus on biogas production produced per gram of COD and the quality of waste produced after anaerobic digestion process with a fermentation time of 30 days in terms of COD values and acidity (pH) levels.

2. Materials and Methods

This research was carried out at the Chemical Engineering Laboratory of Ahmad Dahlan University using the following tools and materials. The primary raw materials were cabbage, kale, and long bean vegetable waste. Vegetable waste was taken from several traditional markets in Yogyakarta, and all parts of the vegetable were used, including stems and leaves—cow dung with pH of 7.5 as a bacterial starter. The research equipment used is a series of anaerobic batch reactors with 700 ml and gasometers. The reactor and gasometer are made of transparent acrylic. The type of gasometer used is a height gasometer, using a saturated, acidified NaCl solution. This type of liquid is considered effective in maintaining the composition and volume of biogas produced [12].

Table 1. Characteristics of vegetable waste [13]

Amount per 100 grams	**Cabbage**	**Kale**	**Long Beans**
Water (g)	91.9	89.6	87.8
Carbohydrate (g)	6.38	4.42	8.35
Protein (g)	0.96	2.92	2.8
Lipid (g)	0.23	1.49	0.4
Sodium (mg)	16	53	4
Potassium (mg)	207	348	240
Iron (mg)	0.07	1.6	0.47
Magnesium (mg)	13.9	32.7	44
Selenium (µg)	0.3	-	1.5

First, reduce the size of vegetable waste using a blender in the sample preparation stage. Then, each vegetable waste was mixed with cow dung and air in the ratio shown in Table 1 and put into each reactor. The reactor was closed and connected to a gasometer. A leak test ensures that no air enters the reactor during fermentation. No pH adjustment was carried out at the beginning of the process. The observation lasted for 30 days by measuring biogas volume, COD levels, and degree of pH at the beginning and end of the process. The volume of biogas was measured and calculated using the gasometer height equation [12]. COD is a measure of the amount of oxygen required to chemically oxidize organic matter in a sample. For solid substrates, COD is used to quantify the extent of organic pollution and the potential impact on wastewater treatment systems. COD levels were measured using Uv-Vis Spectrophotometry method, and the degree of pH was measured using pH meter method. This method uses the SNI 06-6989.11-2004 reference.

Table 2. Substrate composition

Reactor		**Vegetable waste (gr)**	**Digestive Co (ml)**	**Water (ml)**
Reactor 1	Cabbage	200	100	200
Reactor 2	Kale	200	100	200
Reactor 3	Long beans	200	100	200

3. Results and Discussion

The use of anaerobic digestion to process vegetable waste have several advantages, including reducing the levels of harmful substances in the environment, and producing biogas as a renewable energy source. The process of anaerobic decomposition by anaerobic microorganisms consists of several main stages, namely hydrolysis, acidogenesis, and methanogenesis. Out of the three main processes, the type that does not require special conditions is hydrolysis, when organic material breaks into simpler forms [14]. This research examined the quality of the final waste after mesophilic anaerobic digestion process for 30 days. Sample tests were carried out on liquid waste using UV-Vis spectrophotometry method to determine COD value contained in liquid samples of biogas waste. After testing COD levels in biogas liquid waste samples, the results are shown in Table 2 and Fig. 1. COD removal efficiency calculation Formula (1) used is as follows:

$$COD\ removal\ efficiency\ (\%) = \frac{COD_{influent} - COD_{effluent}}{COD_{influent}}\ x\ 100\% \quad (1)$$

Table 3. COD Test Results in Biogas Liquid Waste Using UV-Vis Spectrophotometry Method

Reactor		**COD level (mg/L)**
Reactor 1	Influent	24666.65
	Effluent	14111.10
Reactor 2	Influent	23277.80
	Effluent	12722.20
Reactor 3	Influent	29944.45
	Effluent	20500.00

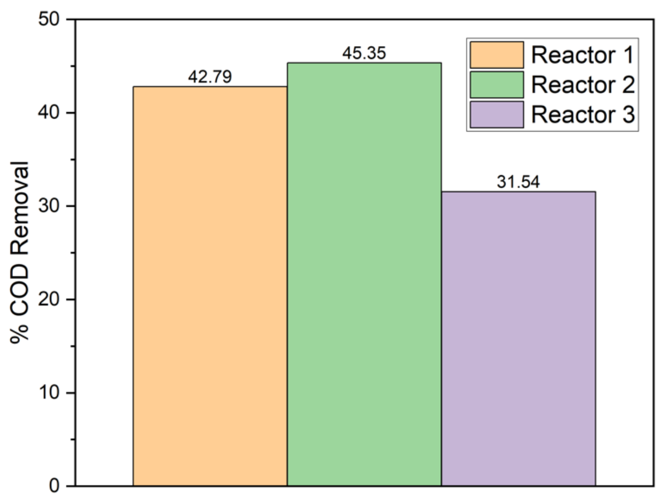

Fig. 1. COD value

Table 2 and Fig.1 show that COD levels on days 0 and 30 in each reactor decreased. The decrease in COD levels is caused by the natural decomposition of organic compounds in waste, hence, COD levels decrease during fermentation [15]. Based on Table 2, COD levels in each reactor are still far from the standard limits for wastewater quality. The maximum threshold considered safe based on LHK Regulation No. 68 of 2016 is 100 mg/L. COD levels far above the quality standard limit meaning the resulting biogas liquid waste must be processed further before being released into the environment to minimize pollution. Under optimal conditions, anaerobic process can reduce approximately 98% compared to the aerobic process with 88% COD removal efficiency [16]. After 30 days of observations, the highest COD removal was 45.35% in reactor 2, which shows that the fermentation time required to achieve COD removal above 90% is more than 30 days. Several investigations show the positive effect of increasing fermentation time on COD removal [17]. Anaerobic digestion process requires a long residence time to reach the desired COD standard, which can be 30-50 days [18]. The low COD removal may caused by the lignin and lignocellulose content in vegetable plants [19]. This content can protect microorganisms from entering and breaking down the organic content of the vegetable. Subsequently, long beans have the lowest COD removal value because they have the highest lignin content compared to cabbage and kale. Based on research, there are several ways to help lignin help anaerobic decomposition process, one of which is high-temperature oxidation for several minutes. This pretreatment positively influences anaerobic process afterward [20]. The pretreatment of waste using acid also positively affects anaerobic processes with influents containing lignin [21].

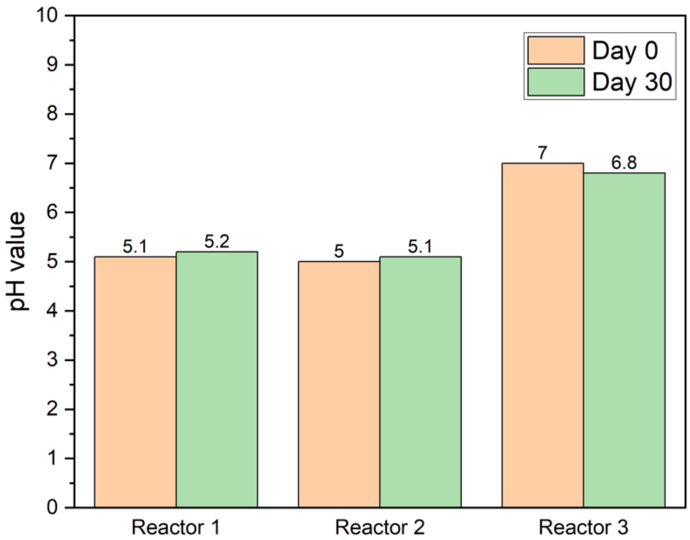

Fig. 2. pH value

pH level of samples taken on days 0 and 30 in reactors 1 and 2 did not experience much change. However, it remained in the acidic conditions shown in Fig. 2, while in reactor 3, the initial and final pH conditions were relative to pH neutral. When anaerobic reactor has an acidic pH, it is possible due to the accumulation of the results of the acidogenic process, namely VFA [22]. Several factors cause the accumulation of VFA, such as the presence of inhibitors and temperature changes [23]. Various toxic substances can be present in vegetable waste, including pesticides and herbicides. These chemicals can inhibit microbial growth and enzyme activity, disrupting the digestion process [24]. However, in this research, the same temperature was used in mesophilic state of 30 ± 2°C, the accumulation of VFA can be caused by a relatively high organic load and inhibitor. The acidic pH conditions at the beginning of the process also cause methanogenic microorganisms not to work correctly because this type of microorganism will work optimally in the neutral pH range, namely 6.8-7.4 [25]. As a result, the process of changing the substrate into biogas will be hampered, causing a decrease in the quantity of biogas [26]. In contrast to the acid levels in reactors 1 and 2, the results of the acid level test in reactor 3 (long beans) showed that the liquid sample at the beginning of the collection process had pH of 7 (neutral), meaning that pH condition of the substrate is at the ideal pH condition for biogas formation.

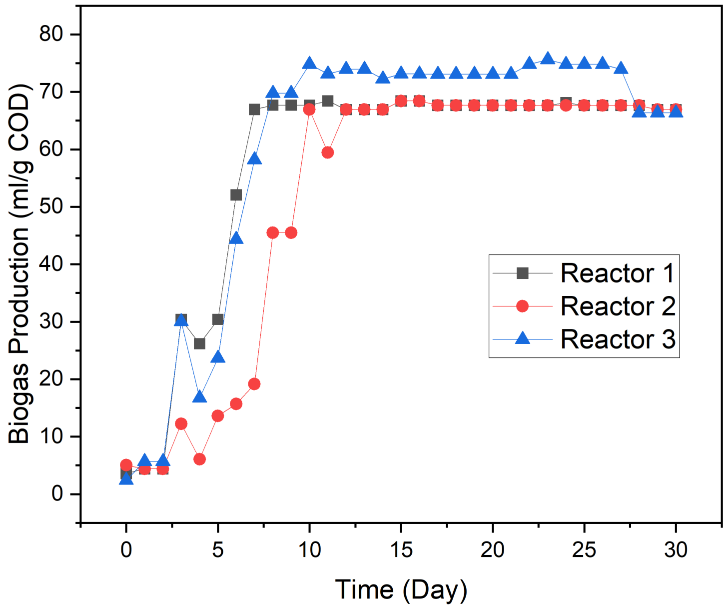

Fig. 3. Daily biogas production

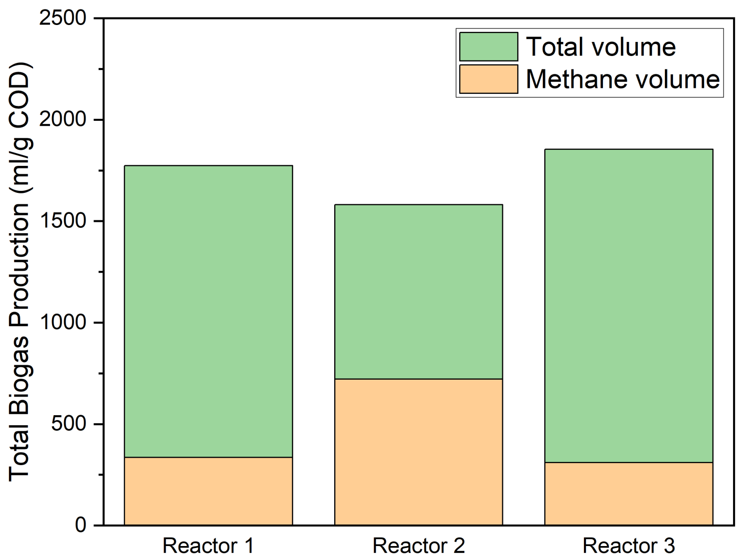

Fig. 4. Total biogas production.

Fig. 3 presents the volume of biogas produced per gram of COD for 30 days. This result calculates the volume produced each time divided by COD reduction each time. Until day 3-5, all reactors are still in the adjustment phase (lag phase), the time lag for microorganisms to adjust to new environmental conditions [27]. After the lag phase ends, microorganisms grow exponentially, as shown by a rapid increase in biogas. Reactor 3 with a long bean substrate produced more biogas than other substrates, total volume biogas production of 1853.762 ml/g COD with a methane gas content of 309.6305 ml/g COD (Fig. 4). This result can be compared with other previous research, biogas produced from a mixture of vegetable waste and organic municipal solid waste was 493.8 mg/g VS [28]. The presence of lignin content in vegetables has a negative correlation with the formation of biogas, thereby the use of substrates with low lignin content is preferred [29]. Although COD removal in reactor 3 was the lowest, the methanogenesis process in this reactor was the best because the neutral pH conditions supported methanogenic microorganisms to perform optimally. One strategy to optimize biogas production is to increase the ratio of starter bacteria (inoculum) and vegetable waste [30].

4. Conclusions

In conclusion, vegetable waste substrate does not meet the ideal biogas criteria, because the methane content was below 50%. Based on this research, the best biogas volume produced from long bean substrate was 1853.762 ml/g COD with a methane gas content of 309.6305 ml/g COD. This result is related to the ideal reactor conditions compared to the other two reactors for gas production, and neutral pH conditions. The test results showed that COD levels in biogas waste in anaerobic digestion process with a fermentation period of 30 days did not meet the quality standards for discharge into the environment. pH levels of influent reactors 1 and 2 were less suitable for the survival of gas-producing microorganisms because they were too acidic. Based on several literature reviews, the presence of lignin in vegetables inhibits anaerobic decomposition process, hence, pretreatment is needed. Although the results obtained have not met the minimum standards for methane content and COD limits, vegetable waste still has the potential to be a substrate for anaerobic processes with additional pretreatment to remove lignin and pesticide content that can inhibit the process. Adjusting pH value is also needed to maintain ideal reactor conditions for methanogenic microorganisms.

Data availability statement

Data will be shared upon request by the readers.

CRediT authorship contribution statement

Firda Mahira A C: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition. Annita Auliyasari: Investigation, Resources, Writing - Original Draft. Feren Nakita: Investigation, Resources, Writing - Original Draft. Farrah Fadhilah H: Formal analysis, Supervision. Nadiatika Amelia: Resources, Data Curation.

Declaration of Competing Interest

The authors of this manuscript declare no conflict of interest or competing interest.

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