Effects of pretreatments and different types of microbial starter on biogas production from food waste

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Abstract. The problem with the slow process of anaerobic biodegradation, especially in food waste, is that the rate of biogas production cannot keep up with market’s high demands for fuel. Several studies have tried out to optimize the rate of biogas formation, such as the addition of microbial starters and pretreatments. The objective of this research is to examine the production and characteristics of biogas made of vegetable market waste added by EM-4 and GP-7 microbial starter using a single batch biodigester system. The specific target is to determine the performance of biogas production process by combining the two techniques. The methods used consists of the design and manufacture of batch system biodigesters, determination of raw material characteristics, preparation of raw materials by pretreatment and addition of starters, namely EM-4 and GP-7. By combining the two techniques, biogas production with greater volumes and concentrations of methane gas can be obtained in a relatively short period. Pretreatment with NaOH 3% solution and the addition of cow dung starter and GP-7 can increase biogas production with the largest methane content on the 45th day and reached 38.32% of CH4 while pretreatment with NaOH with starter EM-4 and cow dung only reached 22.5%.

1. Introduction
Biogas energy is an alternative and renewable fuel that is environmentally friendly with the main component of methane gas (CH4). Biogas is an alternative energy source that has a great opportunity to be developed because it can be produced from anaerobic degradation processes of organic waste, such as: food waste, livestock waste, market waste, plantation waste, palm oil industrial waste and so on.

Biogas contains 60-70% methane gas and 30-40% carbon dioxide, as well as small amounts of other gases such as hydrogen (1-10%), nitrogen (± 3%), oxygen (± 3%), and hydrogen sulphide (± 5%). The gas content is highly dependent on the input material in the biodigester. While nitrogen and oxygen are not the result of the biogas formation process, this indicates the weakness of the system in which air can enter the biodigester. Hydrogen is the result of the acid formation stage, the formation of hydrogen sulphide by sulphate bacteria caused by the concentration of sulphur bonds. In biogas with 60-70% methane content and 30-40% carbon dioxide, normally contains caloric values between 20-26 J/cm3.

Based on Nicholls and Ferguson [1], Chen et a. [2], all organic material contained in plants, such as carbohydrates and cellulose, is one of the raw materials for biogas. Cellulose is normally easily digested by bacteria, but cellulose from some plant materials are slightly difficult to degrade when combined with lignin. Lignin is a complex molecule that has the rigid shape and woody structure of plants in which bacteria can hardly digest. In Table 1 below, there is a comparison of biogas production, methane content
and residence time of several materials derived from plants or from animal waste that can be used to produce biogas.

Table 1. Comparison of several types of biogas raw materials.

| Material                  | Biogas Production (L/Kg TS) | Methane Percentage (%) | Retention Time (Days) |
|---------------------------|-----------------------------|------------------------|-----------------------|
| Banana (Fruit and leaves) | 940                         | 53                     | 15                    |
| Cow Dung                  | 190 – 220                   | 68                     | 20                    |
| Organic Waste             | 380                         | 56                     | 25                    |

Source: [3]

From the data above, it can be seen that organic waste has a fairly good quality biogas (compared to fruit and animal dung). However, the obvious problem is that organic waste requires a very long residence time compared to other types of raw materials. Therefore, a special treatment (pretreatment) is needed on the raw material of organic waste before it is ready to be used as a biogas substrate.

Biogas production technology basically utilizes the digestion process carried out by methanogen bacteria whose products are in the form of methane gas (CH\(_4\)). The methane gas formed by bacterial digestion can reach up to 60% of the total biogas reactor gas, meanwhile the rest is dominated by CO\(_2\). These bacteria work in an anaerobic environment, so this process is also called anaerobic degradation. These methanogenic bacteria are naturally present in wastes that contain organic matter. The success of the digestion process depends on the survival of methanogenic bacteria in the biodigester, thus several conditions that support the proliferation of these bacteria in the biodigester need to be considered, such as temperature, acidity (pH), C/N ratio, and the amount of organic material [4,5].

In practice, the production process of biogas is not a process that can run fast naturally, at the same time as a supply of fuel, biogas needs are demanded to be able to meet high needs. Therefore, some research on optimizing the biogas production process began. Some actions in the biogas manufacturing process that have been carried out to date are, the addition of starter microbes and the provision of pretreatment on raw materials. Currently widely used and are accessible, the products are generally sold under market names such as EM-4 (Effective Microorganism-4) [6]. According to Hidayat [7], there are several methods of pretreatment that can be done such as chemical, physical, biological, or a combination of them.

So far, despite its proven performance, there have not been many studies that combine the two techniques above, namely the provision of microbial starters and initial treatment in the process of making biogas. Therefore, in this research, biogas production will be made with raw materials for market vegetable waste with the addition of a microbial starter and pretreatment, especially chemical and physical treatment. Based on Yulistiani et al. [5], the Biogas production which use 3% NaOH for pretreatment has a faster anaerobic fermentation time (5 days) than the one without any initial treatment (17 days). This also found by Mel et al. that without prior treatments, a slow hydrolysis might occur and biogas production could become low with a long retention time required to produce sufficient amount of biogas [8].

This treatment process is aimed to decompose nitrogen element by adding EM-4 starter bacteria. EM-4 is a brownish-coloured and fresh sweet-scented liquid which contains a mixture of several living microorganisms that are beneficial for the absorption/supply of nutrients in the soil. The good microorganisms consist of photosynthetic bacteria, lactic acid bacteria, yeast, actinomycetes, and fermenting fungi. The EM-4 is an inoculant of microorganisms consisting of 90% Lactobacillus Sp. This bacterium can produce lactic acid so that it can accelerate the overhaul of organic material such as lignin/cellulose which helps the saccharomyces cerevisiae bacteria produce more gas [9]. The lignin / cellulose compound is a compound that is contained in many plants including vegetables, hence the use of EM-4 is one of the right choices to be used as a starter.
Alkalinity is an indicator of buffer capacity in fermenters as well as the content of bicarbonate, carbonate, ammonia and hydroxide. Organic acids and salts also contribute to buffering capacity. According to Gamawati et al. [6] and Brigita et al. [10], the amount of bicarbonate alkalinity for anaerobic waste treatment is in the range of 2.5-5.0 grams CaCO3 / L (25-50 mM) [2,6] the concentration of volatile organic acids is 2.0 g acetate / L (33mM) is an efficient concentration for anaerobic fermentation, where above that concentration will cause poisoning.

2. Research methods
The purpose of pretreatment technology is to reduce or eliminate various compounds which can inhibit the hydrolysis rate. The pretreatment methods include physical, chemical, physical-chemical, and biological treatments [7]. This research is a laboratory-scale experiment which consists of several steps. Detailed research stages are shown in the schematic diagram in figure 1

The first step begins with the related literature study as a reference or knowledge base of the research to be conducted. The second step is to design two of 18 Liters laboratory-scale batch type biodigester, which is equipped with biogas volume, temperature, and sampling facilities. Digester is designed to get the right approach and ensure research to get valid and optimum results. Next is the preparation of raw materials, the raw materials used are market vegetable waste (round cabbage, mustard greens, cauliflower) in a ratio of 1: 1: 1. The raw materials then undergo pretreatment which is consists of physical pretreatment by chopping vegetable waste and followed by chemical pretreatment step (soaking using 3% NaOH solution for 2 days).

After pretreatment, the raw material then rinsed with water (add acid when needed) until neutral, then added water with ratio of 1: 1. Furthermore, the two digesters are used to collect vegetable waste and mixed with a different type of starter for each digester. Biodigester 1 is added by mixture of EM-4 and cow dung starter and Biodigester 2 is added by mixture of GP-7 and cow dung. The GP-7 starter added was 1 gram per liter of total ingredients, while EM-4 and cow dung added was 9% and 10% of total volume consecutively. Finally, the biogas production is carried out through anaerobic degradation for about one and a half months under ambient conditions. The laboratory-scale batch type biodigester unit design is shown by the following figure 2.
2.1. Preparation and pretreatment of biogas raw material
The material used is vegetable waste that has been subjected to pretreatment for several days. Pretreatment of raw materials is done by chopping vegetable waste, then soaking the chopped waste in 3% NaOH solution for two days. After that, the waste is rinsed and neutralized using a dilute vinegar acid solution. The pretreated material then is mixed with a microbial starter (substrate). Ratio between the volume of filling substrate in the biodigester against the volume of biogas rooms formed is 80%:20%. As explained in theory, the optimal water content in the mixture is 80-90% of the total dry matter. So, for initial filling a ratio of about 1:1 between water and substrate had been chosen. During the biogas production process, biodigesters are stored in the POLBAN Energy Conversion Engineering Laboratory at room temperature and naturally degraded by microbes originating from the starter. The process of forming biogas until the methane gas occurs happen on the 3rd day. Ambient temperature and humidity are assumed to be the same throughout the day.

2.2. Testing of raw materials and biogas products
During the biogas production process, biodigesters are stored in the POLBAN Energy Conversion Engineering Laboratory at room temperature and naturally degraded by microbes originating from the starter. The process of forming biogas until the methane gas occurs happen on the 3rd day. Ambient temperature and humidity are assumed to be the same throughout the day.

3. Results and discussion

3.1. The physical-chemical characteristic of substrate for biogas production process
Vegetable waste used as raw material in this study came from Pasar Gede Bage, consisting of cabbage, cauliflower and mustard greens with a composition of 1:1:1. In addition to vegetable waste, cow manure additives are also used, as well as EM-4 and GP-7 (Green phosko-7) starters. The physic-chemical characteristics of the substrate based on laboratory test results of Solid Waste and B3 Department of Environmental Engineering ITB are shown in table 2.
Table 2. The physio-chemical characteristics of substrate and cow dung waste.

| No | Parameters          | Unit | Substrate | Cow Dung |
|----|---------------------|------|-----------|----------|
| 1  | Water Content       | % BB | 87.81     | 81.66    |
| 2  | Total solid (TS)    | % BB | 12.19     | 18.34    |
| 3  | Volatile solid (VS) | % BB | 10.27     | 14.01    |
| 4  | Ash Content         | % BB | 1.92      | 4.33     |
| 5  | VS/TS               | % BB | 84.24     | 76.22    |
| 6  | C-Organik           | % BK | 64.27     | 58.98    |
| 7  | Nitrogen total      | % BK | 3.34      | 1.70     |
| 8  | C/N ratio           | -    | 19.24     | 34.69    |

Source: Laboratory test results of Solid Waste and B3 Department of Environmental Engineering ITB, 2019.

*BB: gross weight; BK: dry weight.

In Table 2 it can be seen that the water content of raw materials both cow dung, and substrate (after pretreatment with 3% NaOH) reaches 80-90%. The VS/TS ratio of vegetable waste is greater than cow dung. C/N ratio of cow manure waste (34.69) approaches the standard C/N ratio of 20-30 Christensen, et.al., [11] and Chen, et.al. [2]. When compared with research data Pramanik et al, [12] and Deressa et al, [13], the ratio of VS/TS cow dung is almost the same around 70% while VS/TS substrate in this study is 76% which is smaller than the study Pramanik, [12] namely 93%.

3.2. Process Temperature and biogas volume

The biodigester temperature profile from test data during the degradation process is shown in Figure 3. From the test results it can be seen that the temperature in both biodigesters is higher than the ambient temperature. The difference in temperature between the environment with the biodigester containing cow dung starter and GP-7 is (1-2°C) higher than the difference between the ambient temperature and temperature of the biodigester containing cow dung starter and EM-4 (0.4°C). Biodigester temperature with cow dung starter and GP-7 reaches around 27-28°C, while the temperature in the biodigester with cow dung and EM-4 starter only reaches around 25.5-26.5°C.

Biogas volume test began on the 6th day with the amount of biogas volume in biodigester with cow dung starter & EM-4 (Biodigester 1) is 1360 ml, and on biodigester with cow dung starter & GP-7 (Biodigester 2) is 820 ml. Furthermore, the increase in biogas volume in measurements every week (7 days) is almost constant. Until the 45th day the volume of biogas in digester 1 reached 6800 ml, and in digester 2 it reached 10190 ml. From these data, it can be seen that the volume of biogas obtained from biodigester 2 with pretreatment using NaOH and a combination of cow dung starter & GP-7 produced the most biogas. Biogas temperature profile and the accumulated biogas volume test results on both biodigesters is shown in figure 3.

![Figure 3. Process temperature and biogas volume.](image-url)
3.3. Biogas composition

The biogas composition test is carried out using Gas Chromatography measurement instrumentation. From the test results on the 6th day until the 24th day, the data obtained as shown in Figure 5 for biodigester with cow dung starter and EM-4, and Figure 6 for biodigester with cow dung starter and GP-7. In biodigesters 1 and 2, EM-4 and GP-7 starters were added to the biodigester on the first day while cow dung starters were added on the 18th day.

![Biogas Composition in Biodigester 1](image1)

![Biogas Composition in Biodigester 2](image2)

**Figure 4.** Biogas composition of Biodigester 1 and 2.

From figure 4 it can be seen that the composition of biogas produced from vegetable waste with an EM-4 starter on day 5 produces a fairly large amount of H₂ gas reaching 41%, CO₂ reaching 7% and other gases namely O₂ and N₂ which are the rest of the air. Whereas in vegetable waste with GP-7 starter the formation of H₂ is smaller which only reaches 13.4%, CO₂ is higher reaching 9.5%, while the remaining N₂ and O₂ are still very high. Furthermore, CO₂ gradually increased, and H₂ on the 11th day began to run out while CH₄ began to appear on the 24th day.

The methane concentrations on the 24th day for biodigester 1 and 2 were 4.5% and 7.25%, while on the 45th day respectively they reached 22.5% and 38.32%. From these data it appears that the methane gas content is still increasing until the 45th day, it shows that the bacterial activity in the anaerobic degradation process of vegetable waste until the 45th day is still active. Whereas after the 31st day on the three biodigesters there is no oxygen (0%), it shows that the biodigester is already in anaerobic condition.

3.4. Methane Gas (CH₄) volume

Based on the methane gas composition data (in Section 4.4), biogas volume (Section 4.3) and material volatile solid (VS) levels, the amount of CH₄ gas in ml / kg VS is shown as shown in figure 5.

![Accumulation of CH₄ produced gas (ml/kg VS) during degradation](image3)

**Figure 5.** Accumulation of CH₄ produced gas (ml/kg VS) during degradation.
In figure 6, it can be seen that the amount of methane gas has increased with the degradation time, and until the 45th day it still looks a pretty good increase. At the time of degradation in the 45th day, the amount of methane reached 2084 ml/kg VS in biodigester 2 and 660 ml/kg VS in biodigester 1. When compared with reference to research results Pramanik et al. [12] and Deressa et al. [13] the amount of methane gas from vegetable food waste reaches 340 ml/g VS, so the methane gas yield in this study is still much smaller.

4. Conclusion
Pretreatment with 3% NaOH solution and the addition of cow dung starter and GP-7 can increase biogas production (the largest methane content on the 45th day produced in biodigester 2 (pretreatment with NaOH and cow dung starter and GP-7) reached 38.32% while biodigester 1 (pretreatment with NaOH with starter EM-4 and cow dung) reached 22.5%. The amount of methane production up to the 45th day degradation time, reached 2084 ml/kg VS in biodigester 2 and 660 ml/kg VS in biodigester 1. When compared with reference to research results Pramanik et al. [12] and Deressa et al. [13] the amount of methane gas from vegetable food waste reaches 340 ml/g VS, so the methane gas yield in this study is still much smaller. The degradation process with the addition of GP-7 starter and cow dung is better and can increase the amount of methane production compared to the addition of EM-4 starter and cow dung.

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