Analysis of vegetable waste degradation effectiveness for biogas feed in single batch reactor

C K Wachjoe*, T M Gantina and A S Kurniasetiawati
Department of Energy Conversion Engineering, Politeknik Negeri Bandung, Jl. Gegerkalong Hilir, Ciwaruga, Kec. Parongpong, Kab. Bandung Barat, Jawa Barat 40559, Indonesia
*ck_wachjoe@polban.ac.id

Abstract. An anaerobic ecosystem requires organic compounds and nutrients, such as nitrogen and phosphorus to produce biogas. The biogas production, in general, needs the C/N ratio of 25–30 for the proper development of a biological process. To reach the optimal C/N ratio, the importance of the balance between the nutrients in the anaerobic digestion process was assessed at laboratory scale. The first method stage used in this study is the utilization of EM-4 microbial starter and 3% of NaOH in the pretreatment process of vegetable waste feed which aim to increase the C/N ratio meanwhile maintain the protein content itself. The second stage is the addition of GP-7 microbial starter and cow dung waste mixture during the methanogens process which shows satisfying results. Regardless the retention time which takes less than two times longer than the process without vegetables waste, the methane gas amount produced in this study (47%) is comparable to the one produced from cow dung waste only (50%). In spite of that methane production still tends to increase after 45 days of processing time.

1. Introduction
Biogas is a gas produced from the fermentation process of organic materials by anaerobic bacteria (without air) and is flammable. The main content of biogas is methane (CH4) and carbon dioxide (CO2). Methane gas is produced by spoilage bacteria by breaking down organic materials such as vegetable waste, food waste, animal waste and others. There are at least ten types of spoilage bacteria from methanogens bacteria that play a role in the decomposition of organic matter [1]. These bacteria are usually found in swamps, river mud, hot springs, and stomachs of herbivorous animals such as cows, buffaloes and sheep. An anaerobic ecosystem requires organic compounds and nutrients (such as nitrogen and phosphorus), as well as other micronutrients such as sulphur, calcium, magnesium, potassium, iron, zinc, copper, cobalt, molybdate and selenium. In general, methane requires organic matter such as vitamin B, fatty acids and a few amino acids for growth. Based on study of Gil et al. [2], the ideal chemical composition of the substrate for its bio-methanization, particularly, are the proportions between organic matter, expressed in COD or carbon, and nitrogen. Furthermore, the carbon-to-nitrogen (C/N) ratio of 25–30 is generally considered the most appropriate ratio for the proper development of a biological process [2]. The optimal ratio of organic, nitrogen and phosphorus composition is 100: 0.44: 0.08, but it is not flat for nitrogen and phosphorus. Some environmental factors that influence the process of degradation and methane gas production during the process of methanogenesis are oxygen, water (humidity), sulphate, pH, alkalinity, volatile acids, temperature,
nutrients and inhibitors [3]. The absence of free oxygen is a requirement for the growth of anaerobic bacteria, and methanogenic bacteria are very sensitive to oxygen.

In the anaerobic degradation of organic minerals food waste will produce methane gas which is the result of decomposition of organic waste by methanogenic bacteria [4]. Water is a compound that is needed in the process of degradation of organic waste. In the process organic waste compounds will react with water to form CO2, volatile fatty acids and hydrogen. Experiments Tanimu et al. [5] and Deressa et al. [6] showed an increase in the rate of biogas production which increased exponentially in the wastewater content between 25-60%. The effect of adding water in addition to limiting oxygen transport, can also facilitate the exchange of substrates, nutrients, buffers, dissolving inhibitors and spreading microorganisms around the waste environment [7].

Sulphate reducing bacteria and methanogenic bacteria are able to convert acetic acid and hydrogen into methane. Some experiments have shown that the presence of sulphate could reduce the methane produced. Methanogenic and acetogenic bacteria are sensitive to pH, where pH (the acidity) is a function of the bicarbonate alkalinity system, the partial pressure of CO2 and volatile acids. A good methane production process occurs in the pH range of 6.6-7.6 with optimum pH of 7.0 and 7.2. The pH below 6.2 will cause poisoning as high pH will cause a problem that is the formation of ammonia [1,8-10].

Ecosystem where the methane is formed is highly influenced by the presence of inhibitors. Ammonia inhibition is one most important thing in the fermentation process. The inhibitor will affect the amount of oxygen, hydrogen, sulphate and proton activity. Inhibitors could significantly affect the concentration of substrate, carbohydrate, salt ions, sulphides, heavy metals and specific organic components. Inhibitors also affect volatile fatty acids and methane gas production [7,11]. Green Phosko-7 (GP-7) is one type of microbial starter which is consist of superior organic materials (municipal waste, agriculture, livestock, and others). Anaerobic bacteria in GP-7 live saprophytically and breathe anaerobically which this activity is then utilized in the process of making biogas. The bacterial from GP-7 could possibly takes 5 to 20 days to produce methane, they will breed and break down organic compounds to produce CH4, H2S, H2, and CO2 gases [12].

The main raw material which will be used as the feed in substrate in this study are come from the traditional market organic waste. As mentioned by Brigita et al., the waste generation rate in Bandung per person is 0,23 – 2 litres/ day. With a composition of 73% organic waste in it, this makes it a very potential source of substrate raw material for anaerobic Biodigester [13]. The organic waste characteristic comparison between the cow dung waste, vegetable food waste and vegetable waste consist of cauliflower, round cabbage, and green mustard is shown by table 1.

Table 1. Characteristic comparison between vegetable food waste, cow dung waste, and vegetable waste.

| Source                  | Carbohydrates (%) | Protein (%) | Lipid (%) |
|-------------------------|-------------------|-------------|-----------|
| Vegetable Food Waste*   | 53.00             | 5.00        | 14.00     |
| Cow Dung**              | n.a               | 0.73        | n.a       |
| Vegetable Waste***      | Composition in (gram/ 100 gram) |           |           |
| Cauli Flower            | 5                 | 1.9         | 0.3       |
| Round Cabbage           | 5.8               | 1.28        | 0.1       |
| Green Mustard           | 4.51              | 2.58        | 0.47      |

* [14], ** [6], ***[15]

This paper will discuss the effect of pretreatment on vegetable waste material by reducing nitrogen elements so as to produce substrate’s quality that are equivalent to cow dung waste. In order to accelerate the process of methane production, the GP-7 microbial starter will be used in addition to the pre-treated substrate of market organic waste. The results of this study will be a comparison of methane product
volume and the retention time which come from the feed of pre-treated substrate and the feed of cow dung waste.

2. Research methods
This research is a laboratory-scale experiment which uses a batch type biodigesters with a volume of 18 liters (equipped with biogas volume, temperature, and biogas sampling facilities). The raw materials used in this study are vegetable wastes which come from Pasar Gede Bage. This vegetable waste consists of round cabbage, cauliflower and mustard greens with a composition of 1:1:1. The method of this study is made of two stages which then divided again into several steps as shown in Figure 1. The initial stage of the study begins with a literature study that aims to study the references relating to this research as a reference. The main stage shows that the biogas production process is carried out in two main steps.

![Figure 1. Research method diagram.](image1)

The ratio between water and the dry matter of the feeding substrate is very important in the preparation of Biogas feed. To decide the amount of substrate to be feed into the Biodigester, the volume ratio between substrate and biogas formed has to be decided first. The ratio between the volume of filling substrate in the biodigester against the volume of biogas rooms formed is decided to be 80%:20%. The volume of the substrate found to be 14.4 Liter which consists of 7.2 Liter of vegetable waste and cow dung waste mixture and 7.2 Liter of water. The schematic of the biodigester unit device is shown in figure 2.

![Figure 2. Schema set of biodigesters.](image2)
Before starting the first steps, the raw material has to go through a pretreatment process. The preparation of raw materials is carried out by chopping vegetable waste, then pretreatment is carried out by immersion using 3% NaOH solution and 9% EM4 (by total weight) for two days. The pretreated raw material is then washed with water to neutral then added by cow dung waste, water, and 14 grams of GP-7. The physical-chemical characteristic of this substrate will be compared to other substrate, which does not use any addition of microbial starter in its pretreatment method. The raw materials which only uses 3% NaOH on its pretreatment will be named Substrate-1 and the one with the addition of EM4 will be named Substrate-2.

Finally, the biogas production is carried out through anaerobic degradation for about one and a half months under an ambient condition. 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 microbial starter. Ambient temperature and humidity are assumed to be the same throughout the day.

Testing the characteristics of raw materials before and after the pretreatment which includes pH, water content, volatile solids, organic carbon and nitrogen content, is carried out in the solid waste laboratory at the Department of Environmental Engineering - ITB. Furthermore, during the biogas production process, measurements are carried out on parameters such as temperature, pH and biogas volume every two to three days. In addition, biogas composition (CH₄, CO₂, H₂, O₂ and N₂) was conducted every once a week. Biogas composition testing is carried out using a Gas Chromatography instrument at the Chemical Engineering Department of ITB.

3. Results and discussion

3.1. The physical-chemical characteristic of substrate for biogas production process

Physical-chemical characteristics based on test results in the Solid Waste Laboratory of the Department of Environmental Engineering ITB are shown in table 2.

Table 2. The Physical-chemical Characteristic Analysis Result of Substrate-1 and Substrate-2.

| No | Parameters       | Unit | Cow Dung Waste | Substrate-1 | Substrate-2 |
|----|------------------|------|----------------|-------------|-------------|
| 1  | Water content    | % BB | 81,66          | 90,76       | 88,94       |
| 2  | Total solid (TS) | % BB | 18,34          | 9,24        | 11,06       |
| 3  | Volatile solid (VS) | % BB | 14,01          | 7,03        | 8,43        |
| 4  | Ash content      | % BB | 4,33           | 2,21        | 2,63        |
| 5  | VS/TS            | % BB | 76,22          | 76,08       | 76,22       |
| 6  | C-Organic        | % BK | 58,98          | 73,28       | 70,42       |
| 7  | Total nitrogen   | % BK | 1,70           | 1,66        | 1,67        |
| 8  | C/N ratio        | -    | 34,69          | 44,14       | 42,17       |

BB : gross weight ; BK : dry weight

Table 2 shows that the water content of Substrate-1 and Substrate-2 is higher than of cow dung waste. The VS / TS ratio of Substrate-2 is the same as the VS / TS in cow dung, which is 76%, whereas VS / TS of Substrate-1, 87%, is greater than cow dung. When compared with research data Pramanik et al. [14] and Gantina et al. [6], the ratio of VS / TS cow dung is almost the same around 70% while VS / TS vegetable waste in this study is 76-87% which is smaller than the study Pramanik et al. [14] that is 93%. The C / N ratio of Substrate-2 is 44, which has increased compared to Substrate-1 which is 17.5 and approaches the C/N ratio of cow dung (34.5) and the standard of C/N ratio. The standard of C/N ratio according to Kjeldsen et al. [7] and Chen et al. [8] is in the range of 20 -30. Thus, the pretreatment process with EM4 can increase the C/N ratio.
3.2. Process temperature and biogas volume test
The biodigester temperature measurement data during the degradation process is shown in figure 3. The test results show that the temperature in the biodigester is higher than the ambient temperature. Biodigester temperature with substrate-2 and mix starter (cow dung and GP-7) reaches around 28-28.5°C, and the average temperature difference between them is around 3.5°C.

Biogas volume measurement starts on the 5th day. Inside the biodigester with substrate-2 and mix starter (cow dung and GP-7) as much as 1.450 ml of gas was obtained. Meanwhile, in the other biodigester only 820 ml gas is formed. Furthermore, the addition of biogas volume on every week (7 days) measurement is almost constant. Until the 45th day the volume of biogas made of substrate-2 reached 10.190 ml and Substrate-1 reached 11.550 ml. From these data, it can be seen that the volume of biogas obtained from biodigesters with pre-treatment with NaOH & EM-4 and cow dung starter & GP-7 produced the most biogas. Temperature profile and the gas volume from test results on the biodigesters is shown in figure 3 and figure 4 below.

![Figure 3. Biogas temperature profile.](image)

![Figure 4. Biogas volume profile.](image)

3.3. Biogas composition test
The biogas composition test is carried out using a Gas Chromatography (GC) instrument. From the results of tests carried out on the 6th day until the 45th day data obtained as shown in Figure 5, which shows that the gases N₂, O₂ was decreasing with the increase of degradation time. CO₂ gas at the beginning of degradation has increased first and then decreased. Meanwhile, methane gas began to form on the 6th day although it was still low at 1.4% and gradually increased until the 45th day reaching 47.2%. From these data where the methane gas content is still increasing until the 45th day it means that the bacterial activity in the anaerobic degradation process of vegetable waste is still active until the 45th day. In addition, after the 31st day, there is no O₂ content (0%) found in all biodigesters, which shows that the biodigester is already in anaerobic condition. As the purpose of this study, the comparison between the composition of gas yield data in this study, figure 5, and the data from biogas composition derived from cow dung waste [16], figure 6, can be seen in below.

![Figure 5. Biogas composition inside Biodigester of Substrate-2.](image)

![Figure 6. Biogas composition inside Biodigester of cow dung waste.](image)
Based on the methane gas composition data, biogas volume and volatile solid content (VS) of the material in table 2, the amount of CH$_4$ gas in ml / kg VS as shown in the following figure 7. It can be seen that the amount of CH$_4$ gas increases with the degradation time, and until the time 45th still looks pretty good improvement. At the time of degradation in the 45th day, the amount of CH$_4$ gas reached 5039 ml / kg VS (5.039 ml / g VS). When compared with reference to the results of research Pramanik et al. [14] and Deressa et al. [6] the amount of CH$_4$ gas from vegetable food waste can reach 340 ml / g VS, so that the CH$_4$ gas results obtained in this study still much smaller.

![Comparison of methane volume from Substrate-1 and Substrate-2.](image)

**Figure 7.** Comparison of methane volume from Substrate-1 and Substrate-2.

### 4. Conclusion

Pretreatment using 3% NaOH and 9% EM-4 can increase the anaerobic degradation process (see Table 2), this treatment could change the physical-chemical character of the substrate so that it increases the amount of methane gas production compared to pretreatment with NaOH only (see Figure 6). Compared to the raw materials of cow dung waste, the retention time of methane formation from substrate-1 is relatively slower compared to cow dung waste as the result of Gantina et al. [16]. To reach up to 50% of methane gas composition in biogas production, it takes 45 days with vegetable waste and 25 days with cow dung waste substrate. Furthermore, methane production still tends to increase after 45 days of processing time.

### Acknowledgments

The authors acknowledge to UPPM Politeknik Negeri Bandung that support the funding of the research and the support from Department of Energy Conversion Engineering Politeknik Negeri Bandung that provide the laboratory facility for the research.

### References

[1] Nicholls D G and Ferguson S J 2013 *Bioenergetics* 4 London; Elsevier

[2] Gil A, Siles J A, Serrano A, Chica A F and Mart M A 2019 Effect of Variation in the C / [ N 1 P ] Ratio on Anaerobic Digestion 00 1–9

[3] Sanjaya I G M 2012 Biokonversi Sampah Organik Pasar Menjadi Biogas Menggunakan Starter Effective Microorganisms (EM4) *Sains dan Mat* 1 17–9

[4] Khoo H H, Lim T Z and Tan R B H 2009 Food waste conversion options in Singapore: Environmental impacts based on an LCA perspective *Sci Total Environ* 440 1–9

[5] Tanimu M I, Ghazi T I M, Harun R M and Idris A 2014 Effect of carbon to nitrogen ratio of food waste on biogas methane production in a batch mesophilic anaerobic digester *International journal of innovation, management and technology* 5(2) 116

[6] Deressa L, Libsu S, Chavan R B, Manaye D and Dabassa A 2015 Production of biogas from fruit and vegetable wastes mixed with different wastes *Environment and Ecology Research* 3(3) 65-71

[7] Kjeldsen P, Barlaz M A, Rooker A P, Baun A, Ledin A and Christensen T H 2002 Present and long-term composition of MSW landfill leachate: a review *Critical reviews in environmental science and technology* 32(4) 297-336

[8] Chen Y R, Varel V H and Hashimoto A G 1980 Methane production from agricultural residues. A short review *Industrial & Engineering Chemistry Product Research and Development* 19(4)
471-477

[9] Oliveira F and Doelle K 2015 Anaerobic digestion of food waste to produce biogas: a comparison of bioreactors to increase methane content–a Review J. Food Process. Technol 6(8) 1-3

[10] Romadhoni A H and Wesen P 2011 Pembuatan biogas dari sampah pasar J Ilm Tek Lingkung 6 59–64

[11] Jewell W J, Davis H R, Gunkel W W, Lathwell D J, Martin Jr J H, McCarty T R and Williams D W 1976 Bioconversion of agricultural wastes for pollution control and energy conservation Cornell Univ. Final Report

[12] Nugraha, M. A. (2014). Kajian laju alir recycle air lindi terhadap kualitas biogas dengan Green Phoskko (GP7) dan reaktor tipe partition (Doctoral dissertation, Politeknik Negeri Sriwijaya)

[13] Brigita G and Rahardyan B 2013 Food waste management analysis in bandung city J Tek Lingkung 19 34–45

[14] Pramanik S K, Suja F B, Zain S M and Pramanik B K 2019 The anaerobic digestion process of biogas production from food waste: Prospects and constraints Bioresource Technology Reports

[15] US Department of Agriculture 2019 Food Data Central

[16] Gantina T M, Maridjo and Nugraha D 2009 Potensi dan karakteristik biogas pada degradasi anaerobik kotoran kerbau menggunakan biodigester fiber tipe kontinyu Proceeding Semin Energi Terbarukan POLBAN