Production of Biogas from Organic Fruit Waste in Anaerobic Digester using Ruminant as The Inoculum

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Abstract. Organic waste, fruit waste and vegetable waste are the best substrate to produce biogas. Waste management system for producing biogas can be used as a solution with the waste problem by converting the wastes into biogas. This study is expected to review of the effect of substrate type and substrate composition for the volume of biogas produced. In this study, materials consist of fruit wastes (oranges, apples, papayas, and tomatoes), cow ruminant, urea, cow dung, Na_2CO_3 buffer, NH_4HCO_3 buffer, and distilled water with variations of the substrate materials, F/ W, and the buffer types. The addition of cow manure and Na_2CO_3 buffer with 1:2 of F/W, production of biogas is greater than variable which is used NH_4HCO_3 buffer and without the addition of cow dung. Variables with addition of cow dung with 1:1 of F/W and using Na_2CO_3 buffer, the result is greater than the variable using the same buffer but without the addition of cow dung and variables with 1:1 of F/W with the addition of cow dung and Na_2CO_3 buffer and variables with the same feed and without the addition of cow dung produce more biogases than variable which is the using NH_4HCO_3 buffer, 1:1 of F/W and without the addition of cow dung.

1 Introduction

In recent years, production of oil in Indonesia decreases because of oil derivation spare [1]. Energy consumption on a moderate increase, especially in rapidly developing countries. The overall size of the world energy market nearly doubled between 1971 and 2003, driven by rapid expansion of energy usage in the developing world, where population and energy activity have grown [2]. This case gives effect to the need of oil (BBM) which is an unchangeable source capacity. Therefore, there should be an effort in order to find out the way of solving this problem. In order to minimize the risk of the environment and human health economically feasible solutions are sought for the treatment of solid waste particularly in urban areas. A plan to turn solid organic waste (kitchen waste) into energy through different technology has been possible.

One of the technologies used for recovering the energy from different types of biomass residues is anaerobic fermentation that has as a primary result the production of biogas. Production of biogas provides a versatile carrier of renewable energy, as methane can be used for replacement of fossil fuels in both heat and power generation and as a vehicle fuel [3]. Related with the existing literature, the field of biogas production and applications is developed at a large scale, the existing studies covering different characteristics of this domain. In connection with the process characteristics, [4] presented an extensive study related with the pH effect on anaerobic fermentation on sludge material, [5]

conducted a review over the solid state anaerobic digestion from organic waste in accordance with methane production, while [6] presented a new technology for biogas production from solid waste and biomass through means of a double-stage solid-liquid biogas process. Studies were conducted also in the field of biogas production enhancement from solid substrates under different technologies [7].

Biogas technology provides an alternative source of energy mainly from organic waste. Anaerobic digestion [8] is a process of controlled decomposition of biodegradable materials under managed conditions where free oxygen is absent, at temperatures suitable for naturally occurring mesophilic or thermophilic anaerobic and facultative bacteria and archaea species, that convert the inputs to biogas and whole digestive. Most organic wastes produced today originate in municipal, industrial and agricultural sector. Biogas research using agricultural waste (organic waste) has been done and has very good results [9-19]. The advantages of anaerobic digestion include low levels of biological sludge, low nutrient requirements, high efficiency and the production of methane, which can be used as an energy source for on-site heating and electricity [20]. If we observe its composition, fruit waste contents actually has something potential to be produced. The composition and material contents of fruit waste consists of a number of microorganisms that functions as organic-non organic material. One way can be done as the solution of to solve the problem is by changing the fruit waste to be biogas source.

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According to Food and Agricultural Organization (FAO), the estimated fruit and vegetable wastes percentage for each commodity group in each step of the food supply chain are 15, 9, 25, 10 and 7% in agricultural production, post-harvest handling and storage, processing and packaging, distribution and consumption respectively in South and South-East Asia. Mostly the solid wastes generated largely in traditional markets including fruit and vegetable wastes are disposed in municipal landfill or dumping sites caused environmental problems. Due to their nature and composition, they deteriorate easily and cause foul smell. Considering the high moisture and organic content, these wastes can be treated in biological treatment like anaerobic digestion than other techniques like incineration and composting [21].

Biogas is flammable gas that is produced from biodegradation of organic material by bacteria which are life in a hermetical air condition (anaerobic bacteria) towards digester organic cesspools as well as in the sanitary landfill. Biogas which is produced from organic waste is flammable gas and it is dominated by methane compound (CH_4) and CO_2 compound [22]. The production process happens in two steps which are ready materials preparation and anaerobic biodegradation process by the microorganism to maintain methane gas. Methane gas is gas that contains an atom carbon and four hydrogen atoms (H) which is flammable.

The waste material that is more used as basic biogas material is animals manure such as cattle and chicken, 1 kg cow manure can produce 0.023 – 0.040 m³ biogas [23], and 1 kg chicken manure can produce 0.065 – 0.116 m³ biogas [24]. Besides animal manure, biogas can be produced from compost heap such as the organic waste of fruit and vegetables. This study is expected to provide a review of the effect of substrate type and substrate composition for the volume of biogas produced.

The use of organic waste as basic biogas composition needs some careful methods such as collection, preparation, management, storage way. Methods collection is based on the number and characteristics of basic composition which are varieties. The nature characteristic of basic composition is solid, semi solid, and liquid. The management system is also goes carefully as well and based on the condition where the production is done.

2 Materials and Methods

2.1 Materials

The materials used in this research are organic fruit waste (lemon, apple, papaya, and tomato), ruminant, cow feces, urea, buffer Na_2CO_3 , buffer NH_4HCO_3 , and distilled water.

2.2 Experimental prosedure

The research is done in some steps such as creating batch digester instruminantt, preliminary experiment,

fermentation process, and biogas volume analysis every two days for 30 days. The pre-experiment is done by total solid observation (TS) of basic composition and substrate intermixture.

Biogas production from fruit waste like lemon, papaya, apple, and tomatoes is starting from creating batch digester instrument which will be used. Then, preparing mixed fruit waste which have been rotten and without water. After that, arranging the substrate composition and water based on its variable F/W (1:1;1:2), adding urea as nutrient as the ratio calculation C/N to the substrate, adding animal manure based on the substrate variable, adding 25 ml ruminant on the substrate, set the starting pH that has 7 each by using buffer based on the variable (Na_2CO_3 and NH_4HCO_3), waiting for fermentation process till biogas is formed (one day), then the formed biogas is connected to the liquid displacement than is fill by water using a pipe. Observe its height difference every day that happen in the liquid displacement to find out the formed biogas volume in every 2 days for 30 days.

3 Results and Discussions

The quality and quantity of biogas yield is affected by substrate composition characteristics on each kinds of substrate compound [25]. The substrate used in biogas production will affect its process. Besides substrate, the volatile solid condition, digester temperature, duration, pH system and ratio C/N also need to be considered when producing biogas [26]. This research is conducted to study about the best substrate composition that can be used in producing total solid biogas per gram every day.

In producing biogas, sometimes the pH decrease significantly at the beginning because of it tendency to form acid. Yet, its hydrogen gas form, carbon dioxide, and some VFA such as propionate acid and butyrate. Low pH can cause the microorganism of biogas which is methane genesis bacteria (ruminant bacteria) in inactive condition [27].

Biogas production will be more optimum if the anaerobic fermentation done is really placed without oxygen. In this research, buffer is used to keep its pH so it will be in good and neutral condition in order to anticipate if there is oxygen when pH control is done. Besides, to make the methane genetic can grow and improve better, it needs buffer addition into the digester to improve its alkalinity. Therefore, this research uses kinds of buffer NH_4HCO_3 and Na_2CO_3 which function as buffer to improve its alkalinity as long as the fermentation process is done. From Table 1, it can be seen of notation formula research.

Table 1. Notation Formula Research

Formula	Symbol	Ratio F/W	Biogas Substrate Production
1	◆	1:1	Fruit Substrate + Ruminant + Urea + Cow dung + Na ₂ CO ₃ + water
2	■	1:2	Fruit Substrate + Ruminant + Urea + Cow dung + Na ₂ CO ₃ + water
3	▲	1:1	Fruit Substrate + Ruminant + Urea + Na ₂ CO ₃ + water
4	X	1:2	Fruit Substrate + Ruminant + Urea + Na ₂ CO ₃ + water
5	*	1:1	Fruit Substrate + Ruminant + Urea + NH ₄ HCO ₃ + water
6	●	1:2	Fruit Substrate + Ruminant + Urea + NH ₄ HCO ₃ + water

Figure 1-4 shows biogas accumulative volume per gram total solid (ml/g total solid) from all various orange, apples, papaya, tomato substrate composition. At the beginning fermentation, biogas production is very fast, this happen because of microorganism that work on the early stage is non methanogen microorganism which grows very fast too. This stage is called acid genesis process that is the acid formulation stage process by acid genesis bacteria. Few days after fermentation process done, methanogen bacteria start and be more active in forming methane gas, CO₂, gas residual such as H₂S and water from H₂, CO₂ gas, and acetate acid that is produced on the acid genesis stage [28].

Fig 1. Biogas Accumulative Volume per Gram Total Solid (ml/g total solid) from All Various Orange Substrate Composition

Fig 2. Biogas Accumulative Volume per Gram Total Solid (ml/g total solid) from All Various Apple Substrate Composition

Fig 3. Biogas Accumulative Volume per Gram Total Solid (ml/g total solid) from All Various Papaya Substrate Composition

Fig 4. Biogas Accumulative Volume per Gram Total Solid (ml/g total solid) from All Various Tomato Substrate Composition

There are four phases of microorganism growth namely lag phase, exponential phase, stationary phase, and end/death phase. The biogas volume which is formed approximately increase from the 1st day to the 12th day, it happens because of the microorganism is on the exponential phase. In this phase, microorganism is considered in the constant phase (metabolic constant activity). The microorganism concentrates to scatter the organic substance from its substrate. Then the biogas volume decrease till it cannot produce more biogas on at the end of fermentation process. This happen because of the bacteria is on the static phase, where in this phase there is accumulation poisonous product or no nutrient.

This phenomenon is also happen on the use of mixed fruit substrate such as fruit waste mixture as shown on figure 5 which shows daily biogas production per gram total solid on fruit waste mixture substrate between orange – tomato. In the figure 6 shows that daily biogas production per gram total solid on fruit waste mixture substrate between papayas – tomato. Figure 7 shows daily biogas production per gram total solid on fruit waste mixture substrate between papaya – apple.

Fig 5. Biogas Accumulative Volume per Gram Total Solid (ml/g total solid) from All Composition Substrates between Tomato and Orange

Fig 6. Biogas Accumulative Volume per Gram Total Solid (ml/g total solid) from All Composition Substrates between Papaya and Tomato

Fig 7. Biogas Accumulative Volume per Gram Total Solid (ml/g total solid) from All Composition Substrates between Papaya and Apple

In producing biogas, there are some processes that directly affect the level and efficiency of biogas including solid volatile, digester temperature, duration, pH system and C/N [26]. As we know that one of the phase in anaerobic organic compound decomposition is acid genesis and asset genesis. In this phase, acid oil which decrease pH in reactor. The whole anaerobic processes happen to pH between 6–8. Even though the methane bacteria former is really sensitive to the pH, but pH reactor is not necessary to be controlled. pH arrangement can be done by keeping the food not too be sour and also controlling its mixture so there is balance reaction between acid genic phase and methane genic phase. When there is no pH balance, then the pH value below 6 of methane bacteria activity will be influenced and if it decreases to 5, 5 there will no bacteria activity. pH concentration in the reactor is most influenced by the number of fatty acid volatile (VFA), ammonia CO₂ and its bicarbonate alkalinity which is produced.

Biological waste process can be differentiated in two types such as aerobic and anaerobic process. The aerobic process happens if only there is oxygen, while the anaerobic process happens the other way around because the oxygen will influence the process. In biogas reactor, there are two kinds of bacteria that play the most important role which are acid genic bacteria and methane genic bacteria. The biogas production will be more optimum if the anaerobic fermentation done is really free from oxygen. That is why this research uses buffer to keep pH so it stays on the neutral condition and to prevent if there is oxygen comes inside the digester when pH controlling done.

In producing biogas, sometimes the pH decrease significantly at the beginning because of its tendency to form acid. Yet, its hydrogen gas form, carbon dioxide, and some VFA such as propionate acid and butyrate. Low pH can cause the microorganism of biogas which is methane genesis bacteria (ruminant bacteria) be in inactive condition [27]. Besides, in order to help methane genic to grow well, it needs buffer addition into the digester to keep up its alkalinity. Therefore, this research uses NH₄HCO₃ and Na₂CO₃ kinds of buffer that function as buffer to increase its alkalinity a long its fermentation process.

From all figure (1 – 7) can be seen that the variable that use feed by formula 2 to produce biogas volume is bigger compared to others. To reach the pH 7 on substrate, bicarbonate ammonium concentration needs to add 0.02 g/ml or 20.000 mg/l. It will be poisonous for the methane genic organism if its ammonium concentration reaches 1500 – 3000 mg/l [29]. It will be poisonous for pH 7.4 if its ammonium concentration reaches 15000 mg/l, and it will be poisonous for all kinds of pH if it ammonium concentration reaches 3000 mg/l [30].

Besides pH, [31], argues that, one of the parameter that influence biogas production is the level of slurry digestion that can be observed from its total solid and its organic composition contents inside the bio – digester. The more Total Solid (TS) it has the easier for pH to decrease and the less TS it has, the less possibility for pH to decrease. This case is as same as the previous research which is done by [32], giving too much substrate into bioreactor causes acidogenic and asetogenic more active and grows faster, and it causes imbalance between these two bacteria. Organic composition that contain less TS is produce easily, makes methane genesis work optimally in producing biogas because of there is less pH reduction (pH controlled). But, containing less TS can reduce the product because its fermentation has substrate limitation that plays role as basic composition.

4 Conclusions

Based on the experiment result, can be conclude that by adding cow dung into oranges waste, apple waste, papaya waste, and tomato waste can increase daily biogas production, also by adding cow dung on fruits substrate can increase daily biogas cumulative production. Using Na₂CO₃ buffer to control F/W 1: 2 ratio can produce daily biogas volume and cumulative compared to F/W 1: 1 substrate ratio composition. For the next experiment, the researcher needs to do test on burning the biogas produced in order to find out the quality of organic fruit waste, besides, needs accurate pH control in which cannot influence the fermentation process.

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References

1. Assegaf, F. (Universitas Jenderal Soedirman, Semarang, 2009)
2. Cioablă, A. E.; Ionel, I.; Pădurean, I.; Țenchea, A.; Popescu, F. & Savu, A., *Metalurgia Internațional XIV*, 3, 40 – 44 (2009)
3. Weiland, P., *Appl Microbiol Biotechnol* (2009)
4. Wu, H., Yang, D., Zhou, Q., Song, Z., *Journal of hazardous materials* **172**, 196 – 201 (2009)
5. Li, Y., Park, S.Y., Zhu, J., *Renewable and sustainable energy reviews* **15**, 821 – 826 (2011)
6. Busch, G., Grobmann, J., Sieber, M., Burkhardt, M., *Water Air Soil Pollut: Focus* **9**, 89–97 (2008)
7. Karellas, *Renewable and sustainable energy reviews* **14**, 1273 – 1282 (2010)
8. WRAP. *Specification for whole digestate, separated digestate, separated liquor and separated fibre derived from the anaerobic digestion of source-segregated biodegradable materials*, (Publicly Available Specification PAS 110, U.K, 2010)
9. Budiyono, Syaichurrozi, I., & Sumardiono, S., *World Applied Sciences Journal*, **26**, 11, 1464-1472 (2013)
10. Budiyono, Syaichurrozi, I., & Sumardiono, S., *International Journal of Engineering, Transactions B: Applications*, **27**, 2, 177-184 (2014)
11. Budiyono, Syaichurrozi, I., & Sumardiono, S., *Research Journal of Applied Sciences, Engineering and Technology* **7**, 13, 2798-2805 (2014)
12. Budiyono, Wicaksono, A., Rahmawan, A., Hawali Abdul Matin, H., Gumilang Kencana Wardani, L., Djoko Kusworo, T., & Sumardiono, S., *MATEC Web of Conferences* **101** (2017)
13. Shitophyta, L. M., Budiyono, & Fuadi, A. M., *AIP Conference Proceedings* **1699** (2015)
14. Sumardiono, S., Budi Riyanta, A., Hawali Abdul Matin, H., Djoko Kusworo, T., Jos, B., & Budiyono., *MATEC Web of Conferences* **101** (2017)
15. Sumardiono, S., Budiyono, & Mardiani, D. T., *AIP Conference Proceedings* **1699** (2015)
16. Syafrudin, Dwi Nugraha, W., Hawali Abdul Matin, H., & Budiyono., *MATEC Web of Conferences* **101** (2017)
17. Syafrudin, Nugraha, W. D., Ardinata, I. H., Kencanawardhani, L. G., Matin, H. H. A., & Budiyono., *Advanced Science Letters* **23**, 3, 2204-2206 (2017)
18. Syafrudin, Nugraha, W. D., Matin, H. H. A., & Budiyono, *Advanced Science Letters* **23**, 6, 5698-5700 (2017)
19. Syafrudin, Nugraha, W. D., Matin, H. H. A., Kencanawardhani, L. G., & Budiyono, *Advanced Science Letters* **23**, 6, 5687-5690 (2017)
20. Nallathambi, V., *Biomass Bioenergy* **33**, 4, 589–596 (2009)
21. Velmurugan B, Alwar Ramanujam R., *Int. J. Emerg. Sci.* **1**, 478-486 (2011)
22. Hastuti, D., *Aplikasi Teknologi Biogas Guna Menunjang Kesejahteraan Petani Ternak* (Fakultas Pertanian. Universitas Wahid Hasyim, 2009)
23. Budiyono, D.A. Putria, dan R.R. Saputro. *Biogas Production from Cow Manure* (Chemical Engineering Department, Diponegoro University, Semarang, 2012)
24. Setyawan A.H., *Pengembangan Biogas Berbahan Baku Kotoran Ternak* (Magister Studi Pembangunan Institut Teknologi Bandung, Bandung, 2010)
25. Kavacik B., dan Topaloglu B., *Biogas Production From Co-Digestion Of A Mixture Of Cheese Whey And Dairy Manure* (Departement of Environmental Engineering, Turkey, 2010)
26. Putri D.A., Saputro R.R., and Budiyono., *Int. Journal of Renewable Energy Development* **1**, 2, 61-64 (2012)
27. Arhoun B., Bakkali A., Mail R.E., Rodriguez J.M., dan, Herruzo G. F., *Bioresource Technology* **127**, 242–247 (2013)
28. Adam, B., *Biogas Markets Amid Fragility and Controversy* (Doctoral School of Organisation and Management Studies PhD Series 17, Denmark, 2010)
29. Kommedal R., Bakke R., Dockery J. and Stoodley P., *Wat. Sci. Tech.* **43**, 6, 129-134 (2011)
30. Nassab A.D.M., T. Amonb., dan H.P. Kaul, *Competition and Yield in Intercrops of Maize and Sunflower for Biogas* (University of Natural Resources and Life Sciences, Department of Applied Plant Sciences and Plant Biotechnology, Austria, 2011)
31. Sjafruddin, R., *Jurnal Teknologi Media Perspektif, Riset And Teknologi* **11**, 2 (2011)
32. Soeprijanto, Ismail, T., Lastuti, M.D. and Niken, B., *Jurnal Purifikasi* **11**, 1 (2010)