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Biogas Production from Vegetables and Fruit Wastes Using Anaerobic Floating Bioreactor

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ABSTRAK: Markets and supermarkets are one of the pillars of the country's economy, besides that, they are also the biggest contributors to vegetable and fruit waste which can cause various environmental problems. Therefore, the abundance of vegetable and fruit waste produced by markets and supermarkets can be utilized as environmentally friendly alternative energy, namely biogas. This study aimed to determine the effect of organic loading rate (OLR) on biogas production and gas composition in a continuous anaerobic floating bioreactor using mixed vegetable and fruit waste. A 40-l anaerobic floating bioreactor was utilized and the hydraulic retention time was 10 days; one kg of vegetable and fruit wastes at a 1:1 mass ratio was added with water to 4 l and introduced during 25 days; the daily biogas production was collected in a floating drum and measured as volume. The maximum biogas yield was 0.0452 m^3/kg, achieved using the OLR of 0.0125 kg/l.day. The use of OLR of 0.0250, 0.0375 and 0.0500 kg/l.d reached biogas yields of 0.0435, 0.0282, and 0.0163 m^3/kg, respectively. The composition of the maximum biogas yield was 68.17% CH_4, 19.34% CO_2, 1.85% H_2S, and 0.64% NH_3.

Keywords: Biogas; bioreactor; HRT; OLR; vegetable waste; fruit waste.

1. Introduction

Energy has an important role and can not be separated into human life. Moreover, at present, almost all human activities are highly dependent on energy. Various supporting equipment such as lighting equipment, motor drives, household appliances, and industrial machines require energy. The utilization of energy such as water energy, solar energy, electrical energy, petroleum energy, and gas as well as mineral and coal energy has indeed been done long ago. Increasing energy demand is caused by several factors including an increase in population, an increase in the standard of living of the community, an increasing number of vehicles, and rapid industrial growth, causing increased energy consumption. The Government through the National Energy Policy issued several solutions to overcome these problems, namely by conducting conversion, diversification, and energy intensification. The utilization of energy that can not be renewed excessively can cause problems of energy scarcity. One symptom of the energy scarcity that occurred lately is the scarcity of fuel oil such as kerosene, gasoline, and diesel. Scarcity occurs because the level of fuel demand is very high and always increases every year. Meanwhile, petroleum raw materials for making fuel oil are limited in number and require millions of years for the formation process. The energy-saving program has been carried out since the supply of petroleum fuels derived from fossil energy sources has been running low, while demand has been increasing steadily. This condition has an impact on increasingly high prices and is difficult to reach by most Indonesians. One way to save fuel is to look for alternative and renewable energy sources. Alternative energy sources in Indonesia are quite available, such as solar energy, wind energy, and water. So far, the most widely used energy is hydropower, however, the development of other alternative energy sources is still open. The alternative energy that is likely to be developed is biogas energy. Biogas technology is one of the appropriate technologies for treating waste to produce energy that utilizes microorganisms that are available in nature to treat various organic wastes placed in airtight spaces. Biogas is one of the effective and efficient solutions for providing alternative energy sources. Biogas is produced from the fermentation process of organic materials assisted by anaerobic bacteria in an environment without involving oxygen, biogas is dominated by methane gas (55% -75%), carbon dioxide (25% - 45%), and several other gases in higher amounts small (Soeprijanto, 2019; Zhang et al., 2014).

Fruit and vegetable waste is a problematic waste as a result of generating huge amounts, the broad range of environmental impacts on causing, for instance, water and air pollution, and also greenhouse gas emissions (Schanes et al., 2018). A landfill is the most used disposal method for fruit and vegetable wastes that contribute to the release of high organic loading leachates and greenhouse gases.
Anaerobic digestion is one of the biological treatments for organic waste that is receiving increasing attention due to its high value for waste (Bong et al., 2018). The waste contains high biodegradability and high volatile solids (Edwiges et al., 2020; Fisgativa et al., 2016). The main advantage of the anaerobic digestion process is the

production of biogas for renewable energy, but also promotes nutrient recovery in the digestate, which can be used as a biofertilizer (Koido et al., 2018). This method has been successfully applied in reducing the volume of waste that enters landfills, thereby decreasing methane emissions produced by decay (Mata-Alvarez et al., 2000; Forster-Carneiro et al., 2008; Bouallagui et al., 2009).

Anaerobic digestion of vegetable waste was carried out by Velmurugan and Ramanujam (2011). They showed that the average methane content in the biogas was 65% and the methane yield was 0.387 l CH_4/g VS for the selected types of wastes in mesophilic conditions using a fed-batch laboratory-scale reactor.

Methane gas has been widely recognized as an environmentally friendly material because it can burn completely so that it does not produce smoke which adversely affects air quality. Because of its nature, methane gas is a gas with high economic value and can be used for various purposes ranging from cooking to driving a steam turbine power plant. The methane content in biogas is a component that can be an alternative fuel as an alternative energy source for fossil fuels. While other components such as CO_2 and N_2 are impurities that have harmful properties. The complexity of the biogas content, making the use of this alternative fuel as a substitute for fossil fuel in energy conversion machines still requires a deeper study. Especially, how the influence of impurities, especially CO_2 on the characteristics of biogas combustion.

Production of alternative biogas energy is relatively easy, where the organic wastes can be used as the raw materials by using biogas digester unit so that the process of integrating organic waste runs quickly, then the organic waste is chopped up before being put into the reactor (Soeprijanto, 2019). This biogas energy is very appropriate to be developed in Indonesia because many Indonesians work as farmers. Besides, biogas energy can be produced by utilizing vegetable and fruit wastes from markets and supermarkets (Bouallagui et al., 2005; Soeprijanto et al., 2019). The market as one of the backbones of a country's economy is also the biggest contributor to vegetable and fruit wastes. These piles of vegetable and fruit waste are rarely used by the community because they are no longer suitable for animal feed (Huang et al., 2016). Usually, vegetable and fruit waste are only left alone, causing odors that can interfere with environmental cleanliness and health. Also, vegetable and fruit waste have long been a serious problem, such as causing odors that interfere with breathing and affect health. Organic waste has the potential to be used as material for biogas production, but it is not yet widely used. Even so far it has caused pollution problems that have an impact on environmental health. According to Soeprijanto et al. (2019), the advantage of making biogas from municipal solid waste is that there is no need to add nutrients because the amount of N and P in municipal solid waste in this research is a very large vegetable waste (Wang et al., 2012).

In this study, fruit and vegetable waste was used as feedstock to produce biogas using a floating anaerobic bioreactor. This bioreactor has an advantage not only to convert agricultural waste to biogas but also to collect the biogas produced.

The purpose of his study was to determine the effect of variations in the loading rate of vegetable and fruit waste on biogas production using anaerobic floating bioreactors.

2. Materials and methods

2.1 Materials

Cow dung was obtained from a Slaughterhouse at Penggirian Surabaya. Vegetable and fruit waste in the form of apples, bananas, papaya, cabbage, mustard greens, and tomatoes were obtained from Supermarkets at Surabaya.

2.2 Methods

In this study, fruit and vegetable wastes (VFW) mixed with cow dung were used as substrates for biogas production in a 40 l cylindrical floating anaerobic digester. The VFW was weighed as much as 1 kg with a ratio of fruit and vegetable of 1:1 (w/w) (a ratio of vegetable wastes of cabbage 1/3, chicory 1/3, and tomatoes 1/3 and a ratio of fruit wastes of papaya 1/3, apples 1/3, and bananas peels 1/3). The anaerobic floating bioreactor (Figure 1) was conducted in a continuous mode with a feeding volume of 4 l per day to achieve a hydraulic retention time (HRT) of 10 days. The biogas production was collected in a floating drum and monitored daily for up to 25 days by observing the level changes on the floating drum. The gas analysis was carried out using gas chromatography to determine the content of methane, carbon dioxide, ammonia, and hydrogen sulfide.

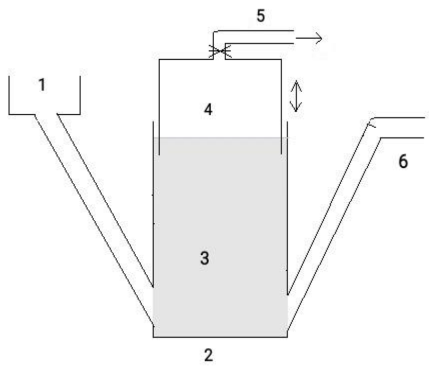

Figure 1. Schematic diagram of the digester.
(1= influent feeding; 2 = floating anaerobic digester; 3 = slurry; 4 = gas in floating drum; 5 = gas pipe; 6 = effluent)

3. Results and discussion

The content of vegetable and fruit waste is one of the important parameters in the formation of biogas. The analysis results are shown in Table1.

Table 1. Analysis results of vegetable and fruit waste samples.

Parameter	Percentage
Cellulose	28%
Hemicellulose	14%
Lignin	5%
Protein	4.08%
TS	70.3%
VS	27.6%

3.1 Biogas production

The continuous anaerobic digestion was carried out in this study. Organic loading rate (OLR) is one of the parameters that determine the formation of biogas. Figure 2 shows there is a correlation between daily biogas production with OLR that has been carried out for 25 days of operation. The results depicted during the stable operation, the mean daily biogas productions were 4240 ml/day with OLR of 0.0125 kg/l.day, 8120 ml/day with OLR of 0.0250 kg/l.day, 8220 ml/day with 0.0375 of kg/l.day, and 6160 ml with OLR of 0.050 kg/l.d, respectively (Figure 3). Of the four OLRs, the maximum daily biogas production was found to be in the OLR of 0.0375 kg/l.day, with an average volume of 8220 ml/day.

This result is consistent with the other authors (Al Mamun, 2014; Babaee and Shayegan, 2011; Deublein, 2008; Dhanalakshmi et al., 2012; Dhanalakshmi and Ramanujam, 2012) which stated that the greater the amount of substrate contained in the waste, thus the organic burden that must be described in microbes that is also greater. This is due to the increasingly limited number of active decomposing microorganisms, thus the ability to degrade the substrate is increasingly limited (Soeprijanto, 2019). Biogas production depends on the volatile organic solid load that was fed per day to the digestion. This means that the amount of biogas produced depended on the number of substrates. Organic loading rate (OLR) that is too high can produce a saturated state where volatile fatty acids increase (Soeprijanto, 2019). Biogas production will decrease and the proportion of CO_2 increases. OLR is an important factor for the survival of microorganisms and their optimum activity; and is a very important control parameter in a continuous system. If the higher OLR that is fed will require more bacteria, this causes the system to not work properly, if not properly prepared. Also, an overload of organic matter can cause a significant increase in volatile fatty acids which cause acidification in the medium and will ultimately end the inactivity of all bacteria due to low pH which causes system failure (Soeprijanto, 2019). There are also fluctuations in biogas production, which is an increase and decrease that is not following the literature this is because the anaerobic process is highly dependent on the activity of microorganisms that are very susceptible to fluctuations. Air contamination causes biogas-producing bacteria which are obligate anaerobic bacteria will experience growth inhibition and even die (Deublein, 2008). Al Mamun and Torii (2014) showed the daily biogas production varied from a minimum of 0.8 l/day and a maximum of 39 L/day for CW:VW: FW (0.5:1.0:1.5) ratio and CW:VW: FW (1.0:1.0:1.0) ratio, respectively. The anaerobic digestion of a mixture of vegetable wastes was carried by Dhanalakshmi et al. (2012). They operated a single-stage mesophilic anaerobic reactor in a 2 l with the HRT of 25 days for two OLR of 0.25 and 0.5 gVS/l.d. The results indicated the mean biogas production was 0.150 and 0.300 l/day, respectively. Dhanalakshmi and Ramanujam (2012) studied in a batch anaerobic reactor using vegetable waste. The organic loading rate (OLR) used in the experiment was in the range of 0.06 - 0.47 g VS. They found the maximum cumulative gas production was 3764 ml for 0.26 g VS OLR. Babaee and Shayegan (2011) experimented to evaluate the production of biogas from vegetable wastes using an anaerobic digester. They showed the biogas production was in the range of 0.12-0.4 m^3/kg, the methane content was in the range of 49.7- 64% and The methane yield was 0.25 m^3/kgVS with the reduction of 88% VS at OLR of 1.4 kg VS/m^3.day.

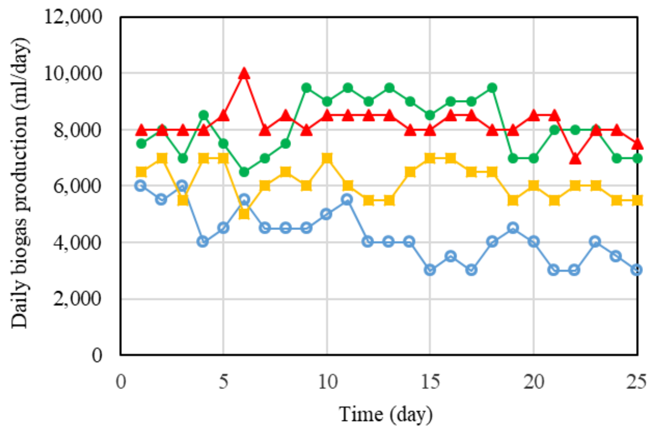

Figure 2. Effect of OLR on biogas production(○ = OLR of 0.0125 kg/l.d; ■ = 0.0250 kg/l.d; ▲= 0.0375 kg/l.d; ● = 0.050 kg/l.d.)

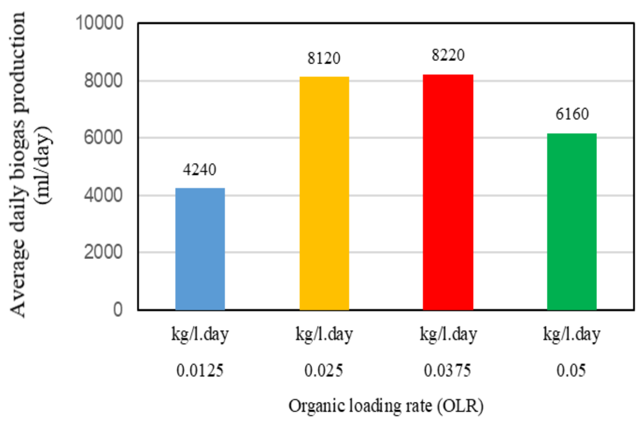

Figure 3. Effect of OLR on average daily biogas production.

3.2 Cumulative biogas production

Figure 4 shows the effect of OLR on cumulative biogas production. The results showed that there was an increase in the cumulative value of biogas production for 25 days. Biogas produced every day had a different volume composition, with the highest biogas production achieved at OLR of 0.0250 kg/l.d, was 205,500 ml (1,059 ml/g VS), then followed by OLR of 0.0250 kg/l.d was 203,000 ml, OLR of 0.050 kg/l.d was 154,000 ml (793.70 ml/g VS), and OLR of 0.0125 kg/l.d was 106,000 ml (546.31 ml/g VS), respectively. However, when compared to the other authors, these studies had the highest values, as most of the results found by the other authors conducted on a batch mode. Forster-Carneiro et al. (2008) reported biogas production of 180 ml/g VS for the mono-digestion of source sorted OFMSW. Scano et al. (2014) and Lin et al. (2011) found the mean yields of methane of 430 ml/g VS and 420 m/g VS, respectively, for VFW digestion. Pavi et al. (2017) showed the average cumulative biogas and methane yield in the co-digestion for OFMSW was 493.8 ml/g VS and in the mono-digestion was 396.6 ml/g VS, respectively.

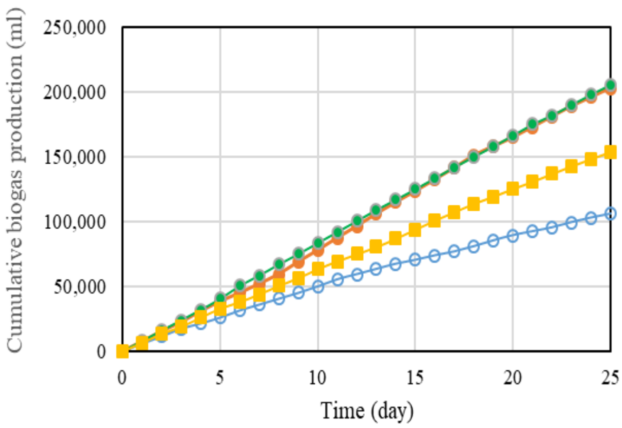

Figure 4. Effect of OLR on cumulative biogas production. (○= OLR of 0.0125 kg/l.d; ■ = 0.0250 kg/l.d; ▲= 0.0375 kg/l.d; ● = 0.050 kg/l.d.)

3.3 The content of biogas production

Figure 5 shows the relationship between OLR and the resulting biogas composition. The results indicated that with an OLR value of 0.0125 kg/l.d the content of methane was 68.17%, OLR of 0.0250 kg/l.d produced 67.91%, OLR of 0.0375 kg/l.d produced 69.29%, and OLR of 0.050 kg/l.d produced 68.58%, respectively. There was no significant difference in the composition results of each OLR. Similar results were also found by other authors. Borowski (2015) reported the contents of methane in the range of 55- 60% for the mono-digestion of OFMSW and the range of 58-66% for the co-digestion of OFMSW and sewage sludge. Bouallagui et al. (2003) showed methane contents of 64% in biogas for anaerobic digestion of VFW, while Scano et al. (2014) reported mean methane contents of 75% in short time lapses. However, Li et al. (2011) reported lower average methane contents in the range of 53.7% and 63.8%.

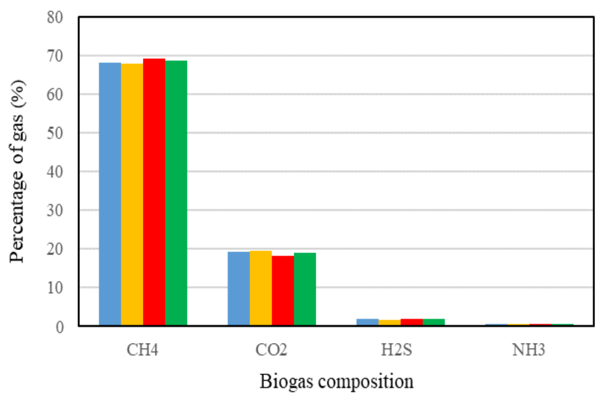

Figure 5. Effect of organic loading rate on biogas composition (○ = OLR of 0.0125 kg/l.d; ■ = 0.0250 kg/l.d; ▲= 0.0375 kg/l.d; ● = 0.050 kg/l.d.)

3.4 The yield of biogas production

The effect of OLR on biogas production is shown in Figures 6 and 7. The results showed the biogas yields obtained were 0.0452, 0.0435, 0.0282, and 0.0163 m^3/kg at OLR of 0.0125, 0.0250, 0.0375 and 0.0500 kg/l.d, respectively. In this study, the highest biogas yield was 0.0452 m^3/kg, reaching an OLR of 0.0125 kg/l.d. The use of OLR of 0.0250, 0.0375 and 0.0500 kg/l.d reached biogas yields of 0.0435, 0.0282, and 0.0163 m^3/kg, respectively.

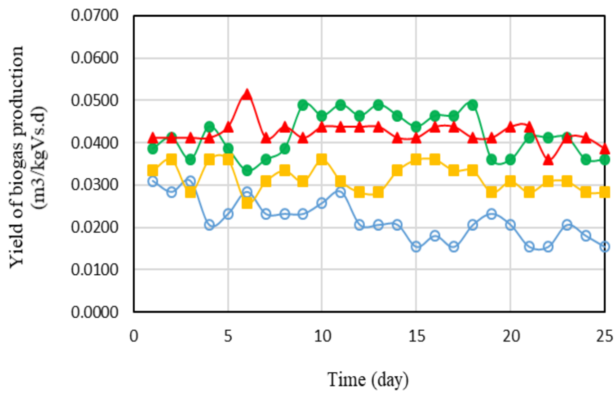

Figure 6. Effect of organic loading rate on yield of biogas production.(○ = OLR of 0.0125 kg/l.d; ■ = 0.0250 kg/l.d; ▲ = 0.0375 kg/l.d; ● = 0.050 kg/l.d.)

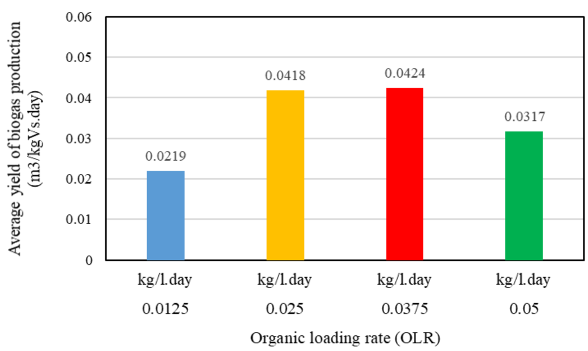

Figure 7. The correlation between OLR and an average yield of biogas production.

Conclusion

It was concluded in this study that the vegetable and fruit waste had a potential for biogas production and the by-product of the anaerobic digestion is useful for fertilizer. The floating anaerobic bioreactor is not only a treatment of agricultural waste to produce biogas but also to have a function of biogas store. The maximum biogas yield was 0.0452 m^3/kg, achieved using the OLR of 0.0125 kg/l.day, and had a composition of 68.17% CH_4, 19.34% CO_2, 1.85% H_2S, and 0.64% NH_3.

In future work, to obtain the increased biogas production will be improved by hydrothermal pretreatment before feeding to the anaerobic digestion.

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List of Notation

C_{spl} = sample concentration [g/l]
CW = cow dung waste [g]
FW = fruit wastes [g]
V_{spl} = sample volume [ml]
C_{std} = standard concentration [g/l]
V_{std} = standard volume [ml]
VW = vegetable wastes [g]
P = pressure [atm]
T = temperature [^{o}C]
t = time [second, hour]
V = volume [ml, l]

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