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Biogas recovery from anaerobic digestion process of mixed fruit -vegetable wastes

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Abstract

Anaerobic digestion of a mix of fruit and vegetable wastes has been carried out in a 200-liter digester within 14 weeks. The wastes were anaerobically digested in an anaerobic digester at ambient temperature. The objective of this paper was to study the performance of the anaerobic process used mixed fruit vegetable wastes as substrates in a single stage fed-batch anaerobic digester for biogas production. The feed consisted of mixed fruit-vegetable wastes were collected from a traditional market in Pontianak city. The wastes were taken based on grab sampling method with a composition of ± 78 % vegetable waste, ± 4% tuber waste and ±18% fruit wastes. The total waste weight was 160 kg, mixed manually once in the feeding. Chemical analysis of initial waste and bioreactors slurry was performed using standard methods. The COD of the leacheate was in the range of 7.2-56.4 g/l, pH in the range of 5.3-6.8 and temperature of 28-46°C. The highest methane content in the biogas was 65% with the biogas flow of 20-40 ml/min.

Keywords: anaerobic digestion; biogas; fed-batch; fruit-vegetable wastes; methane content

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1. Introduction

1.1. Fruit and vegetable wastes

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 [1]. 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 [2]. As the solid waste from traditional market are tremendously produced nuisance for environmental, this paper proposed anaerobic digestion for treating solid organic wastes mainly consisted of vegetable waste and recovering bioenergy from the process.

1.2. Biogas recovery from anaerobic digestion

Anaerobic digestion is a process in which microorganisms break down biodegradable materials in the absence of oxygen. The process is widely used to treat wastewater sludges, industrial and farm wastes because it provides volume and mass reduction up to 50% from the input material [3]. It is considered a renewable energy source because the methane-rich biogas produced is suitable for energy production and can replace fossil fuels. As part of an integrated waste management system, anaerobic digestion reduces the amount of methane that would be sent into the atmosphere if the waste was just sent to the landfill.

The advantage of using anaerobic digestion in an urban environment to treat organic waste as opposed to composting it is that anaerobic digestion produces biogas with a high percentage of methane (CH_4) which can be used as fuel whereas composting produces mostly carbon dioxide (CO_2) which could not be used as fuel. The methane in biogas can be burned to produce both heat and electricity (CHP) using internal combustion engines or microturbines in a cogeneration arrangement where the electricity and waste heat generated are used to warm the digesters or to heat buildings. Any excess electricity can be sold to suppliers or put into the local grid. In order to configure an anaerobic digestion system in an urban environment, special consideration must be paid to standing gas, fire, and building codes as well as health and safety regulations for handling the waste [4].

Biogas can also be used to fuel generators to produce steam and electricity. In some cases, the electricity can be sold to a local utility, possibly in a net metering arrangement. This option should be explored early, however, to make sure the utility is amenable to such arrangements. The objective of this paper is to study the performance of mixed fruit and vegetable wastes in a single stage fed-batch anaerobic reactor for biogas production.

2. Materials and methods

According to [5], there are different types of reactors used for energy recovery from solid wastes, including batch reactors, one stage and two stage reactors. In batch reactors, wastes are fed in to the system and all the degradation steps are allowed to follow sequentially. In one stage systems which are commonly preferred for full scale anaerobic digestion of organic solid wastes in the world, all the reactions simultaneously take place in a single reactor. In two stage systems, two different reactors are used for acidogenesis and methanogenesis. One stage systems are preferred than the batch and two stage systems because of their easier and simpler designs and low in investment costs.

2.1. Digester set-up

In this research, a single stage fed-batch anaerobic digester with total volume of 200 liters was used. It was operated at ambient temperature in the emsophilic range (27-31°C), yet the temperature and moisture were monitored daily using thermo-hygrometer. A gas collector was provided for collection and determination of the amount of biogas. The content of methane concentration produced in the reactor was monitored weekly.

2.2. Feedstock

The feed consisted of mixed fruit-vegetable wastes were collected from a nearby traditional market in Pontianak city (Flamboyan Market). The wastes were taken based on grab sampling method with a composition of ± 80 % vegetable waste and ± 20% fruit wastes. The total waste weight was 160 kg and mixed manually during the feeding. The feeding was carried out for two weeks. The starter using in this research was an inoculum from cow rument and mixed with the wastes just before the digester was closed. Chemical analysis of initial waste and bioreactors slurry was performed using standard methods.

3. Result and discussion

3.1. Waste characterization

Waste analysis is one of the most important steps in the anaerobic digestion process. Knowing the general composition of the substrate (input material) to the system is essential for calculating the amount and composition of the biogas produced as well as the amount of energy contained in the biogas. The focus of this paper is on a general mixed fruits and vegetables waste that is found traditional market in Pontianak city. A major limitation of anaerobic digestion of vegetable wastes is the rapid acidification due to the lower pH of wastes and the larger production of volatile fatty acids (VFA), which reduce the methanogenic activity of the reactor. The characteristics of the waste substrate used as feed were shown in Table 1. The moisture content of waste was found to be ~ 48%. The high moisture content verified that the fruit and vegetable waste was not ideal for incineration or landfilling. The relationship between the amount of carbon and nitrogen in the organic material is presented by the C/N ratio. Bacteria normally use up carbon 25-35 times faster than they use nitrogen.

Table 1. Analysis of bulk waste substrates used as feedstock in digester

Parameters	Units	Value
Moisture Content	%	47.78
Total Nitrogen	% DW	0.59
Total organic carbon	% DW	22.27
Total phosphorus	m/kg	523.032
Calorific value	Cal/g	4,418.22
C/N	% DW	37.74
Total Solids	% weight	10.4

Therefore, at this ratio of C/N (25-35) the digester is expected to operate at an optimal level for gas production. The C/N ratio of the substrate was 37.74, slightly higher than the optimum C/N ratio. A high C/N ratio is an indication of a rapid consumption of nitrogen by the methanogens and results in a lower gas production. On the other hand, a lower C/N ratio causes ammonia accumulation and pH values exceeding 8.5, which is toxic to methanogenic bacteria. Total solids were found 10.4. For the purpose of gas generation the solid content of feed material should be approximately 10-15 percent [6].

3.2. Temperature and pH

The production of biogas is depended on the optimum biodegradation process. Temperature is a process parameter which plays an important role in the anaerobic process. The microorganism can survive from freezing to 70°C. Moreover the bacteria work in temperature of mesophilic condition (25-40°C) with the optimum temperature of 35°C and thermophilic (50-65°C) with dengan suhu optimum <55°C. Besides temperature, pH is another important factor that affected the growth of microorganisms worked in organic degradation anaerobically. Bacteria actively work in the range of specific pH and shows maximum activity in the optimum pH. The optimum pH needed by acidogenic bacteria is in 5-6.5, whereas the optimum pH for methanogenesis bacteria is higher than 6.5 [7].

Fig.1 shows the variation in pH and temperature within the digester during the process. The digester temperature was in about 28-29.8°C during the first two weeks of the digestion process. Then, from the third week it rose and reached the highest temperature which was ± 46°C in the 5th week. After that, it decreased up to a range of 32-37°C until the end of the 14th week. It can be seen that the digestion process ran mostly in the mesophilic condition.

Meanwhile, the acidity of the digester as shown in Fig.1, tend to decreased from the first three weeks from pH of 6.7 to 5.3 until the 9th week and rose again to neutral condition. This result shows that the digester worked mostly in pH value lower than the optimum pH for anaerobic digestion process (6.8-7.4). The decrease of pH represented that there was acid accumulation caused mostly by high concentration of volatile fatty acid in the digester. When the acidogenic bacteria have worked, the organic acid was produced and decreased the digester pH [7].

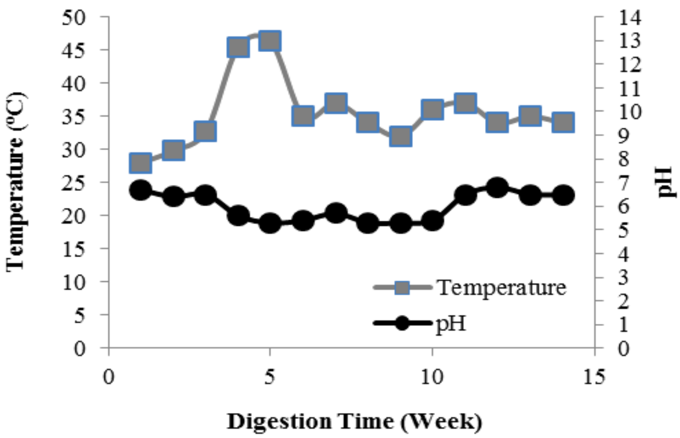

Fig. 1. Temperature and pH of the digester during the anaerobic process

The decreasing of pH revealed that the digester was in the acidogenic phase, whereas after the 9th week, the digester started the methanogenesis phase. Yet, a stable and neutral pH was not easy to reached, showing that the digester needed a longer time to be in the methanogenesis phase. In an anaerobic system, the acetogenic bacteria convert organic matter to organic acids, possibly decreasing the pH, reducing the methane production rate and the overall anaerobic digestion process unless the acids were quickly consumed by the methanogens. Basically, pH in the range of 6.8 to 7.4 should be maintained in the anaerobic digestion process, which is the optimum range for methanogens growth. If the pH could not be controlled, the appearance of volatile organic acid and carbonic acid will increased the acidity of digester. In this research, the decreasing of pH was significantly occurred and reached 5.3. Maintaining pH of the reactor was found difficult in the initial period up to 9 weeks. Thus, in the research, an appropriate amount of 5M $NaHCO_3$ has added to maintain the pH.

3.3. Biogas recovery

The COD profile and weekly CH_4 content are shown in Figure 2. As shown in Figure 2, the CH_4 content in the digester during the experiment was varied in the range of 8 - 65 %. Moreover, the highest methane concentration was detected during the 13th week. Besides that, the biogas flow during the experiment was in the range of 20 - 40 ml/min. It can be seen that digester need long time to do the methanogenic process.

This might be due to the difficulty in maintaining the acidity as well. Methanogenic bacteria may have long mass doubling times in anaerobic reactors and this makes it very difficult to obtain fast acting reactors without retaining most of the biomass normally washed out with the effluent. A work on anaerobic digestion of vegetable wastes, (Banana stem, Cabbage and Ladies finger) has been carried out in a single stage fed-batch [3]. Moreover it reached the similar result with this research: average methane content in the biogas was 65% and the methane yield of 0.387 l CH_4/g VS added for the selected types of wastes.

If sufficient buffering is provided, these wastes can be better utilized for energy production. Since protein rich substrates provide good buffering capacity, highly nitrogenous wastes can be co-digested with Vegetable Wastes to increase the stability of the reactor. Many advantages using co-digestion processes include increase in waste organic load, potential toxic compounds can be diluted, nutrient balance can be improved and increase in biogas yield.

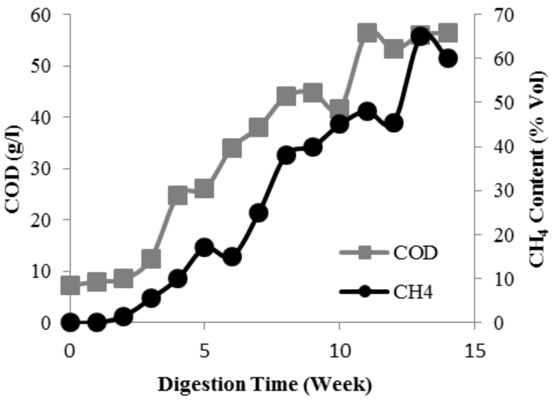

Fig. 2. The value of COD of leachate and CH_4 content within 14 weeks of anaerobic digestion process

Table 2. Typical biogas composition [a]

Types of Gases	Value
Methane (CH_4)	55-70% by vol.
Carbon dioxide (CO_2)	30-45% by vol
Hydrogen sulphide (H_2S)	200-4000 ppm by vol
Energy content of Anaerobic Digestion gas product	20-25MJ/standard m^3
Energy content of CH_4 per ton Municipal Solid Waste	167-373MJ/Ton MSW

[a] Reprinted from Regional Information Service Centre for South East Asia on Appropriate Technology (RISE-AT) (Nov 1998), Review of current status of Anaerobic Digestion Technology for treatment of MSW

A typical biogas composition in Table 2 illustrated the types of gases obtained during anaerobic digestion; comprises of methane, carbon dioxide, some inert gases and sulfur compounds. The CH_4 composition (65%) recovered in this research was within the range of CH_4 composition in typical biogas as presented in Table 2. Moreover, the main advantage in using anaerobic digestion is the biogas production and its potential to be used for generation renewable energy sources. From Table 2, it seemed that the energy content from anaerobic digestion could reached 20-25 MJ/standard m^3.

4. Conclusion

An aerobic digestion is an appropriate technology for handling the waste especially organic fraction of solid waste as fruit and vegetable. The waste characterization shows it is more suitable to be treated anaerobically than other treatment such as incineration. The present set-up digester in this study appeared to be quite effective to treat large amount of mixed solid wastes of fruit-vegetables, giving CH_4 up to 65% vol./10.4 % TS with a flow rate of 20-40 ml/min. It was noteworthy that vegetable wastes were potential source for energy production. Although further study is required to improve the reactor design and temperature control, the renewable energy produced from anaerobic digestion process can be seen as a good reason for many communities to start transformation of valuable resources.

Acknowledgement

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References

[1] Global Food Losses and Food Waste: Extent, Causes and Prevention', FAO, 2011

[2] Velmurugan B, Alwar Ramanujam R. Anaerobic Digestion of Vegetable Wastes for Biogas Production in a Fed-Batch Reactor. *Int. J. Emerg. Sci*. 2011; **1**:478-486.

[3] Shokri S. Biogas Technology, Applications, Perspectives and Implications. *International Journal of Agricultural Science and Research*. 2011; **2**:53-60.

[4] Linga S, Guowei R, Tianhui Z, Rukun Z. Experimental Study on Miniature Biogas Generating System. *Energy Procedia*. 2011; **11**:2615-2623.

[5] H. Bouallagui, Y. Touhami, R. Ben Cheikh, M. Hamdi. Bioreactor performance in anaerobic digestion of fruit and vegetable wastes. *Process Biochemistry*. 2005; **40**:989–995.

[6] C. Polprasert. *Organic Waste Recycling*. 2nd ed., John Wiley and sons Publication: Chichester; 1996.

[7] A. Buekens. Energy recovery from residual waste by means of anaerobic digestion technologies. *In Conference The Future of Residual Waste Management* in Europe, 2005.