Performance of Two Phase Anaerobic Digestion on Food Waste for Biogas Production

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Abstract Every year, the total amount of solid waste generated in Peninsular Malaysia grew, according to the Malaysia government. The typical solid waste management system practiced in developing country brings many problems that can cause risks and hazards for living things and the environment in Malaysia if there are not managed properly. For example, illegal dumping cause groundwater and soil pollution. The methane gas produced from the landfill causes greenhouse effect. Food waste is categorized under household waste, where it is produced in residential areas, restaurants, cafeteria, markets and commercial areas. Therefore, anaerobic digestion process is introduced for organic waste with higher solids contents such as food waste as an alternative method. The effectiveness of anaerobic digestion process can be investigated through this process. In this study, two phase of anaerobic digesters was proposed. The reactor was operated at a temperature 35 °C, analyzed for biogas

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production, pH values and C/N ratio. The highest biogas production in this study is 50.4%. For a co-digestion containing more sludge can increase the pH value and biogas production.

Keywords Anaerobic digestion · Two-phase reactor · Food waste · Biogas

1 Introduction

Municipal solid waste is primarily consists of waste produced by domestic households, even though it includes some commercial and industrial waste. This waste is made up of waste, organics and recyclable materials with the municipality overseeing its disposal. Municipal solid waste is collected then separated to send to landfill or recycling centre for recycling. The waste that is sent to landfill is dump into designated cell, compacted and covered [1].

Due to the demand of Malaysian for quality of life increase, the solid waste generation rate also increase. In year 2001, the solid wastes were generated from 16,200 tonnes/day to 19,100 tonnes/ day in year 2005 in Peninsular Malaysia. Then, total amount of solid waste that were generated in Malaysia has increased to 1.3 kg/capita/day in year 2006 and expected to reach 1.5 kg/capita/day in most cities [2].

Developing country can causes many problems when practiced the conventional solid waste management system such as open dumping without regard for air and water pollution, as well as vermin and fly breeding. These problems can cause risks and hazards for living things and the environment if there are not managed properly [3]. Besides, approximately 95–97 percent of collected waste transferred to landfill for disposal, which necessitates the construction of additional landfills for dumping and only the remaining of waste is taken for intermediate treatment. They are sent for treatment at small incineration plants; diverted to recyclers and reprocessors or dumped illegally [4]. Illegal dumping cause groundwater and soil pollution. The methane gas produced from the landfill causes greenhouse effect.

One alternate option for tackling the concerns mentioned above is anaerobic digestion. This is a biological treatment that can help to reduce the air and water pollution, landfill usage, control groundwater and soil pollution and harness biogas as a sustainable energy source such as cooking gas, electricity and fuel. Anaerobic bacteria compost organic materials in the absence of oxygen and produces leachate, carbon dioxide and methane gas [5].

Food waste is classified as household waste because it is generated in residential areas, restaurants, cafeterias, markets and commercial areas. It typically has a total solids content of 18.1 percent to 30.9 percent, and the anaerobic digestion system requires a large amount of water to homogenize it. These require more energy for pumping, mixing and heating. Therefore, for organic waste with larger solids contents, such as food waste, dry anaerobic digestion procedure has been introduced [6, 7].

In order to facilitate solid waste degradation, two phase anaerobic digestion, which separates acidogenesis and methanogenesis, is an appealing enhancement over single phase digestion for solid waste decomposition. Each phase which tuned separately, resulting in high rate of degradation and energy recovery [8].

Two reactors make up a two phase anaerobic digestion system. The first rector performs hydrolysis, acidogenesis and acetogenic reactions, while the second reactor uses those acids for methanogenesis. Anaerobic digestion by microbial digestion of the organic part of wastes. The organic matter component of food waste is turned into biogas during the anaerobic degradation process in a chain process that consists primarily of four phases. Hydrolysis, acidogenesis, acetogenesis, and methanogenesis are the four reactions involved [5].

The application of anaerobic digestion as a process in a solid waste management system was proposed in this research to reduce the impact of waste on the environment and human health, as well as landfill utilization in Malaysia. The method used in this study is also discussed.

2 Materials and Method

2.1 Material

For this anaerobic digestion, the food wastes used were collected from the food stall area of campus, which is located at Campus Jejawi, Perlis. This is represented kitchen waste from food stores area. It contained residues of chicken, fish and meat, as well as spoiled rice. The bones and shells from food waste were taken out before fed into the reactor.

Two phase anaerobic digestion was made up from two reactors, which are acidogenic reactor for first reactor and methanogenic reactor for second reactor. In this study, two identical glass fabricated reactors measuring 20 cm in diameter and 30 cm in height with capacity of 7L were used. The inoculum, which are sludges from Taman Tunku Sarina (TTS) and Kulim were used for this anaerobic digestion process.

2.2 Method

The first reactor was fed with 1 kg of food waste and 1 kg of inoculum while second reactor was fed with 2 kg inoculum and left in mesophilic condition (35 °C) and acclimatized for 2 weeks. Feeding and loading were carried out manually by opening the cap of valve and pump out the sample. After 2 weeks of acclimatization, 400 ml of leachate from acidogenic reactor is transferred to methanogenic reactor and then 400 ml of food waste is fed into acidogenic reactor to maintain the weight of the reactor. The sludge from TTS was used in both reactor and sludge from Kulim was used together during day 40 in the second reactor. Sample was taken from acidogenic reactor and methanogenic reactor for every 3 days and 7 days respectively to do the tests [5].

Anaerobic digestion needs a suitable sludge to perform well. Parameters such as pH determination after sampling, carbon and total nitrogen (HACH method) were carried out after the process. The inoculum and Calcium Carbonate ($CaCO_3$) was added to increase the pH in the reactor [9]. The amount of leachate that is transferred from acidogenic reactor to methanogenic reactor should be maintain with same amount of feeding. Gas production was measured and analyzed before the samples were collected for biogas analysis using the portable gas analyser GA5000. A tedlar gas sample bag attached to the reactor was used to collect gas.

3 Result and Discussion

Anaerobic digestion is one of the methods that apply in the Malaysia in the waste management. Sludge and food waste co-digestion show positive effect in the methane gas production. To determine the methane gas production that can be achieved through co-digestion, two types of reactors can be used: single phase and two phase reactors. In this study, two-phase reactor was used to determine the methane gas production. The gas was measure in the both reactors. Before being fed into the reactor, the pH of food waste was measured, and it range from 5.88 to 6.62.

This research focused on methane gas production and the characteristics of sludge that affect gas production. Before food wastes were feeding in the reactor 1, the inoculum was acclimatized and the main composition for both inoculum from TTS and Kulim were shown in the Table 1.

Figure 1 shows that the pH and methane gas production the reactor 1. The food wastes were feeding on the 11th day and the pH become acidic on the 14th day, which the value is below 4.3. The pH was drop from 7.7 to 4.1 on that day. The values of pH decrease on day 15 and slightly increase on the 27th day. This condition happened due to acidogenesis phase occurs and turn to acidic condition.

During the stage of hydrolysis and fermentation, non-methanogenic microorganisms are playing role and adapting to low pH [10]. The high concentration of volatile acid in the early phase causes the pH values to drop as well and caused unsuitable condition for the growth of methanogenic [11]. To increase the pH in the reactor 1, the Calcium Carbonate ($CaCO_3$) was added on the 32th day, however the pH still

Table 1 Main composition of inoculum from TTS and Kulim

Test parameter	Unit	TTS	Kulim
Organic matter	%	5.1	29.6
Nitrogen	%	1.6	2.6
C/N ratio	%	0.35: 1	5.69: 1
pH	–	7.5	7.7

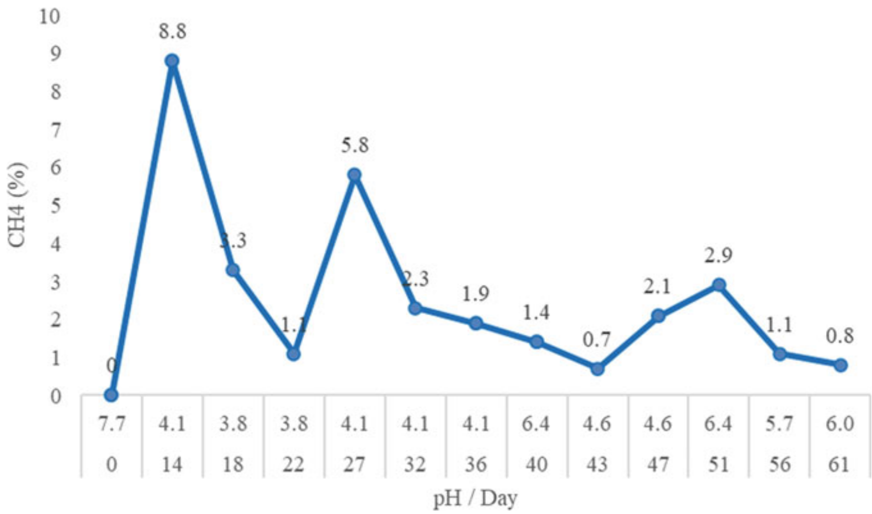

Fig. 1 Results of pH and CH_4 for Reactor 1

maintains at pH 4.1, which is acidic. Then, the dosage of $CaCO_3$ was used increase from 10 to 40 g on day 36. From the result, it showed that the pH was increase on day 40 to 6.1. $CaCO_3$ was used for controlling the pH in the reactor 1.

Figure 2 shows the pH values of reactor 2 of inoculum slightly increase during acclimatized from 7.7 to 8.2 on the 14th day. However, the pH value dropped back to 7.7 on day 18 after feeding time on day 14 and the pH value slowly dropped after feeding time. The pH value increase from 6.7 to 7.2 because on day 40, 2 kg of

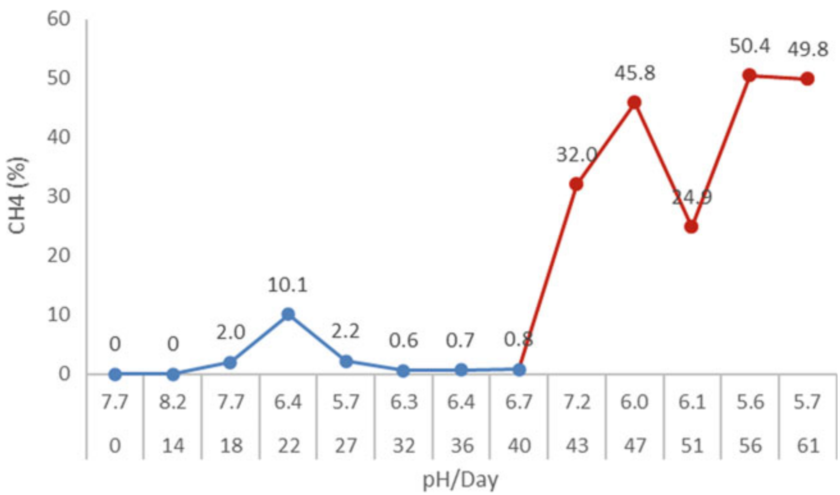

Fig. 2 Results of pH and CH_4 for Reactor 2

inoculum from Kulim was added. Inoculum was added to maintain the pH and to increase the methane production. However, the pH also slowly drops after feeding on the next day.

The methane gas production low in reactor 1 because hydrolysis and acidogenesis occurs in this phase. However, the methane gas production in reactor 2 also low and the higher percentage of methane gas produced only 10% on the 22th day. Then, the inoculum from Kulim was added in the reactor 2 on the 40th day and the methane gas production increase on the 43th day with 32.0%. The highest production of methane gas was on 56th day with 50.4%. Small pH changes affect the methane formers (methanogens) in anaerobic digestion, whereas the acid producers can work adequately over a large pH range. The buffering capacity of the digestive contents affects digestion stability [12]. The acid and methane fermentation phases were well separated, as evidenced by low and high methane yields of 15% and 60%, respectively, in the first and second phases [13].

Figure 3 shows the C/N ratio for both reactors. The C/N ratios for inoculum for both reactors are 5.69. The range of C/N ratio for reactor 1 is 18.78 on the 18th day and 40.96 on the 51th day while for reactor 2 are 5.83 on the 18th day and 14.5 on the 56th day. When the inoculum from Kulim was added on the 40th day in the reactor 2, the C/N ratio was drop from 14.84 to 7.65. This is occurred because of the C/N ratio for the inoculum from Kulim is 0.35 and it is give effect to the C/N ratio in the reactor 2. The C/N ratio for reactor 1 and reactor 2 is 37.48 and 14.25 respectively that produce highest methane gas on day 56. The optimal condition for biogasifcation is 29.6 for C/N ratio in mesophilic condition [14].

Bacteria need a suitable ratio of carbon to nitrogen (C:N) for their metabolic processes. If the C/N ratio is less than 1.0, the bacterial community will digest the substrate more quickly, using carbon 25–30 times faster than nitrogen. A excess of nitrogen will result in the formation of ammonia, which will inhibit digestion [10]. According to Cheerawit [15] a high nitrogen content results in a high C/N ratio, which

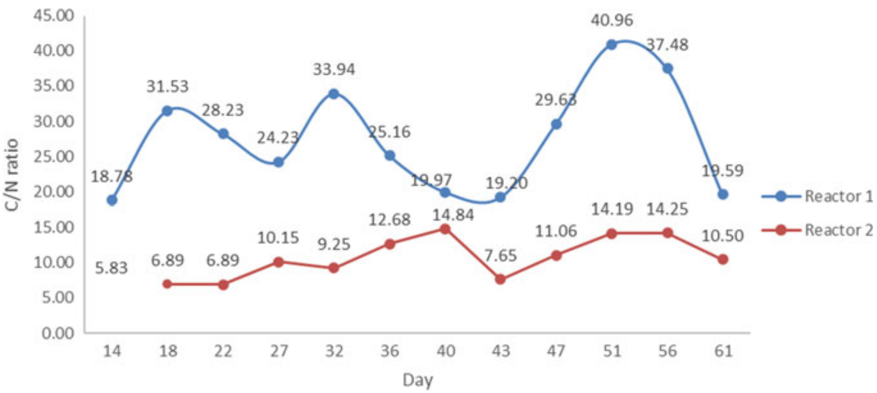

Fig. 3 Results of C/N ratio for Reactor 1 and Reactor 2

increases nitrogen consumption during the starting process, reducing lignocellulosic biomass and led to poor anaerobic digestibility.

The pH values in the reactor 1 can give effect to the pH values in the reactor 2. $CaCO_3$ can be used to maintain the pH in the reactor 1 and need to be added when the feeding occurs. The pH value in the reactor 2 was affected by the sludge from reactor 1. Therefore, for pH value in reactor need to maintain in range 6.5–5.5. For methane gas production, the amount of inoculum is important. The inoculum were added during the feeding also can increase the pH values and the gas production in the reactor 2.

4 Conclusion

In conclusion, the pH value and C/N ratio of co-digestion of food waste and sludge give impact to the production of methane gas. The effectiveness of anaerobic digestion process in two phase anaerobic digester was shown from the methane production, which increased from 32.0% to 50.4%. The amount of sludge used also influenced on the methane gas production for mesophilic condition. In this condition, it can contribute to the microorganism in the sludge that needed for anaerobic digestion, which the process for acidogenesis, hydrolysis and methanogenesis also depends on the microbe from the sludge.

An anaerobic digestion system can become one of the ways to reduce the organic municipal waste and reduce the impact of waste on environment and human health in Malaysia. Waste management system in the Malaysia can be more develop by using this method.

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