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Methane gas production from organic fraction municipal solid waste (OFMSW) via anaerobic process – the application method for Malaysia condition

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ABSTRACT

Solid waste management in Malaysia encounters more problems which includes low collection coverage on average, irregular collection services, inadequate equipment used for waste collection, crude open dumping and burning without air and water pollution control, inadequate legal provisions and resources constraints. This problem contributes various impacts on the development of solid waste management system in Malaysia.

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Biological method will be implemented to improve solid waste management in Malaysia such as anaerobic digestion process. Anaerobic digestion has been suggested as an alternative method to remove high-concentration of organic waste. Many research groups have developed anaerobic digestion processes using different substrates. This research study will conducted two type of anaerobic digester which simulated landfill bioreactor (SLBR) and anaerobic solid-liquid bioreactor (ASLB) of organic fraction municipal solid waste (OFMSW) from food waste. The reactor will be operated at temperature range between 35°C to 60°C. Both reactors will be analyzed for biogas production, volatile fatty acid (VFA), total organic carbon (TOC), total kjeldhal nitrogen (TKN) and microbiology activity.

Keywords - *anaerobic digestion; organic fraction municipal solid waste; food waste; methane gas; Malaysia.*

INTRODUCTION

Municipal solid waste contains significant portions of organic material that produced a variety of gaseous products when dumped, compacted and covered in landfills. Anaerobic bacteria thrive in the oxygen-free environment, resulting in the decomposition of the organic materials and the production of primarily carbon dioxide and methane. Carbon dioxide is likely to leach out of the landfill because it is soluble in water. Methane, however is less soluble in water and lighter than air, is likely to migrate out of the landfill. Landfill gas energy facilities capture the methane and combust it for energy (Landfill gas (http://www.eia.doe.gov) retrieved on 12/01/07).

Landfill gas also known as biogas. Biogas is produced by means of a process known as anaerobic digestion. It is a process whereby organic matter is broken down by microbiological activity and it is a process which takes place in the absence of air. It is a phenomenon that occurs naturally at the bottom of ponds and marshes and gives rise to marsh gas or methane, which is a combustible gas.

There are two common man-made technologies for obtaining biogas; the first is the fermentation of human and/or animal waste in specially designed digester also known as anaerobic digester. The second is a more recently developed technology for capturing methane from municipal waste landfill sites. The scale of simple biogas plants can vary from a small household system to large commercial plants (Biogas and Liquid Biofuels (http://www.itdg.org) retrieved on 12/01/07).

Biogas is mainly composed of 50% to 70% of methane (CH_4), 30% to 40% of carbon dioxide (CO_2) and low amount of other gases as shown in Table 1. Biogas is about 20% lighter than air and has an ignition temperature in the range of 650°C to 750°C. It is an odorless and colorless gas that burns with clear blue flame similar to that of LPG gas. Its calorific value is 20Megajoules (MJ) per m^3 and burns with 60% efficiency in conventional biogas stove (SD Environment: A

System approach to biogas technology (http://www.fao.org) retrieved on 20/01/07).

The same anaerobic digestion process that produces biogas from animal manure and wastewater occurs naturally underground in landfills most landfill gas results from the decomposition of cellulose contained in municipal and industrial solid waste. Unlike animal manure digesters, which control the anaerobic digestion process, the digestion occurring in landfills is an uncontrolled process of biomass decay.

Table 1: Composition of Biogas

Substance	Symbol	Percentage (%)
Methane	CH_4	50-70
Carbon dioxide	CO_2	30-40
Hydrogen	H_2	5-10
Nitrogen	N_2	1-2
Water vapor	H_2O	0.3

Source: (Biogas technology: a training manual for extension. (FAO/CMS, 1996) (http://www.fao.org/sd/Egdirect/Egre0022.htm)retrieved on 25/2/07).

The solid waste management in Malaysia displays a problem such as not enough places to dispose, low collection coverage, crude open dumping and etc. These problems can caused from various factors which have an impact on development of waste management system in Malaysia. Besides that, current issues that always being concern are the increment in the global fuel price, decreasing in fuel source and also environmental issue like water pollution and air pollution (Lau, 2004).

Approximately 95-97% of waste collected is taken to landfill for disposal. The remaining waste is sent to small incineration plants, diverted to recycler or is dumped illegally (Idris et al. 2004). However, this method of disposal causes pollution of groundwater and soil. Furthermore, there is no utilization of biogas from food waste for commercial usage as a potential energy source recently. In particularly, Malaysian food waste is putrefies because of its high water content, where makes its transport and storage difficulty and can cause a serious problem with the leachate produced when it being dumped in the landfill.

Anaerobic digestion can be suggested as an alternative method to cope all the problem mention above. This is one type of biological treatment that can reduce the usage of landfill sites, control the groundwater and soil pollution and the biogas from this process can become the renewable energy with the useful application such as cooking gas, electricity and fuel.

Anaerobic digestion is the natural process where bacteria convert the organic matter into the biogas. The process occurs in anaerobic condition (absence of oxygen) through the acid- and methane-forming (methanogenic) bacteria that break down the organic material and produce methane (CH_4) and carbon dioxide (CO_2) and also a trace of other gaseous that form a biogas. This process can be described as a four staged process.

Phase I – Enzymatic Hydrolysis
Complex wastes in organic matter such as proteins, carbohydrates and fats are converted biologically to less complex soluble organics by hydrolytic bacteria for use as a source of energy and cell carbon.

Phase II – Fermentation Stage
The acidogenic bacteria convert the less soluble organic compounds to organic acids such as acetic acid, butyric acid and propionic acid (also known as volatile fatty acids, VFAs), alcohols and other intermediates.

Phase III- Acetogenic Stage
In this phase, the alcohols and higher VFA are converted into acetic acid, carbon dioxide and hydrogen by acetogenic bacteria.

Phase IV- Methanogenic Stage
Methane is produced from acetic acid and to form carbon dioxide and hydrogen by methanogenic bacteria.

Organic fraction municipal solid waste (OFMSW) can be defined as a specific waste, characterized by its complexity. It is also can be described as a complex substrate and requires more complex metabolic pathway to be degraded (Checchi et al., 2003).

According to Zhang et al. (2007) many factors affect the design and operation conditions. The physical and chemical characteristics of the organic waste also important for designing and performance of anaerobic digestion; this is because it will affect the production of biogas.

Food waste was under the household waste category which means it's generated from the residential area, restaurants, institutional cafeterias and kitchens and commercial area. Food waste is comes from the preparation of food and consists of fruit/vegetable residues, dairy, meats (including bones) and breads also other starchy foods. Almost all food waste is sent to the landfill sites. Anaerobic process will occur in this area and significantly produce methane gas and leachate in landfills (Lay et al., 1997 and Scott et al., 2005).

The characteristics of food wastes that should be added in the anaerobic digestion feedstock with the percentage concentrations of moisture content (88-91%), total solid (9-12%), volatile solids (7-9%) and COD (7.5-15%) (Ağdağ and Sponza, 2007).

In this research, we are tried to propose an application of anaerobic digestion process into solid waste management system and also to minimize the usage of landfill area in Malaysia. Besides that, to discuss the method that can be applied in the research.

MATERIALS AND METHODS

Organic fraction of municipal solid waste especially food waste was collected from the university cafeterias which represent as the kitchen waste of residential area. It contained the components associated with food preparation such as residual fish, chicken and meat, fruit and vegetables, spoiled rice and noodles. The waste should be sort out to different type and then will shred into particles with an average size 6mm. The percentages of each component of food are,

a) Group A: carbohydrate such as rice, noodles, 45%;
b) Group B: protein and fat such as meat, chicken, fish, prawn and others seafood, 30% and,
c) Group C: vegetables, 25%.

The moisture content was assumed 90% and the volatile solids (VS) content was 74% of total solids (TS). This food waste was fed into the reactor after separating bones and shells.

The seed sludge was taken from the anaerobic pond of the palm oil mill factory at Nibong Tebal, Pulau Pinang. Partially of the granulated sludge from the anaerobic digester will feed into the reactor. Both of this seed sludge was in the mesophilic condition. It should be acclimatized to thermophilic condition for 2 weeks.

This research will involve in batch process. Experiments will conduct in lab-scale reactors. Two lab-scale reactors will be used in this study. These reactors operated in one (all in one) phase process and two phase (acidogenic and methanogenic) process respectively. For these two types of reactors will be operated from mesophilic to the thermophilic conditions (35°C - 65°C).

These two reactors were modified and operated by previous researcher Ağdağ and Sponza, 2007 and Xu et al., 2002. First reactor also known as simulated landfill bioreactor bioreactor (SLBR) (Ağdağ and Sponza, 2007) and second reactor is the anaerobic solid-liquid bioreactor (ASL) (Xu et al., 2002). From these two reactors the activity and microbial populations will be examined and will compared to get the most efficient and feasibility used in Malaysia condition.

Simulated Landfill Bioreactor (SLBR)

Glass fabricated reactor also will be used in this study. With 20cm in diameter and 30 cm in height were designed. The schematic diagram of this reactor is shown in Figure 1. This reactor also operated at a temperature of 35 to 65°C under anaerobic conditions. The leachate was collected at the top of the reactor and recycled by using peristaltic pump. Another option to maintain the condition of food waste without supernatant in the reactor is by using the stirrer, with the slowest speed. This reactor will be operated in the water bath instruments.

All the reactors were loaded with food waste and mixed with the sludge/microbe. The first (control reactor, no sludge/microbe added), the second (Run 1) and third (Run 2) were operated with flow rate 400ml/d food waste since it was effective in enhancing the degradation rate of the waste and gas production in the reactor. To consider it was under the anaerobic condition, N_2 gas was injected every time when loading and sampling sample. The weight ratio of the food waste and sludge was 1kg food waste to 2kg of sludge (1:2) and 2kg of food waste to 1kg of sludge (2:1). The operating reactors was run at 35°C, 45°C, 50°C, 55°C, and 60°C.

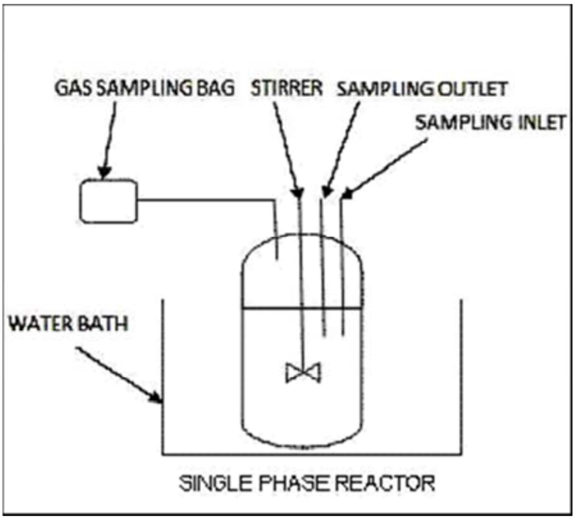

Figure 1: Single phase reactor

Anaerobic Solid-Liquid Bioreactor (ASL)

An anaerobic solid –liquid bioreactor consists of one acidification reactor and one methanogenic reactor. The schematic diagram of the reactor is shown in Figure 2. three runs of experiment (Run A, run B and Run C) were conducted at 35°C, 45°C, 50°C, 55°C, and 60°C. the acidification reactor were designed with the inner diameter (ID) was 140mm with total effective volume of 5L and the methanogenic reactor with working volume of 3L.

In Run A, pre acidification in acidogenic phase was initiated by inoculating 1kg of food waste with 2kg of sludge. After 3 weeks acclimatization (pH monitoring), the acidogenic reactor was connected to the methanogenic reactor to establish the ASL reactor. The leachate from the acidification reactor (400ml) was fed into the methanogenic reactor. The operating conditions of Run A, both in pre-acidification stage and methanogenic stage, were the same as that in Run B and Run C. Run A no sludge added, Run B and Run C added in with sludge/ microbe by weight ratio food waste to sludge 1:1 and 1:2 respectively. The mature granulated sludge (pH 6 – 7) was added to methanogenic reactor. The methanogenic reactor was injected with N_2 every time when feeding and sampling.

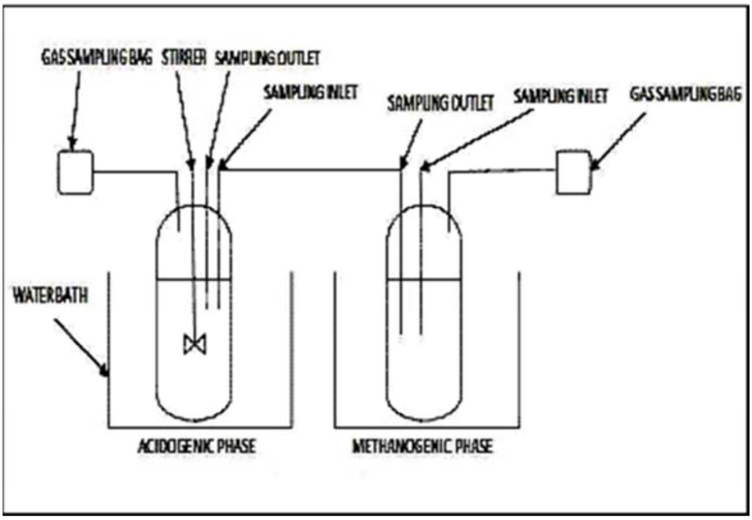

Figure 2: Anaerobic solid-liquid bioreactor

Laboratory Analysis

Leachate characteristic analysis will be done such as pH to determine immediately after sampling to avoid any change due to CO_2 stripping, Chemical Oxygen Demand (COD) follow the standard method 5520B (APHA, 2005), volatile fatty acids (VFA) to determined acetic acid, propionic acid and butyric acid by following the standard method 6200B (APHA, 2005), Total Kjeldhal Nitrogen (TKN) to determined dissolved nitrogenous compounds (Standard method 4500-N_{Org})(APHA, 2005), Energy to determine total energy and energy recovery and Microbial analysis to determine bacteria population and morphology by bacteria counting (CFU) and gram staining respectively.

Biogas Analysis

Gas production was monitored daily by using portable gas analyzer GA2000 Plus. It also was collected by using Tedlar gas sample bag. It then was sampled by inserting gas syringe into the bag and volumetric composition of biogas (CH_4 and CO_2) was analyzed by using Gas Chromatography. Besides volume of methane gas was measured by using water displacement system with liquid solution containing 5% NaOH (w/v) (Isa et al., 1993).

RESULTS AND DISCUSSIONS

Anaerobic digestion is still a new method that going to be applied in Malaysia condition. From the literature review and previous study done by many researchers, it shows that co-digestion of food waste and sludge has a positive effect to the volume of methane production.

Two types of reactors which are single phase reactor and two phase reactor were used to compare for their effectiveness and the optimum volume of methane gas that can be achieved. From the previous study, which have been done 2 years ago, shows the positive results. Table 2 shows the characteristics of the digestion mixture. The pH value of Mixture 2 is higher compare to other mixtures because of the combination between food waste and sludge. Where the amount of sludge was higher; 2kg compare to other mixture.

Table 2 Characteristics of digestion mixtures

Types	pH Ff Sludge	pH of Mixture	Size of Food Waste After Blend (mm)	Moisture Content of Mixture	Amount of Food Waste Used	Amount of Sludge Used
Mixture 1	7.41	6.57	1-5	92%	2kg	1kg
Mixture 2	7.52	7.01	1-5	97%	1kg	2kg
Mixture 3	7.29	6.89	1-5	95%	1.5kg	1.5kg

In this paper, we focusing to the production of methane gas, to prove that food waste have its potential to produce the optimum methane gas. Figure 3 shows the percentages of methane production for Mixture 1, 2 and 3. From the plotted graph, initially the percentage of methane gas production was low. This situation was due to the high concentration of volatile fatty acid in the early phase so the situation was unsuitable for methanogenic bacteria to growth. However after the concentrations of volatile fatty acid decreased, methanogenic bacteria became very aggressive (Marchaim and Krause, 1993 and Fukuzaki et al., 1990).

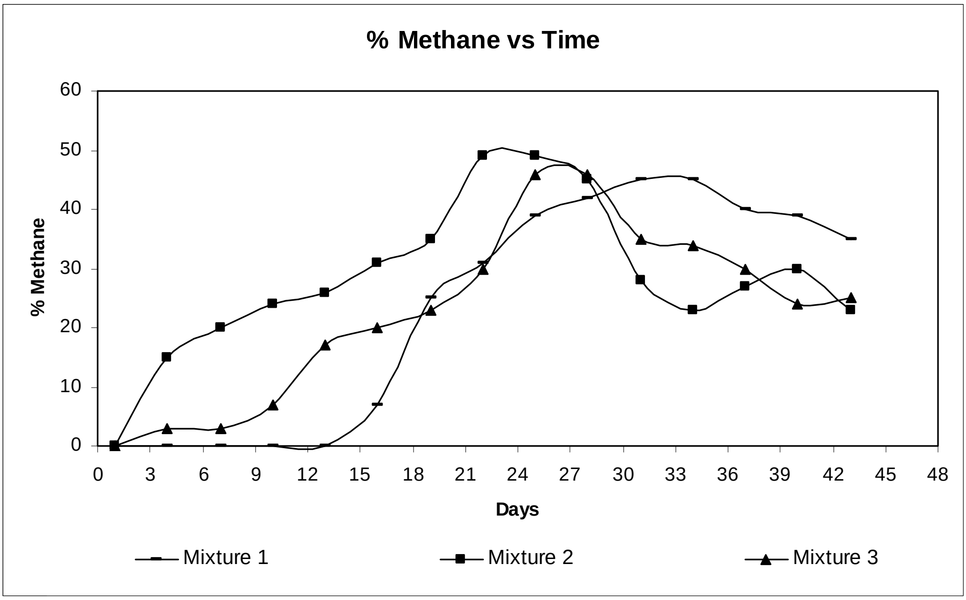

Figure 3: Percentage of methane gas in three mixture

For Mixture 1, the production of methane gas was very slow. This is because the amount of sludge in this mixture was low compared to other mixtures. Reaction between food wastes and microorganisms were also low because of this sludge amount. Besides, the concentration of volatile fatty acids was the highest compare to other mixture. Mixture 1 started producing methane gas only after 16th day (7%). The optimum percentage methane was produced on the 31st day (45%).

Mixture 2 got the optimum percentage of methane gas on day 22 with 49%. When compare to other mixtures, Mixture 2 has the sludge content, this showed the reaction between microorganisms with the wastes was faster when compared to other mixtures (Ağdağ and Sponza, 2005). However, there were several fluctuations on the 31st, 34th and 37th day. For Mixture 3, the optimum methane was on the 25th day with 46%. Generally the plotted graph for Mixture 3 is stable. This is because the food waste content and sludge is balance (1.5kg: 1.5kg). Based from the result, the highest percentages and most production of methane gas were for Mixture 2, and then followed by Mixture 3 and Mixture 1. This probably was due to the amount of food waste and sludge.

As a comparison to this study which was under thermophilic conditions, methane gas production was found to be faster in thermophilic than mesophilic condition. In this study, optimum methane was formed around 20th – 30th day. However the percentage of methane from this study was low compare the result from a study by Ağdağ and Sponza, 2005. This was because total volatile fatty acids concentration was not higher compared to this study. Volatile fatty acid concentration can cause inhibition of methanogenic activity.

CONCLUSIONS

This study shows the effectiveness of co-digestion of industrial sludge and food waste in thermophilic conditions. The amount of sludge used influences the time to get the optimum percentage of methane production. This is because sludge contains microorganisms required for anaerobic digestion process. If the contains highest in the mixture, the process will be faster to achieve the optimum percentage.

Anaerobic digestion system has a potential to become a new resource of renewable energy in Malaysia. This research should be one of the recommended methods that can be applied.

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REFERENCES

[1] Ağdağ, O.N., and Sponza, D.T. (2007). **“**Co-digestion of mixed industrial sludge with municipal solid wastes in anaerobic simulated landfilling bioreactors.” J. Hazard. Mater. 140. 75-85.

[2] Ağdağ, O.N., and Sponza, D.T. (2005). **“**Co-digestion of industrial sludge with municipal solid wastes in anaerobic simulated landfilling bioreactors.” Process biochemistry, vol. 40. issue 5.

[3] American Public Health Association (APHA). (2005). Standard methods for examination of water and wastewater, 21st Ed., Washington D.C., USA.

[4] Checchi, F., Traverso, P., Pavan, P., Bolzonella, D., and Innocenti, L. (2003). “Characteristics of the OFMSW and behaviour of the anaerobic digestion process”, Biomethanization of organic fraction of municipal solid waste, Mata-Alvarez, J (ed), IWA Publishing, UK. p. 141-179.

[5] Fukuzaki, S., Nishio, N., shobayashi, M., and Nagai, S. (1990). “inhibition of butyrate metabolism by acetate and hydrogen, acetate, and propionate.” Application Environment Microbiology. **56**(3), 719-723.

[6] Idris, A., Inanc, B., and Hassan M.N. (2004). **"**Overview of waste disposal and landfills/dumps in Asian countries". J. Mater. Cycles Waste Manage. **6**,104-110.

[7] Isa, M.H., Farooqi, I.H., and Siddiqi, R.H. (1993). Methanogenic activity test for study of anaerobic processes. Indian J. Environ. Hlth. **35,** 1-8.

[8] Lau, V.L. (2004). **"**Case study on the management of materials in Malaysia." Forum Geoökol. **15,** 7-14.

[9] Lay, J.J., Li, Y.Y., Noike, T., Endo, J., and Ishimoto, S. (1997). **"**Analysis of environmental factors affecting methane production from high solids organic waste." Water Sci. Technol. **36,** 493-500.

[10] Marchaim, U., and Krause, C. (1993). "Propionic to acetic acid ratios in overloaded anaerobic digestion." Bioresour. Technol. **46**, 195-203.

[11] Scott, N.R., Jianguo, M., and Brian, S.A. (2005). Using food wastes in farm-based anaerobic digesters. Northeast Dairy Business. **7,** 14-15.

[12] Xu, H-L., Wang, J-Y., and Tay, J-H. (2002). **"**A Hybrid Anaerobic Solid-Liquid Bioreactor for Food Waste Digestion." Biotechnol. Lett. **24,** 757-761.

[13] Zhang, R., El-Mashad, H.M., Hartman, K., Wang, F., Liu, G., Choate C., and Gamble, P. (2007). **"**Characterization of food waste as a feedstock for anaerobic digestion." Bioresour. Technol. **98**, 929-935.