BIOGAS PRODUCTION FROM MUNICIPAL WASTE

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor (Hons.) of Chemical Engineering

Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

April 2012

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"BIOGAS GENERATION FROM MUNICIPAL WASTE"** was prepared by **NITHIYAA MANIKAM** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Bachelor of (Hons.) Chemical Enginnering at Universiti Tunku Abdul Rahman.

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Supervisor : Ms.Bee Soo Tueen

Date : ___________________________

Specially dedicated to
my father and mother.

ACKNOWLEDGEMENTS

First and foremost, I offer my sincerest gratitude to UTAR for providing a precious opportunity to pursue my interest in Bachelor of Chemical Engineering by conducting my final year project in the specified area.

Besides that, I owe my deepest gratitude to my supervisor, Ms.Bee who has supported me throughout my journey completing my final year project programme with her patience and knowledge whilst allowing me the room to work with her without any position borders. One simply could not wish for a better or friendlier supervisor. She is a person full of knowledge where she was very generous in sharing me her knowledge while guiding me on the tasks which were assigned for me.

Furthermore, this report would not have been possible unless with the guidance of my colleagues who shared me their experiences and wisdom when I was doing my projects and report. They correct me if I do any mistakes in the tasks which were assigned to me. In addition, the guide and some techniques from both Professor Dr.Sivanesan and Dr.Elango from Anna University, India have also helped in my report writing as well as experiment conduct.

Besides that, I would like to show appreciation to my parents for giving me moral support throughout the project in UTAR besides guiding me on this report writing. I would like to also thank them for giving me both the physical and financial support to make this report a success.

Last but not least, I heartily thankful to god for giving me a golden opportunity to inculcate self-esteem and confidence in myself by performing in this project. In short, I offer my regards and blessings to all of those who supported me in any respect during the completion of this report and during my project duration.

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ABSTRACT

Waste management problem has raised a huge attention from many authorities. Besides that, non-renewable energy depletion caused awareness to the society on curbing the issue. Due to these current issues in Malaysia, biogas production from municipal waste was being introduced. The method to produce the biogas was anaerobic digestion. Anaerobic digestion is a digestion process of organic wastes without the presence of oxygen. A lab scale anaerobic digester for batch mode was designed and built using mechanical parts. Methane production from municipal waste specifically food waste (fruit, grain and vegetable) was conducted for a period of two weeks respectively. The digestion was conducted by using temperature range of 27 °C to 36 °C and pH 6.5 to 7.5 to yield an optimum condition for the digestion process. The anaerobic condition was maintained by purging nitrogen gas into the digester for 20 minutes whereas the pH value was maintained by adding and mixing 50 ml of sodium hydroxide (NaOH) into the feedwaste. The digestion process was done by the aid of inoculums which was cow dung as the amount of methanogens is high. Methane production was monitored everyday by the height of water in the measuring container and the total methane production was summed after two weeks. The highest yield for methane was grain waste with the value recorded was 2546 ml due to the high content of carbohydrate. The next was fruit waste since the amount of glucose was high and followed by vegetable waste which contains high fibres and cellulose walls. For the fertilization test, fruit waste demonstrated the best observation for the growth of plant due to high content of potassium and followed by vegetable waste. The least effective fertilizer was grain waste due to less content of nutrients essential for plants.

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LIST OF SYMBOLS / ABBREVIATIONS

MW	Municipal Waste
MSW	Municipal Solid Waste
AD	Anaerobic Digester
WWTP	Waste Water Treatment Plant
MP	Malaysian Plan
TS	Total Solid
MHLG	Ministry of Housing and Local Government
WTE	Waste to Energy
GC	Gas Chromatography
SEM	Scanning Electron Microsocpy
LS	Low Solids
MS	Medium Solids
HS	High Solids

CHAPTER 1

INTRODUCTION

1.1 Background

Waste is well defined as something for which do not have any further uses and which is better to get rid of. Municipal waste is a type of waste which is generated by households and industrial area which consist of food wastes, papers, unwanted containers and other solid wastes. In the early times, the disposal of human and other wastes did not pose a significant problem as the amount of waste generated was very small and the land area available for the assimilation of waste was large which is no more the case now. In addition, economists have defined waste as a material that is cheaper to throw than to use.

In olden times, wastes generated by human were trivial caused by the less population and also industrialization. On the other hand, waste exploitation was low contributing to low population. The generated wastes which mainly consist of biodegradable waste were disposed locally on the ground with less environmental impacts. Soon, when the industrialization and developments took over, dumping of wastes were practiced and techniques like incineration, pyrolisis and gasification were found out. Day by day with the peak rises of development, industrialization and also population contributes to higher generation of municipal waste. At present, worldwide municipal solid waste generation is about two billion tons per year, which is predicted to increase to three billion tons by 2025 (Charles, Walker, & Ruwisch, 2009). These wastes are further dumped into the specified landfills causing more and more landfills being opened. In small countries like Singapore, space issues are being an eyesore. Elango, Pulikesi, Baskaralingam, Ramamurthi, & Sivanesan, (2006) stated that space constraints and losses of valuable lands which are potential for other activities occur due to landfilling.

Many methods can be applied for waste management. Gasification is a process where organic wastes are heated in an organic-starved environment to produce a medium or low calorific gas. Pyrolysis is a process where wastes are exposed to a very high temperature in the absence of air, causing the wastes to decompose. Last but not least, incineration is a combustion process of organic matters in waste. It uses heat to convert the wastes into ash. Waste management using above techniques have been applied since very long. The typical way of dumping waste to landfills contributes to climate change. On the other hand, incineration, gasification and pyrolysis are potential to jeopardy human health by releasing toxic emissions such as acid gases, nitrogen oxides, lead, sulphur dioxide and etc. Moreover, the heating process requires big lump sum of energy and indirectly increases the cost of it. Landfilling and other waste management methods harm the earth by polluting the air and water. Related to this, odour and taint issues are also a concern and these methods do not provide odourless process.

Furthermore, energy is an essential need to the mankind. Lungkhimba, Karki, and Shrestha (2010) mentioned that the increasing energy prices and needs for reducing the consumption of fossil fuels have drawn increasing attention to the development of alternative technologies to produce renewable energy. Thus, conversion of waste into energy or also called as waste-to-wealth is believed to bring many energy, environmental and public health benefits (Ofoefule et al., 2010). Hence, it is believed that cost can be saved and a green method can be applied. For instance, in United Kingdom, Xuereb (1997) reported that, although the use of biogas for electricity generation was still at an experimental stage, it has already accounted for 0.5% of the total electricity output.

One of the green methods to manage waste is through the anaerobic digestion as many benefits can be obtained from this method. Azlina and Idris (2009) mentioned that anaerobic digestion is a method of decomposition of organic matters in the absence of oxygen to produce biogas as fuel gas and generates odour-free residues rich in nutrients. It produces a large scale of methane and small scales of other by products. Biogas with its main component methane (CH_4) and sub component of carbon dioxide (CO_2) is a gas which is produced from the digestion of organic matters and without the presence of oxygen (O_2). Biogas is generally composed of 48 to 65 % methane, 36 to 41 % carbon dioxide, up to 17 % nitrogen, less than 1 % oxygen, 32 to 169 ppm hydrogen sulphide and traces of other gases (Ward, Hobbs, Holliman, & Jones, 2008). In addition, biogas stands strong for its definition as by product of the biological breakdown and it is also known as swamp gas, marsh gas and Gobar gas (Mattocks, 1984). Biogas is a high quality renewable energy source that can be substituted with other costly energies and needed for developmental activities. Biogas energy therefore can reduce cost and also generate power. For example, in Sweden many city busses are generated by biogas and some gas stations there offer biogas instead of other fuels (Charles et al., 2009).

Hence, applying pyrolysis, incineration and gasification is tantamount to peril the earth and as the wisest creature, humans should preserve the earth for the coming generations. A green way to transform these wastes to wealth is through anaerobic digestion. This is why anaerobic digestion method was chosen for this study as it is the most suitable type to produce biogas in environmental friendly way.

1.2 Problem Statement

Energy is a vital need for all living beings. The unsustainability of conventional energy together with their pollutions to the earth made renewable energy as the prime need for time being. Renewable energy has high value of commerciality as it can be used as substitution for fuel to generate electricity. Municipal waste generation is increasing tremendously with the population and also the development by industrialization and urbanization. Municipal waste is being a nuisance to the earth by volatile organic compounds emission, leachate formation, attracting vectors (rodents, birds and insects) and also being jeopardy to the public health (Scaglia, Confalonieri, DÍmporzano, & Adani, 2009). As mentioned above, the municipal wastes are dumped to many landfills which causes space constrains in small countries and losses of valuable lands which are potential for other commercial activities (Elango et al., 2006). Other waste management methods such as incineration and pyrolysis causes air pollution problem. The purpose of this study was to conduct the production of biogas through anaerobic digestion and determine whether it is a green method or otherwise.

1.3 Aims and Objective

The main objective of this project was to use lab scale, batch type anaerobic digestion method to observe the production of methane from the kitchen waste in coherence to solving the waste management. In order to achieve the main objective the following sub objectives were needed:

i) To design a lab scale anaerobic digester;
ii) To compare three types food wastes consist of vegetable waste, fruit waste and grain waste which were fed into the digester;
iii) To determine the amount of methane produced for each waste;
iv) To study and compare the morphology of the sample waste;
v) To observe the efficiency of each waste residue as fertilizer.

1.4 Scope of Study

Therefore, the scopes of this project were:

i) Design and building the digester from low cost items.
ii) Three types of wastes which were used in this research are fruit, vegetable and grain waste. Fruit and vegetable wastes were collected from Genting Klang Market. Bread waste was collected from Sweetly

Bakery, Genting Klang and the rice waste was collected from Restoran Genting Klang.

iii) Measurement of methane was done by measuring the height of water level in measuring container everyday for period of two weeks.

iv) Scanning electron microscopy (SEM) of samples from each waste was done to study the morphology of the waste.

vi) The remaining residue in the digester was dried using tray dryer and blended using power blender. The dried residue was used to fertilize the plants every week and observation was carried out for one month.

CHAPTER 2

LITERATURE REVIEW

2.1 Background of Biogas and Methane

Biogas production from municipal waste has been practiced since a period of time. However, the effectiveness of the production has not been confirmed. Biogas is the gas which is produced from the decomposition of organic matters. Any wastes which are organic can be used to produce biogas. According to Dangoggo and Fernando (1986), biogas is a high quality renewable energy which can be a substitute for the non-renewable energy.

Biogas originates from the bacteria in the process of bio-degradation of organic material under anaerobic (without oxygen) conditions. Diaz, Bwanika, and Tumwesige (2008) found that biogas mainly consists of methane gas depending on different types of feedstock which produces other minor biogas composition. Biogas is about 20 % lighter than air and has an ignition temperature in the range of 650 °C to 750 °C (Diaz et al., 2008). The typical yield of biogas composition from four major types of organic wastes is shown in Table 2.1. It was proven that variety of feedstocks such as landfiils, wastewater treatment plant (WWTP) and sewage sludge yield different percentage level of biogas compositions. According to Rasi (2009), biogas is considered a waste based biofeul and it is used widely as vehicle fuel which emits lower amounts of nitrogen dioxide, hydrocarbon and carbon monoxide emissions than petrol or diesel engines.

Table 2.1: Composition of Biogas from different types Feedstock (Naesko Environment's Association, 2009).

COMPONENT	HOUSEHOLD WASTES	WWTP SLUDGE	AGRICULTURAL WASTES	FOOD INDUSTRY WASTE
CH_4 % VOL	50-60	60-75	60-75	68
CO_2 % VOL	38-34	33-19	33-19	26
N_2 % VOL	0-5	0-1	0-1	-
O_2 % VOL	0-1	0-0.5	0-0.5	-
H_2O % VOL	6(40° C)	6(40° C)	6(40° C)	6(40° C)
TOTAL % VOL	100	100	100	100
H_2S mg/m_3	100-900	1000-4000	3000-10000	400
NH_3 mg/m_3	-	-	50-100	-

From the Table 2.1, it can be seen that the percentage of biogas yielded varies for the four types of waste. Since the major concern for this research is the methane yield, other than the household waste all the other waste has high methane percentage. According to a research done by Bruijstens et al. (2008), the food waste which has the maximum methane content can reach as high as 85 % compared to other waste. Thus, in this study food waste was chosen as feedstock and the types of food wastes were varied accordingly.

The sustainability and demand of biogas can be said solely due to the methane content in the gas. The methane gas is the primary factor which causes the commerciality of biogas. Due to the presence of high percentage methane, biogas is widely used in many facets. Methane is a chemical compound with chemical formula of CH_4. It is a colorless, odorless gas with a wide distribution in nature. Besides that, is known as one of the most abundant organic compound on earth. At room temperature, methane is a gas less dense than air. It melts at –183 °C and boils at –164 °C (Shakhashiri, 2011). It is not very soluble in water. Nevertheless, methane is combustible, and mixtures of about 5 % to 15 % in air are explosive. This particular characteristic made fuel as principal use. The combustion of methane is highly exothermic as shown in Equation 2.1 (Shakhashiri, 2011).

Though, due to methane's shorter atmospheric lifetime (twelve years), it is believed that global emissions would only need to be reduced by about 8 % from the current levels to stabilize methane concentration in the environment (Talyan, Dahiya, Anand, & Sreekrishnan, 2006). Thus, it is important to reduce methane's concentration for balancing the environment as methane is a relatively potent greenhouse gas (GHG). The energy that is released from the methane's combustion is the main cause for the high demand as fuel substitution. A source from Hensher and Button (2003), the concentration of methane in earth in 1998 expressed as mole fraction was 1745 nmol/mol and ten years after in 2008 it was raised to 1800 nmol/mol. Methane (CH_4) is twenty five times more potent than carbon dioxide (CO_2) in a 100 year basis leads to contribution of greenhouse gases (GHG) (Naesko Environment's Association, 2009).

$$CH_4\,(g) + 2\,O_2\,(g) + CO_2\,(g) + 2\,H_2O\,(l)\ \text{Ä}H = -891\ kJ \qquad (2.1)$$

Even though methane has a very commercial value, its emission to the environment causes greenhouse effect. Referring to Figure 2.1, methane percentage shows as second top priority for greenhouse gases contribution. Consequently, the earth is becoming warmer and humans are no longer protected from the divine chain of earth. The major cause of greenhouse gas emission is due to landfilling which was mentioned in a study conducted by Lungkhimba et al. (2010). Open landfilling is defined as where the waste is dumped and causes rapid aerobic digestion to produce methane gas. This issue is becoming an eyesore thus the society and authorities are pin pointing to each other which is tantamount to condoning it. Landfiiling can only be a temporary choice to managing waste as in long term, it will cause many drawbacks.

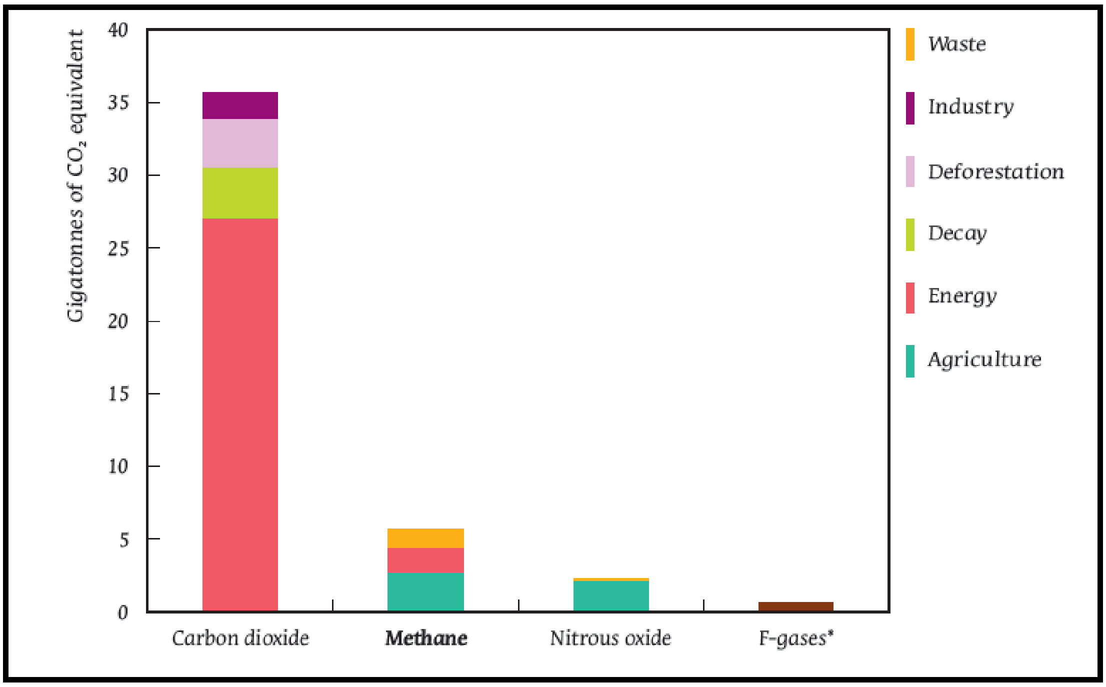


Figure 2.1: Methane as the Second Most Important Greenhouse Gas (GHG) (International Energy Agency, 2009).

From the Figure 2.1, it can be seen that methane contributes to greenhouse gases after CO_2. In addition, the yellow part shows methane emission due to waste accumulation. Besides that, the pink colour shows the greenhouse gases production from non-renewable energy. Hence, it is clear that landfilling causes production of methane and the usage of fossil fuels also contributes to global warming. Therefore, the importance of producing methane from municipal waste is undoubtedly proven. Supposing, the methane which is released should be used as fuel to substitute the non-renewable energy. Any substances on this world are a remedy if it is used in correct amount and it is poison when used more than the limit. Hence, the demand on methane should be commercialized in proper way and at the same time landfilling which causes greenhouse gases can be overcome.

Biogas has many benefits to the society nowadays. Day by day, the demand of biogas is increasing due to its high quality as a renewable energy. One of the main advantages is biogas as a source of energy. Energy is one of the basic requirements of all living beings. The unsustainability of conventional energy resources and their associated environmental pollutions made renewable energy the prime need of present time (Lungkhimba et al., 2010). The methane gas is useful as a fuel substitute for petrol, diesel, and electricity, depending on the nature of the task, local supply conditions and constraints with great efficiency and productivity.

Biogas as an energy source can be used as fuel in transportation and also cooking which was mentioned in Ninth Malaysian Plan (9MP). Since, it is a flammable gas which was fermented under anaerobic digestion, it fulfils the energy fuel requirement. It burns with pale blue flame and has a calorific value between 25.9-30 J/m3 depending on the percentage of methane in the gas (Sagagi, Garba, & Usman, 2009). One biogas plant is computed to save 32 liters of kerosene and four tonnes of firewood every year. Biogas is preferred to replace petrol as the ozone forming potential of engine emissions would be decreased by 50 %. Furthermore, NO_X emissions will be decreased by 25 % and greenhouse gases would be reduced significantly by 63.3-77.2 kg of CO_2. Moreover, concentration of methane in biogas can improve the performance of spark ignition engines and reduces hydrocarbon emissions (Rasi, 2009).

Biogas production is one of the methods to reduce the municipal waste generation (MW) as mentioned earlier. Municipal waste generation is increasing tremendously due to the industrialization and urbanization. Other waste managing methods such as incineration, pyrolysis and also gasification yields green house gases and leachate formation. This is not environmental friendly and causes global warming. Hence, biogas from municipal waste indirectly provides a waste management method. Besides that, biogas technology transforms organic waste to high quality fertilizers (Mshandate, Kivaisi, Rubindamayugi, & Mattiasson, 2004). It is known that the digestion of the organic wastes will produce bio fertilizers and was proven to give the plants sufficient nutrients to grow well. Biogas also helps in promoting a hygienic environment with less odour and vectors such as rodents, flies and pathogens. This is due to the reduction of waste by using them for biogas production and thus amount of municipal waste will be minimized. Thus, cleaner surrounding where less smell will be obtained. Rodents, flies and other vectors will be prevented when there are less dumping areas.

2.2 Demand in Malaysia

The usage of methane or biogas as an alternative fuel has been widely spread around the world hundreds of years ago. However, the application is still low in Malaysia even though when there are many criteria which can contribute to the biogas industry. The demand for non-renewable energy as well as green method for waste managing has peaked up in Malaysia. Nowadays, many people are finding opportunities to conserve the energy at the same time to reduce the cost expenses.

Oil and gas industry has been the pillar in Malaysia. The industry has been estimated that the gas reserves will be estimated to last another thirty three years and oil reserves another nineteen years (Institution of Engineers Malaysia, 2008). According to STAR newspaper (2003), Malaysia has been estimated to be third highest for GHG emission in ASEAN countries. The countries with the highest GHG emission are Brunei and followed by Singapore. The emission has increased tremendously from the year 1994 to 1998 due to inefficient usage of energy. Compared to international level, the GHG emission is three to four times higher. The uprising amount of carbon emission has brought the implementation of Kyoto Protocol. Although by international standards, industrialized nations had values three to five times higher, and Malaysia should not be complacent by its achievement. Yet, Malaysia should maintain the amount of GHG emission to the environment to set an example among the ASEAN countries.

Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change. The major feature of the Kyoto Protocol is that it sets binding targets for 37 industrialized countries and the European community for reducing greenhouse gas (GHG) emissions .The major gases involved were water vapour, carbon dioxide and methane but the major concern is methane. The crucial of methane emission should be always bared in mind. Since, a protocol was established to save the nature worldwide, every country should play their role to sustain earth for future generation. Malaysia as well has to take actions before it is too late to mend.

Biogas industry has a very bright future in Malaysia. The weather and humidity in this country makes an optimum condition for the breakdown of the organic compounds. A review and outlook of gas industry in Malaysia for upcoming years are summarized below which was adapted from the official website of Gas Malaysia. The Malaysian oil and gas industry has established several specific strategies which were mentioned in the Ninth Malaysia Plan (9MP). 9MP is a comprehensive blueprint prepared by Malaysia's Economic Planning Unit of the Prime Minister's Department and the Finance Ministry on the national budget allocation. In relation to gas, the following were highlighted in Ninth Malaysia Plan (Gas Malaysia Berhad, 2012):

i) Intensify the development of domestic resources and secure overseas resources to sustain long-term supply of natural gas.
ii) Additional 54 natural gas stations to be constructed including development of dedicated natural gas stations.
iii) Review further incentives to encourage natural gas conversions.
iv) Review energy (including gas) prices so as to ensure more market reflective prices.
v) Undertake review to gradually reduce subsidies.
vi) Reconsider other energy sources for power generation.
vii) Support ASEAN efforts in energy cooperation.

From above, it is clear that Malaysian Government is supporting sustainability towards the green future. The natural gas industry will be an answer to support the green future. The natural gas industry can be divided into many facets depending on the source to produce natural gas. Malaysia government is supporting the ideas of running vehicles with natural gas and many stations are being built. Thus, biogas production should be commercialized here as biogas is the most green and environment friendly method. Many researches were done all over Malaysia to commercialize biogas.

2.2.1 From Waste to Energy, Semenyih Selangor (STAR, June 21, 2011)

A dairy farmer built a biogas plant for proper waste management for his farm since the overwhelming stench of the manure instantaneously brought large army of flies to the particular area. Due to this, it brought an impression to the public that the farm was unhygienic and poor quality.

From the Figure 2.2, is shown where the bacteria digest the sludge into energy to generate the electricity through a power generator. The biogas produced is used for various reasons such as for powered hot showers, cooking stove, rice cooker and also water boiler. Furthermore, a generator is used to convert the gas into electricity for lighting and vacuum pumps for extracting milk from the cows. In total, the farm produces gas up to 5 kW which is more than enough for the total usage of the farm.

Figure 2.2: Biogas Chamber in Dairy Farm in Semenyih (Star, 2011).

2.2.2 Turning Waste into Viable Income (STAR, December 28, 2010)

Krubong landfill was chosen as a source to generate energy from the waste by the Chief Minister and other related parties from Malacca Statistically, people in Malacca produce between 1.3 to 1.4 tonnes of waste daily with the cost of disposing them reaches up to RM70, 000 daily. The Krubong landfill can only last for another three years and the other landfill in Sungai Udang can only last another five years and have to be replaced with new sites. More biogas plants are yet to be built prior to increment of waste.

2.2.3 Turning Waste the Modern Way, Bangi (STAR, May 3, 2011)

The stacks of food containers in the landfill area caused a research officer, Shyful Azizi Abd Rahman to request dumping the wastes into a 60 kg composting machine. All the waste goes into a 60 kg composting machine. The machine is known as Cowtech Composting & Biogas Production Machine and it breaks down organic waste with the help of bacteria to yield nutrient-rich compost and biogas. From the experiments that were done, agricultural waste produced the least methane and when compared to food waste, it generated very high biogas about five to six litres daily.

Figure 2.3 shows the Cowtech system where waste is composted anaerobically (without oxygen) inside the composting machine. Methanogenic bacteria (inoculated into the machine during manufacture) break down the waste into compost, while releasing biogas which is typically made up of methane (50 % to 70 %), carbon dioxide (24 % to 50 %), hydrogen sulphide (3 %) and small amounts of nitrogen, hydrogen and oxygen. The biogas produced is used for direct heating of stoves and lamps and also to generate electricity.

Figure 2.3: The 60 kg/day Cowtech composting machine at the Malaysian Nuclear Agency (STAR, 2011).

2.2.4 Turning Pig Waste into Energy, Sitiawan (STAR, March 15, 2011)

A pig farm was chosen to generate renewable energy from animal waste. A biogas plant was built to convert the waste into methane to generate electricity. It is believed that the plant can generate up to 500 kW of electricity. The farm will be powered by the electricity which is generated by the biogas plant and it can save up to RM35 000 every month.

In the case with incentives provided by the state government, the plant can operate more efficiently. There are around 131 pig farms in Perak itself and country can pursue the goal towards greener environment if all the suitable parties can adapt this technology.

2.2.5 Power from Oil Palm Waste, Kota Kinabalu (STAR, May 7, 2010)

Kota Kinabalu, is one of the top state for oil palm production and as a consequence producing very large amount of oil palm waste. Chief Minister Datuk Musa Aman, mentioned that instead of turning the wastes into environmental hazard, oil palm waste such as fronds, harvested fruit bunches and trunks could be collected for electricity generation and also as fertilizers.

This action is expected to alleviate problems associated to oil palm waste disposal. This should be more priority for fruit bunches which emit methane the largest. Besides, this will open a path for the oil palm's industry to move towards earning the sustainability label.

2.3 Municipal Waste (MW) Generation in Malaysia

As mentioned earlier, biogas is produced from organic waste. Nowadays, biogas production is applied as a method for managing wastes. The municipal waste generation is increasing massively with the increment of world's population. Municipal waste is largely composed of solids that are regarded as useless, unwanted, and generated from commercial and domestic units of urban centres (Igoni, Abowei, Ayotamuno, & Eze, 2008). It is a non-fluid type of waste and this makes its handling and management relatively difficult, compared to other types of waste that can flow from one location to the other or even vaporize (Igoni et al., 2008). Solid wastes are those wastes from human and animal activities including liquid wastes like paints, old medicines, papers, tins, plastics etc and municipal waste contains largest amount of organic matter.

Early municipal waste management consisted of digging pits near either temporary or permanent dwellings and burying the refuse. This practice turned out to be unsustainable due to the interest of archaeologists who attempted to determine the type of population at certain areas. Nonetheless, some householders threw the wastes into drain and river causing contamination and jeopardy to health. Subsequently, few authorities were introduced to measure the amount and types of wastes which were dumped. This was the benchmark for the management systems that Malaysia is having now. In Malaysia, current population growth has reached 27 million of total population and the municipal waste generation also increases proportional with population. Population growth of 2.4 % per annum or about 600000 per annum since 1994 will be increasing in the future as well (Amirhossein, Ezlin, & Shahrom, 2009).

It is estimated that the amount of municipal waste by the year 2020 will reach up to nine million tons per year. Figure 2.4 shows that the average amount of MW generated per year is 2 % which considered high. This composition will keep increasing due to rise in population. In 2006, about eight million tonnes of solid waste were generated in Malaysia, enough to fill up 42 buildings. Chua, Yip, & Nie, (2008) stated that in 2006, a study was carried out by Japan international corporation agency which shows that 45 % of Malaysia consists of food waste. Now, focusing into the city of Kuala Lumpur where in 1991, the city has spent roughly around RM25.2 million costs for managing solid waste. Due to that, Environment Protection Society Malaysia (ESPM) called for an official policy for recycling solid waste in 1979 and mentioned that waste should be separated accordingly and organic waste should be used in biogas plant.

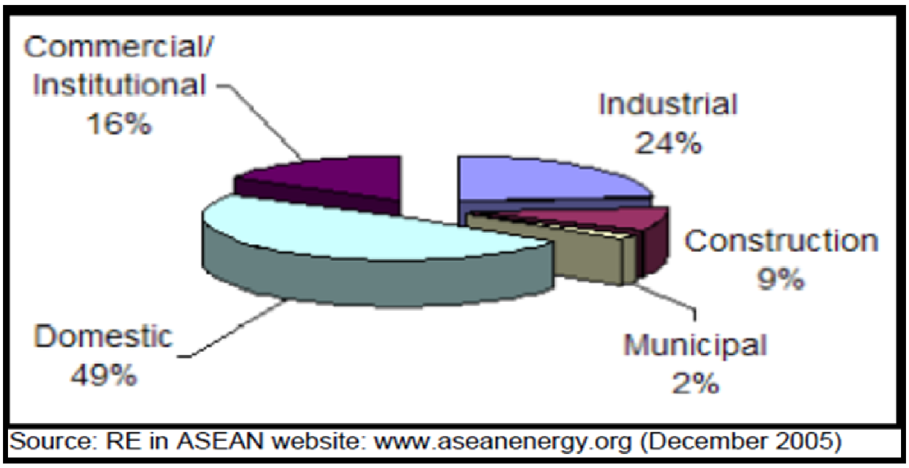


Figure 2.4: Composition of Waste in Malaysia (ASEAN Organisation, 2005).

The industrial area in Malaysia is mainly concentrated in KL, Penang and Johor (Saeed, Hassan, & Mujeebu, 2009). Municipal waste generated in KL in 2002 is shown in Table 2.2. From all the most developed states in Malaysia, garbage contributes the highest to the total municipal solid waste in Malaysia. The amount of garbage generated is almost 50 % from the overall composition as shown in Table 2.2. Garbage or in other word is known as food waste is defined as uneaten portion of meals, leftover and trimmings from food preparation from restaurants, kitchens and cafeterias (Chua et al., 2006).

Table 2.2: Solid Waste Compositions of Selected Locations in Peninsular Malaysia (Saeed et al., 2009).

Waste Composition	Kuala Lumpur	Shah Alam	Petaling Jaya
Garbage	45.7	47.8	36.5
Plastic	9.0	14.0	16.4
Bottles/Glass	3.9	4.3	3.1
Paper/Cardboard	29.9	20.6	27.0
Metals	5.1	6.9	3.9
Fabric	2.1	2.4	3.1
Miscellaneous	4.3	4.0	10.0

In addition, Table 2.3 clearly shows that in the year 2023 that population will be keep increasing until 4.21 million and corresponding to it, municipal waste generation also increases. The total municipal waste that will be generated in future is in a large amount. Space constraints, odor problems, hygiene problems and health problems will soon arises due to the high amount of waste. The municipal waste generated in 2023 will double the amount generated in 2011 which is approximately 3.5 million as shown in Table 2.3. Since, food waste has the highest composition and its one type of organic waste, managing the food waste portion will be equally good to conserving and sustaining the earth.

Table 2.3: Prediction of Total MW in Kuala Lumpur (Saeed et al., 2009).

Year	Population of K.L. city Millions	MSWG Kg/Cap./day	MSWG Tons/day	MSWG Tons/year
2009	2.43	1.66	4029.85	1470895.25
2011	2.63	1.72	4534.78	1655194.70
2013	2.85	1.79	5102.97	1862584.05
2015	3.08	1.87	5742.35	2095957.75
2017	3.33	1.94	6461.85	2358575.25
2019	3.60	2.02	7271.50	2654097.50
2021	3.90	2.10	8182.59	2986645.35
2023	4.21	2.19	9207.84	3360861.60

Figure 2.5 shows the percentage of waste which can be recycled in Kuala Lumpur alone. Among all, the percentage of food waste is the highest. Thus, it is clear that developed states in Malaysia contribute to high food waste which directly caused garbage as the highest percentage in Malaysia. In addition, statistics show that only 3 % to 5 % of the solid waste is being recycled. The volume of waste generated in Malaysia is expected to increase 2 % per annum. Only disposal of solid waste is done solely by dumping to landfills (Wahid, Hassan, & Muda, 1996).

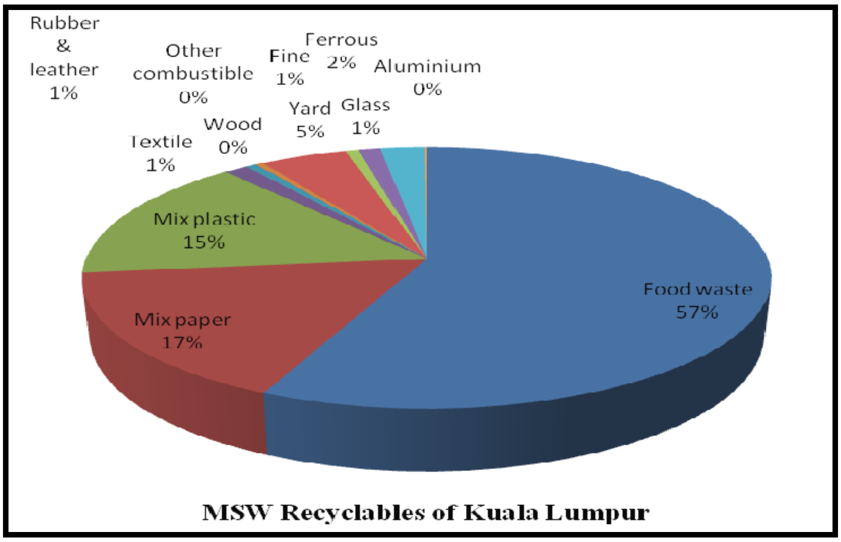
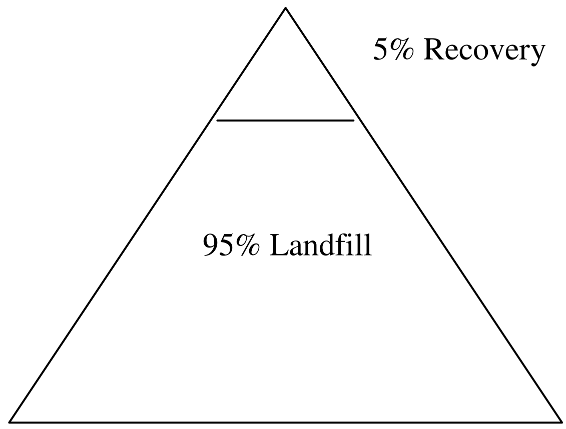


Figure 2.5: Municipal Solid Waste fraction in Kuala Lumpur (Wahid et al., 1996).

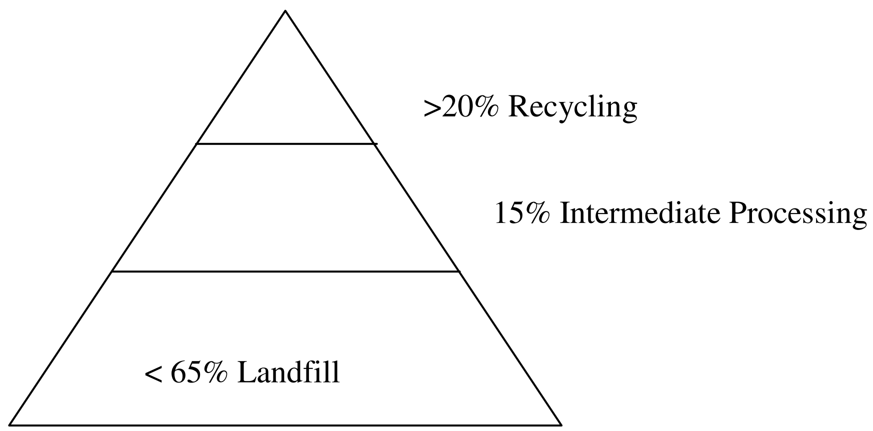
Between all the countries in the world, only Denmark has a reduction of total generation of wastes annually. Even in Malaysia, due to the massive increment of waste causes enormous rise in landfills area. Below is a short summary and statistics on the number of landfills in Malaysia. Survey by Sakawi (2010) revealed that in 1998, there were 230 official dumping sites and about 49 were landfills. In the year 2002, there were roughly 161 disposal area and approximately 50 % are open dumps. Sanitary landfills were less likely to be practiced and the only private operated, engineered and modern sanitary landfill is the Air Hitam Sanitary Landfill. Currently, 290 landfills are operating in Malaysia and only seven of them are sanitary landfills (Wahid et al., 1996).

Sanitary landfill is a dumping area where waste is isolated from the environment until it is safe. It is considered when it has completely degraded biologically, chemically and physically. The disappointing fact is that in Malaysia, most of these landfills are just open dumps. There are three times more illegal dumping areas in whole country. Lack of proper sanitary landfills and increasing the amount of generated waste do not show a good future for municipal solid waste in Malaysia (International Energy Agency, 2009). In the Seventh Malaysia Plan (1995-2000), the Federal government had spent RM 20.9 million to build nine sanitary landfills and upgrade 27 existing landfills in 34 local authorities (Ministry of Housing & Local Government, 2012).

The current status of waste hierarchy in Malaysia and the future goal by 2020 is shown in Figure 2.6. According to Eight Malaysian Plan (MP 8), this country will be pursuing environmentally sustainable development to enforce long term growth. Even though, there are several plans and policies in Malaysia towards green future, lack of realization is present among the public. From the Figure 2.6, it is clearly shown that Malaysia would like to reduce the number of dumping areas. This goal should be obtained by the year 2020. Ministry of Housing and Local Government has identified the way forward to reach the goal which is enhances the waste minimization and also sustainable waste management (Ministry of Housing & Local Government, 2005).



a)



b)

Figure 2.6 (a) & (b): Malaysia's Waste hierarchy 2011 and 2020 (targeted) (Ministry of Housing & Local Government, 2005).

Hence, in this study food waste is chosen as feedstock for the biogas production. This will allow us to determine which type of food waste will yield highest biogas production and biogas production will be the 'green' answer for managing municipal waste. Municipal waste decomposes by the action of microorganism under anaerobic conditions to produce biogas. The total solids (TS) concentration of the wastes influences the pH, temperature and effectiveness of the microorganism in the decomposition process. Municipal waste management becomes global issue concerning worldwide including Malaysia. With the generation rate 1.5

kg/capital/day of municipal waste, Ministry of Housing and Local Government (MHLG) currently face big problems dealing with it.

Thus, waste to energy (WTE) method is being implemented. As mentioned before, producing the biogas from municipal waste should be implemented. The increasing municipal waste generation causes many drawbacks. Space constraints, loses of valuable lands and also odour and rodents contribution are some of the shortfalls. In small countries, spaces are being a major concern to the community. Countries like Singapore, they have a very limited space and with the increasing municipal waste will causes more landfills being built. This is indirectly related to the loss of valuable lands. Some lands are very much potential to be commercialized for other activities. For example, the soil might contain very high nutrients where it will be suitable for agriculture purpose. When the space is used for landfill purposes, the high potential spaces and lands will be wastage.

Besides, as mentioned earlier landfills can attract vectors such as rodents and flies. The increasing municipal waste causes more landfills to build and the dumping of the waste causes the contribution of vectors to that landfill. The odour of the dumping and their toxic emissions can causes jeopardy to human health. ’Hold Paramount the Safety, Health and Welfare of the Public’ is the first code in Code of Ethics for Engineers. As a wise engineer, designing and researches should be done coherence to the Code of the Ethics. Furthermore, waste collection and dumping system that are being practiced in Malaysia are the most expensive activity in waste management system. This is due to the two types of cost being covered which are direct and indirect cost. Direct cost includes all direct expenditures incurred in the management of solid waste in an area. It also includes transportation and disposals. Conversely, indirect cost refers to that includes environment damage cost of hazard storage and collection disposal practices (Institution of Engineers Malaysia, 2008).

Biogas can be produced from many methods such as rotary drum reactor, continuous stirred reactor and etc. The method that was used in this project was anaerobic digestion specifically small scale laboratory batch reactor. Anaerobic digestion is a biochemical technology for the treatment of organic wastes and the production of biogas, which can be used as a fuel for heating or co-generation of electricity and heat (Mashad & Zhang, 2009).

Below are some of the opinions on factors why biogas production through anaerobic digestion should be commercialized in Malaysia and directly shows the purpose of this study.

i) Methane gas is highly produced from food waste or also known as garbage.
ii) Malaysia has the highest percentage of food waste generation.
iii) Statistics show that the percentage of food waste generated in Malaysia will be kept on increasing even until 2023.
iv) The climate of Malaysia where temperature of 30 °C – 40 °C is the optimum temperature for anaerobic digestion.
v) Less or no temperature fluctuations during night and day in Malaysia due to its' location near Equator.
vi) Demand of other green energy as substitution for petrol.
vii) Poverty in some areas in Malaysia needs methane gas for cooking as it reduces cost.
viii) Reduce green house gas emission which is becoming an eyesore in Malaysia.
ix) Replacing industrially produced chemical fertilizers and fossil fuels.
x) Less cost, better energy and simple equipment

2.4 Anaerobic Digestion Technology

Anaerobic digestion has slowly received people's attention throughout worldwide. It is a process by which almost any organic waste can be biologically transformed into another form in the absence of oxygen. Anaerobic digestion is one of the promising technologies which convert the waste into both biogas and odour-free residues rich in nutrients which can be used as fertilizers.

2.4.1 History of Anaerobic Digestion (AD)

Xuereb (1997) states that in the modern age after the discovery of methane emissions, people started to collect the natural biogas and used it as fuel basically for lighting. Industrialization of anaerobic digestion began in 1859 in Bombay while in England they used biogas to fuel street lamps. However, it took until the end of the 19th century until anaerobic digestion was applied for the treatment of wastewater and solid waste. In Europe itself, development of anaerobic digestion has been carried out since 1770 where the Italian Volta collected biogas and tested its burning and currently there are roughly 400 plants exists.

The history of anaerobic digestion can be tracked back two thousand years ago of animal manure in China and India. In China, the first plant was built by a rich family and by 1970s, Chinese government has promoted dynamically. Nevertheless, as early as 1850s, development for biogas plants was detected in India. The very first digestion plant was reported to have been built at a leper colony in Bombay, India in 1859. Later, in 1970s enormous increments of plants were due to government support (Xuereb, 1997). Hence, it can be summarized that government has been a very important backbone for biogas development in India and China.

2.4.2 Types of Anaerobic Digester

Typically, there are various types of anaerobic digesters. Each digester that is designed has its' advantages and disadvantages. Digesters are varied due to the climate differences, types of feedstock, amount of feedstock, process duration and etc. Vandevivere, De Baere, and Verstraete (2000) mentioned that a design of a digester will be concerned with the rate, stability and completion of biochemical reactions.

2.4.2.1 System of Anaerobic Digester

Anaerobic digestion system can be divided into two which is wet and dry system. This depends on the amount of total solid content in the system.

(a) Wet system

Erickson, Fayet, Kakumanu, and Davis (2004) mentioned that the MSW feedstock is mixed with a large quantity of water to provide a dilute feed of 10 % to 15 % dry solids. Consequently, dilution with water is essential to acquire total solid contents less than 15 %. The disadvantage of wet process is large amount of water used results in high reactor volume and expensive post-treatment technology (Burke & Dennis, 2001). At the end of the process, a dewatering step is required to remove the excess water from the feedstock.

(b) Dry system

Even though industries refer dry system as ‘dry’, this system is actually meant to be lacking with water and not without water since it operates with a moisture content of 50 % (Austermann & Whiting, 2007). In this system, the dry solid content of feedstocks will be around 20 % to 40 %. Reed (2011) did a feasibility study to generate green power and mentioned that dry system leads to lower energy requirements for plant needs because less energy is used for heating process water as well as dewatering anaerobic digester reactor contents.

While dry system is applied to process high dry solid feed materials such as energy crops and residues from farm, wet system is then used to treat manures and sludge. Frequently, various waste streams are mixed together to obtain an appropriate input consistency (Austermann et al., 2007).

2.4.2.2 Modes of Anaerobic Digester

Anaerobic digester (AD) can be further divided in terms of mode of operation. Batch and continuous are the two mode types used in anaerobic digestion.

(a) Batch mode

In a batch mode, digester is fed with raw feedstock and inoculated with digestate from a different reactor. It is then tightly closed and sealed until the overall degradation or digestion occurred (Eliyan, 2007). When the organic matters are loaded in the digester, a period of retention time is set for the digestion process to take place. Temperature, total solid and moisture are some of the factors which affecting the retention time. The digester is emptied once the digestion completed and a new batch of organic feedstock is fed. The effluent or residues are removed to allow the new process to take place. Commonly, it is essential to have numbers of digesters in a batch process so that alternate loading and emptying can be done. Batch digester is preferred as it is the easiest and cheapest to be built. Moreover, batch digester is more robust against inhibitor as it produces low gas, lower loading rate and carries a lesser risk of explosion during emptying of the reactor (Erickson et al., 2004).

(b) Continuous mode

In a continuous mode, feed is fed regularly and constantly into the digester. Typically, a pumping system is fixed for moving the feed into the digester. According to Erickson et al. (2004), the application of continuous mode is widely applied in large scale operations with a consistent composition of feed. A digestate dry matter content of 20 % to 40 % will be produced. An interruption during the pumping will affect the biogas production.

2.4.2.3 Mechanical Design of Anaerobic Digester

In anaerobic digester there is several type mechanical building of digesters. The three major types of anaerobic digesters are covered anaerobic lagoons, plug flow digesters and complete mixed digester.

(a) Covered Anaerobic Lagoons

Anaerobic lagoons are ponds which are covered. Feedstock is fed at one end and the residue is removed from another end (Burke, 2001). Nelson and Lamb (2002) who carried out a project in Minnesota mentioned covered lagoon digesters are used for liquid manure (less than 2 percent solids) and require large-volume lagoons. Figure 2.7 shows how a covered anaerobic lagoon looks like. Typically, this type of digester is used to generate and collect biogas from manure. Basically, a covered anaerobic lagoon usually used to generate and collect biogas from manure. A plastic with impermeability cover used to collect the gas which is produced (Nelson et al., 2002). This type of digester is widely used for swine or dairy operations with a flush system to transport the manure. However, this method has some drawbacks including low rate of reaction from solid to gas as the reaction temperature is low. Besides, the solids tend to coagulate to the bottom of the digester, thus less contact between the bacteria and feed occurs. Consequently, no mixing occurs since the lagoon is closed and higher energy is used to screen out the solids which can causes hygienic problems. This method has been widely applied in cold climate countries. Nevertheless, applying covered anaerobic lagoons needs a very low expenses and easier to be set.

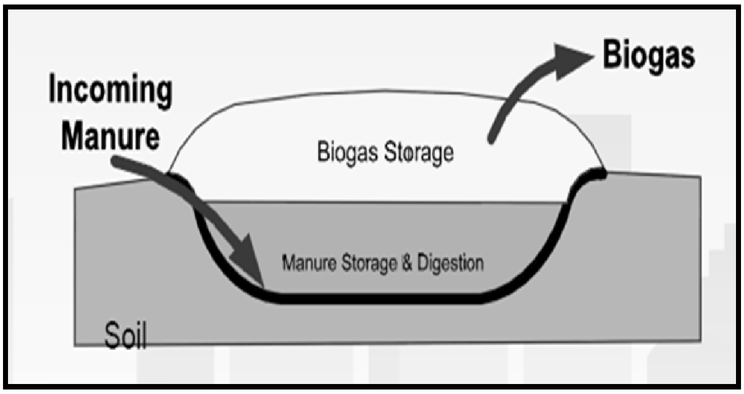


Figure 2.7: Covered Anaerobic Lagoon (Schanbacher, 2009).

(b) Plug Flow Digester

In plug flow digester, a long tubular digester is used. Waste is moved from one end to another end. At the end of the digester, the waste is digested fully and more feedstock will be introduced from the front (Lazarus, 2009). Their ability is associated with feedstock which has higher solid content. Typically, a solid content of 11 % to 14 % is used such as cow manure. In this digester, solid could not stay longer in the solution and hence yielding lower digestion (Schanbacher, 2009). Figure 2.8 shows a design of plug flow digester. This type digester requires less maintenance as fewer moving parts are available. Plug flow digester can be fixed either vertically or horizontally, horizontal direction is more preferred. Since there is no simple manner of removing the solids, the reactor should be shut down throughout the cleaning period. The cost of cleaning can be considerable. Since the plug flow digester is a growth based system, it is less efficient than a retained biomass system. The amount of gas which is converted from waste is small. The plug flow reactor is a simple yet economical system.

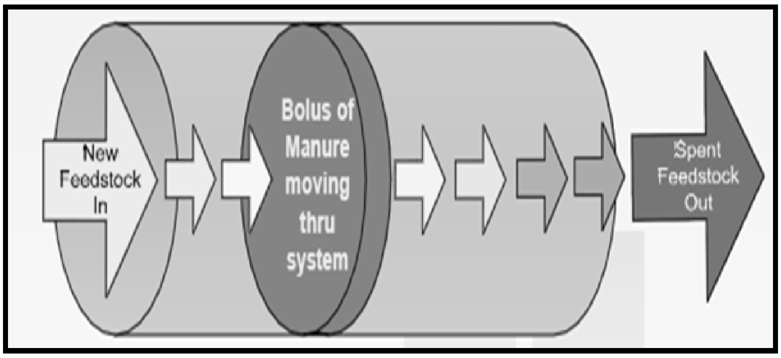


Figure 2.8: Plug Flow Digester (Schanbacher, 2009).

(c) Total Mixed Digester

In this system, all the animal waste or other are combined together into one single tank and an agitation system is introduced to mix the content while it is being digested. Variety of gas mixer can be used such as the mechanical mixers, and draft tubes with mechanical mixers or simply recirculation pumps (Burke, 2001). The most efficient one would be in terms of power consumed per gallon mixed is the mechanical mixer. Vandevivere et al. (2002) stated that this system is suitable for handling manure with 3 % to 10 % solids and they can be more expensive than plug flow digester. A flush system is fixed to collect the remaining residue as shown in Figure 2.9. Usually, process manure will be heated above or below ground. This process is widely used in industries to convert waste into gas (Nelson et al., 2002). The amount of floating materials present caused the cost of mixing to be high. The advantage of the completely mixed reactor is that it is a proven technology that achieves reasonable conversion of solids to gas.

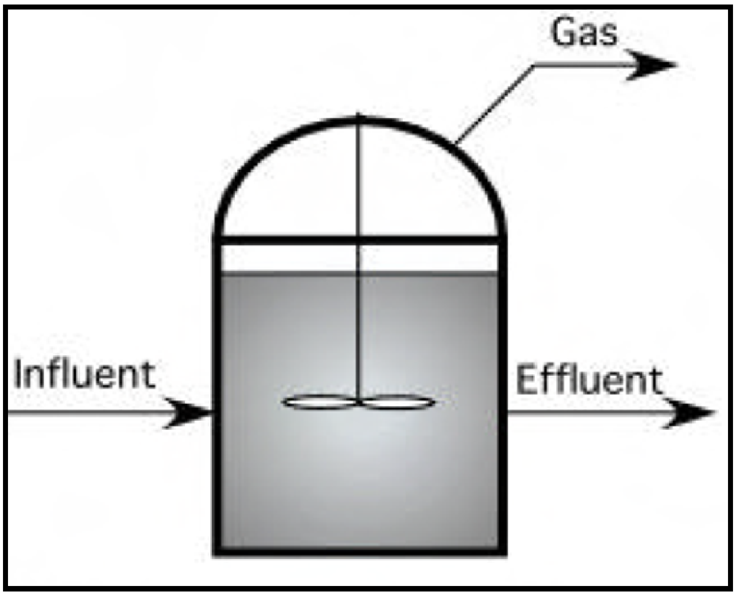


Figure 2.9: Total Mixed Digester (Burke, 2001).

2.4.3 Process of Anaerobic Digestion (AD)

The application of anaerobic digestion is due to its purpose to reduce and stabilize solid waste. Until now, anaerobic digestion has been developed and being practiced until these days.

Anaerobic digestion (AD) with its name is recognized as biodegradation of organic materials proceeds in the absence of oxygen. As mentioned earlier, the biogas produced from anaerobic digestion consists of methane, carbon dioxide, nitrogen, oxygen and also hydrogen sulphide. Normally, anaerobic digestion is carried out in two ways known as thermophilic and mesophilic each varied by its temperature. Mesophilic is carried out at 35 °C to 40 °C whereas thermophilic is carried out at 53 °C to 55 °C. Anaerobic digestion can be divided into three major steps hydrolysis, acidogenesis and methanogenesis.

The first stage of hydrolysis is related to converting the complex substances into simple matters as shown in Figure 2.10. The fermentative bacteria will convert the complex substances such as sugars, amino acid and fatty acids (Nayono, Gallert,

& Winter, 2009). Monomers like cellulose, peptides and alcohols are the results of the complex hydrolyzed by the enzymes such as lipase, proteases and amylases. Sometimes, the rated of biodegration is limited due to high rate of waste and the addition of chemical reagents ease the burden of the bacteria. Examples on hydrolysis process including lipid to fatty acid, polysaccharides into monosaccharides and also protein to amino acid (Li, Park, & Zhu, 2011).

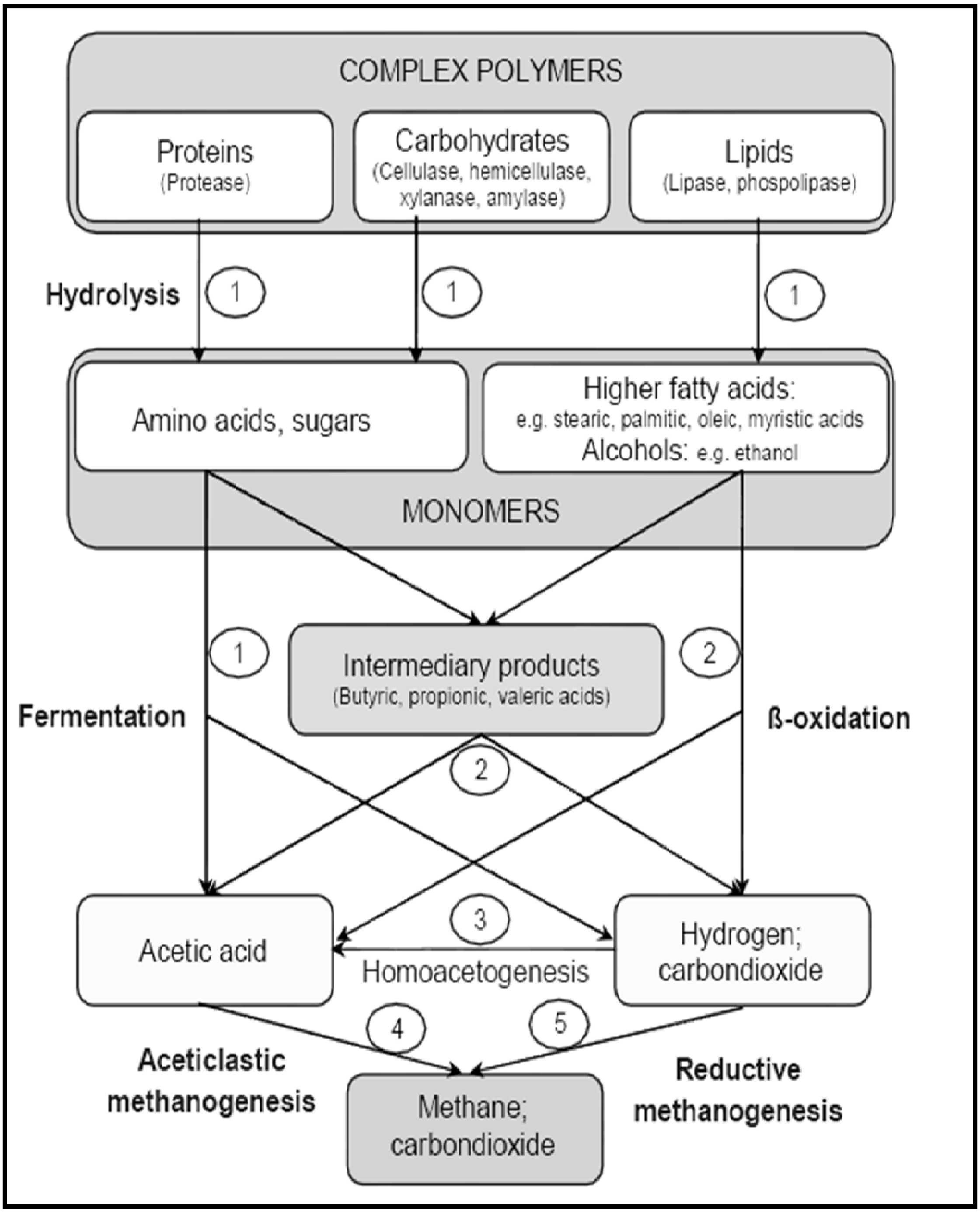


Figure 2.10: Processes in Anaerobic Digestion (Stronach et al., 1986).

In the second stage, acetogenic bacteria, also known as acid formers, convert the products of the first phase to simple organic acids, carbon dioxide and hydrogen as shown in Figure 2.10. The principal acids produced are acetic acid (CH_3COOH), propionic acid (CH_3CH_2COOH), butyric acid ($CH_3CH_2CH_2COOH$), and ethanol (C_2H_5OH). The products formed during acetogenesis are due to a number of different microbes, e.g., s*yntrophobacter wolinii*, a propionate decomposer and s*ytrophomonos wolfei*, a butyrate decomposer. Other acid formers are *clostridium spp., peptococcus anerobus, lactobacillus*, and *actinomyces.* Nielsen, Seadi and Popiel (2009) mentioned that an acetogenic reaction can be shown as the Equation 2.2.

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \qquad (2.2)$$

Finally, in the third stage methane is produced by bacteria called methane formers (also known as methanogens) in two ways, either by means of cleavage of acetic acid molecules to generate carbon dioxide and methane, or by reduction of carbon dioxide with hydrogen. Methane production is higher from reduction of carbon dioxide but limited hydrogen concentration in digesters results in that the acetate reaction is the primary producer of methane (Babaee et al., 2010). The methanogenic bacteria include *methanobacterium, methanobacillus, methanococcus and methanosarcina*. Methanogens can also be divided into two groups: acetate and H_2/CO_2 consumers. Methanosarcina spp. and methanothrix spp. (also, methanosaeta) are considered to be important in anaerobic digestion both as acetate and H_2/CO_2 consumers. The methanogenesis reactions can be expressed as follows in equation 2.3, 2.4 and 2.5 (Nayono et al., 2002).

$$CH_3COOH \rightarrow CH_4 + CO_2 \qquad (2.3)$$

(acetic acid) (methane) (carbon dioxide)

$$2C_2H_5OH + CO_2 \rightarrow CH_4 + 2CH_3COOH \qquad (2.4)$$

(ethanol) (carbon dioxide) (methane) (acetic acid)

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \qquad (2.5)$$

(carbon dioxide) (hydrogen) (methane) (water)

2.4.4 Factors Affecting Anaerobic Digestion Efficiency

Anaerobic digestion (AD) is a sensitive process and there are many factors affecting this process. This is because the microorganisms may vary according to the steps involved and causes variability in each step.

2.4.4.1 pH Level

The first parameter was pH level. The optimal pH values are different for both acidogenesis and methanogenesis. Monnet (2003) mentions that the production of acetic, lactic and propionic acid during acidogenesis will cause the pH to fall whereas methanogens are very sensitive to acidic condition and their growth can be inhibited due to the low pH level. Acid condition has pH level less than seven and vice versa for alkaline condition. Chua et al. (2008) mentioned that methane producing bacteria require a neutral to slightly alkaline environment (pH 6.8 to 8.5) in order to produce methane. Alkalinity and pH in anaerobic digestion can be controlled by chemicals like calcium hydroxide or sodium nitrate. Addition of these chemicals should be done slowly to prevent any impact to the bacteria. Besides that, hydrolysis and acetogenesis occurs at pH 5.5 and 6.5 respectively.

2.4.4.2 Temperature

The next parameter will be the temperature. Temperature is a very important aspect indeed which determines the anaerobic digestion process particularly the methagonesis and hydrolysis. Khalid, Arshad, Anjum, Mahmood, and Dawson (2011) stated that lower temperature during the process is known to decrease the microbial growth, substrate utilization rates and biogas production. In contrast, Khalid et al. (2011) also mentioned that highest temperatures yields lower biogas due to production of volatile gases such ammonia which suppress methanogenic activities. Basically, anaerobic digestion can be divided into three ranges of temperature. They are psychrophilic, mesophilic and also thermophilic. The temperature range varies from 15 °C to 25 °C, 30 °C to 37 °C and 50 °C to 65 °C respectively. Even though, thermophilic digestion results in higher gas yield and production rate, it is rarely applied due to municipal sludge digestion facilities due to inexperience with the process and increased heating requirements.

Hence, anaerobic digestion is carried out at mesophilic temperature. This is due to the operation in mesophilic seemed to be more stable and requires a smaller energy expense. Mesophilic bacteria are supposed to be more robust and can tolerate greater changes in the environmental parameters including temperature (Nayono et al., 2009). Although, it requires longer retention time, it compensates with the stability of the process. Thermophilic process offers faster kinetic, higher methane production as well as pathogen removal. Nevertheless, thermophilic is sensitive to toxic substances and changes of parameters. Besides that, the process seems to be less attractive due to its higher energy requirement compared to mesophilic (Monnet, 2003). Since, this study focusing to create a green method, thermophilic will be less desirable due to its energy usage.

2.4.4.3 Mixing

Furthermore, mixing is an imperative parameter in anaerobic digestion. Proper mixing of digestion contents is important for efficient performance of digestion. Proper mixing ensures that solid remain in suspension avoiding formation of dead zones by sedimentation of sand or heavy solid particles. Besides, mixing enables particle size reduction as digestion progresses and the release of produced biogas from the digester contents (Shuler & Kargi, 2002). One should know that mixing is not only limited to mechanical mixers while recirculation of slurry or injection of produced biogas can also be used. One major problem consistently reported in municipal waste digestion literature is inadequate mixing, resulting in the formation of thick scum layers which reduce the efficiency of digester operation and also avoids temperature gradients within the digester (Monnet, 2003). However, excessive mixing can disrupt the microbes, so slow mixing is preferred (Khalid et al., 2011).

2.4.4.4 Total Solid (TS)

Total solid can be defined as the matter that is suspended or dissolved in water. When the liquid in a sample is evaporated, the residue left is known as total solid. Total solid and COD are directly proportional. Kalloum, Bouabdessalem, Touzi, Iddou, and Ouali (2011) stated that COD reduction should be followed by TS decrease due to organic matter transformation into biogas. Low solids (LS) Anaerobic digestion systems contain less than 10 % TS, medium solids (MS) about 15 % to 20 % and high solids (HS) processes range from 22 % to 40 % (Talyan, 2007). An increase in TS in the reactor results in a corresponding decrease in reactor volume. When the TS are relatively low, it is known as wet digestion and dry digestion when TS is high.

2.4.4.5 Carbon to Nitrogen Ratio (C/N)

This ratio in organic material plays a crucial role in anaerobic digestion. Bacteria need both nitrogen and carbon for assimilation into their cell structures. Optimum C/N ratio in anaerobic digestion is from twenty to thirty (Vandevivere et al., 2000). According to Khalid et al. (2011), the gas production will be low which indicates rapid consumption of nitrogen by methanogens is due to high C/N ratio. On the other hand, a lower C/N ratio causes ammonia accumulation and pH values exceeding 8.5, which is toxic to methanogenic bacteria. Optimum C/N ratios of the digester materials can be achieved by mixing materials of high and low C/N ratios, such as organic solid waste mixed with sewage or animal manure.

2.4.5 Advantages of Anaerobic Digestion to the Society

Even though there are many methods to produce biogas, anaerobic digestion is always preferred. Other methods which are associated in producing biogas include rotary drum, aerobic digestion, composting and etc. There are many gains which can be attained by applying anaerobic digestion method.

2.4.5.1 Odour Control

Despite many benefits associated with anaerobic digestion, one of the major reasons anaerobic digestion widely applied is due to the ability of odour control. Worldwide usage of anaerobic digestion is prominent among the farmers, rural areas citizens, wastewater industry and other industries which releases high odour to the environment. Odour free process is the natural result from the anaerobic digestion. Susan (2011) stated in her Minnesota Project that anaerobic digestion functions to reduce the odour from the wastes by stabilizing the organic material in the waste that are responsible for undesirable odour. This can be done by the process to break down the highly odour organic waste with the aid of bacteria. Fly propagation also will be controlled compared to fresh manure and digested manure (Nelson et al., 2002).

2.4.5.2 Renewable energy production

Anaerobic digestion system will allow for the production of renewable energy. Some of the other methods are suitable to transform the waste into odour free waste but not suitable for producing energy. According to Nelson et al. (2002) using the gas to generate energy may offer considerable economic payback depending on farm scale. Most usually the gas is burned in an engine-generator to generate electricity, and the waste heat can be used to create hot water for heating the digester.

2.4.5.3 Electricity Generation

From a statistics by Susan Reed (2011), the majority of 85 % anaerobic digester projects in the United States utilize biogas produced by the anaerobic digester to generate electricity. From those projects, anaerobic digesters generate around 331 million kW of electricity annually. The generated electricity can be applied for electricity utility, including voltage support and power loss reduction through transmission.

2.4.5.4 Fertilizer Production

The amount of fertilizers can be commercially produced by using anaerobic digestion. Turning waste into fertilizers is a vast gain to the industry as the cost for producing synthetic fertilizers can be reduced. Erickson et al. (2004) said that the digestion process converts organic nitrogen into a mineralized form (ammonia or nitrate nitrogen) that can be taken up more quickly by plants than organic nitrogen. It is also believed that the fertilizers produced have better efficiency and nutrients for the plant to absorb and consequently growing.

2.4.5.5 Pathogen Reduction

As mentioned before anaerobic digestion can be conducted using three types of temperature range. Anaerobic digestion using thermophilic temperature with 50 °C to 65 °C has the potential to destruct many types of pathogens thus reducing the chances for water pollution. Nonetheless, the high potent methane gas can be capture by performing anaerobic digestion. The methane which is captured will benefit by generating energy as well as slowdown the rate of global warming. The benefits of anaerobic digestion are summarized in Table 2.4.

Table 2.4: Advantages of Anaerobic Digestion (Erickson et al., 2004).

ADVANTAGES
1. Couples the treatment of waste and production of energy
2. Reduction of odor
3. Suitable for large scale operation
4. Methane is used in place fossil fuels
5. Reduces greenhouse gases and thus minimizes the pollution
6. Fertilizers from waste
7. Reduces chemical and biological oxygen demand, total solid and volatile solids.
8. Destroys or reduces the pathogens, bacteria and insects

2.5 Literature Study on Various Feedstock

Anaerobic digestion process has been carried commercially worldwide years ago. Many researched came up with various ideas on completing the digestion efficiently using different type of feedstock as well as digesters. One of the oldest researches was conducted by Johnson, Kunka, Decker, and Forney (1987) where the used two litres measuring cyclinder as digester and collected the biogas using balloon. They used four type of feedstock, one with pure sewage sludge, a mixture of sewage sludge together with garbage, a mixture of sewage plus cow manure and a mix of sewage and grass clippings. Among all, the grass clippings mixture contributes the highest biogas with a total of 12190 ml and 7905 ml methane. The descending order of gas produced is mixture of grass clippings, cow manure, garbage and pure sewage. The lowest which is the pure sewage recorded 2735 ml biogas and 1748 ml methane. This experiment was conducted without any aid of inoculums. A total of 14 days were chosen as the retention time.

Focusing into Malaysia, two experiments were conducted in UNITEN and UPM. Azlina et al. (2009) used leachate from municipal waste as feed into one litre digester which was carried out in batch mode. There was no inoculums used as well and the amount of biogas detected was 1.2 to 1.5 ml/ml leachate /day. Twenty days were selected as the retention time for the digestion to take place. Chua et al. (2008) used a 50 kg feed which consist of various type of food and it was hold for digestion period of 35 days. Three feed waste was initially mixed with oil, chicken manure and pure food waste respectively. In the end of the digestion period, chicken manure feedstock yielded the highest biogas of 24 ml. The lowest was with oil content which yielded only about 7 ml. This research was conducted without the use of inoculums.

Some of the peculiar feedstock used was paper waste and also coffee waste. Anaerobic digestion of coffee waste was done in Portugal in 2005. Ribeiro, Oliveira, and Alves (2005) decided to use coffee waste as feedstock to reduce cost of one of the coffee plant there. Sewage sludge was used as inoculums for the ease of digestion. A total of 1100 ml of methane was produced. Ofoefule et al. (2010) created a difference in anaerobic digestion by using paper waste with the blend of cow dung. Retention period of 43 days were used and the amount of biogas produced was 9.34 dm^3/kg slurry.

Sagagi et al. (2009) decided to conduct experiment on fruit together with vegetable waste due to accumulation of the waste in a nearby market. Orange and pineapples are the fruits used whereas spinach and pumpkin is the vegetable used. Cow dung was used as another control sample and a total of nine weeks were used as retention time for around two kg slurry of feed. Among all, cow dung produced the highest of 1554 cm^3 biogas, followed by pineapple, orange, pumpkin and spinach. In comparison, fruit waste has produced higher biogas compared to vegetable. In Tehran, a semi continuous mode operation was applied for anaerobic digestion of vegetable waste. A total volume of 70 L was used for the digester. Retention time of 25 days was maintained with a feeding of 2.4 L of substrate and removing 2.4 L daily (Babaee & Shayegan, 2010). Biogas production was measured to be the highest with a value of 40 L/ day.

Elango et al. (2006) did a research on the amount of biogas produced from sewage water and municipal waste. Municipal waste is one of the major nuisances in India. Hence, this research opened a new and green way to overcome this problem. The biogas measurement was done using the manual way of water displacement method. Five litres digester was used with a daily feeding of semi-continuous mode. The results yield that the highest biogas produced is when the amount of total solid fed is highest. The highest value was 0.36 m^3/kg where the highest amount of biogas attained. In the city of Adrar, Kalloum, Bouabdessalem, Touzi, Iddou, and Ouali (2011) produced biogas from the sludge of municipal wastewater plant. A bioreactor of one litre was used as digester and water displacement method was applied. A total retention time of 35 days was used and the highest biogas measured on the 20^{th} day by pressure measurement.

CHAPTER 3

METHODOLOGY

3.1 Materials

Food waste, chemicals and inoculums were used in this research.

3.1.1 Food Waste

Three types of waste were used which are vegetable waste, fruit and grain waste (mixture of rice and bread). The vegetable and fruit waste were collected from the Genting Klang market while the bread and rice waste were collected from Pistachios Bakery and other restaurants. Each waste was weight around 3 kg and was collected according to grab samples method from the Standards Methods for the Examination of Water and Wastewater. Grab samples are single samples collected at a specific spot over a short period of time.

3.1.2 Chemicals

Sodium hydroxide (NaOH) with the purity of 99 % was supplied by PROCHEM. Polyethene tarpaulin with the mesh size 16 x 11, weight 170 GSM was supplied by Kong Hui Canvas Manufacturer and nitrogen gas grade with purity of 99.5 % was supplied by MOX-LINDE GASES.

3.1.3 Inoculum

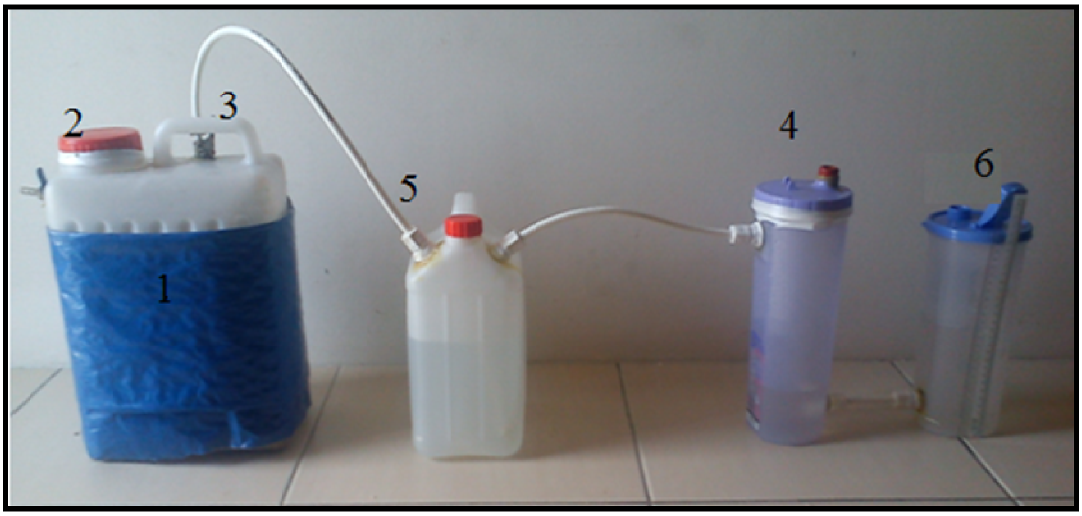
Cow dung was used as inoculums in this experiment. Cow dung was collected from a cow farm in Sentul Farm. Cow dung was collected only during the day of experiment to provide fresh inoculums for efficiency purpose.

3.2 Apparatus

The main apparatus for anaerobic digestion was the digester. A digester was designed to carry out the experiment.

3.2.1 Design of Anaerobic Digester

An 8 L batch type anaerobic digester was designed in this experiment. The laboratory scale digester was constructed using a plastic container with two openings as shown in Figure 3.1. The openings of the digester were drilled and fixed with valves. Each valve was further fitted with rubber rings to ensure no air was entering. The first opening was specialized for nitrogen (N_2) purging purpose on the other hand the other opening was drilled to enable the biogas to flow from the digester. Nitrogen was purged to fill up the whole system. Since, N_2 is an inert gas, the system was assumed to be inert during the initial and final period. The opening was connected with a 1 cm diameter rubber piping to a chemical container. This container contained 3 mol/dm^3 sodium hydroxide (NaOH) to dissolve all carbon dioxide (CO_2) and all hydrogen sulphide (H_2S) which passed through the container. Oxygen (O_2) molecules were avoided from entering since the system was designed air tight to provide anaerobic condition. Next, the chemical container was further connected to a water container where the methane gas pushes the water into the last container to show the level of methane was produced. From Figure 3.1, the design of the system helped to provide reading only for the methane production due to all the specifications and design. A smaller experimental system with a batch digester should be suitable as the digester has only to be loaded once. The digester was operated at room temperature varying from 27 °C to 36 °C and pH ranged of 6.5 to 7.5 throughout the experiment with constant feed of 2 kg. This was the optimum condition for the anaerobic digestion for high biogas generation (Chua et al., 2008).



1. Digester (V=8 L) capacity
2. Feed inlet
3. Gas opening
4. Water displacement jar
5. Gas outlet
6. Measuring jar

Figure 3.1: Design of Anaerobic Digester

3.3 Equipments for Analysis

3.3.1 Scanning Electron Microscopy (SEM)

The model of the SEM used is Hitachi Scanning Electron Microscopy of BS 340 TESLA. Before the SEM testing, the samples were coated with gold coating using EMITECH SC7620 Sputter Coater for three to four minutes. This was done to ground the electrons as the samples are non conductive.

3.3.2 Tray Dryer

A tray dryer of model Lotus Scientific (LS-32008, 220/415 VAC) was used in this experiment to dry the residues from the digester for the fertilization test. Wastes were evenly spread on the tray and dried at 65 °C for 10 hours.

3.3.3 Blender

A suitable blender was purchased from Panasonic with the model number MX-337-RF. Blender was used after the drying process of the residues to increase the cross sectional area. Higher cross sectional area of the dried residues eased the fertilization process.

3.4 Sample Preparing

3.4.1 Feed Source

Three types of food waste which were used are vegetable waste, fruits waste and grain waste. The vegetable and fruit waste were collected from the Genting Klang market while the grain waste was collected from Pistachios Bakery Danau Kota, Setapak. Each collected waste was weighing 3 kg approximately. Once collected, the wastes were transported immediately to Science Lab of Universiti Tunku Abdul Rahman. The wastes were further sorted, weighed and chopped into smaller units to allow ease of bio-degradation and to reduce chocking problems. Collected wastes were refrigerated until the lab started to avoid decomposition by the bacteria at early stage. The techniques used for collection and preservation of samples were in accordance to Standard methods for the examination of water and wastewater. The collected samples should be stored in containers that are free of analytes interest.

3.4.2 Formulation

In this project, three experiments were conducted, each experiment represent fruit waste, grain waste and vegetable waste. The amount of each waste fed into the digester was kept constant which is 2.0 kg. Table 3.1, 3.2 and 3.3 shows the formulation involved to prepare the feed for fruit, vegetable and grain waste respectively.

Table 3.1: Formulation Table for Fruit Waste

Substances	Amount
Fruit Waste	2.0 kg
Cow Dung (Inoculums)	1 L
Water	1 L

Table 3.2: Formulation Table for Vegetable Waste

Substances	Amount
Vegetable Waste	2.0 kg
Cow Dung (Inoculums)	1 L
Water	1 L

Table 3.3: Formulation Table for Grain Waste

Substances	Amount
Rice Waste	1.2 kg
Bread Waste	0.8 kg
Inoculum	1 L
Water	1 L

3.5 Experimental

3.5.1 Digestion Process

The yield of methane accordance to the type of waste was to be determined respectively. The batch digester was filled with fresh prepared fruit waste as feed. Then, the digester was flushed with nitrogen gas for 20 mins to provide anaerobic conditions. For each digestion process, 800 ml of cow dung as inoculum was added to the batch digester. The digester was allowed to stabilize for 1 week. During this stabilization period, digester temperature was maintained 27 °C to 36 °C. In order to cater for sharp fluctuations, the digester was covered with polyethene tarpaulin. The pH was closely maintained to 6.5 – 7.5 by adding sodium hydroxide ($NaOH$). From the waste feed onwards, the methane generation was monitored. The digester tank was shaken for 1 min once a day to provide stirring aid for optimal methane production. The volume of methane produced during the decomposition of the organic wastes was determined by measuring the volume of water displaced in the measuring cylinder.

3.5.2 Fertilization Process

The residues in the digester were examined for fertilization purposes. The residues from the digester were dried using a tray dryer. Initially, the fruit waste was evenly spread on the tray and dried at 65 °C for 10 hours. Then, the dried waste was placed into a blender and blended into smaller units. Next, these wastes were used as fertilizers. These fertilizers then were used for the plants. These procedures were also repeated for both vegetable and bread waste. Each fertilizer was used for one plant respectively. Thus, there were three plants representing each waste with another plant used as control. The plants were fertilized once a week and watered frequently while the control plant was watered the equal amount without any fertilizers added. In total, there were four plants and their growth was compared.

3.6 Tests and Measurements

3.6.1 Methane Measurement

Methane production was measured daily by determining the height of water in the measuring cylinder. Each day, the amount of water was increased due to the methane generation. Thus, the methane production for a particular day was obtained by subtracting the previous water level from the current water level. Methane production was lacking near the final stage of decomposition of the organic matters. Higher amount of biogas generation does not mean it has the higher amount of methane (CH_4). This is due to the composition of biogas which also consists of carbon dioxide (CO_2) and hydrogen sulphide (H_2S).

3.6.2 Morphology Testing

Before the digestion process, a sample from each waste was observed under the scanning electron microscopy. Papaya, rice and spinach were chosen as representation of the fruit, grain and vegetable waste respectively. The morphology of each waste was observed and compared.

3.6.3 Fertilization Test

The residues from the anaerobic digestion was collected and turned into fertilizers. Four plants of *Ixora coccinea* species were used as the experimental material, one for each waste and one as control without any fertilizers added. The fertilizer was sprinkled every week for the three plants and equal amount of water was used for watering purposes. The condition of the plant was observed everyday and the growth of each plant was compared with each other.

CHAPTER 4

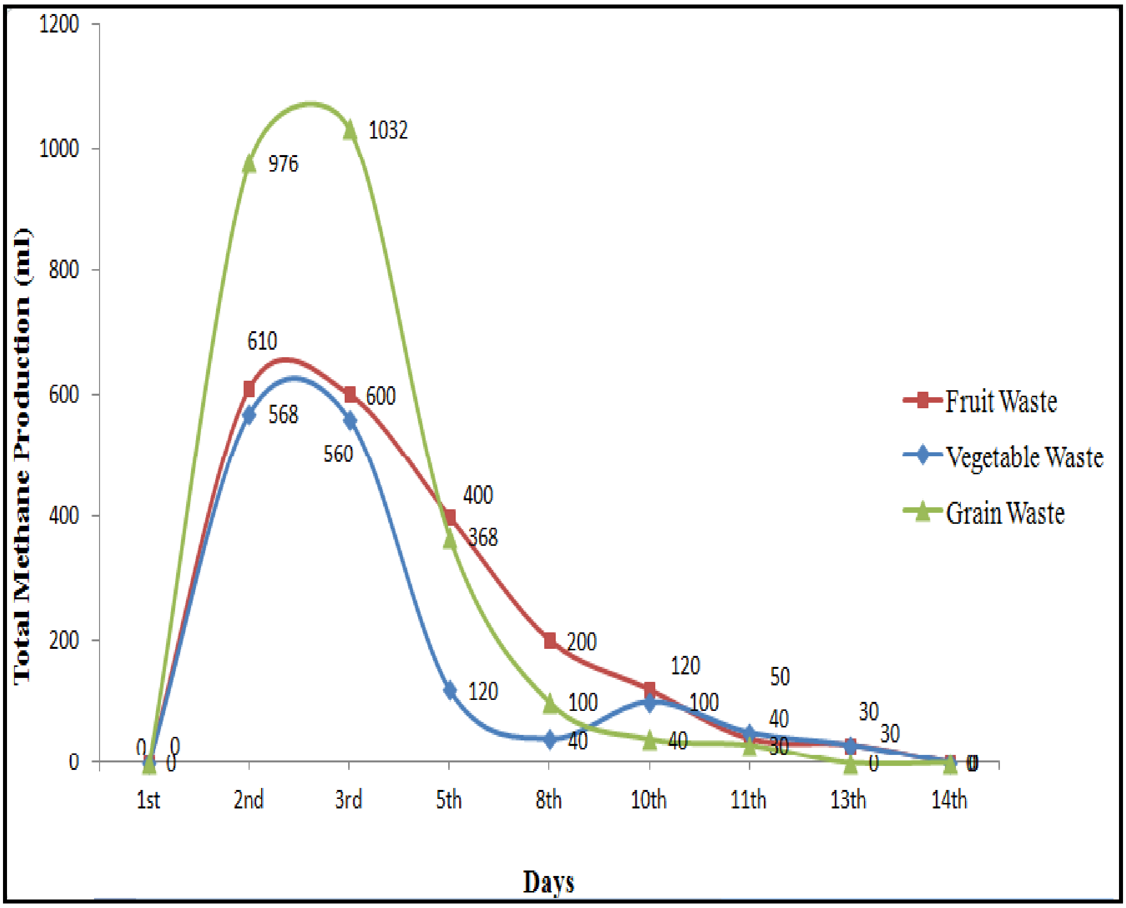
RESULTS AND DISCUSSION

4.1 Methane Production from Waste

All the three wastes successfully produced methane gas. Each waste has certain amount of methane produced and their respective results are shown in the Figure 4.1 and 4.2 below. Therefore, it was proved that anaerobic digestion method can be applied for the food waste. In addition, the designed anaerobic digestion system was applicable as the results obtained were consistent and reliable.

In this study, the wastes were blended together before inserting into the digester. The three wastes were left two weeks respectively and the results obtained are shown in Figure 4.1. Methane gas was successfully produced from the waste as expected before. From the Figure 4.1, observation can be made that the waste started to digest from the second day itself. Besides that, the Figure 4.1 shows that the grain waste increases significantly compared to fruit and vegetable waste. The highest amount of methane was recorded as 1032 ml for grain waste on third day. On the ninth day onwards, the methane production gradually decreased. Thus, it was likely that grain waste had a massive digestion from second to ninth day.

Figure 4.1: Amount of Methane Gas Produced for Grain, Fruit and Vegetable Waste



As shown in Figure 2.2 in chapter 2, hydrolysis takes place in the early stage of anaerobic digestion. In the hydrolysis process, the complex substances which are protein, lipid and carbohydrates was transformed into simpler unit. Since the grain waste contains very high carbohydrates, hydrolysis caused the carbohydrates to convert into sugar or monosaccharide. The sugar was further transformed into intermediary products such as acetic acid (CH_3COOH), propionic acid (CH_3CH_2COOH), butyric acid ($CH_3CH_2CH_2COOH$), and ethanol (C_2H_5OH). The third stage, methane was produced by means of cleavage of acetic acid molecules to generate carbon dioxide and methane, or by reduction of carbon dioxide with hydrogen (Arsova, 2010). Whereas, the fruit and vegetable waste are highly consist of fibres caused a limited range of hydrolysis process. The high hydrolysis of grain waste caused more methanogens to be produced to ease the digestion process. Nielsen et al. (2007) stated that methanogens are methane producing bacteria and the methanogens simultaneously produce biogas from the acetate, or from hydrogen and carbon dioxide. The amount of methane produced was directly proportional to the amount of carbohydrate. Consequently, grain waste can produce higher methane compared to fruit and vegetable waste.

According to Diaz et al. (2008), their results of biogas production showed that the highest biogas producers were rice with inoculums of matooke (African bananas). Both these were rich in carbohydrates and thus they produced the highest biogas in their experiment. Besides that, their results showed similar results where the digestion process was more significant on the first three days and consequently producing more biogas the first three days. Since, the methane percentage is highest in the biogas composition, it can be concluded that the results from Figure 4.1 is comparable with the results from Diaz et al. (2008).

Fruit waste was recorded to produce methane the second highest as shown in Figure 4.1. Papayas, pineapple, mangoes and bananas are the fruits contained in the waste were used here. The highest amount of methane for fruit waste was recorded as 610 ml on the second day. Fruit waste started to have a rapid gas production from second to tenth day onwards and it has the highest methane production during the end period of digestion. Fruit waste contains natural glucose in it causes digestion to occur better than vegetable waste with the aid of acetogenens. Acetogenens can be defined as acid formers bacteria which convert the products of the first phase to simple organic acids, carbon dioxide and hydrogen in the acetogenesis phase. Referring to Figure 2.2 from chapter two, acetogenens transform the sugar under fermentation process into intermediary products such as acetic acid (CH_3COOH), propionic acid (CH_3CH_2COOH), butyric acid ($CH_3CH_2CH_2COOH$), and ethanol (C_2H_5OH). The third stage, methane was produced by means of cleavage of acetic acid molecules to generate carbon dioxide and methane, or by reduction of carbon dioxide with hydrogen. The production of methane is directly proportional to the amount of sugar. The natural content of sugar in the fruits caused the high production of methane.

Sagagi et al. (2008) did a research on various types of fruits and vegetable and their respective yield of biogas. From their research, pineapple and orange waste produced higher biogas yield compared to pumpkin and spinach. The pineapple waste produced a total of 965 ml/day of biogas and spinach waste produced 373 ml/day respectively. Thus, the results are comparable with the result obtained from this research as shown in Figure 4.1 and Figure 4.2. Fruit waste had produced higher biogas compared to vegetable waste. The composition of methane is the highest in biogas and methane production is proportional to biogas production.

The last one is the vegetable waste with the lowest amount of methane production as shown in Figure 4.1. The vegetables waste that was used here was consisted of tomatoes, onion, spinach, cucumber and brinjal. Vegetable waste produced a similar trend of methane production as grain waste. The production of methane climbs steeply for first four days, decreases until eighth day and fluctuates a little by the end of the digestion process the maximum amount of methane was produced on the second day with the amount of 568 ml. Vegetable waste consist in high fibres and cellulose which consequently lead to lower production of methane. Tomatoes, cucumber, and spinach have limited life span according to US Food and Drug Administration, (2009) compared to onion and brinjal. Tomatoes, cucumber and spinaches digested faster and yielded a small amount of biogas. At the end of ninth day, the fluctuation of vegetable waste shown in Figure 4.1 describes the digestion of high fibre vegetables which needs higher period to be digested.

Another research whereby the waste was consisted of cabbage leaves with inoculums of matooke (African bananas) showed that the amount of biogas produced was less than the rice and highest production of biogas was during the third day and was satisfying before and after that (Diaz et al., 2008). Thus, it can be concluded that the results of this research were found to be consistent with other researches worldwide such as Sagagi et al. (2008), Mshandete et al. (2004) and Mashad et al. (2010).

For the Figure 4.2, the cumulative methane production is increasing in ascending order for grain, fruit and vegetable waste. At the end of two weeks period, grain waste had a total of 2546 ml of methane, 2000 ml for fruit waste and 1468 ml for vegetable waste. However, during the first three days the amount of methane produced was almost similar for both fruit and vegetable waste. In this experiment, a combination of rice and bread waste was used to prepare the sample for grain waste. Hence, clarification can be made where this sample contained a very high amount of carbohydrate which contributed to methane production. The total cumulative of fruit was also high due to natural sugar content in fruits as mentioned earlier. The high fibre and cellulose content in vegetable waste contributed to low yield of methane as this waste was hardly digested.

Figure 4.2 also portrays that the three wastes had a rapid production of methane starting of the digestion period and the methane production was gradually decreased. Since, this is a batch type process, the inoculums and waste were only added once in the beginning of the process. Thus, the aid of inoculums was more significant in the beginning. Hence, the digestion process was more intense during the first five days for all the wastes. This is the reason for highest methane production during the early stage of digestion as shown in Figure 4.2. The inoculums which contained with a lot of methanogens helped the digestion process by converting the complex structures into simpler ones. As the days passed, the amount of methanogens reduced momentously causing the methane production to reduce as well. The amount of methane produced was proportional to the amount of inoculums left. As the days increased, inoculums left in the waste gradually diminished as well. The amount of methanogens during the whole process can be described with Figure 4.3.

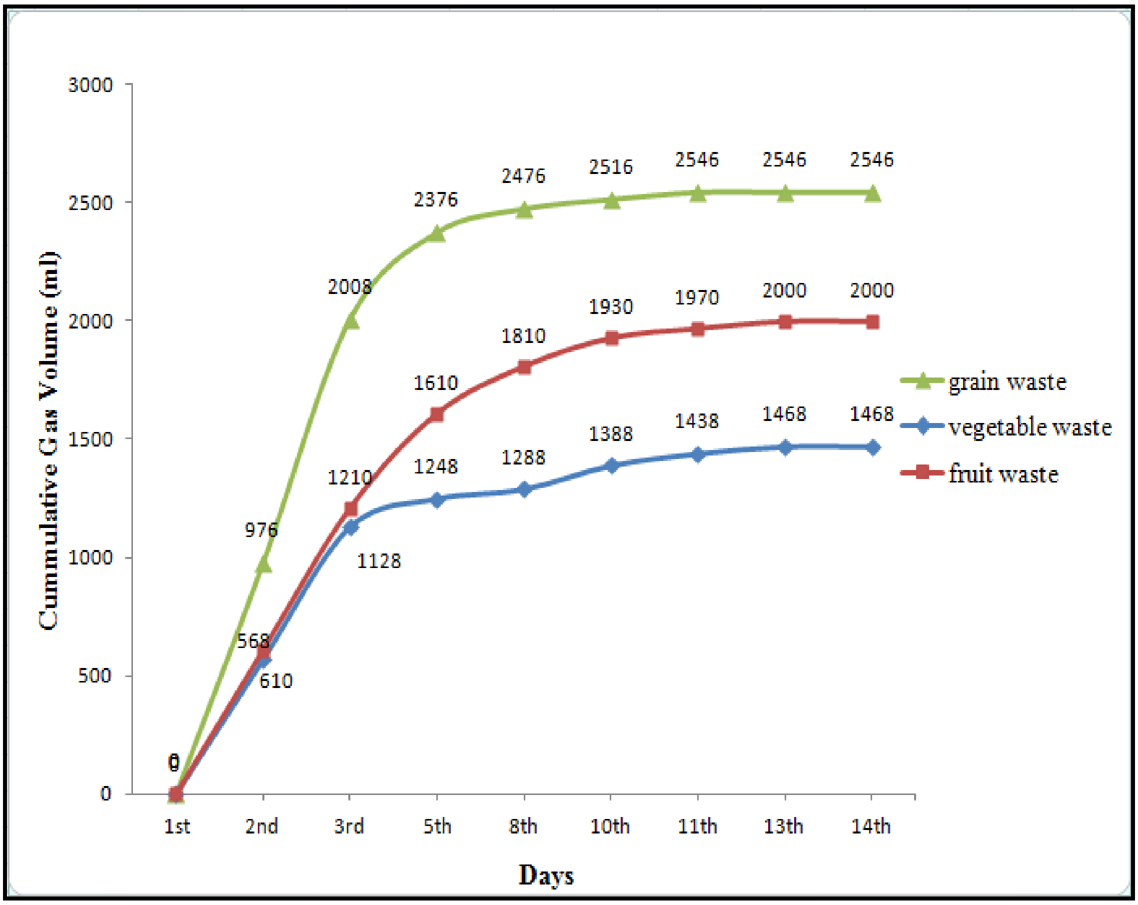


Figure 4.2: Cumulative Methane Production for Grain, Fruit and Vegetable Waste

From Figure 4.3, lag phase is the time adaption for the inoculums to the new environment or medium and this process can be short or length depending on the medium. In this study, the lag phase of the inoculums was short around one to two days. The methane production was rapid on the second day where the inoculums have entered exponential growth phase. In this phase, the inoculums multiplied rapidly and reached a maximum rate. The log phase shown in Figure 4.3 can be represented using the Equation 4.1.

This equation shows the exponential growth of the microbial in the system.

$$x_t = x_0 \mu^{et} \qquad (4.1)$$

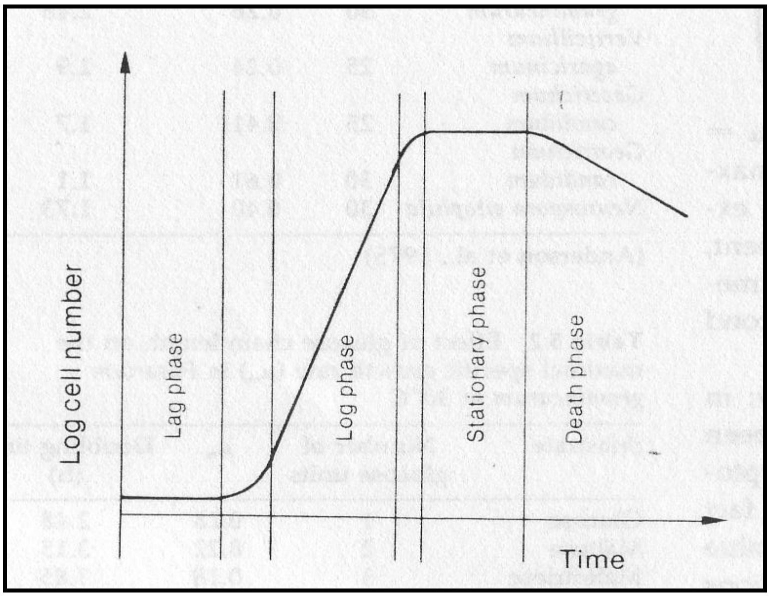


Figure 4.3: Cumulative Methane Production for Grain, Fruit and Vegetable Waste (Shuler et al., 2002).

As the end of digestion period, the inoculums reached a state where the inoculums were used up and caused the digestion rate to decrease. This state is called stationary phase where the inoculums have stopped dividing and the growth rate has declined zero. In the thirteenth day onwards, the inoculums have reached the final stage of death phase. This occurs due to depletion of waste substrates or toxic product accumulation (Shuler et al., 2002). The toxic accumulation caused the pH to lower and acidic. Since the anaerobic digestion is a pH sensitive process where the optimum pH is 6.7 to 7.6, the methane production diminished due to deviation from optimum pH.

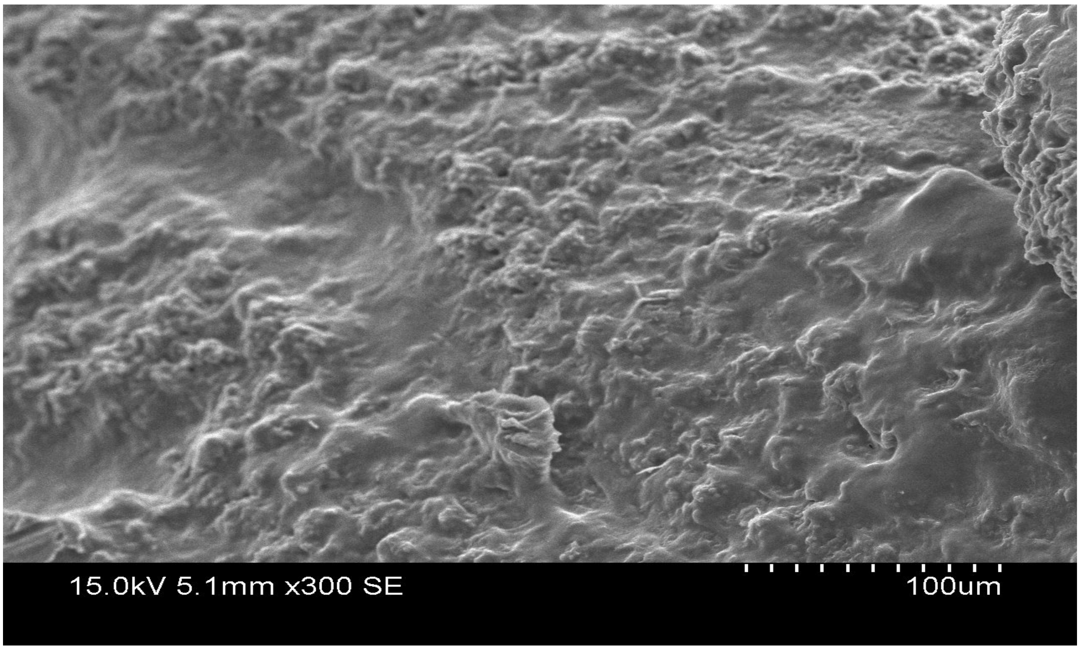
Moreover, it can be said that the digestion process was reaching completion during the tenth week as the amount of waste was considered small of 2 kg. A research which was conducted by Chua et al. (2008) with a total weight 50 kg of food wastes were left to be digested for 35 days. Consequently, from a small proportion it can be proven that 2 kg amount of waste is sufficient to be digested the fullest approximately two weeks as conducted in this study. The research conducted by Chua et al. (2008) also showed a decrease of gas production during the end periods.

4.2 Morphology of Fruit, Grain and Vegetable

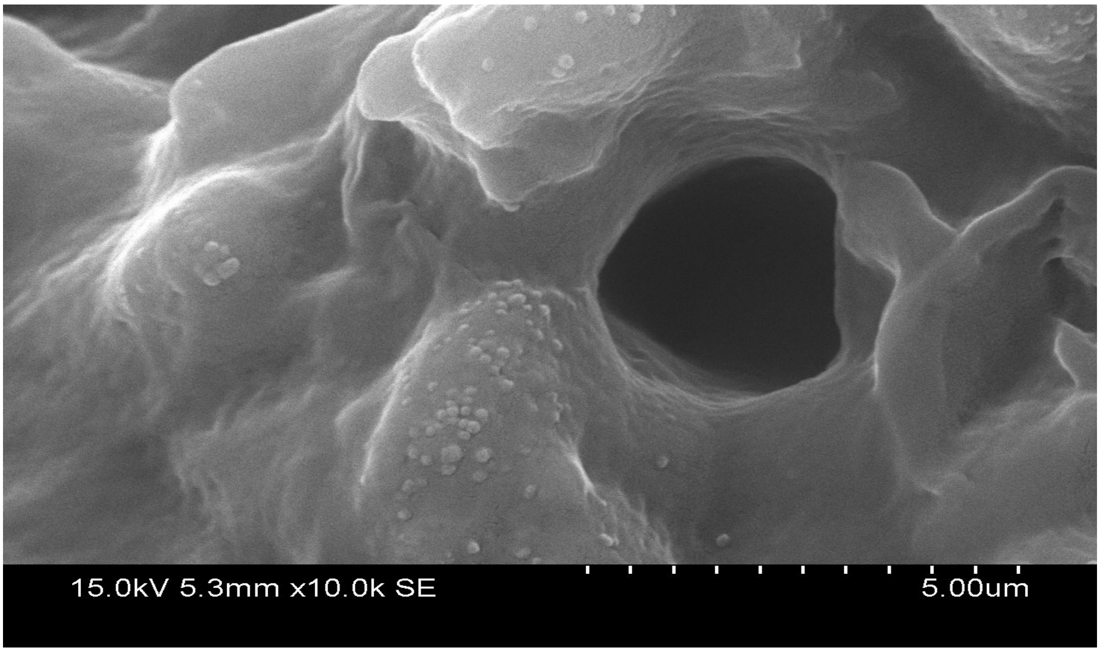
Structures of the waste were studied by the morphology from the Scanning Electron Micsroscopy (SEM).

4.2.1 Rice and Bread Waste

Figure 4.4 (a) shows the overall look of a sample of rice with the magnification of 300 times. The structure of the rice shows an uneven surface where the agglomeration of starch is rapid on the surface. The starch which contains high carbohydrates caused the massive production of methane. Rice also contained many porous like structures as showed in Figure 4.4 (a). A clearer and magnification of 10000 times shows the porous to be deep as in Figure 4.4 (b). These porous helped to absorb the water and eased the digestion of the wastes. Inoculums had higher probability to enter deep into the wastes and consequently consumed the waste into simple form. The water absorbed into the porous region ultimately weakens the strength of the structure. Inoculums had better chance to digest the waste.



(a)



(b)

Figure 4.4 (a) & (b): Surface Morphology of Rice under Magnification of 300 times and 10000 times respectively.

It is believed that the porous structure or spongelike behaviour also exist in bread structures. As shown in Figure 4.5 with the magnification of 20000 times, there are number of porous regions on the bread waste. Consequently, bread would utilize less period of digestion as their bonds are easily broken. This was due to the absorption of liquid into the porous region. The absorption caused the expanding of the region and at one point the region broken to allow the liquid to flow out. Besides, inoculums had higher probability to enter deep into the wastes and consequently consumed the waste into simple form. In addition, the uneven porous on the surface as portrayed in Figure 4.5 reduces the strength towards resistance. Thus, comparing between the other wastes, rice and bread can be easily degraded to complete the digestion process faster.

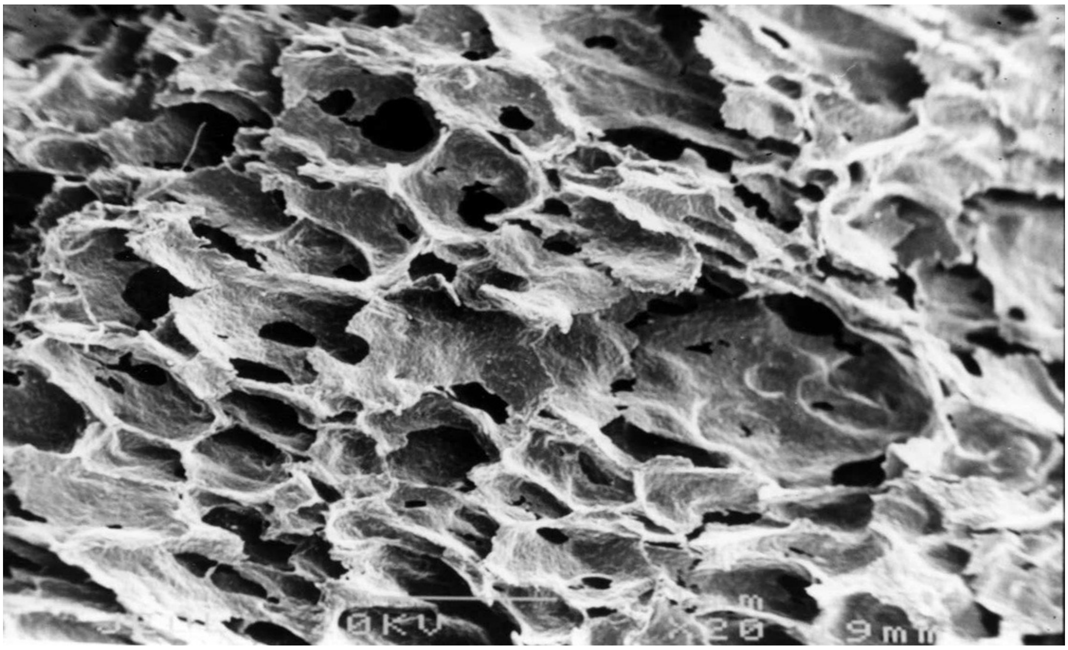
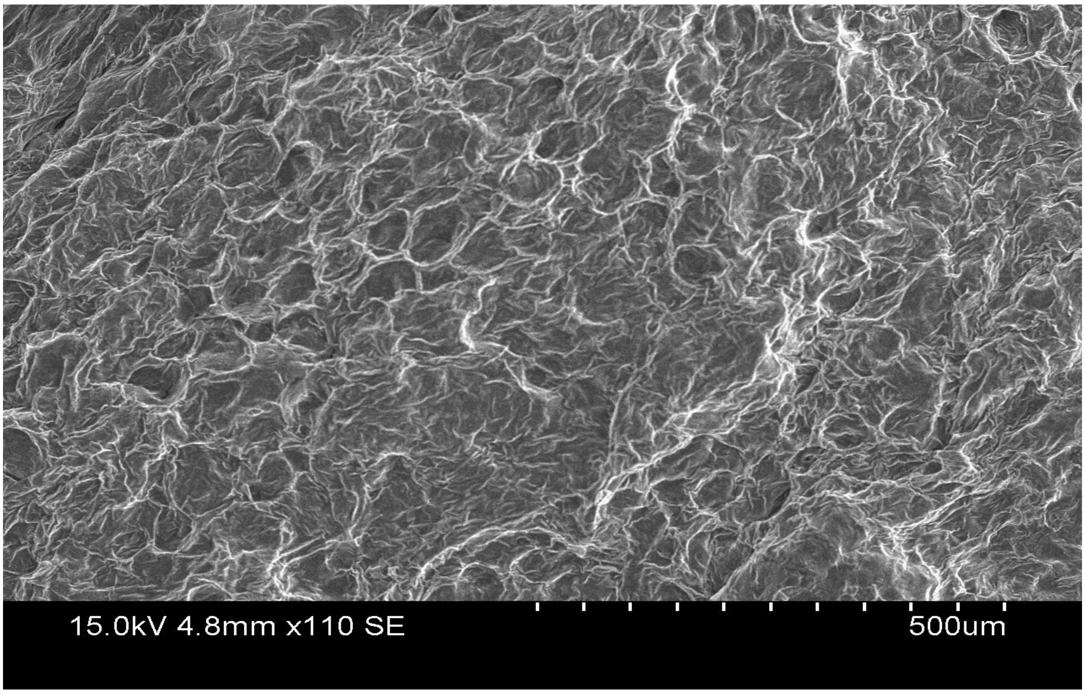


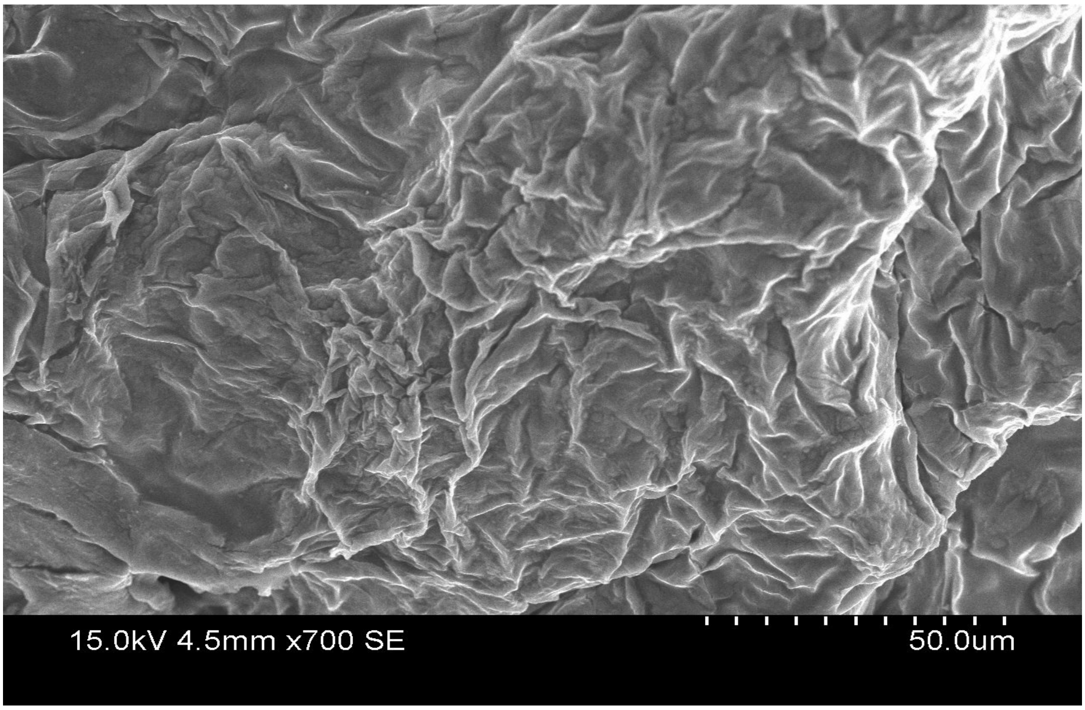
Figure 4.5: Surface Morphology of Bread under Magnification of 20000 times (Davis, 2010).

4.2.2 Fruit Waste

Papaya was used to give a view of structures of fruits surface. Figure 4.6 (a) demonstrates the overall view of the structure with the magnification of 110 times. The surface can be seen that the fruit waste contains smaller portion of porous regions. The inoculums and water are more likely to move into the porous region and digest the waste into simpler structures. Figure 4.6 (b) illustrates a magnified view of 700 times and the surface shows various crosslink and complicated linkages compared to the magnified view of rice in Figure 4.4 (b) and Figure 4.5. Both Figures 4.5 and 4.4 (b) show many porous and bigger porous on the surface. However, Figure 4.6 (b) shows the surface to be uneven and rough. This might be the reason of methane yield lower than the grain waste and higher than the vegetable waste. The inoculums easily can move on top of the surface region while slight difficulty to move into the regions of the fruits and to further digests the fruits.



(a)



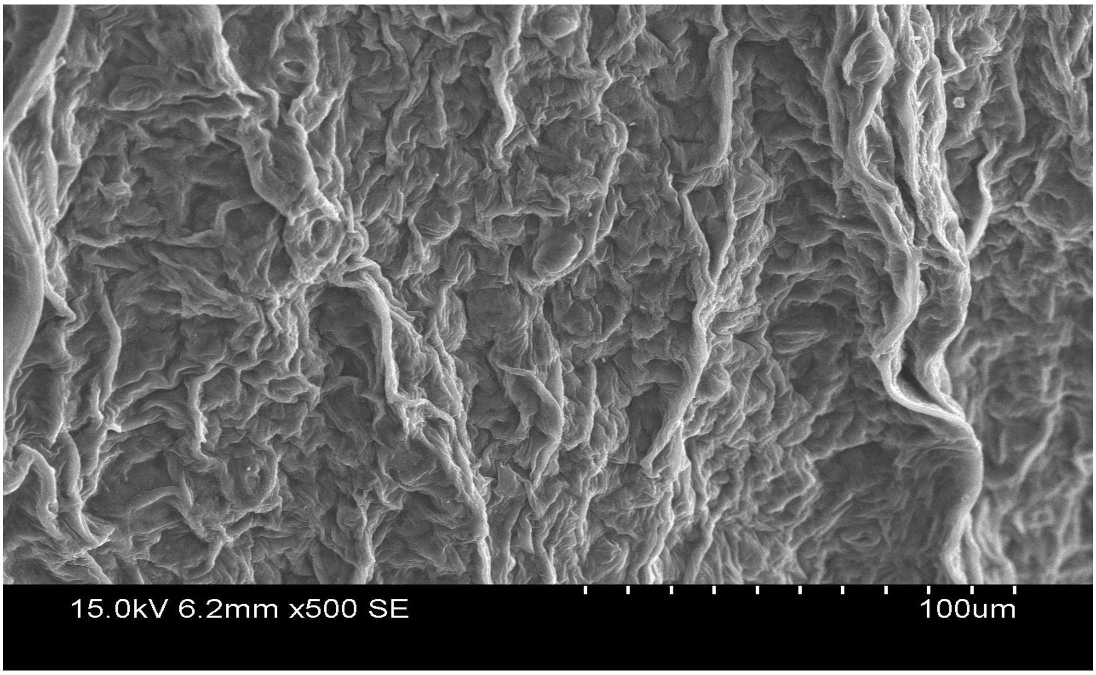
(b)

Figure 4.6 (a) & (b): Surface Morphology of Papaya under Magnification of 110 X and 700 X respectively.

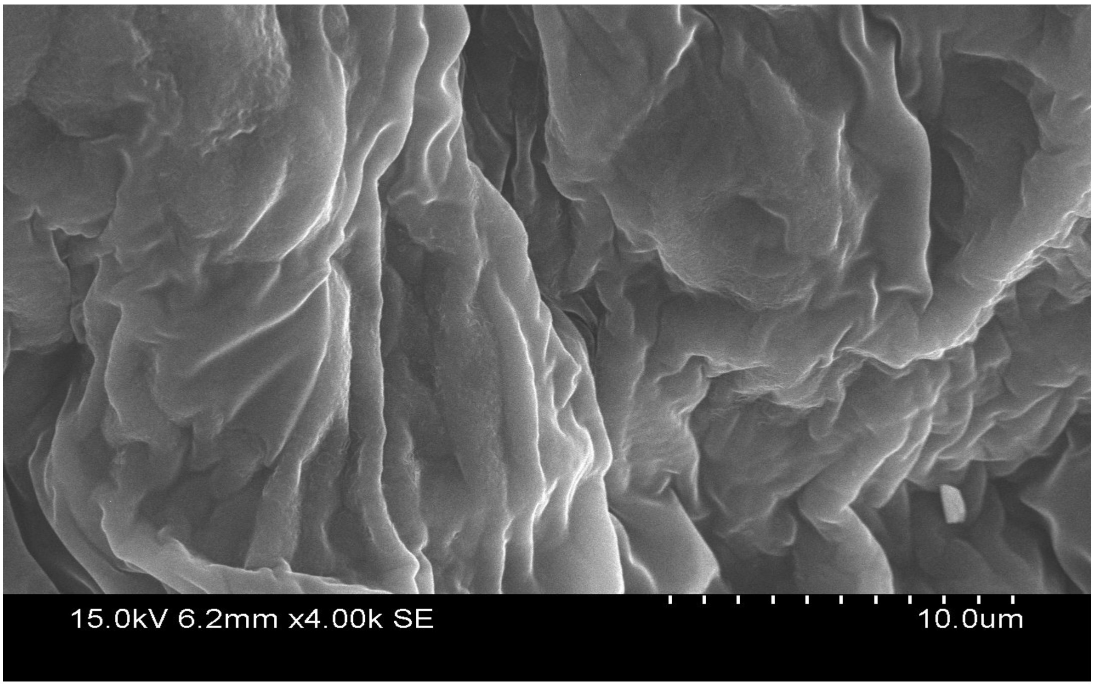
4.2.3 Vegetable Waste

Spinach leaf was used to give a view of structures of vegetable surface. Vegetable waste consists of high cellulose and organic matters. Cellulose is an insoluble matter and it must be converted into soluble matters such sugar, amino acid and fatty acid. Figure 4.7 (a) shows the overall structure of the spinach leaf with the magnification of 500 times where the structures were rather complex and strong due to the cellulose wall. The cellulose wall is not easy to be broken as it is strong compared to the other wall cells. Hence, it can be assumed that the aid of inoculums helped to break the cellulose walls during the initial and as the inoculums diminished, the cellulose wall was not easily broken. Figure 4.7 (b) portrays a magnified view of the spinach leaf with the magnification of 4000 times. The structure tends to be thick and uneven. No porous regions were detected and this caused difficulty for the inoculums to enter and digest the waste.

This is also an explanation for the reason of fluctuation at the end of vegetable digestion. Some of the easily digested vegetables were digested with the aid of inoculums during the early stage of digestion while hardly digested vegetables needed water to enter in the cellulose wall to weaken the strength of the wall. Therefore, these vegetables were digested during end of the digestion period where some inoculums and the weak wall caused them to be like that. Apparently, a slight fluctuation at the end of the vegetable digestion was obtained. Babaee et al. (2008) carried out a research on vegetable with a total retention time of 25 days. The results which were obtained explained that the methane percentage was highest during the initial period and subsequently decreased with fluctuations in between.



(a)



(b)

Figure 4.7 (a) & (b): Surface Morphology of Spinach under Magnification of 500 X and 4000 X respectively

4.3 Fertilization Test

In this research, the residues from the anaerobic digestion were further used as fertilizers after being dried and blended. *Ixora coccinea* is the species of the plants used and all plants were successfully grown. The three types of fertilizers were fruit, vegetable and grain waste. The fertilizers were used on three plants respectively and one plant was used as control. Figure 4.8 shows the initial level of the four plants. All the plants were approximately the same height and branching. After one month, the total growth of plants was recorded. Figure 4.9 portrays the final growth and branching of plants.

Figure 4.8: The Initial Growth and Branching of Plants

Among all the plants, the plant which was fertilized by fruit waste showed the highest growth with a total of 15 cm as shown in Figure 4.9. Plant growth of vegetable fertilizers demonstrated the second highest reading of 11 cm and followed by the plant growth of grain fertilizers of 7 cm. The control plant established a growth of 5 cm. Comparing in terms of plant branching, the order follows as well with highest fruit fertilized plant, vegetable fertilized plant, grain fertilized plant and control plant. The total growth and branching of the plants are compiled in Table 4.1.

Figure 4.9: The Final Growth and Branching of Plants for One Month Duration

Table 4.1: Total Growth of Plant After 1 Month Duration

Plants	Height obtained after 1 month (cm)	Branching obtained after 1 month
Fruit Fertilized	15	High
Vegetable Fertilized	11	Moderate
Grain Fertilized	7	Low
Control (not fertilized)	5	Low

The three major nutrients uptake by plant growth are nitrogen, phosphorus and potassium (Olowolafe, 2008). Hart, Gangwer, Graham, and Marx (1997) stated that secondary nutrients such as calcium, magnesium and sulphur are needed in large amount and micronutrients are needed in small amounts only. The micronutrients consist of iron, zinc, boron, manganese, and chlorine. In this research, the fertilizers that were used were initially mixed with cow dung which was used as inoculums. Cow dung is one of the essential organic fertilizers for plants. Cow dung consists of high nitrogen (N), phosphorus (P) and potassium (K) which contributes to a rapid growth of plants. Olayiwola, Olajumoke, and Abidemi (2011) mentioned in their research that cow manure contains the highest amount of nitrogen, phosphorus and potassium compared to chicken, sheep and goat manure. The cow manure has contributed the equal amount of minerals and nutrients for all the three fertilizers.

The variation in the growth of plants was due to the content of major sample consisting in each fertilizer. The highest growth of plant was associated with fruit fertilizer and Table 4.2 shows the nutrition facts of fruits that were contained in the fruit waste in this research. Fruits contain the higher amount of potassium compared to vegetables and grain as shown in Table 4.2, Table 4.3 and Table 4.4. The amount of calcium and iron which was needed by the plants to grow was high for fruits compared to vegetable and grain. The average values of potassium, calcium and zinc from Table 4.2 is higher than the values in Table 4.3. Hence, can be concluded fruit fertilizers give higher chances for the plants to grow rapidly. Vegetable fertilizer contains a comparable amount of potassium, calcium and zinc as shown in Table 4.3 but the amount of minerals are not as high as in fruit fertilizers. This is the reason vegetable fertilized plant yielded a shorter height of growth compared to fruit fertilized plants.

Table 4.2: Nutrition Facts of Fruits (US Food and Drug Administration, 2009).

FRUITS	CARBOHYDRATE (g)	POTASSIUM (g)	CALCIUM (g)	IRON (g)	FIBER (g)
BANANA	30	0.45	1	2	2
PINEAPPLE	13	0.12	0	2	1
PAPAYA	20	0.26	4	3	1
MANGO	17	0.16	2	2	1.8
AVERAGE	20	0.25	1.75	2.25	1.45

Table 4.3: Nutrition Facts of Vegetables (US Food and Drug Administration, 2009).

VEGETABLES	CARBOHYDRATE (g)	POTASSIUM (g)	CALCIUM (g)	IRON (g)	FIBER (g)
CUCUMBER	2	0.14	2	2	2
BRINJALS	5	0.19	0	2	2
ONION	2	0.19	0	0	1
TOMATO	7	0.34	2	2	1
SPINACH	4	0.17	4	5	2
AVERAGE	4	0.21	1.6	2.2	1.6

Table 4.4 illustrates the nutrition in grain and typically grain contain high protein whereas low minerals which are needed for the plants. The grain waste used in this research consists of a mixture of rice and bread and their respective nutrition are shown in Table 4.4. The amount of potassium is not applicable for rice and bread. Grains contain a small amount of zinc and iron which are essential for plants growth but the values are small as shown in Table 4.4. The average values for fibres are ascending from grain, fruits and vegetables. The total amount of fibre represents the easiness of fertilizers degradation into the soil. The high amount of fibre in vegetables signifies that the process of absorption of nutrients into the plants was slower compared to fruits and grain. Since, grain has very less minerals needed for plants, the faster rate of absorption is not a controlling factor here. The fibre content in fruits is higher than grain and lower from vegetable. The control plant has approximately the same growth with the grain fertilizer plant. This was due to the fewer amounts of minerals in the grain fertilizer. The slight difference of 2 cm for the control plant and grain fertilized plant was might due to the cow manure content in the grain fertilizers. The plant growth was highest for fruit due to the moderate absorption rate and also the amount of mineral content. In summary, all the fertilizers contributed to the growth of plants. The minerals and nutrients consisting in each fertilizer determine the amount of the growth for each plant.

Table 4.4: Nutrition Facts of Grain (US Food and Drug Administration, 2009).

GRAINS	CARBOHYDRATE (g)	PROTEIN (g)	ZINC (g)	IRON (g)	FIBER (g)
RICE	40	6.8	0.5	1.2	0.6
BREAD	39.1	12.3	0.015	0.074	0.7
AVERAGE	40	9.55	0.26	0.64	0.65

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, all the three waste can be used for anaerobic digestion process. Grain waste contributes to the highest methane and the total methane recorded was 2546 ml. Fruit waste contributes to second highest of methane production and followed by vegetable waste. The total amount of methane measured for fruit and vegetable waste was 2000 ml and 1468 ml respectively. The amount of carbohydrates and sugar in each waste has determined the total methane production. The amount of carbohydrates and sugar is the highest in grain waste followed by fruit waste and vegetable waste. For the plant fertilization test, fruit fertilizers contributed to the 15 cm of overall growth of plant. Vegetable fertilizers and grain fertilizers based plants recorded 11 cm and 7 cm respectively. Besides that, fruit fertilizer based plant had the better branching compared to the other three plants. Hence, it can be concluded that anaerobic digestion is a privilege opportunity to produce an alternative fuel, managing the waste accumulation and also to obtain an organic fertilizers.

5.2 Recommendations

This research was done for a period of three months and with available facilities. Due to time constraints and unavailability of apparatus, this research could not be varied in various parts to perform a better testing. There are many recommendations can be done to make this research more efficient.

1. The first recommendation is to conduct a flame test. A flame test is usually done to determine the physical characteristics of flame produced from the gas (Ojolo et al., 2008). The importance of flame test is to investigate the relationship between types of feedstock and flame characteristics. This test will be important for determining the application of the biogas produced from waste for fuel energy substitution. The biogas with rapid and vigorous flame has potential to be substitution for fuel energy.

2. The method used in this research was displacement method where the amount of methane produced will push the water in the measuring container and the height will be equivalent to the methane produced. A more efficient method is by using gas chromatography since it will involve analytic approach to detect the amount of methane produced. A combination of both methods is recommended due to this combination will provide better and reliable data as conducted by Azlina et al. (2009) in their researches. Hence, both methods can be applied to determine the correct amount of methane produced.

3. Literature review shows that anaerobic digestion can be divided into many aspects such as modes of operation, types of system and also types of digester. Varying the methods of research will provide better understanding on anaerobic digestion and consequently the best system can be designed for industrialization purposes. For example, in this research the biogas production can also be produced using semi-continuous mode at thermophilic temperature or continuous mode at mesophilic temperature. Therefore, various experiments are recommended to be used to produce the methane so that the best system can be found and further commercialize it. Palm oil mill can produce biogas from any methods but will produce the highest biogas by

using closed digester and at high mesophilic. Variation in research experiments lead to higher probability to attain best system for a particular feedstock.

4. The system which was designed in this research was simple and the mixing of feed in the digester was done manually every day. For industrial and larger scale purposes, a magnetic stirrer is recommended to be used at the bottom of the digester for better mixing and higher probability for inoculums to move into the waste. Thicker and high solid content feedstock, a mechanical mixer is recommended to be fixed as the feed can be mixed thoroughly.

5. Polyethylene tarpaulin was used as insulation material for the digester in this research. For better temperature stabilisation and to avoid temperature fluctuations, a steel or glass based digester can be designed with proper insulation so that the digestion process occurs effectively.

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