PRODUCTION OF METHANE FROM POULTRY MANURE

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Thesis submitted to the Faculty of Chemical and Natural Resources Engineering in partial fulfillment of the requirements for the degree of Bachelor of Engineering

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering.

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I hereby declare that the work in the thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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We certify that the thesis entitled "Production of Methane from Poultry Manure" is written by Lai Wi Ven. We have examined the final copy of this thesis and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor in Engineering. We herewith recommend that it be accepted in fulfillment of the requirements for the degree of Bachelor in Engineering specializing in Chemical Engineering (Biotechnology).

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ABSTRACT

Poultry industry is a fast growth industry globally in line with high demand in the Halal meat at Islamic countries especially in Malaysia. Increasing number in broiler production creates a lot of environment issues. The recent stunning issue that attracts the attention of the public is about 400 tons of unsolved chicken dung in Selangor that arisen air, water and soil pollution. Fermentation process is the ideal way to solve the problem with win-win situation. Besides producing clean energy with low carbon emission, the sludge obtained after fermentation process is very suitable for landfill as fertilizer. There are 3 same size carboys with 25 liter volume fabricated as fermenters. They are fed-batch with inoculums fermenter, fed-batch without inoculums fermenter and lastly a batch fermenter. After adding 17 liters of sample with 10% TS w/v for each fermenter, the fermenters are purged with pure nitrogen gas for 30 minutes and later placed inside a fabricated polytank with heating system as water bath to maintain the temperature within 55 degree Celsius which is thermophile anaerobic condition. An additional of 1.7 liters of sewage sludge (inoculums) is added to the inoculums fermenter .The quantity of gas produced is checked and recorded every days by gas displacement system and the gas composition is checked gas analyzer once a week. For fed-batch fermenters, one sixth of 17 liters is withdrawn once a week, at the same time, same amount of fresh diluted sample is pumped in by using peristaltic pump. By comparing batch with and without inoculums fermentation, applications of inoculums in batch fermentation shorten the lag phase and leads to a shorter fermentation cycle in batch system. By comparing the same thermophile system between batch and fed-batch fermentation process, both of the process give similar result in term of biogas production and methane gas composition during lag phase. However, the biogas production for thermophile fed-batch system keep maintaining at log phase whereas thermophile batch system encounter its' stationary phase at the day 14^{th} and death phase at day 40^{th}. In short, application of inoculums in fermentation accelerates the biogas production and fed-batch fermentation is suitable for commercial purpose as the biogas produced is continuous with low down time.

ABSTRAK

Industri ternakan berkembang pesat sejajar dengan permintaan yang tinggi terhadap daging Halal di negara Islam terutamanya di Malaysia. Produksi ayam ternakan yang banyak membawa impak kepada alam sekililing sehingga menimbulkan isu-isu seperti yang berlaku di Selangor,di mana kira-kira 400 tan tahi ayam tidak dapat dilupuskan dan menyebabkan penecemaran udara, air serta tanah yang teruk. Proses penapaian adalah cara yang ideal untuk menyelesaikan masalah ini dengan 'win-win' situasi. Selain dapat menghasilkan tenaga bersih dengan pengeluaran karbon yang rendah, enapemar yang diperolehi adalah sangat sesuai untuk dijadikan sebagai baja. Terdapat tiga jenis fermenter, fed-batch fermenter tanpa inocula, batch fermenter tanpa inocula, dan batch fermenter dengan inocula. Tiga-tiga fermenter ini diubahsuai daripada tiga 25 liter carboys. Selepas 17 liter 10% TS w/v sampel dimasukkan dalam fermenter, gas nitrogen telah disalur masuk kedalam fermenter selama 30 minit untuk menyingkirkan kandungan oksigen dalam fermenter. Selepas itu, fermenter direndam dalam tangki poli untuk mengekalkan suhu fermenter sebanyak 55 ℃. 1.7 liter inocula telah ditambah masuk ke inocula fermenter. Kuantiti gas yang dihasilkan telah direkodkan setiap hari, komposisi gas telah dianalisis sekali seminggu dengan menggunakan Gas Analyzer. Sebanyak 3 liters sampel dikeluarkan dari fed-batch fermenter sekali seminggu, pada masa yang sama, 3 liters sampel baru dipam masuk dengan bantuan pam peristalsis. Dengan membandingkan biogas yang dihasilkan di batch inocula dengan batch tanpa inocula fermenter, penggunaan inocula dalam penapaian batch dapat memendekkan lag phase serta menyebabkan kitaran penapaian yang pendek. Dengan membandingkan batch dan fed-batch penapaian, kedua-dua proses memberikan hasil yang sama bagi kuantiti biogas yang dihasilkan serta komposis methane yang dihasilkan pada lag phase. Namun demikian, biogas yang dihasilkan oleh penapaian fed-batch mengekalkan pada log phase manakala penapaian batch menghadapi stationary phase pada hari ke-14 serta death phase pada hari ke-40. Sebagai kesimpulan, penggunaan inocula dalam penapaian dapat mempercepatkan penghasilan biogas. Selain itu, penapaian fed-batch adalah sesuai untuk tujuan komersial kerana biogas yang dihasilkan daripada cara ini adalah berterusan dengan "down time" yang singkat.

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LIST OF SYMBOLS

℃	Degree Celsius
℉	Degree Fahrenheit
%	Percentage
×	Times
Wt%	Weight Percentage
w/v	Weight per Volume
±	Plus and Minus
L	Liter
ml	Milliliter
cm	Centimeter
KG	Kilogram
Min	Minutes

LIST OF ABBREVIATIONS

TS	Total Solid
AD	Anaerobic Digestion
CH_4	Methane
CO_2	Carbon Dioxide
pH	Potential Hydrogen
HRT	Hydraulic Retention Time
SRT	Solid Retention Time
PVC	Polyvinyl Chloride
PSM	Projek Sarjana Muda
POME	Palm Oil Mill Effluent

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Poultry is defined as domestic fowls reared for the table, eggs or feathers (Mike Johanns, 2011). There are about 10,000 species of birds in the world but only 12-13 species can be considered as poultry; such as chicken, ducks, turkeys, capons, geese, etc. (Md. Mukhlesur Rahman, 2009). Rapid economic and population growths in Malaysia fuel the massive increase in demand-driven consumption for food of animal origin especially the poultry (Paraguas, 2006). According to the report issued by Malaysia's Department of Veterinary Services, over the 2000-2010 periods, the local consumption of chicken livestock has increased from 635,000.21 metric tons to 1,013,000 metric tons which is the highest per capita consumption rates in the world for chicken (Abbott, 2010).

The demand on poultry is high in Malaysia because it is the cheapest source of meat protein moreover poultry is a halal product which is homogeneous to all religions and ethnics all around the world (Paraguas, 2006). The concept of halal is associated with food products which are of high quality in term of cleanliness, sanitation and compliance with religious requirement (Fayed, 2011). Subsequently, the production cycle time for poultry is relatively short and profitable under the industrialized production system (Tey & Yeong-Sheng, 2009).

Owing to the high demand on poultry meat in Malaysia, it leads to rapid growths in broiler (chicken meat) production in poultry industry (FLFAM). There are about 3,391 broiler grower farms in Malaysia and near about 26 parent stock farm companies in the Peninsular part of Malaysia (FLFAM, 2007). Along with the increasing

production of broiler, the amount of poultry manure is also rising. The daily excrements of a laying hen can be estimated with 138g/day (25% dry substance) and 90g/day (40% dry substance) of a broiler. A non-appropriate treatment of poultry manure can lead to soil and groundwater pollution; threaten environment and humans' health besides supporting the spread of disease (Roeper et. al., 2005). However, poultry manure especially chicken dropping can be a beneficial commodity if it has been treated properly.

1.2 PROBLEM STATEMENT

The dramatically increment of poultry farm in Malaysia has risen a lot of environment issues and public community problems. A chicken farm located in Kuala Sungai Baru, Melaka has disseminated chicken dropping smell and troubled the residents of vicinity about 6 years. The seriousness of the chicken manure odour issue comes to the extent that causes dizziness, dry throat and lung infections among the residents (New Straits Time, 2009). Furthermore, Selangor state government has ordered a poultry farm in Sungai Buloh to shut down temporarily to remove the 400 tons of chicken dropping which causes unpleasant odour and flies problems to the nearby residents (Zavier, 2010). This issue is no longer an fresh issue for developed countries like Japan, Korea and also European's countries because the application of anaerobic digestion technique is well-developed but it is a great problem when comes to third world countries likes Malaysia, Thailand, Indonesia, etc.

This study will be conducted to determine the efficiency of methane production by using fed-batch reactor, operating at thermophilic temperature range ($\pm$ 55℃) with regular feed amount of manure every 42 days to maintain the anaerobic fermentation at exponential phase.

1.3 RESEARCH OBJECTIVES

Research objectives of this experiment are:

1. To study the efficiency of fed-batch fermentation towards methane production.
2. To study the effect of inoculums in batch fermentation.
3. To investigate the quality of the biogas produced.

1.4 RESEARCH SCOPE

In order to achieve these objectives, the following scopes have been identified to limit the scope of study;

1.4.1 To produce methane gas from raw chicken manure by anaerobic digester.

1.4.2 To investigate the time taken to bring an anaerobic digester of raw chicken manure to maximum bacterial activity.

1.4.3 To analyze the percentage of methane composition from the biogas yield by using gas analyzer and sample probe.

1.4.4 To compare the production rate of biogas between digester with inoculums and digester without inoculums.

1.5 RATIONALE AND SIGNIFICANCE OF STUDY

The significances of conducting this research are to improve the production rate of methane gas by using fed-batch reactor as a renewable and clean source of energy. The environment problem can be solved in a more efficient and environmental friendly way instead of incineration and dumping at estate area which will lead to serious ground, water and air pollution. Besides, this is a commercial project which highly demanded by foreign and local poultry investors.

All in all, this research is marketable with win-win situation. Besides producing clean energy for farm usage, it can protect our environment by reducing pollution as well.

CHAPTER 2

LITERATURE REVIEW

2.1 ANAEROBIC DIGESTION

Anaerobic digestion is a biological process that involves the breakdown of organic material by a microbial population that lives in an environment with little or no oxygen (Warmer Buletin, 2008). The term 'anaerobic' means literally without air. Although anaerobic digestion can occur naturally within a landfill, the term generally describes an artificially accelerated operation in closed vessels (Friends of The Earth, 2007). Almost all of the organic materials like waste paper, leftover food, industrial effluents, sewage, animal waste and manure can be processed with anaerobic digestion (Warmer Buletin, 2008). During anaerobic treatment process, organic nitrogen compounds are degraded to ammonia, phosphorus compounds are degraded to orthophosphates, sulfur to hydrogen sulfide, and sodium, calcium, and magnesium are converted to a variety of salt. Through appropriate process, the inorganic constituents like ammonia, hydrogen sulfide, and orthophosphate can be converted to a variety of marketable products. When organic matter is decomposed in an anaerobic environment, the bacteria produce biogas by converting putrid organic materials to a mixture of methane, carbon dioxide and trace amounts of other gaseous, nutrient rich organic slurry, and other valuable inorganic products.

The biogas generated during anaerobic digestion can be used as fuel or as a chemical feedstock. Subsequently, the effluent of the process containing particulate and soluble inorganic and organic materials can be separated into its particulate and soluble constituents. The particulate solids can be sold as fertilizer from the poultry farm while the nutrient rich liquids are applied to the land or vegetable farm (Burke, 2001).

2.1.1 Definition of Biogas

Biogas is a by-product of the anaerobic breakdown of organic matter like animal manure or agriculture waste in the farm. It is a clean and environment friendly renewable fuel. Biogas consists of a mixture of methane, carbon dioxide and small amounts of nitrogen, hydrogen, hydrogen sulfide, and water vapour. Methane is the most crucial component of biogas because it is a flammable gas that can be used for cooking; generate electricity, heat and hot water systems, refrigeration, and even use in engine. The heat content of biogas is according to the amount of methane and is around 600 BTUs per cubic foot.

Table 2.1: Chemical Composition of Biogas

Components	**Household waste**	**Wastewater treatment plants sludge**	**Agricultural wastes**
CH_4 % vol	50-60	60-75	60-75
CO_2 % vol	38-34	33-19	33-19
N_2 % vol	5-0	1-0	1-0
O_2 % vol	1-0	< 0.5	< 0.5
H_2O % vol	6 (à40 °C)	6 (à40 °C)	6 (à40 °C)
Total % vol	100	100	100
H_2S mg/m^3	100 - 900	1000 - 4000	3000 – 10 000
NH_3 mg/m^3	-	-	50 - 100
Aromatic mg/m^3	0 - 200	-	-
Organochlorinated or organofluorated mg/m^3	100-800	-	-

*Data obtained from “The Biogas” from http://www.biogas-renewable-energy.info/biogas_composition.html

2.1.2 Bioconversion Process of Turning Organic Materials into Fuel

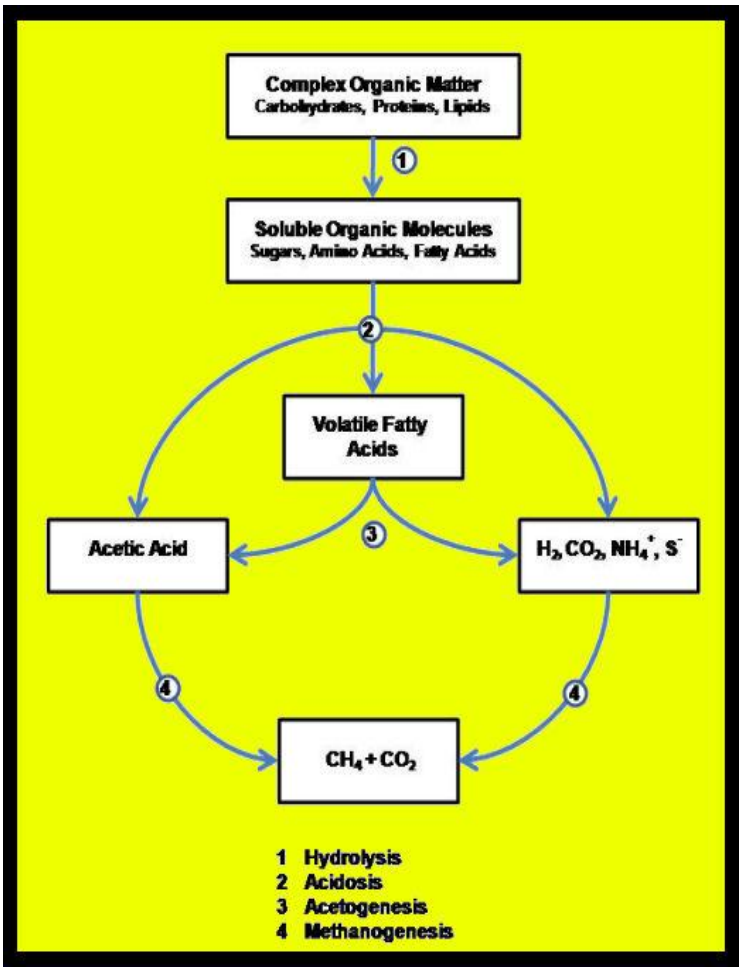


Figure 2.1: Steps in anaerobic digestion (Hamilton, 2010)

Anaerobic digestion (AD) is carried out by a group of bacteria which approximately more than 100 different anaerobic microbes working together to convert organic matter to biogas and inorganic constituents (Burke, 2001). These bacteria are organized into a number of interlinked communities. AD is a multi-stage process that primarily consists of four steps; they are hydrolysis, acidogenenisis, acetogenisis, and methanogenisis (Hamilton, 2010).

Hydrolysis is the phase of anaerobic digestion where insoluble or complex organic polymers such as carbohydrate, cellulose, proteins and lipids are broken down and liquefied by enzymes produced by hydrolytic bacteria into simpler organic molecules. The release of extra-cellular enzymes by a variety of bacteria hydrolyzes the

complex organic matter into simple sugars, amino acids, and fatty acids (Friend of The Earth, 2007).

Acidogenesis is where simple organic molecules are further broken down by acidogenic bacteria (acid-forming bacteria) into volatile fatty acids-principally acetic acid (vinegar) and producing carbon dioxide, hydrogen sulfide and ammonia as byproducts (Friend of The Earth, 2007). Acidogenesis and hydrolysis are normally lumped together and called anaerobic fermentation (Hamilton, 2010).

Acetogenesis is where the simple molecules from acidogenesis which is fatty acids are digested by acetogens bacteria into carbon dioxide, hydrogen and mainly acetic acid. Acetogenesis along with acidogenesis represents the transition from simple organic molecules to the methanogenic substrates.

Methanogenesis is where methanogenic substrates such as volatile fatty acids, hydrogen gas, carbon dioxide gas, acetic acids and water have been utilized by methanogens to form methane. Methanogens in methanogenesis process consists of two main camps depending on the pathway they use to produce methane. Hydrotrophic methanogens reduce CO_2 and H_2 into CH_4 and H_2O exclusively whereas acetotrophic methanogens convert volatile fatty acids and some of the simple organic compounds to CH_4 and CO_2.

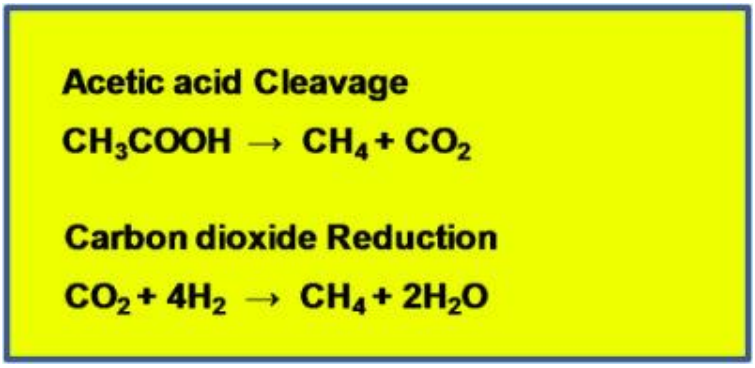


Figure 2.2: Major pathways of methane (CH_4) formation (Hamilton, 2010)

2.2 Phase of Microbial Community Growth

The growth of methanogens or human beings is similar with the growth pattern shown below if the communities of organism do have ample food supply, sufficient room to expand and also absence of predators or competing organisms (Hamilton, 2010). Microbial growth curve consists of five phases; they are lag phase, growth phase, decline phase, stationary phase and death phase (Abedon, 1998).

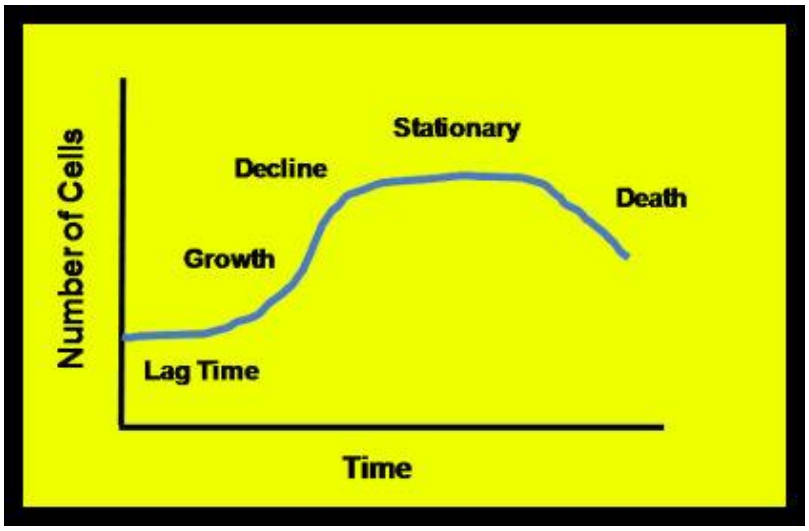


Figure 2.3: Generalized microbial growth curve (Hamilton, 2010)

Lag phase occurs as the organisms adapt to new environment or medium. Upon a change in medium from rich environment to poor environment, there is always a lag before division resumes. As an example, stationary phase of E.coli placed in an excess of sterile broth will undergo a lag phase which allow them to expand in cell size but do not divide. The bacteria will start to divide once they have achieved the size of a cell which is about to divide during log phase. In other words, there is no change in the quantity of bacteria but an increase in mass (Abedon, 1998). "The length of the lag phase is determined in part by characteristics of the bacterial species and in part by conditions in the media---both the medium from which the organisms are taken and the one to which they are transferred. Some species adapt to the new medium in an hour or two; others take several days. Organisms from old cultures, adapted to limited nutrients and large accumulated wastes, take longer to adjust to a new medium than do those transferred from a relatively fresh, nutrient-rich medium" (Black, 1996, p. 138).

The next is growth phase or known as log phase and exponential phase which is a physiological state where the population doubles in number every generation time (Fankhauser, 2008). Food is not limiting during growth phase and the population expands rapidly then divide, thus the bacteria rapidly decreasing in mass while increasing in number (Hamilton, 2010). For example, if there are 10 methanogens present at time 0 during log phase, and 100 methanogens present at time 10, then at time 20 there will be 10,000 cells present (Abedon, 1998). Then it follows by decline phase where the bacterial growth slows down and started to meet the shortage of food supply (Hamilton, 2010).

During stationary phase, the food supply become limiting causes the rate of bacterial division equals the rate of bacteria death, in other words, viable bacteria number remains constant (Fankhauser, 2008). It is a physiological adaption to bacteria excess where bacteria is too crowded with high concentration causes the environment is no longer able to support the requirement of exponential growth (Abedon, 1998). During stationary phase, the microbial community goes into hibernation and the reproduction does not cease until the death rate approaches the reproduction rate (Hamilton, 2010).

Death phase or endogenous growth phase occurs when a limited food supply is exhausted or an inhibiting element causes the death rate exceeds the birth rate. The end products of a community's metabolism are referred to the inhibitory elements which cause endogenous growth in the communities (Hamilton, 2010).

In short, anaerobic digestion is the work of a mixed community of organisms where they taking up the end products of other communities as food supply. The mixed community in the anaerobic digester assists one another in order to get the final product which is biogas. "The beauty of anaerobic digestion is that it is the work of a mixed community of organisms. The toxic end product of one community is the food supply of another. Acid forming bacteria consume the simple sugars that might inhibit hydrolytic communities. Methanogens use the acids formed in fermentation to produce CH_4 and CO_2. And in the end, CH_4 and CO_2 leave the digester as biogas" (Hamilton, 2010).

2.3 Digester Start-up

Materials that contain methanogens such as biosolids from a sewage treatment plant and sludge from an active manure treatment lagoon or known as inoculum are commonly applied into digester to initiate the anaerobic digestion so that to make sure that there is a viable population of methane producing microbes, it is known as a "hot start" (Hamilton, 2010). Inoculum function in seeding the feedstock with an active anaerobic culture which is rich in methanogens to initiate activity and reduce any lag time required to bring the digester on line (Kirk and Faivor, 2010). In some cases, digester is established by a "cold start" which means that manure is slowly added to a liquid filled digester without the addition of inoculum until biogas starts to produce. Hot starts are definitely reacts faster than cold starts. Basically, a hot start takes between one to six months to bring a digester to reach steady-state but it is depending on the digester type used as well. As for a cold start, it may take six to a year time to bring the digester on line (Hamilton, 2010).

2.4 Factor Controlling the Conversion of Poultry Manure to Biogas

The objectives of this study are to investigate the yield of methane from poultry manure (chicken manure) in fed-batch fermentation medium, to study the efficiency of fed-batch fermentation towards methane production and lastly to analyze the quality of the biogas produced. In order to achieve the objectives, there are seven factors need to be take in consideration, they are reproduction time, temperature, steady food supply, hydraulic retention time (HRT), solid retention time (SRT), oxygen, pH.

2.4.1 Reproduction Time

To increase the efficiency of anaerobic digester in producing methane gas, the microbial communities must be designed to remain in exponential phase. Reproduction time is known as doubling rate of an organism which is very important in maintaining the microbial communities in exponential phase as this is the time taken by a population to double in size (Hamilton, 2010). Hence, it is very crucial to make sure that the food supply does not limit the microbes' communities in producing the biogas.

2.4.2 Temperature

The endurable temperatures ranges for anaerobic microbes' communities are from below freezing to above 135℉ (57.2℃). The methane producing bacteria, methanogens thrive best under two temperature ranges which are thermophilic (54.4℃) and mesophilic (36.7℃). Degradation and biogas production occur faster at thermophilic range rather than mesophilic range. This is because thermophilic methanogens are fast growing with the reproduction time of 10 to 15 days only whereas mesophilic methanogens has a 30 days reproduction time which is approximately 2 times slower than thermophilic methanogens. However, thermophilic methanogens are highly sensitive to disturbances, they are not able to tolerate at wide range of temperature which centred on 55℃ and sensitive to the temperature changes in feed materials. In addition, higher temperature of thermophilic digestion has an advantage in completely destructing the weed seeds and pathogenic organisms, but produces an odorous effluent if compared to mesophilic digestion (Burke, 2001). On the other hand, mesophilic methanogens is able to operate in a wide band of temperature and functioning optimally at 35℃.

In order to optimize the production of methane gas, the anaerobic digester must be maintained at a constant temperature so that the bacterial activity will not affect by the rapid changes.

2.4.3 Steady Food Supply

Food is very vital for microbes' reproduction and growth; hence a steady food (manure) supply in the digester is very important in maintaining the microbial growth in exponential phase so that the food does not limit the growth of microbes. Methanogens is able to go dormant if the food is insufficient. The benefit of this criterion is, long periods of inactivity in anaerobic digester can be easily getting restart. Besides, burst of biogas production will occur when there is sudden elevation in feeding, which causes foaming in the digester.

2.4.4 Hydraulic Retention Time (HRT)

Anaerobic digestion normally occurs in liquid form which designed to retain the manure for several periods. If the microbes in the reactor are completely suspended in the reactor then HRT is the number of days the microbes retain in the tank with zero net flow. The HRT equals to the volume of the remaining liquid in the reactor divided by the flow rate.

$$HRT=V/Q$$

HRT is vital as it shows us the time of bacterial growth and also the conversion of organic materials to biogas. The population of microbes within the reactor is considered stable when the reproduction time of the microbes equals the HRT of a completely mixed reactor. "Wash out" will occur when the HRT is shorter than the reproduction time which means that the leaving microbes are greater than the one being produced (Burke, 2001).

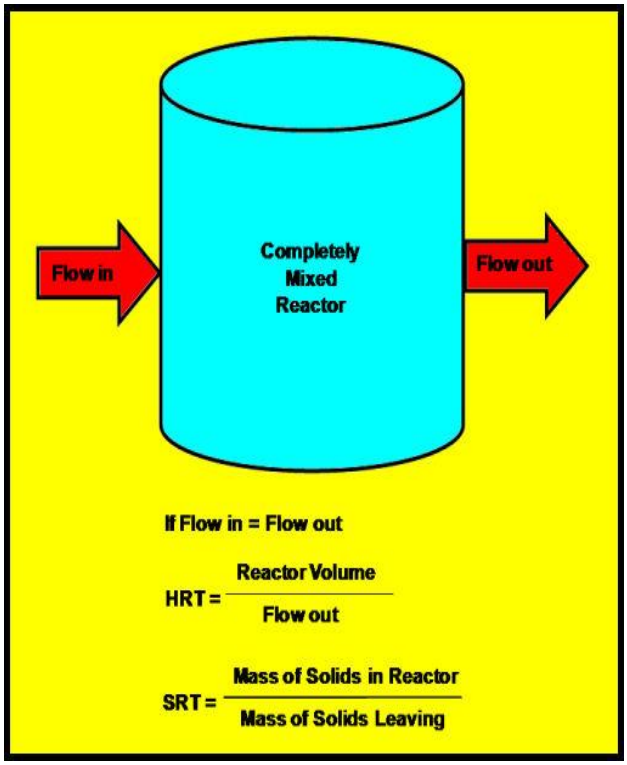


Figure 2.4: Relationships between reactor volume, flow, solids mass, and retention times in a completely mixed reactor. (Hamilton, 2010)

2.4.5 Solids Retention Time (SRT)

Solids retention time (SRT) plays role in maintaining digester stability and controlling the conversion of solids to gas. The microbial population in the anaerobic digester remains stable when the cell retention time equal to reproduction time of cell. SRT can be obtained by dividing the quantity of solids maintained in the digester with the quantity of solids leaving the digester each day.

In most cases, mass of living cells is hard to be measured rather than total mass of solid particles suspended in liquid, thus, SRT can be applied in approximating the cell retention time. For example, a screen is set up on the outlet of the digester to trap the leaving microbes, then; cell retention time can be calculated by dividing the mass of microbes maintained inside the digester with the mass of microbes trapped at the screen each day.

$$\mathrm{SRT} = \frac{(\mathrm{V})(\mathrm{Cd})}{(\mathrm{Qw})(\mathrm{Cw})}$$

Where V is the digester volume; Cd is the solids concentration in the digester; Qw is the volume wasted each day and Cw is the solids concentration of the waste (Burke, 2001).

2.4.6 Oxygen

Methanogens react well at oxygen free condition; even existence of least amount of oxygen will cause poison in the methanogens community. Methanogens indeed is strict anaerobes unlike acid forming bacteria which is more tolerant to oxygen. Therefore, the existence of oxygen in anaerobic digester will boost the production of carbon dioxide and lead to the reduction of methane gas concentration.

2.4.7 pH

The optimum pH for methane producing bacteria (Methanogens) is neutral to slightly alkaline environment (pH 6.6 to 7.6). In anaerobic digestion, acid forming bacteria is always growing much quicker than methane producing bacteria. If acid forming bacteria grows too fast, it means that more and more acid (Acetic acid) which is methanogens substrate will be produced. When the production of methanogens substrate is faster than the bacteria can consume, it will cause excess acid builds up in the digester. pH drops in anaerobic digester will inhibit the activity of methanogens and causes low productivity or zero production of methane gas. However, within an anaerobic digester, it exists naturally a pH buffer system, with carbonate-bicarbonate and organic acid-ammonia being the most crucial buffers.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 THERMOPHILIC FERMENTATION SYSTEM FABRICATION

Thermophilic fermention system consisted of three parts. They were anaerobic fermenter fabrication, water displacement system fabrication, and temperature relay system fabrication. These fabrications will be described in detail at following section.

3.1.1 FERMENTER FABRICATION

Basically, there were four fermenters had been fabricated for fed-batch fermenter, batch without inocula fermenter, batch with inocula fermenter and the last one as spare fermenter. The materials needed were four 25L carboys, four rubber stoppers, twelve units of valves, twelve pieces of 13cm long metal tubes, twenty four units of clampers, rubber tubes and silicon.

Firstly, each rubber stoppers were marked with a same angle triangle shape as shown in figure 3.1. Then three holes had been drilled at each angle of the triangle by using drilling machine. Twelve pieces of 13cm long metal tubes had been cut and bended 90 degree.

Figure 3.1: Rubber stopper and metal tubes

Then the metal tubes were fixed into the three holes as shown in figure 3.2. These tubing were responsible as gas sampling point, inlet and outlet for nitrogen purging. The two holes besides functioning as purging purpose, it also function as outlet for biogas produced to gas displacement system and feeding and discharging point for the medium.

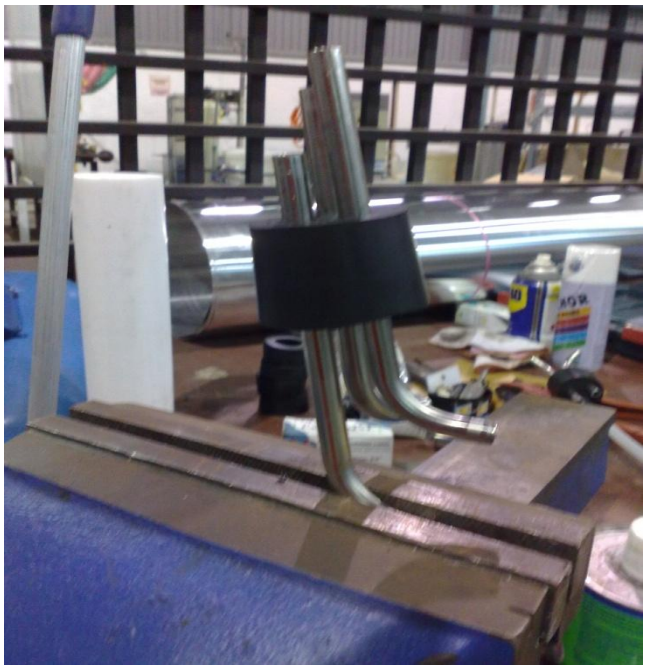


Figure 3.2: Fixing metal tubes into rubber stopper

After that, one of the metal tubes was fixed with rubber tube. The length of the rubber tube had to be made sure can reach the bottom of the fermenter so that it can function as nitrogen purging point or medium feeding discharging point. Then, the rubber stoppers with the metal tubes were fixed inside the opening of the carboys as shown in figure 3.3. To make sure the fermenters were fully air-tight; silicon had been applied on the joints between the carboy and the rubber stopper. Then, the valves were connected to the metal tubes by using rubber tubes and clampers.

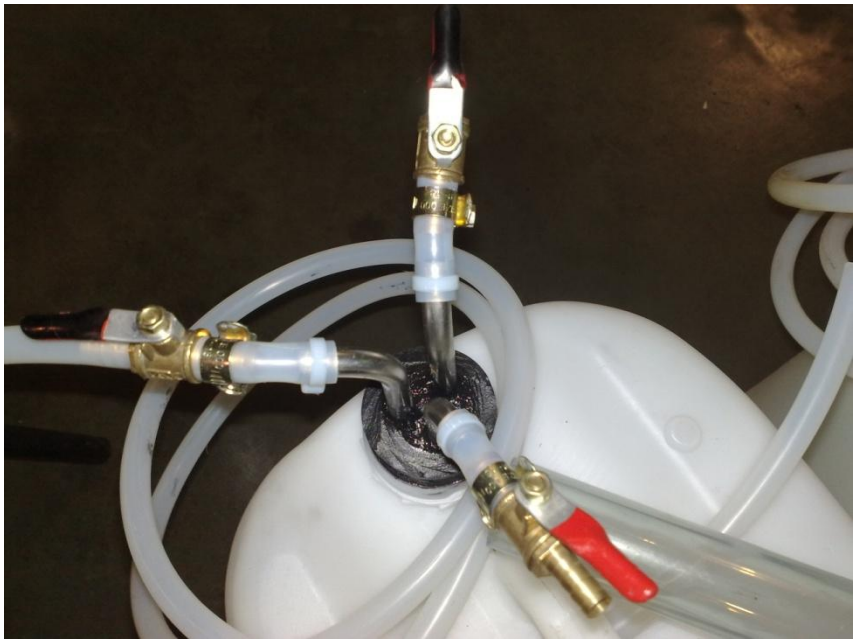


Figure 3.3: Anaerobic fermenter

3.1.2 WATER DISPLACEMENT SYSTEM FABRICATION

The materials needed for this fabrication were three 60cm long transparent tubes, three PVC elbows, three valves and silicon. Initially, three 60cm long transparent tubes were cut. Then, caps of PVC elbows were drilled and fixed with the valves as shown in figure 3.4. Silicon had been applied on the joint between transparent tube and elbow to make sure the tube was fully air-tight.

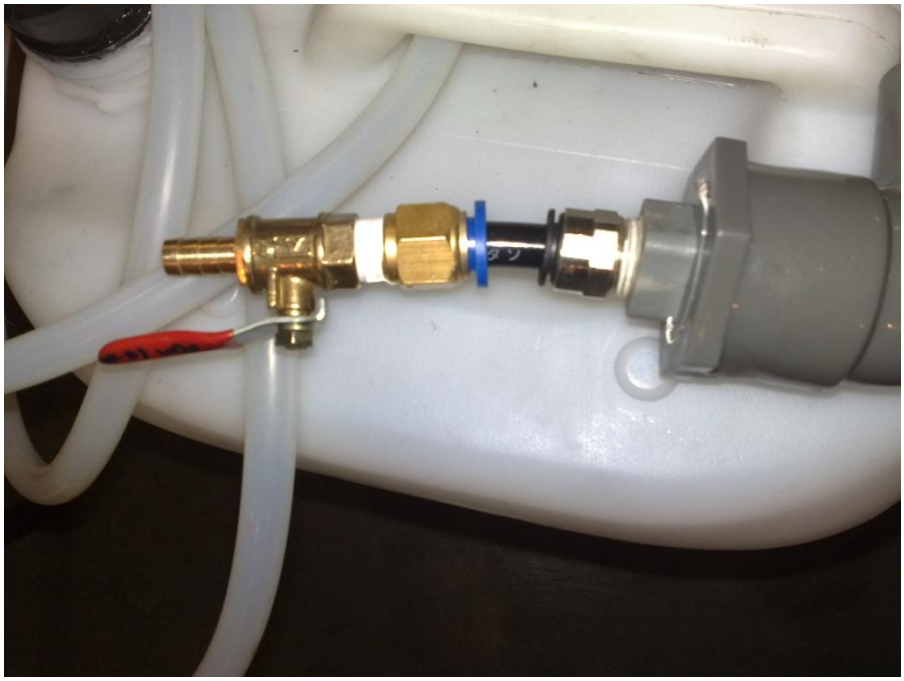


Figure 3.4: Connection between elbow and valve

3.1.3 TEMPERATURE RELAY SYSTEM FABRICATION

This heating system basically consisted of three parts. They were installing of heaters, circuit and panel box fabrication and panel box stand fabrication. The materials needed for temperature relay system fabrication were metal steel, panel box, temperature relay circuit board and components, temperature sensor, sprayer, three plug sockets, two heaters, wires, two plugs, silicon and cable tights.

First, the electronic components were soldered on the circuit board according to the guide. Panel box stand was fabricated with metal steel. Then, it had been sprayed by green color sprayer to protect the metal steel from corrosion. Next, panel box was drilled for fixing three indicators light, one locker, one main switch, and a temperature controller as shown in figure 3.5. Then, the completed circuit board was installed into the panel box.

Two holes were drilled at the poly-tank to install the heaters. Silicon had been applied to avoid water leakage. The locations of the heaters, aquarium pump, and temperature sensor were showed in figure3.6.

Figure 3.5: Temperature Control Panel Box

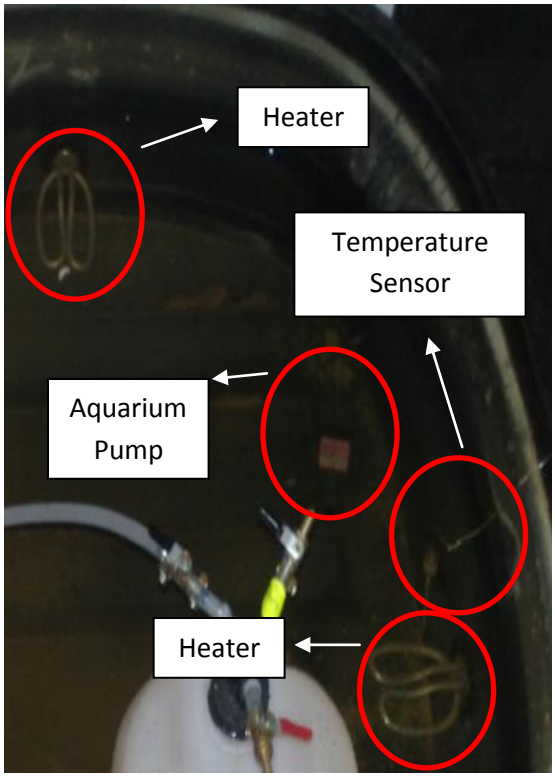


Figure 3.6: Heater installation

The temperature sensor was placed near the heaters as it could detect faster when the temperature deviated from 55 ℃. As for the aquarium pump, it functioned as a heat homogenizer to disperse and homogenize the heat generated from the heaters. So that, the temperature throughout the water bath is even. The most suitable location for the aquarium pump was between the two heaters as shown in figure 3.7 where the water was circulating well in the water bath.

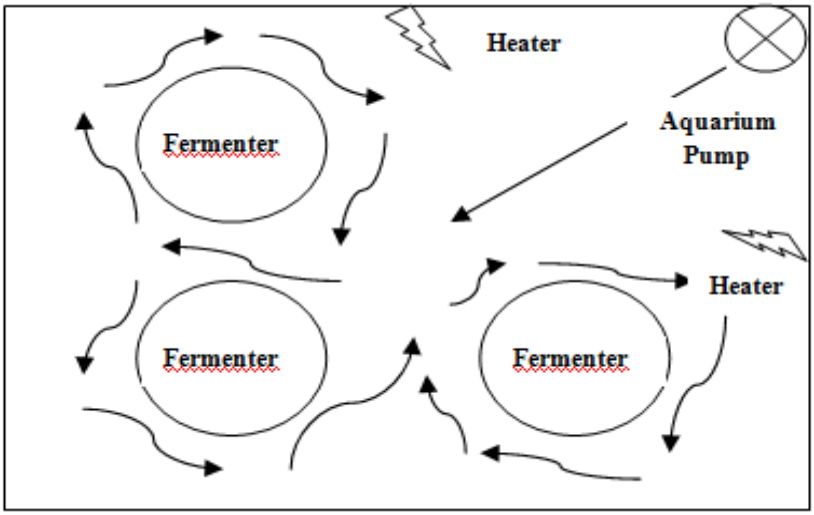


Figure 3.7: Water circulation pattern

3.2 APPARATUS SETUP

The apparatus setup was shown in figure 3.8 which consisted of three fermenters, one water bath, three gas displacement system, three retord stands and rubber tubing. The fermenters were submerged into the water bath. The biogas produced was channel to the gas displacement system by using rubber tubes. The connection between rubber tubes and valves had to be clamped properly to avoid leakage.

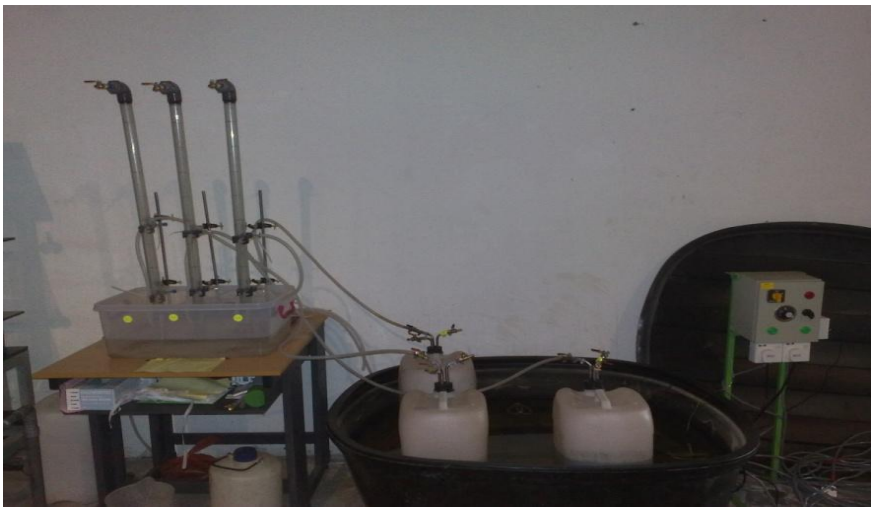


Figure 3.8: Apparatus Setup

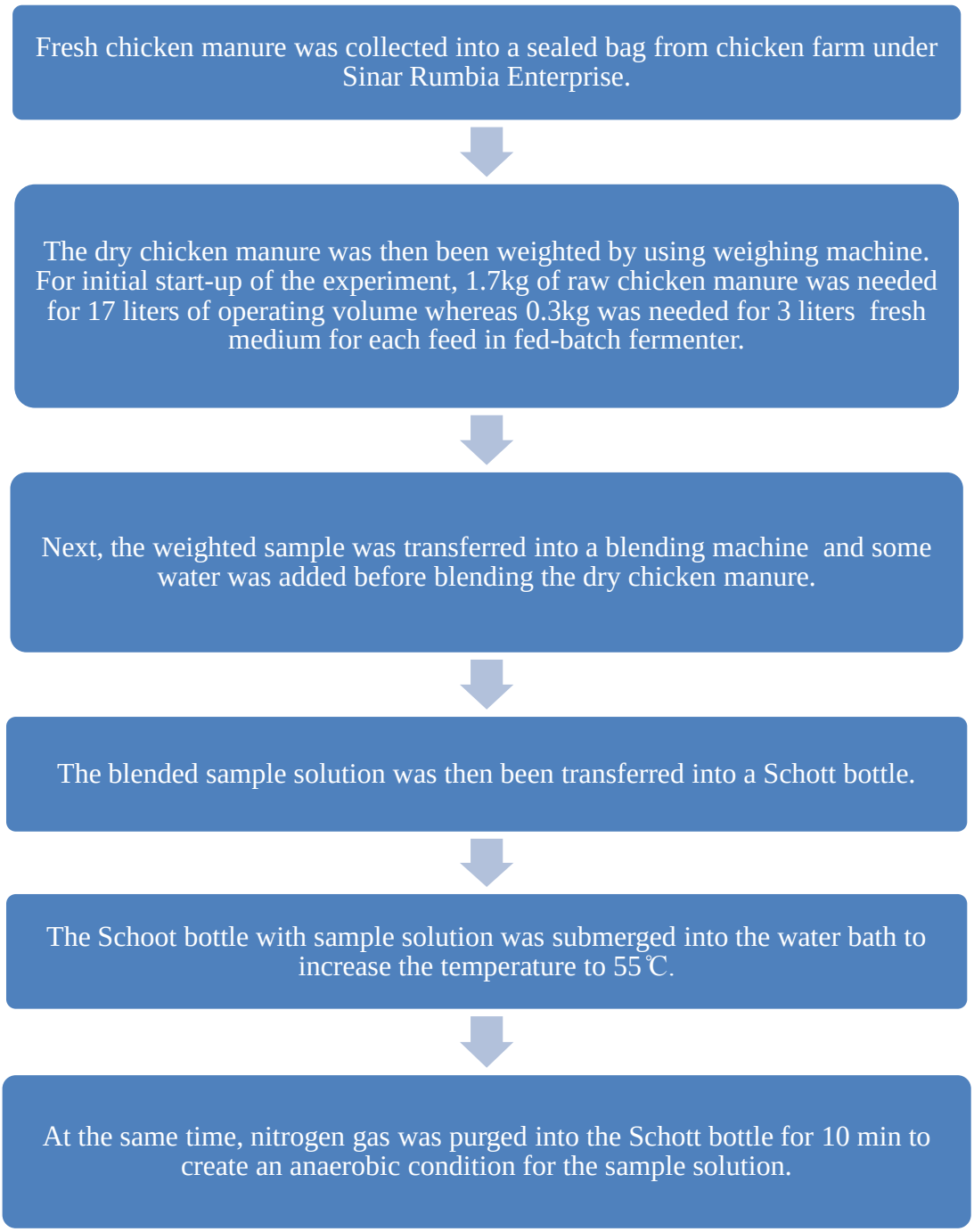
3.3 RESEARCH DESIGN

An experiment will be carried out in a 10 liters anaerobic digester with the temperature maintaining at thermophile (55℃) in the water bath, pH ranges from 6.6 to 7.6, oxygen free condition, with steady feed of 3 liters fresh diluted chicken manure with 10% TS from the storage tank and same amount of effluent will be removed from the digester once a week. The biogas produced will be collected by the water displacement system and the gas quality will be tested by using gas analyzer once a week.

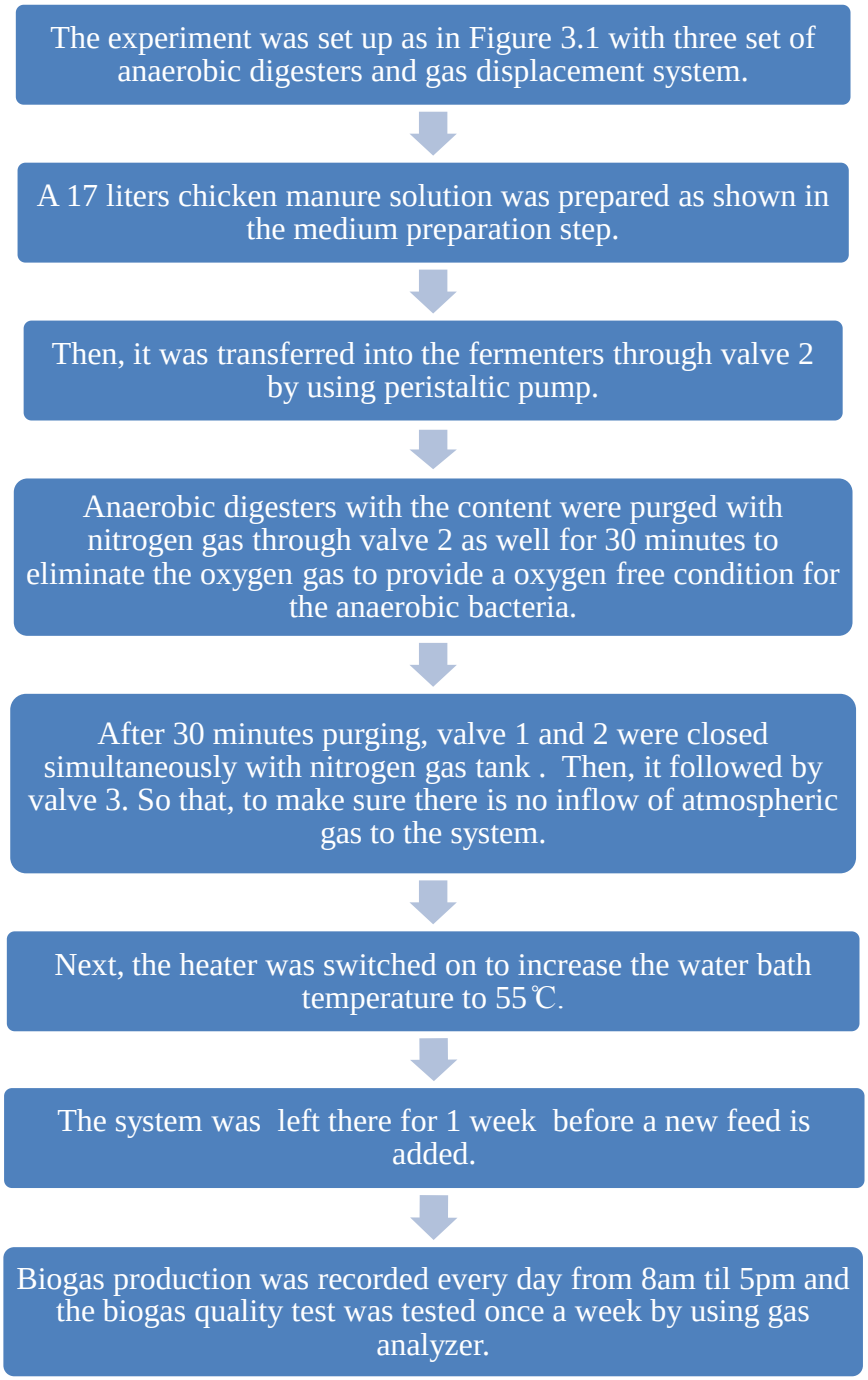
The experiment will be carried out by the following procedure:

1. Preparation of 10% TS content chicken manure solution.
2. Experiment start-up.
3. Transferring and removing sample solution from fermeter.

3.3.1 PREPARATION OF 10% TS CONTENT CHICKEN MANURE SOLUTION

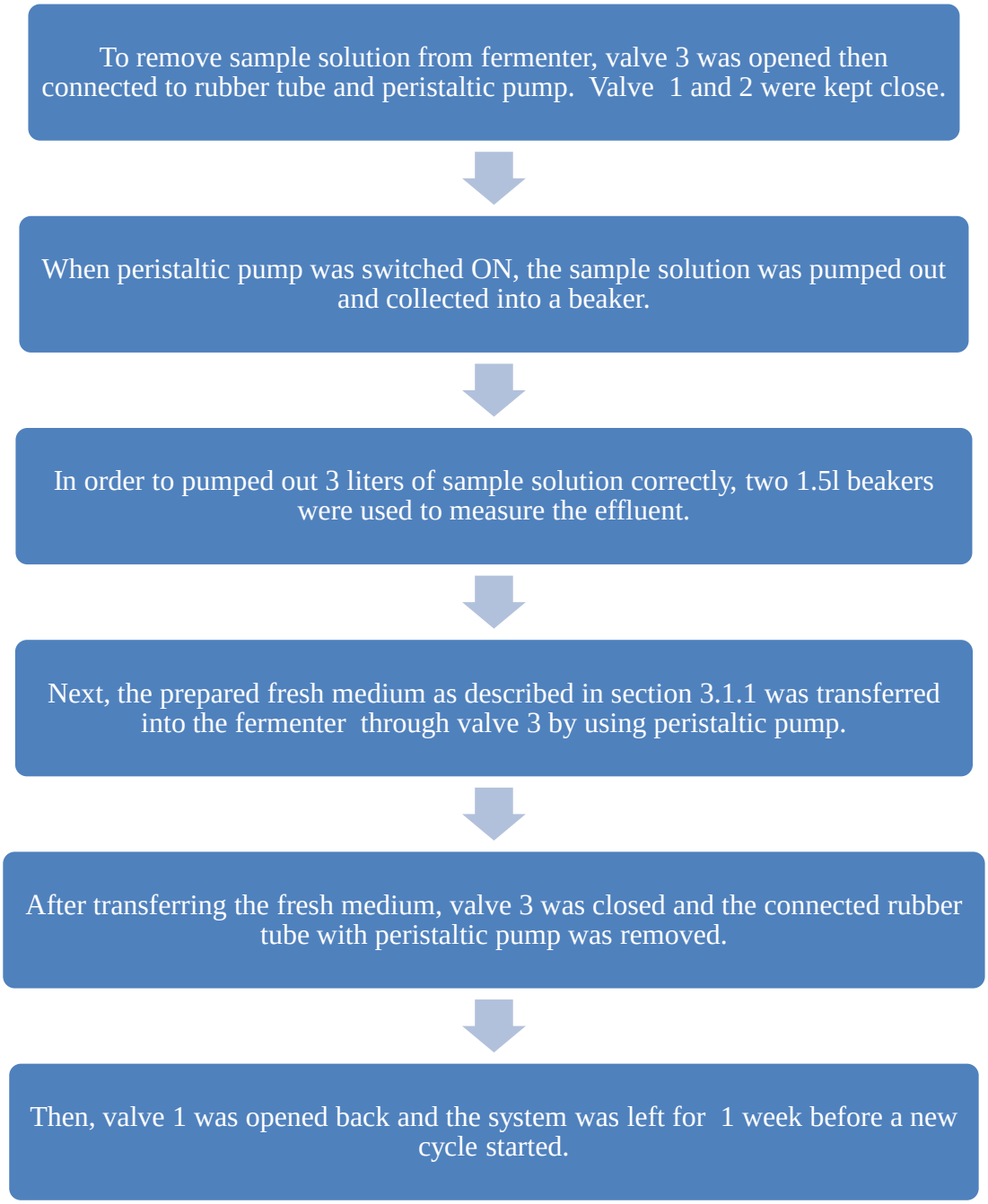


3.3.2 EXPERIMENTAL START-UP



3.3.3 REMOVING & TRANSFERRING SAMPLE SOLUTION INTO FERMENTER

For fed-batch fermenter, 3 liters of sample solution had to be removed once a week. At the same time, 3 liters of fresh medium had to be transferred into the fermenter. The following shows the procedure in removing and transferring the sample solution into the fermenter:



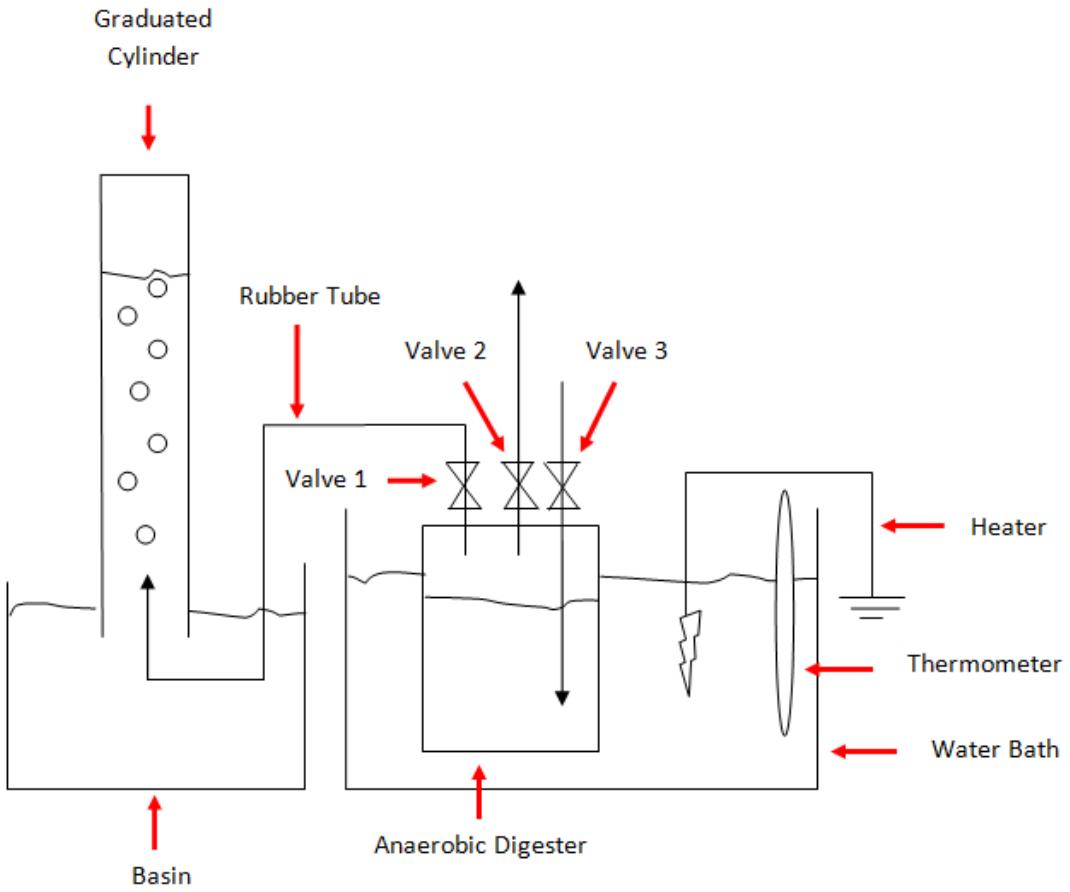


Figure 3.9: Experimental setup

3.4 SAMPLING TECHNIQUE

The sample used in this research which is chicken manure was obtained from a commercial broiler farm under Sinar Rumbia Enterprise. Raw chicken manure was collected every week for the preparation of the feed for the fed-batch digester. The chicken manure was stored in sealed bags at 29℃ and diluted with 10% TS content of chicken manure (Mahajoeno, Sugiyarto and Suranto, 2010). Then, the diluted sample was stored in a Schott bottle which will later be connected to the inlet of the fed-batch digester. The fresh medium prepared was submerged in a 55℃ water bath before transferring into the digester. This is because the process is highly sensitive to disturbances, such as changes in feed materials or temperature as described by Darling in her research paper.

3.5 RESEARCH INSTRUMENT AND APPARATUS

For this research, apparatus needed are 3 anaerobic tanks (25L), 1 thermometers, 2 heaters with relay system, 3 graduated cylinder (500ml), 2 beakers (1500ml), 8 valves, water bath, peristaltic pump and rubber tubing. The instrument needed to test the quality of biogas produced is gas analyzer with standard sample probe.

Figure 3.10: Gas Analyzer

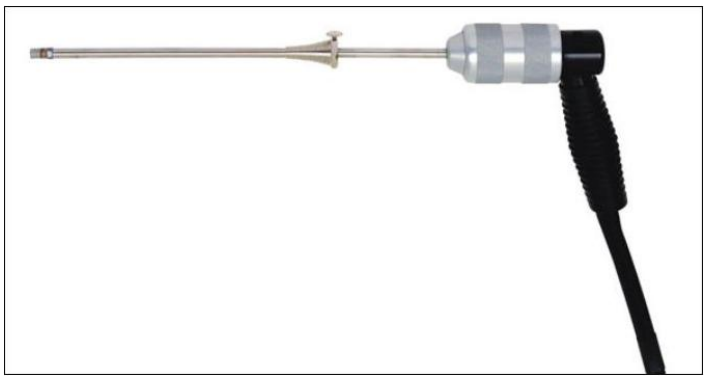


Figure 3.11: Standard sample probe

3.6 DATA ANALYSIS

All the experimental result such as production rate of biogas and quality of biogas obtained were tabulated in table every week. Various curves or charts were drawn to represent the data precisely. Microsoft Office Excel was used in the analysis of data.

3.5 CONCLUSION

Overall, this research revealed the trend of biogas production rate, the quality of biogas produced within each cycle, and also the time taken to bring a fed-batch anaerobic digester to maximum bacterial activity.

CHAPTER 4

RESULT AND DISCUSSION

4.1 RESULT TABLE

Data gathered from the experiments are tabulated into individual tables based on the biogas quality test and biogas production. This provides a better platform to analyse the data as it is more organised and structured.

4.1.1 GAS ANALYSIS TEST RESULTS

The following table showed the gas analysis test results from three different anaerobic digesters. They are fed-batch without inoculums fermenter, batch without inoculums fermenter and batch with inoculums fermenter. Gas analysis was done once a week started from 8th of November until 13th of December. There were six sets of data in total for the following analysis.

Table 4.1: Methane Gas Composition

Date	Methane gas composition, %					
	Fed-batch without Inoculums		Batch without Inoculums		Batch with Inoculums	
	CH4	O2	CH4	O2	CH4	O2
11/8/11 (1 week)	0.93	19.2	1.93	19.6	4.45	19.8
11/16/11 (2 week)	1.12	21.3	4.5	23.2	1.52	15.1
11/23/11 (3 week)	1.13	20.4	4.6	19.4	2.3	16
12/3/11 (4 week)	5.08	18.8	4.8	20.3	4.1	18.5
12/6/11 (5 week)	4.8	20.9	4.07	21.6	4.4	20.2
12/13/11 (6 week)	5.3	22.1	2.07	23.5	4.84	20.7

4.1.2 BIOGAS PRODUCTION RATE

The table below consists of biogas production rate collected from three fermenters every day from eight o'clock morning until 5 o'clock evening. The data presented below is the average biogas production rate for the period of time taken. Three of these fermenters are in thermophilic condition whereby the fermenters are submerged into a temperature controlled water bath in 55 ℃.

Table 4.2: Biogas production rate

Date	Biogas Production Rate, ml/h		
	Fedbatch without inoculum	Batch without Inoculum	Batch with Inoculum
1-Nov	0	0	0
10-Nov	39.33	33.17	30.83
11-Nov	47.67	17.83	34.33
12-Nov	25	26.2	20.6
13-Nov	21.2	12.4	19.6
14-Nov	16.43	10.71	12
15-Nov	16.46	16.31	40.46
16-Nov	-	-	-
17-Nov	50.43	25	33.33
18-Nov	-	-	-
19-Nov	-	-	-
20-Nov	-	-	-
21-Nov	59	0	9.17
22-Nov	60.46	2.5	47.5
23-Nov	65.43	3.41	2.95
24-Nov	57.63	3	2
25-Nov	64.33	1.6	2
26-Nov	-	-	-
27-Nov	-	-	-
28-Nov	-	-	-
29-Nov	68.64	40	2.78
30-Nov	54.48	23.33	5.56
1-Dec	59.62	71	2
2-Dec	61.11	17.67	2.09
3-Dec	63.45	23.46	1.92
4-Dec	-	-	-
5-Dec	68.2		4.44
6-Dec	65.78	27.38	2.86
7-Dec	62.4	23.04	0.87
8-Dec	-	-	-
9-Dec	-	-	-
10-Dec	60.39	39.41	2.94
11-Dec	57.6	15.1	2.1
12-Dec	57.2	20.67	2.67

4.2 DATA ANALYSIS

Data acquired are analysed using graphical methods by plotting the data into relevant graphs. This provides a better understanding as well as interpretation of the trend acquired through the data. Clear data analysis produces a better and more solid conclusion.

4.2.1 EFFCT OF INOCULUMS ON METHANE GAS COMPOSITION IN BATCH THERMOPPHILE FERMENTATION SYSTEM

According to figure 4.1, the methane gas composition in the batch inoculums system reached its exponential phase at the very beginning of the experiment. The amount of inoculums that applied in the fermentor is ten percent from the total operating capacity of the medium. Inoculums that applied in the system were in its late-log phase, meaning that the bacteria growth in the inoculums was at its optimum stage which was approaching to stationary phase. Thus when it was applied in the fresh medium, methanogenic substrate was no longer become the limiting factor for the bacteria growth of the inoculums applied. Methanogens in the inoculums consumed the fresh medium then grew and divided rapidly. Methanogens utilized the methanogenic substrates in the fresh medium and converted it into methane gas and carbon dioxide (Hamilton, 2010). By applying inoculums, the methane composition in the biogas produced is comparably higher than the one without inoculums at the starting of the fermentation process as shown in figure 4.1. Based on the result, fermentation with inoculums reached exponential phase earlier than the system without inoculums. The system skipped the lag phase and straight forward to its exponential phase at the beginning of the experiment which is around day three. Throughout the 42 days of fermentation, methane gas composition kept on increasing as shown in figure 4.1. It implied that the medium or food supply in the fermenter was still sufficient for the bacteria growth. Owing to it was fermentation, it was expected that the methane gas composition will have the same trend as microbial community growth curve. The system will come to its stationary phase and death phase at the end of the process.

Methane gas composition in the batch without inoculums system was relatively low at the beginning of the experiment compared to inoculums system. Organic matters

in the fresh medium had to undergo hydrolysis, acidogenesis and acetogenesis before methanogenesis process was taken place. During the first week of the experiment, the system was mainly in hydrolysis process to convert complex organic polymers into simple organic molecules and acidogenesis, acetogenesis process to convert the simply organic molecules into methanogenic substrate which will later be utilized by methanogens to produce biogas. Besides that, a fresh medium that without inoculums had low population of methanogenic bacteria, thus the existing methanogen in the system had to take time to acclimatize, grow and divide into larger population before reacting with the methanogenic substrate in the fermenter to produce biogas. Then, the system gradually transited into exponential phase where the methanogens population became larger and started reacting with the substrate vigorously. During the second week of the experiment, the system encountered its late-log phase which is a transition stage from exponential to stationary phase. During this stage, the methanogenic substrate (food) gradually became limiting factor for the methanogens reproduction, at the same time affect the methane production. The system came to death phase at week five where the methanogens population became saturated at the system while the methanogenic substrates were becoming exhausted. Thus, it caused the death rate of bacteria exceeded the birth rate.

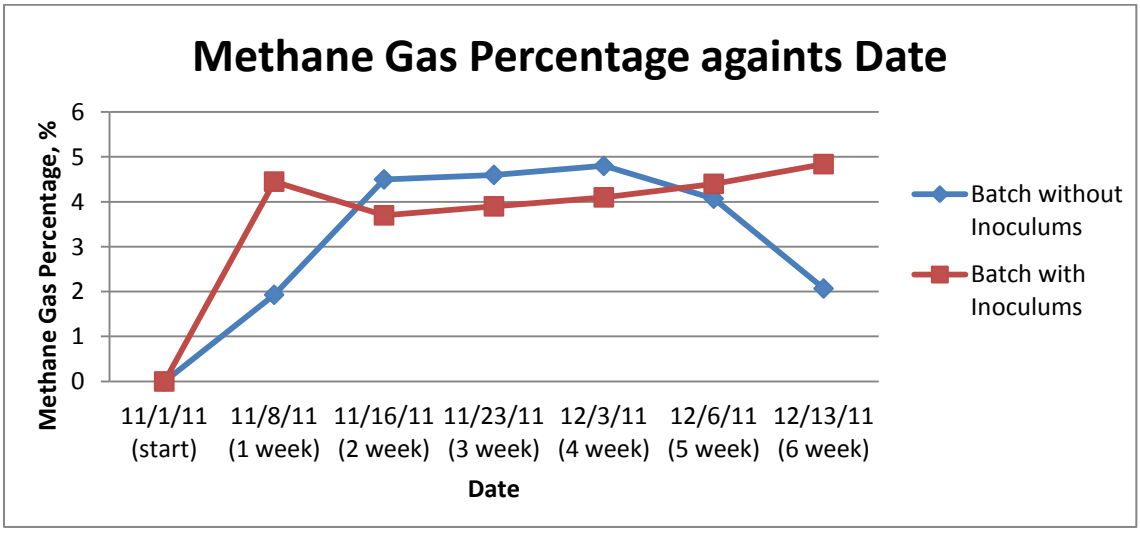


Figure 4.1: Methane gas percentage in batch with and without inoculums system

4.2.2 COMPARISON BETWEEN FED-BATCH AND BATCH WITHOUT INOCULUMS SYSTEM ON METHANE GAS COMPOSITION

According to figure 4.2, the methane gas composition was low during the first three weeks for fed-batch system, this is because the system undergone hydrolysis, acidogenesis and acetogenesis to convert the organic matter into methanogenic substrate. Based on the result, lag phase for fed-batch without inoculums system was two weeks longer than batch without inoculums system. Both of the systems suppose to have the same period for lag phase. However, the experiment result shown that fed-batch system had longer lag phase than batch system. This trend occurred probably is due to wash-out occurred during the first three weeks of the experiment. As per description in methodology, the actual amount to be discharged and fed into the fermenter every week is 3 liters for 17 liters operating volume. For the first two weeks, I encountered difficulties in transferring the fresh medium from Schott bottle to the fabricated fermenter where only 1.5 liters and 2 liters of fresh medium had successfully transferred into the fermenter instead of 3 liters. This lead to insufficient transferred of fresh medium to the fermenter, at the same time 3 liters of medium had been removed. Wash-out occurred where the leaving microbes are greater than the one being produced in the fermenter (Dennis A. Burke P.E., 2001). The problem of transferring medium had been solved at week three of the experiment, an obvious elevation in methane content had been observed at week four. According to figure 4.2 regarding the fed-batch system, the methane gas composition kept on increasing at week four, five, and six. This implied that the methanogens growth were maintained in its exponential phase with continuous discharged and fed of fresh medium (food) to the system where the methanogens population growth no longer limited by the food supply. The bacterial had ample of food to grow; at the same time, biogas had been produced as product of methanogenesis process. On the contrary, batch system encountered a death phase at week 5. This is because the batch fermentation had come to the end of the process where the food was fully utilized by the bacterial and the methanogenic substrate became the limiting factor to the fermentation process.

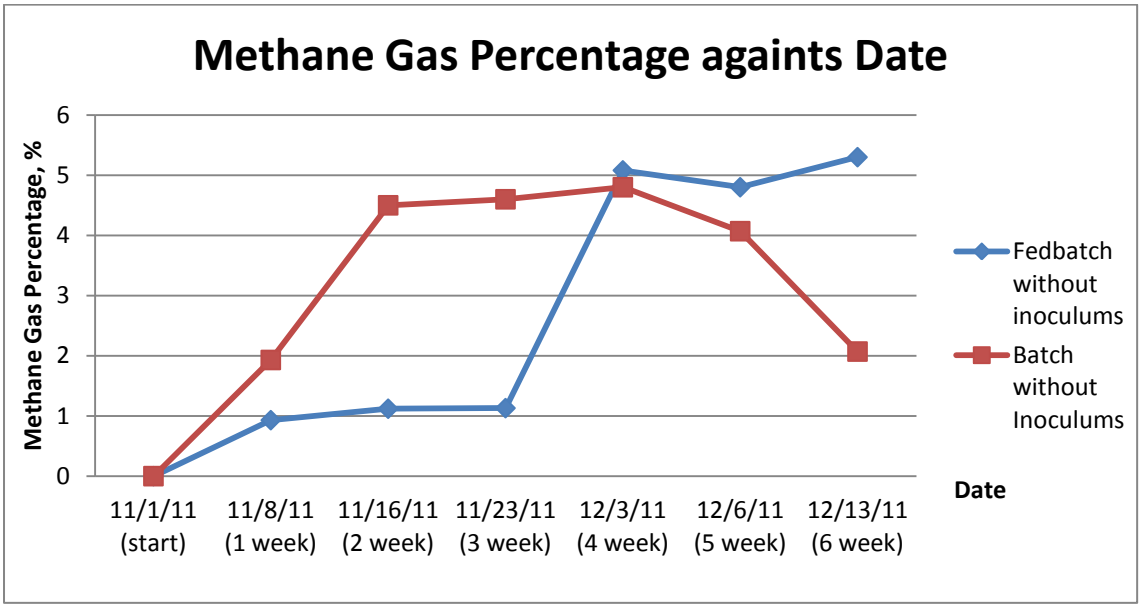


Figure 4.2: Methane gas percentage in fed-batch and batch system

4.2.3 COMPARISON BETWEEN FED-BATCH AND BATCH FERMENTATION ON BIOGAS PRODUCTION RATE

According to figure 4.3, biogas production rate for batch without inoculums system were relatively low during the first two weeks of the experiment. Then, the system reached exponential phase during the third week of the experiment and stationary phase maintained at week four and five. Lastly, the system encountered death phase at week six. This trend was similar to the methane gas percentage for batch without inoculums system as per discussed at section 4.2.2. The bacterial was taking time to acclimatize to the environment during the first two weeks as lag phase. When the bacterial population grew until certain extend, the biogas started vigorously being produced in the system along with the increasing population of mathanogens. Large population of methanogens reduced the methanogenic substrates such as hydrogen, carbon dioxide, acetic acids, water and volatile fatty acids into methane gas, carbon dioxide and water.

Biogas production for fed-batch without inoculums system was quite low during first week of fermentation, then it started increasing at the second week and maintaining at exponential phase until the end of the experiment. In fed-batch system, the biogas

production was continuous because fresh medium was fed in to the system once a week, thus there was ample of food for the bacterial to react with. Food was no longer a limiting factor for the bacterial in fed-batch system. Continuous biogas production can be achieved with lower down time comparing to batch fermentation. For fed-batch fermentation, hydraulic retention time (HRT) was very important to make sure that wash-out does not occur throughout the experiment. HRT must always be longer than reproduction time of microbes so that the living microbes in the system are greater than the one being removed.

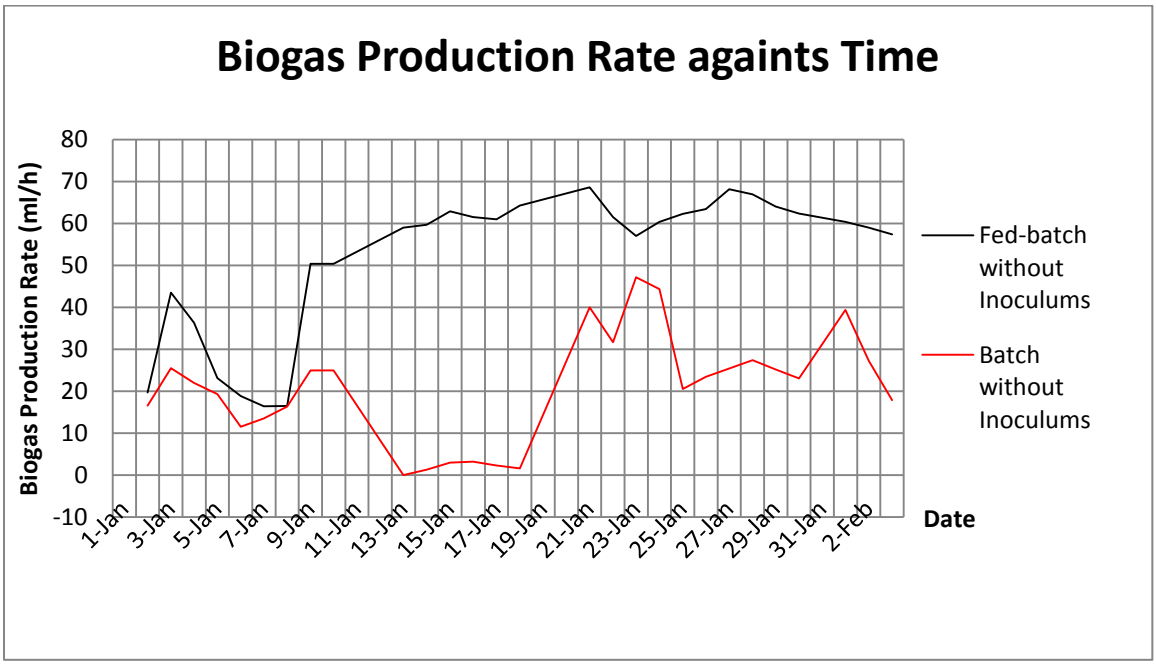


Figure 4.3: Biogas production rate between fed-batch and batch fermenter

4.2.4 EFFECT OF INOCULUMS ON BIOGAS PRODUCTION IN BATCH THERMOPHILE FERMENTATION SYSTEM

Based on the figure 4.4, biogas production rate for batch with inoculums fermenter was high although was first few weeks of the experiment. This result proved that application of inoculums may shorten the lag phase of the fermentation process. The system straight forwarded to exponential phase during the first week of the experiment. It reached exponential phase two weeks earlier than the one without inoculums. Biogas production was kept high for three weeks then the system started encountering its death phase at week four then maintaining at low production level during week five and six. The inoculums applied needed less than one week times to acclimatize in the thermophile system, it boosted the biogas production at the first week of fermentation. The system encountered death phase earlier because the limited food supply was exhausted along with the vigorously expands in microbes population since the starting of the experiment.

On the contrary, biogas production for batch without inoculums system was relatively low during first two weeks of the experiment. Then it reached exponential phase in week three and maintained at stationary phase in week four and five. It encountered its death phase in week six. The microbes spent two weeks in lag phase to adapt to the medium and expand in cell size. The microbes had achieved the size of a cell which was about to divide in week three which was log phase. Then, the bacteria population doubled in number every generation time at log phase (David B. Fankhauser, 2008). Food was not limiting during this phase and the population expanded rapidly. The stationary last for two weeks whereby the food supply became limiting factor caused the rate of bacteria division equaled the rate of bacteria death.

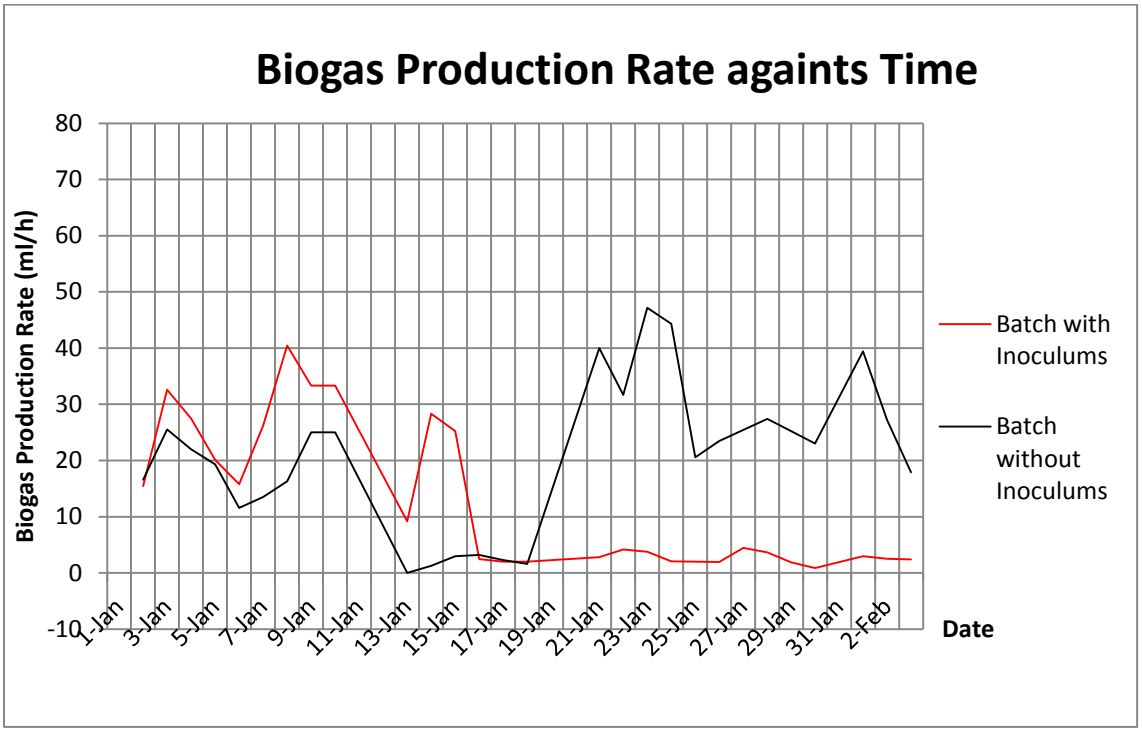


Figure 4.4: Biogas production rate between batch with and without inoculums fermenter

4.2.5 UNUSUAL OXYGEN CONTENT IN ANAEROBIC FERMENTATION

According to the result shown in table 4.1, oxygen gas was detected by gas analyzer throughout the experiment for three of the fermenters. The oxygen gas detected for three of these fermenters was ranged from 15-20%. This was an unusual phenomenon in anaerobic digestion whereby the system supposed to be in fully oxygen free condition since nitrogen gas had been purged during the start-up of the experiment. Besides, the fabricated fermenters were specifically designed for anaerobic system where whole the joints had been fully sealed by silicon. Furthermore, leakage test had been carried up before the experiment and there were no leakages found for the fermenters.

The hypothesis for this unusual phenomenon is that there are unknown microbial or unknown chemical reactions that can produce oxygen besides photosynthesis process. The first argument is that the fermenter itself is always in positive pressure due

to biogas production and water vapor thus if there is any leakage occurred, the biogas will leak to the atmosphere. So, there is low possibility for the atmosphere air to be drawn into the fermenters since the pressure in the fermenters are greater than atmosphere all the time. The second argument is by comparing the result from other projek sarjana muda (PSM) named "Kinetic Evaluation of Palm Oil Mill Effluent (POME) with Membrane Anaerobic System". According to the same anaerobic fermentation process by using different raw material which is palm oil mill effluent (POME), the result obtained also contained oxygen which ranges from 10-15%. Subsequently, the same results were obtained for both gas analyzer test and gas chromatography test. Thus, equipment malfunction is not an acceptable reason for this case.

The existence of oxygen in anaerobic fermentation remained as an unsolved mystery in this experiment. So, it is suggested to verify the actuality of this experiment by repeating the same experiment to make sure the result obtained is not an error. If oxygen content still exists in the repeating experiment, an experiment is suggested to carry out to find out what sources contribute to the oxygen production in anaerobic system.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This study was carried out to investigate the quality and production rate of methane gas from poultry manure (chicken manure) in fed-batch and batch thermophile fermentation medium. Fermentations were carried out for fed-batch without inoculums, batch without inoculums and batch with inoculums thermophile system for 42 days. The biogas produced from each fermenters were tested with gas analyzer. Finding have shown that fed-batch fermentation have higher yield of biogas with higher methane gas content compared to others. Besides, result also showed that regular feeding of fresh medium in fed-batch fermentation was able to maintain the biogas production in exponential phase. Performance of fed-batch system in term of biogas production rate and methane content was better than batch system as regular feeding in fed-batch system provided ample of fresh medium for methanogens so that methanogenic substrates would not limit the fermentation process. Besides, fed-batch fermentation has lower down time compared with batch fermentation. As for the batch with and without inoculums system, the result showed that fermentation with inoculums had shorter lag time, the system reached exponential phase at day three of experiment which is one week earlier than batch without inoculums system. However, based on the biogas production result, batch with inoculums system reached death phase about 2 weeks earlier than batch without inoculums system. Thus, application of inoculums was able to shorten the fermentation period if applied in batch system. However, the methane content for three of the fermentations ranging from 3-6% was significantly lower than the result shown in journal which is 60-70%. This might be caused by unusual production of oxygen by unknown microbial or chemicals. Some recommendation had been suggested in the following section to improve this experiment for the future.

5.2 RECOMMENDATIONS

There are a few problems during the experiment that affected the result. The following are the recommendations in order to improve this experiment for the future.

5.2.1 LOW METHANE GAS CONTENT AND HIGH OXYGEN CONTENT

The biogas production throughout the experiment is quite high but the methane content is considerably low ranging from 3% to 6% if compared to the journal which is 60-70% (Huang and Shih, 1981). As for the oxygen content, it is maintaining between 18-20% throughout the experiment. High level of oxygen content inhibits methanogens activity because methanogens are strict anaerobes. There are some recommendations in order to get a higher yield of methane and develop a fully anaerobe condition:

i. Fabricate a concrete or fully sealed fermenter for large scale experiment or use bioreactor if in lab scale experiment so that the gas leakage problem can be avoided into the lowest.

ii. Swagelok valve which is compatible to the portable gas chromatograph machine should be installed instead of connecting the sampling point to the machine by using rubber tube.

iii. Avoid using rubber tube as connector for the fabrication. This is because there is high possibility for leakage to be occurred at the joint and on the rubber tube itself.

iv. Purge the fresh medium with nitrogen upon start-up of the experiment to create anaerobic condition for the methanogens.

v. The fresh medium that is going to be transferred into the fermenter must be submerged into the water bath to bring up the temperature before transferring into the fermenter as thermophilic methanogens are very sensitive to temperature changes.

5.2.2 PROBLEM IN TRANSFERRING FRESH MEDIUM INTO FED-BATCH FERMENTER

There are few problems about medium transferring encountered during the experiment. For fed-batch fermentation, the fresh medium is hardly pumped into fermenter from Schott bottle. Rubber tube is stuck while removing the medium from the fermenter. Below are some recommendations in order to counter the problems:

i. The chicken dung must be blended with water before transferring into the fermenter so that rubber tube would not be easily stuck while removing from fermenter.

ii. The rubber tube used for Schott bottle must be in the same size as the transferring tube in the fermenter. This is because peristaltic pump cannot be functioned if the tubing size is different.

REFERENCES

Paraguas, M. D. S. (2006.). Estimation of Meat Demand System In Malaysia: Model Selection Between The Rotterdam Model And The Fdlaids Model. Master Thesis. Universiti Sains Malaysia. Retrieved March 25, 2011, from Universiti Sains Malaysia Digital Theses.

Abbott, R. (2010). *Another Positive Year for Malaysia's Broiler Producers*. Retrieved March 25, 2011, from http://www.wattagnet.com/Another_positive_year_for_Malaysia%E2%80%99s_broiler_producers.html

Abedon, S.T. (1998). *Supplemental Lecture: Microbial Growth*. Retrieved March 25, 2011, from http://www.mansfield.ohio-state.edu/~sabedon/biol2025.htm

Tey & Yeong-Sheng (2009). *A managerial economists forecast for meat consumption in Malaysia.* (2010). Retrieved March 25, 2011, from http://www.docstoc.com/docs/6109513/A-managerial-economists-forecast-for-meat-consumption-in-Malaysia

Anaerobic Digestion. (n.d.). Retrieved March 25, 2011, from http://www.rpi.edu/dept/chem-eng/Biotech Environ/Biocontrol/AnaerobicDigestion.html

Black, J.G. (1996). *Microbiology. Principles and Applications.* (3rd ed.). Prentice Hall. Upper Saddle River, New Jersey. pp. 136-140, 151-153.

Burke, D.A. (2001). *Dairy Waste Anaerobic Digestion Handbook: Options for Recovering Beneficial Products from Dairy Manure.* Retrieved March 25, 2011, from http://www.makingenergy.com/Dairy%20Waste%20Handbook.pdf

Climate Techbook: Anaerobic Digesters. (2009). Retrieved March 25, 2011, from http://www.pewclimate.org/docUploads/Anaerobic%20Digesters%2008%2031%2009%20final_0.pdf

Griffin, M.E., McMahon, K.D., Mackie, R.I., & Raskin, L. (1997). *Methanogenic Population Dynamics during Start-Up of Anaerobic Digesters Treating Municipal Solid Waste and Biosolids.* Retrieved March 25, 2011, from http://homepages.cae.wisc.edu/~tmcmahon/PDFs/Griffin_1998_BB.pdf

Darling, D. (2009). The Encyclopedia of Alternative Energy and Sustainable Living: Anaerobic Digestion. Retrieved March 25, 2011, from http://www.daviddarling.info/encyclopedia/A/AE_anaerobic_digestion.html

Energy Justice Network: Anaerobic Digesters. (n.d.). Retrieved March 25, 2011, from http://www.energyjustice.net/digesters

Fankhauser, D.B. (2008). *Bacterial growth curve: Escherichia coli grown on minimal salts versus complex media.* Retrieved March 25, 2011, from http://biology.clc.uc.edu/fankhauser/labs/microbiology/growth_curve/growth_curve.htm

Fayed, S. (2011). About.com*: Middle Eastern Food*. Retrieved March 25, 2011, from http://mideastfood.about.com/od/glossary/g/halal_def.htm

Federation of livestock farmers' associations of Malaysia. (2007). Retrieved March 25, 2011, from http://www.flfam.org.my/main.php?section=industry&page=industry_poultry_broiler

Friends of the Earth: Briefing Anaerobic Digestion. (2007). Retrieved March 25, 2011, from http://www.foe.co.uk/resource/briefings/anaerobic_digestion.pdf

Hamilton, D. W. (n.d.). Oklahoma Coopertive Extension Service: Anaerobic Digestion of Animal Manures: Understanding the Basci Precess. Retrieved March 25, 2011, from http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-6278/BAE-1747web.pdf

Henry, C., & Koelsch, R. (2000). Manure Matters. What is an Anaerobic Digester? *UNL's Livestock Environmental Issues Committee,* 7(10), 1-3

Hoh, R. (2010). *USDA foreign agricultural Service: Global Agricultural Information Network.* Retrieved March 25, 2011, from http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Grain%20and%20Feed%20Annual_Kuala%20Lumpur_Malaysia_2-19-2010.pdf

Johanns, M. (2011). *Brainy Quote*. Retrieved March 25, 2011, from http://www.brainyquote.com/words/po/poultry205508.html

Kirk, D.M., & Faivor, L. (2010). Extension*: Feedstocks for Biogas*. Retrieved March 25, 2011, from http://www.extension.org/pages/Feedstocks_for_Biogas

Last, S. (2011). *Biogas Digester: Heart of the Anaerobic Digestion Process*. Retrieved March 25, 2011, from http://www.anaerobic-digestion.com/html/the_biogas_digester.php

Malaysia: Consumption of Livestock Products. (2010). Retrieved March 25, 2011, from http://www.dvs.gov.my/c/document_library/get_file?uuid=aee39613-c581-4eee-b8d3-070195dd8573&groupId=28711

Malaysia Industrial Development Authority. (2011). Retrieved March 25, 2011, from http://www.mida.gov.my/en_v2/index.php?page=food-industries

Malaysia: Malacca Chicken Manure Causes Sheep Deaths. (March 21, 2009). *New Straits Times*, p. 12.

Zavier, M. F. (2010). Selangor kicks up a stink over chicken droppings. (May 14, 2010). The Malaysian Insider. Retrieved March 25, 2011, from http://www.themalaysianinsider.com/malaysia/article/selangor-kicks-up-a-stink-over-chicken-droppings/

MREC: Anaerobic Digestion and Biogas. (2006). Retrieved March 25, 2011, from http://www.mrec.org/anaerobicdigestion.html

Processing Biomass into Biogas. (2011). Retrieved March 25, 2011, from http://www.extension.org/pages/Processing_Biomass_Into_Biogas

Residua: Warmer Bulletin. (2008). Retrieved March 25, 2011, from http://www.residua.com/Residua/Welcome.html

Robert, E. (2011). *Extension: Introduction to Biogas and Anaerobic Digestion.* Retrieved March 25, 2011, from http://www.extension.org/pages/Introduction_to_Biogas_and_Anaerobic_Digestion

Robert, E. (2011). *Extension: What is Biogas?* Retrieved March 25, 2011, from http://www.extension.org/faq/27583

Roeper, H., Khan, S., Koerner, I., & Stegmann, R. (2005). *Low-Tech Options for Chicken Manure Treatment and Application Possibilities in Agriculture.* Retrieved March 25, 2011, from http://www.environmental-expert.com/Files/0/articles/78421/pAPER.pdf

The Biogas: Biogas Composition. (2009). Retrieved March 25, 2011, from http://www.biogas-renewable-energy.info/biogas_composition.html

The Encyclopedia of Alternative Energy and Sustainable Living: Anaerobic Digestion. (n.d.). Retrieved March 25, 2011, from http://www.daviddarling.info/encyclopedia/A/AE_anaerobic_digestion.html

Zinder, S.H., Anguish, T., & Cardwell, S.C. (1984). Applied and Environment Microbiology: *Effects of Temperature on Methanogenesis in a Thermophilic (58 ℃) Anaerobic Digestor*. Retrieved March 25, 2011, from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC239768/

Aminuddin ,B. and Suhaimi, A.T. 2006. *The Prospect of Energy From Sewage Sludge in Malaysia.*

Armando, G.S., Sergio, R. and Marc A.D. 2008. Alkaline Biofiltration of H_2S Odors. *Environment, science and technology*, **42** :7398-7404.

ASEAN RE-SSN and UNEP. 2004. *Country Paper of Malaysia*. Proceedings of Conference on.

Collins, E.R. and Hughes, H.A. 1976. Biogas and anaerobic digestion.(online) http:// www.biogas.psu.edu. (2 December 2011)

David ,A.K, and Robet. A.L. *Estimate of Methane Emission*.

Fadhilah ,A.R., Mahendran, S., Amir,H.H. and Izham, Z.A. 2006. Forecasting the Maximum Demand of Electricity in Malaysia.

Gerardi, M.H. 2003. The microbiology of anaerobic digesters. *Wiley-Interscience*.

Huub, H.J., Cox and Marc, A. 2003. Biotrickling filters.

Huub, H. J.,Cox ,Thomas, S., Zarookm, S. and Marc. A.D. 2001. Thermophilic

Biotrickling Filtration of Ethanol Vapors. *Environment, science and technology*, **35**: 2612-2619.

Jaafar, Z. 2005. *The Way Forward, Malaysia's Energy Plan, Malaysia Energy Center.*

Jonsson and Persson. 2003. *Biogas as a transportation fuel* . Swedish Gas Centre.

Ligy, P. and Marc, A .2003. Sulfur Dioxide Treatment from Flue Gases Using a Biotrickling Filter-Bioreactor System. *Environment, science and technology*, **37**: 1978-1982.

Malaysia Power Report Q3. 2011. *Business Monitor International (BMI).*

Mart ń, R.J., Manuel, G.G. and Domingo, C. 2009. Removal of hydrogen sulfide by immobilized Thiobacillus thioparus in a biotrickling filter packed with polyurethane foam *Bioresources technology*, **100** :4989-4995.

Masjuki, H.H. 2003. *Energy and Electricity Consumption Analysis of Malaysian Industrial Sector.*

Pusat Tenaga Malaysia. 2005. *Renewable Energy Resources and Applications in Malaysia.*

Remade, S. 2003. *An Introduction to Anaerobic Digestion of Organic Wastes.*

Rosenani, A.B. and Kala, D.R. 2008. Charecterization of Malaysia Sewage Sludge. *Malaysian Journal of Soil Science*.

Seongyup, K. and Marc, A. D. 2005. Understanding the limits of H_2S degrading biotrickling filters using a differential biotrickling filter.*Chemical*

Engineering Journal, **113**:119-126.

Soreanu, G., Beland ,M., Falletta ,P., Edmonson ,K. and Seto, P. 2004. Laboratory pilot scale study for H2S removal from biogas in an anoxic biotrickling filter. *Environment Canada Wastewater Technology Centre.*

SME Corp Malaysia Official Website. 2010. *Green Technology Financing Scheme (GTFS).*

Statistic of Electricity Supply Industry in Malaysia, 2004.

APPENDIX

GAS ANALYZER

Table 1: Measure specifications

Sensor	Standard Range	Max. Range*	Accuracy	Resolution
Oxygen, O_2	0 to 25.0 % Vol.	0 to 30.0 % Vol.	±1 %	±0.1 % Vol.
Carbon Monoxide, CO (low)	0 to 2 000 ppm	0 to 10 000 ppm	±2 %*	±1 ppm
CO (H_2) compensated	0 to 2 000 ppm	0 to 4 000 ppm	±2 %*	±1 ppm
Carbon Monoxide, CO (high)	0 to 4 %	0 to 10 %	±2 %*	±1 ppm
Sulphur Dioxide, SO_2	0 to 2 000 ppm	0 to 5 000 ppm	±2 %*	±1 ppm
Nitric Oxide, NO	0 to 1 000 ppm	0 to 5 000 ppm	±2 %*	±1 ppm
Nitrogen Dioxide, NO_2	0 to 100 ppm	0 to 1000 ppm	±2 %*	±1 ppm
Hydrogen Sulphide, H_2S	0 to 200 ppm	0 to 1 000 ppm	±2 %*	±1 ppm
Carbon Dioxide, CO_2 **	0 to 25.0 % Vol.	-	±0.5 % Vol	±0.1 % Vol.
Hydrocarbons	0 to 5.0 % Vol. (Application dependent)			
Flue Gas/Ambient Temperature	Measured			
Draft	± 51 cm / 20 " Water Gauge ***			
Flow (velocity)	1 to 50 m/s			

Note: Special ranges are available

**Calibration per CTM034 or LAND factory procedure*

***True measurement if sensor fitted (calculated if not)*

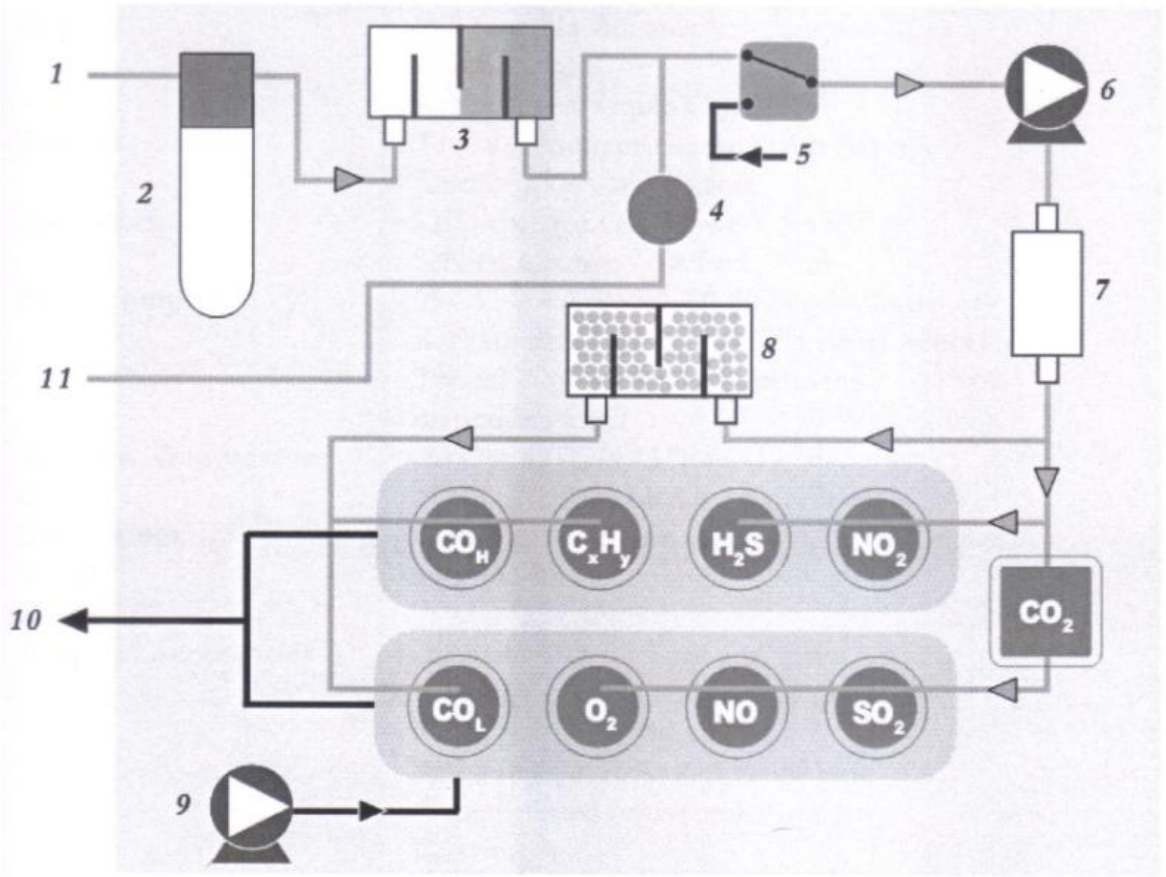
****Reduced to ± 26 cm / 10 " Water Gauge when used with flow probe*

**Operating at maximum possible range may affect sensor life and accuracy*

Table 2: Sensor type

Sensor Type	Gas
Electrochemical	CO Low, CO High, CO Low H_2 compensated, O_2, NO, NO_2, SO_2 and H_2S
Infrared	CO_2
Pellistor/Catalytic	C_xH_y

Table 3: Mechanism of function



Key

1. *Sample Gas Inlet*
2. *Water Catchpot*
3. *Particulate Filter*
4. *Pressure Sensor*
5. *Air Input*
6. *Sample Pump*
7. *Expansion Chamber*
8. *Chemical Filter*
9. *Purge Pump*
10. *Exhaust*
11. *Flow Probe Inlet*

Table 4: Specification

Display	Full function alphanumeric/graphic LCD with backlight 40 x 8 Matrix Liquid Crystal
Keypad	Tactile membrane (integral with display) functions keys and cursors
Indicators	LED type for ON (Power), Stand-by, Service, Charge, Low Batt., Fault
Power Supply	95-265 V a.c. ±10%, 50-60 Hz, 30 Watts Rechargeable battery 2 x 6 V 4 Amp. hours Typical 8 hr. operation, dependent on options fitted
Ambient Temperature	-5 °C to 45 °C (+23 °F to 113 °F)
Case	Medium density blended polyethylene
Dimensions	453 x 120 x 245 mm (17.8" x 4.7" x 9.6 inches)
Weight	6 kg (13 lb)
Standard Accessories	Integral water catchpot and filters Rechargeable lead acid battery (internal) Mains power supply cable Probe handle, Hose and Probe pipe (Lengths listed below under options) Carrying case Thermal printer Data logging

Options

Min of 3 to max 9 gases in total, from a selection of 9 gases
Probe length options - 0.3, 1.0, 1.5, 2.0, 3.0m/1, 3.3, 5, 6.5, 10ft
Alternative probes available - *Refer to Data Sheet Reference PDS198 for details*
Hose length options - 3 m/10 ft or 10 m/33 ft
Draught Measurement
Flow Measurement, probe length options - 0.7, 1.2, 2.2, 3.0 m/2.3, 3.9, 7.2, 9.8 ft
Smoke Measurement, probe length options - 0.3, 0.75, 1.0 m/1, 2.4, 3.2 ft
Insight Data Acquisition Software system - *Refer to Data Sheet Reference PDS205 for details*
Analogue outputs (12 current loops, independently configurable)
Wake and Sleep facility (Semi-continuous monitoring)
Language display options