An investigation on the energy recovery potential of sewage sludge in Malaysia through biogas generation

by

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CERTIFICATION OF APPROVAL

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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

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September 2011

CERTIFICATE OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

V.JAGENDRAN NAIDU A/L VEERANNAN

ABSTRACT

In a world where energy is being a primary concern, extracting energy from waste has been a common interest in world today which is striving for energy. The research title is "**An investigation on the energy recovery potential of sewage sludge in Malaysia through biogas generation".** This research will be focused mainly on recovering energy through biogas generation while using sewage sludge as the feed source. Sewage sludge is basically produced from the treatment of domestic wastewater and consists of two basic forms which is raw primary sludge (basically faecal material) and secondary sludge (a living 'culture' of organisms that help remove contaminants from wastewater before it is returned to rivers or the sea). The material that remains after the digestion process is referred to as biosolids. The main purpose of coming up with this research is because the current cost of disposing sewage sludge in Malaysia is around 1billion ringgit annually. There is also very limited landfill land that is available now in Malaysia for the sludge disposal. Sludge cannot be dispose freely and need a proper disposal method as it contains bacteria and can cause health problem. Based on all this causes, this research concentrate on reducing the sludge content and at the same time extract energy from the waste which is in this case is sewage sludge. Based on the background study, anaerobic digestion method has been identified as the most efficient process that can be applied to recover energy from domestic sewage sludge and at the same time reduce the sludge content as well. This finding is explained in the report below. Anaerobic digestion is basically a natural process that occurs from the breakdown of organic material by micro-organisms in the absence of oxygen. This digestion process reduces the primary sludge content, and the byproduct of this will be biogas. In order to carry out this project, a simulation of anaerobic digestion plant will be designed using HYSYS simulation. In this research, this simulation will be studied thoroughly to get the most output from the applied feed rate. Later from the simulation the amounts of electrical energy that can be recovered from the biogas will be calculated. The outcome of this result will conclude the potential of recovering energy from sewage sludge. Therefore, this study of energy recovery potential through biogas generation by using sewage sludge becomes economically and ecologically attractive for us in Malaysia.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Sewage sludge from wastewater has long been narrowly viewed as an expensive nuisance, fit only for treatment and disposal. Utilities, however, have increasingly begun to explore technologies designed to help extract energy and other valuable products from wastewater sludge. As these technologies mature, the market opportunity for resource recovery will grow from $25 million today to $45 million in 2020, according to a recently released Lux Research report titled ("Technologies Turn Waste into Profit." April 10, 2010)

As for Malaysia in December last year, Prime Minister Najib Razak announced Malaysia's voluntary commitment to reduce up to 40% of carbon emissions intensity relative to GDP by 2020. Central to this is a proposed Renewable Energy Act. These provide opportunities for us in Malaysia to investigate the energy recovery potential of sewage sludge in Malaysia.

First of all sewage sludge itself is basically a semi-solid mixture of bacteria, virus-laden organic matter, toxic metals, synthetic organic chemicals, and settled solids removed from domestic and industrial waste at sewage treatment plants. (Harper-Collins Dictionary of Environmental Science). Sludge can be a very good source of carbon, nitrogen, phosphorus and other nutrients for many microbial processes. Sewage consists of some 99.9% by weight of water containing dissolved organic material, suspended solids (>100 µm-colloidal), microorganisms and other components. Typically sewage sludge contains 75% of suspended solids and 40% of the dissolved solids are organic (Table 1). In Malaysia, its generation is top listed (64.4%), followed by animal husbandry wastes (32.6%), agro-based (1.7%) and industrial effluent (1.3%) in terms of the BOD load (Alam *et al.*, 2008). Roughly Malaysia produces about six million metric tons of sewage sludge annually. The country has to adopt a practical, economic and acceptable approach in managing and disposing sewage sludge since the treatment and disposal of sewage sludge is an important phase in sewage treatment.

Sludge digestion is the primary means of stabilizing the volatile organic material in the sludge. Biologically degradable organics account for 60-65% of the total solids in the sludge. The organic sludge contains bound water molecules within it. Digestion releases most of the bound water in the sludge. As the sludge decomposes the organic material is converted into gases. This results in a reduction in the volume of sludge that will ultimately have to be disposed. If the digestion process is anaerobic the gases produced will be carbon dioxide (CO_2), methane (CH_4) and hydrogen sulfide (H_2S). If it is aerobic, the only gas that is produced is carbon dioxide. (Corbitt, 1990).

Before proceed with the energy recovery mechanism, characterization of the sewage sludge is the first step. The characterization and energy profiling will be involved with combustion properties and chemical composition. Some of the parameters involve will be moisture content, heating value and chemical properties which can be determine from proximate and ultimate analysis.

The biodegradable fraction of municipal sewage sludge contains anywhere from 15%-70% water. Themelis and Kim (2002) showed that a representative average molecular formula for organic wastes, excluding nitrogen and other minor components, is (major organic constituent: $[C_6H_{10}O_4]_n$). The anaerobic decomposition of organic materials yields principally methane (CH_4), carbon dioxide (CO_2) and a solid compost material that can be used as soil conditioner.

Biogas emissions can also cause damage to the environment due to the presence of the pollutant hydrogen sulphide, which is harmful to human beings and animals. At lower concentrations, this gas has an unpleasant odour; at higher concentrations, it can be life-threatening. The recommended industrial exposure limits are from 8 to 10 ppm for 8 hours a day per week (Horikawa, 2001).

On the other hand, biogas is an attractive source of energy due to its high methane content. However, direct utilization of biogas as fuel without removal of H_2S leads to the formation of sulphur dioxide (SO_2), which is another toxic pollutant and a major contributor to acid rain in the atmosphere. In order to get a more efficient energy recovery process, there will be a purification system for this energy recovery plant from sewage sludge.

As for this research this highly composed methane will act as the main source of energy that will be concentrated for further conversion of energy from heat energy to electrical energy. After considering many effects from cost to the sludge disposal and, compared to all this, recovering methane from sewage sludge by using anaerobic digestion method is found out to be the optimum way to recover energy from sewage sludge.

1.2 PROBLEM STATEMENT

The management of the ever-increasing volume of domestic and industrial organic wastes has been one of the prime environmental issues in Malaysia. Approximately 4.2 million cubic meters of sewage sludge (pure organic waste without mixing with the industrial waste) is produced annually by Indah Water Konsortium (IWK), a national sewerage company in Malaysia and the total cost of managing is estimated at Ringgit Malaysia (RM) 1 billion (US$ 0.35 billion) (Fakhru'l-Razi *et al*., 2002).

Each year some 590-880 million tons of methane are released worldwide into the atmosphere through microbial activity. About 90% of the emitted methane derives from biogenic sources, example from the decomposition of biomass. The remainder is of fossil origin (e.g. petrochemical processes). In the northern hemisphere, the present tropospheric methane concentration amounts to about 1.65 ppm(parts per million). [18] (*ICAR paper)*

Other than the purpose of recovering energy from sewage sludge, there were few problems associated with disposing the sewage sludge in Malaysia. One of the problems is that in many areas, landfills are approaching the available capacity of land and it is becoming less popular due to the generation of odor as town and cities expand into the proximity of landfill sites (I.A.Nges, 2010). This quantity of sludge is expected to increase every year which makes the disposal of sludge a problem of growing importance representing up to 50% of the current operating costs of a wastewater treatment plant. (Lise Appels, 2008)

1.2.1 Significant of the project

Unlike fossil fuel combustion, biogas production from sewage sludge is considered CO_2 neutral and therefore does not emit additional Greenhouse Gases (GHG) into the atmosphere. [18] (*ICAR paper)*

However, if biogas is not recovered properly, it will contribute to a GHG effect 20 times worst than if methane is simply combusted. Therefore, there is a real incentive to transfer biogas combustion energy into heat and/or electricity. [18] (*ICAR paper)*

1.3 OBJECTIVE

The objectives of this research are:

- To generate energy recovery plant using HYSYS simulation.
- From the generated simulation investigate the potential of recovering energy from sewage sludge produced in Malaysia.

1.4 SCOPE OF STUDY

This project will concentrate on setting up an anaerobic digestion plant using HYSYS simulation where this HYSYS software is used to show the process overview that converts the methane produced from the anaerobic digestion process into electricity. Based on the output of electricity produced, the potential of recovering energy from sewage sludge can be estimated. So in order to come out with the right design the proper research on the process involved will be covered.

The research study of this project can be broken down into four stages, first the identification of the appropriate method to recover energy from sewage sludge. The second concentration is to study on enhancing the methane extraction from the sewage sludge and to indentify the most suitable process to purify the biogas produced from the anaerobic process. Third is to identify the energy recovering mechanism from methane into electricity. The fourth will be to use HYSYS software to generate the simulation of the energy recovery plant and explore the processes involved in recovering energy from sewage sludge.

1.4.1 Relevancy of the Study

This project will focus on the energy recovery potential from the sewage sludge. The research topic is much related to energy course of Mechanical Engineering studies such as in the chapter of Heat Transfer, Thermodynamics and Facilities Engineering & Storage (Petroleum Major). Restrictions and the knowledge of Fluid Mechanics are also needed to perform research for this project.

1.4.2 Feasibility of the project within the scope and time frame

Research will be done in order to understand better on the wastewater and the treatment method. The processes of anaerobic digestion have to be studied carefully in order to understand the methane production potential from the sewage sludge. The second part will focused on eliminating the pollutants from the biogas to extract methane(CH_4). The third part of the study will be focused more on converting this produced methane into electrical energy and to apply the whole Anaerobic Digestion plant into HYSYS.

CHAPTER 2

THEORY

For the study of potential energy recovery in terms of biogas generation from Malaysian sewage sludge, there are several research papers that were reviewed and studies in order to understand the phenomena. The research done was divided into to three categories which are to understand the anaerobic digestion process, understanding of method to purify the biogas to extract methane, and study on produce electricity from the methane produced.

THEORY

2.1 Indah Water Konsortium (IWK)

IWK had developed various methods of sewage treatment systems over the last fifty years to meet the need to protect public health and the environment. For urban centers where the population is concentrated and the receiving environment is not able to cope with the waste discharge, sophisticated treatment systems have evolved, which produces a high quality effluent. Simpler systems have been used to service small communities although ever increasing environment standards means that even these areas must eventually install better treatment systems.

Treatment processes are divided into two categories, which utilizes oxygen to breakdown organic matter (aerobic) and treatment, which doesn't utilizes oxygen (anaerobic). The breakdown of organic matter can occur while in suspension (suspended growth) or on the surface of some type of media (attached growth). In addition, processes using ponds are also sometimes used where large areas of land are available. Treatment processes are categorized in this manner as shown in the table below.

Aerobic Processes	Suspended Growth	Activated Sludge
		- plug flow - complete mix - sequencing batch reactor - extended aeration * - oxidation ditch * - deep shaft * -Aerated Lagoons *
	Attached Growth	Trickling Filters
		- low rate - high rate * - Rotating Biological Contactors * - Submerged Biological Contactors *
	Combines	Biofilter Activated Sludge
		* Trickling Filter Activated Sludge
Anaerobic Process	Suspended Growth Attached Growth	Anaerobic Contact Anaerobic Filter Expanded Bed
Pond Processes		
		Aerobic Stabilization (Oxidation) Facultative Anaerobic

* Systems used in Malaysia.

Table 1: Major Biological Sewage Treatment Processes

From this table it is shown that activated sludge, aerated lagoons, rotating biological contactors and trickling filters are the treatment systems most commonly used. This shows that anaerobic digestion is not being the primary treatment method because Indah Water Konsortium (IWK) have not fully discover the energy recovery potential from sewage sludge.

By doing this study about energy recovery potential from sewage sludge, it will at least contribute to increase the percentage of adapting to the anaerobic digestion method as well supports our government to emphasis on renewable energy and increasing energy efficiency.

2.2 Sewage Sludge

Sewage sludge is formed during mechanical, biological and chemical sewage treatment. Sewage sludge obtained as a by-product reflects the chemical composition of the treated sewage, but the composition of sewage itself is determined by the industrial wastewater inflow to the treatment catchment. Quantitative and qualitative composition of the sewage sludge is very complicated. It is rich in organic matter, nitrogen, phosphorus, calcium, magnesium, sulphur and other microelements necessary for plants and soil fauna to live. So it is characterized by the large manurial and soil-forming value. Except the indispensable elements to live, sludge can contain toxic compounds (heavy metals, pesticides) and pathogenic organisms (bacteria, eggs of parasites). (P. Kosobucki, 2000)

According to technical report for Connecticut Resources Recovery Authority (CRRA), there are 3 forms of sludge that can be utilized for energy recovery:

1) Liquid sludge (solids 3-6%, generated in settling tanks and basin).
2) Sludge cake (mechanical dewatering of liquid sludge, dry solid is 15-30%).
3) Dried sludge, solid greater than 90%, produced by thermal drying.

2.3 The Anaerobic Digestion Process

Anaerobic biodegradation of organic material proceeds in the absence of oxygen and the presence of anaerobic microorganisms. Table 2 depicts in detail the types of microorganisms and populations involved in anaerobic digester. It is the consequence of a series of metabolic interactions among various groups of microorganisms that produces the methane.

Anaerobic Digestion (AD) is a series of chemical reactions during which organic material is decomposed through the metabolic pathways of naturally occurring microorganisms in an oxygen depleted environment. AD can be used to process any carbon-containing material, including food, paper, sewage, yard trimmings and solid waste, with varying degrees of degradation. The Organic Full Municipal Sewage Water (OFMSW), for example, is a complex substrate that requires an intricate series of metabolic reactions to be degraded (Ostrem, 2004). This section describes these reactions detailing the intermediary products produced and the bacteria involved.

The full process can be considered to occur in four stages as illustrated in Figure 1, hydrolysis, in which complex molecules are broken down to constituent monomers;acidogenesis, in which acids are formed; acetogenesis, or the production of acetate; and methanogenesis, the stage in which methane is produced from either acetate or hydrogen. Digestion is not complete until the substrate has undergone all of these stages, each of which has a physiologically unique bacteria population responsible that requires disparate environmental conditions.

Group	Cell/mL
Total hydrolytic bacteria	10^8-10^9
Proteolytic	10^7
Cellulolytic	10^5
Hemicellulolytic	10^6-10^7
Hydrogen-producing acetogenic	
Bacteria	10^8-10^9
Homoacetogenic bacteria	10^6
Methanogens	10^5-10^6
Sulphate reducers	10^4

Table 2: Bacterial population from anaerobic digester
Source: Khanna et al., 1995

2.3.1 Hydrolysis/liquefaction

In the first stage of hydrolysis, or liquefaction, fermentative bacteria convert the insoluble complex organic matter, such as cellulose, into soluble molecules such as sugars, amino acids and fatty acids. The complex polymeric matter is hydrolyzed to monomer, e.g., cellulose to sugars or alcohols and proteins to peptides or amino acids, by hydrolytic enzymes, (lipases, proteases, cellulases, amylases, etc.) secreted by microbes as shown below in the illustration of hydrolysis reaction. The hydrolytic activity is of significant importance in high organic waste and may become rate limiting.

In general, hydrolysis is the rate limiting step if the substrate is in particulate form. The rate of hydrolysis is a function of factors such as pH, temperature, composition and particle size of substrate, and high concentration of intermediate products (Veeken, et al., 2000). Some industrial operations overcome this limitation by the use of chemical reagents to enhance hydrolysis. The application of chemicals to enhance the first step has been found to result in a shorter digestion time and provides a higher CH_4 yield (Verma, 2002). In some processes, this initial step is catalyzed by the use of an acid or alkali. In some industrial processes, hydrolysis process is added at the beginning stage to substantially degrade the hydrocarbon content of the solid waste before it is added to the digester.

This provides a higher CH_4 yield and gives a shorter digestion time. It also reduces the thick fibrous scum that can form on top of the digesting mixture and generally makes it less viscous and easier to process (RISE-AT, 1998). The degradation of complex polymeric substances found in solid waste includes lingocellulose, proteins, lipids and starch. In general MSW contains 40-50% of cellulose, 12% of hemicellulose and 10-15% of lignin by dry weight (Wang, et al., 1994). Carbohydrates, on the other hand, are known to be more rapidly converted via hydrolysis to simple sugars and subsequently fermented to volatile fatty acids (Mata-Alvarez, 2003).

Illustration of hydrolysis reaction:

- Lipids → Fatty Acids
- Polysaccharides → Monosaccharides
- Protein → Amino Acids

Equation 1: $C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + 2H_2$

(Glucal) + (Water) → (Glucose) + (Hydrogen)

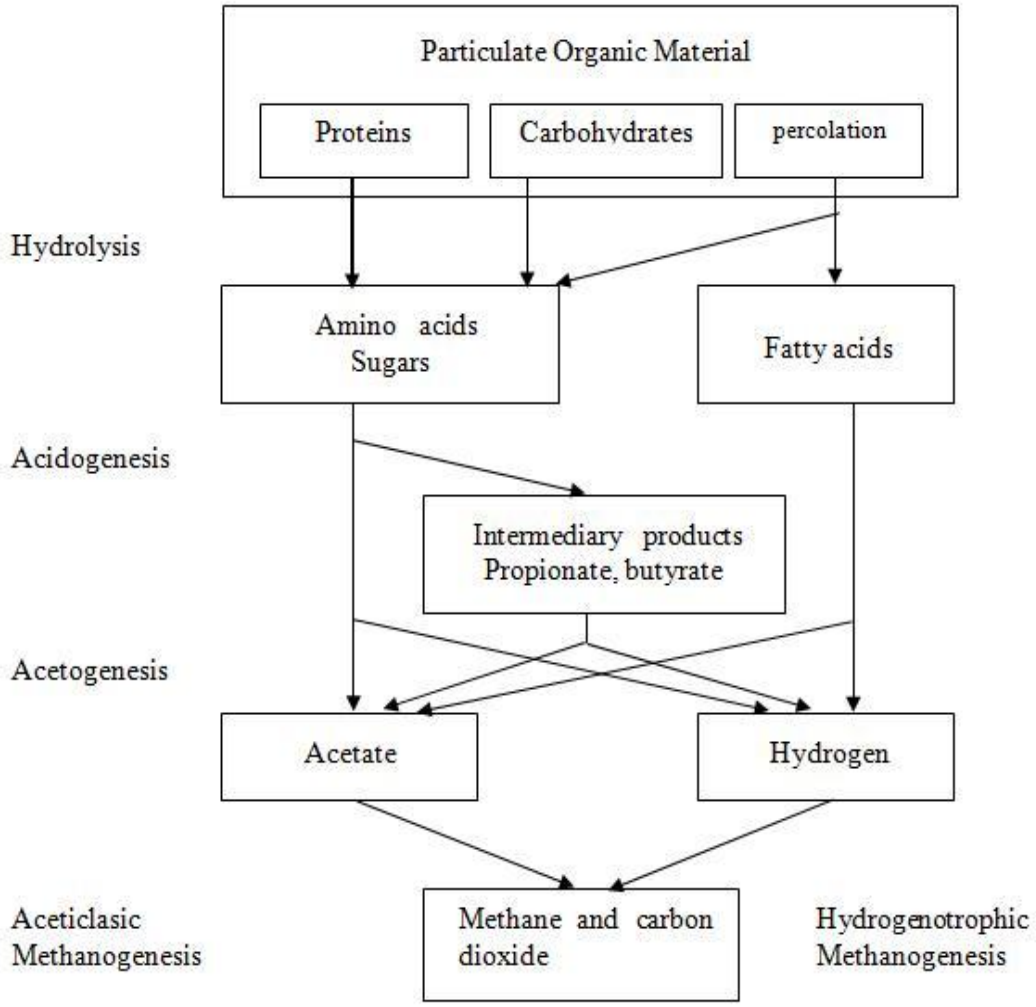


Figure 1: Breakdown of organic matter by anaerobes (Mata Alvarez, 2003)

2.3.2 Acidogenesis

Soluble organic components including the products of hydrolysis are converted into organic acids, alcohol, hydrogen, and carbon dioxide by the action of acid forming bacteria known as acidogens shown in the illustration below:

$$\text{Soluble organic}\left\{\begin{array}{l}\text{Amino acid}\\ \text{Monossacharide}\\ \text{Fatty acids}\end{array}\right\}\xrightarrow{\text{Acidogens}}\left\{\begin{array}{l}\text{Intermediate products}\\ \text{(Propionate, butyrate,}\\ \text{alcohol, etc.)}\end{array}\right\}$$

The complete chemical reaction for Acidogenesis process is shown below:

Equation 2: $C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2$

$\text{(Glucose)} \leftrightarrow \text{(Ethanol)} + \text{(carbon dioxide)}$

Equation 3: $C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O$

$\text{(Glucose)} + \text{(Hydrogen)} \quad \text{(Propionic Acid)} + \text{Water}$

Equation 4: $C_6H_{12}O_6 \longrightarrow 3CH3COOH$

$\text{(Glucose)} \longrightarrow \text{(Acetic Acid)}$

2.3.3 Acetogenesis

The simple monomer blocks formed in hydrolysis act as substrate feedstock for the fermenting, acid forming anaerobic bacteria. It may be difficult to distinguish this stage from the previous one for some molecules which will be absorbed without further break down and can be degraded internally (Meynell, 1982). Acetogenic bacteria, also known as acid formers, convert the products of the first phase to simple organic acids, carbon dioxide and hydrogen as illustrated in Figure 2.8. 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., *syntrophobacter wolinii*, a propionate decomposer and *sytrophomonos wolfei*, a butyrate decomposer. Other acid formers are *clostridium species, peptococcus anerobus, lactobacillus*, and *actinomyces* (Verma, 2002).

Illustration of acetogenesis reaction:

$$\text{Intermediate products (Propionate, butyreate, alcohol, etc.)} \xrightarrow{\text{Acetogens}} \text{Acetate, carbon dioxide and hydrogen}$$

The complete chemical reaction for Acetogenesis process is shown below:

Equation 5: $C_6H_{12}O_6 + 2H_2O \leftrightarrow 2CH_3COOH + 2CO_2 + 4H_2$

(Glucose) + (Water) ↔ (Acetic Acid) + (Carbon Dioxide) + (Hydrogen)

Equation 6: $CH_3CH_2OH + 2H_2O \leftrightarrow CH_3COO^- + 2H_2 + H^+$

(ethanol) (water) ↔ (acetate) + (hydrogen) + (hydron)

When the digester becomes too acidic, this means acid forming bacteria is producing faster than the methane formers. The "acid formers" produce too much acid for the "methane formers" to digest, causing the imbalance condition, which means that a high acidic condition exists. This sours the digester and prevents the formation of methane gas. One method to correct this situation is to add sodium bicarbonate into the digester. This counteracts the acid and brings the balance back to normal (NFEC, 1999).

2.3.4 Methanogenesis

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. Methanogenic bacteria are highly sensitive to oxygen concentration in the system, resulting in an inactive phase in the system as well as a high concentration of fatty acids in the environment (Sharma et al., 2000).

Methane production is higher from the reduction of carbon dioxide but limited hydrogen concentration in digesters results in an acetate reaction, which is the primary producer of methane. The four methanogenic bacteria include methanobacterium, methanobacillus, methanococcus and methanosarcina. Methanogens can also be divided into two groups: acetate and H2/CO2 consumers. Methanosarcina species and methanothrix species or methanosaeta; are considered to be important in AD both as acetate and H_2/CO_2 consumers. The methanogenesis reactions can be expressed as follows:

Equation 7: $2C_2H_5OH + CO_2 \rightarrow CH_4 + 2CH_3COOH$

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

Equation 8: $CH_3COOH \rightarrow CH_4 + CO_2$

(acetic acid) (methane) + (carbon dioxide)

Equation 9: $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

(carbon dioxide) + (hydrogen) → (methane) + (water)

About two thirds of methane is derived from ethanol conversion by methanogens. The other is the result of carbon dioxide reduction by hydrogen (WD, 2006). Although AD can be considered to take place in these four stages, all processes occur simultaneously and synergistically, in as much as the first group has to perform its metabolic action before the next can take over, and so forth (Ostrem, 2004). All the reaction above is form of exothermic (outside heating) chemical reaction where the energy is released in the form of heat. The concentration of H_2 and CO_2 ensures the reaction rate of ethanol and Acetic Acid into methane (CH_4).

Figure2: The sewage sludge digesters at Tilburg Plant in the Netherlands
Ref: http://www.scribd.com/doc/57135609/3/Figure-1-The-digesters-at-Tilburg-Plant-in-The-Netherlands

2.4 System parameters

The digester performances are determined by system parameters. These indicators are based on gas production, destruction of volatile solid matters, alkalinity, volatile acid content and pH. Some of the parameters are described below.

a. Gas production

The gas is produced as a result of breakdown of organic material. Thus the volume of gas produced is an indication of high rate of breakdown of the substrate in the reactor which was utilized by microorganisms.

b. Volatile solid destruction

The destruction is limited to organic matter since digestion is a biological process. The net change or loss in volatile solid is a measure of decomposition. It is the different between the volatile matter of substrate fed and solid residue remain after digestion atsome period of time. The actual breakdown of organic material is higher than that is indicated by the loss, since a portion of organic matter is converted into microbial cellular. The loss is in the form of CO_2 and CH_4 of complete degradation occurs. Otherwise, the loss is in the form of an intermediate compound such as VFA if the degradation is incomplete.

2.5 Factors That Affects the Anaerobic Digestion Process

The rate at which the microorganisms grow is of paramount importance in the Anaerobic Digestion process. The operating parameters of the digester must be controlled so as to enhance the microbial activity and thus increase the anaerobic degradation efficiency of the system. Some of these parameters are discussed in the following section.

2.5.1 pH Level

Anaerobic bacteria, specially the methanogens, are sensitive to the acid concentration within the digester and their growth can be inhibited by acidic conditions. The acid concentration in aqueous systems is expressed by the pH value, i.e. the concentration of hydrogen ions. At neutral conditions, water contains a concentration of 10-7 hydrogen ions and has a pH of 7. Acid solutions have a pH less than 7 while alkaline solutions are at a pH higher than 7. It has been determined (RISE-AT, 1998) that an optimum pH value for Anaerobic Digestion lays between 5.5 and 8.5. During digestion, the two processes of acidification and methanogenesis require different pH levels for optimal process control. The retention time of digestate affects the pH value and in a batch reactor acetogenesis occurs at a rapid pace. Acetogenesis can lead to accumulation of large amounts of organic acids resulting in pH below 5. Excessive generation of acid can inhibit methanogens, due to their sensitivity to acid conditions. Reduction in pH can be controlled by the addition of lime or recycled filtrate obtained during residue treatment. In fact, the use of recycled filtrate can even eliminate the lime requirement. As digestion reaches the methanogenesis stage, the concentration of ammonia increases and the pH value can increase to above 8. Once methane production is stabilized, the pH level stays between 7.2 and 8.2.

2.5.2 Temperature

There are mainly two temperature ranges that provide optimum digestion conditions for the production of methane – the mesophilic and thermophilic ranges. The mesophilic range is between 20°C-40°C and the optimum temperature is considered to be 30°C-35°C. The thermophilic temperature range is between 50°C-65°C (RISEAT, 1998). It has been observed that higher temperatures in the thermophilic range reduce the required retention time (National Renewable Energy Laboratory, 1992).

2.5.3 Carbon to Nitrogen Ratio (C/N)

The relationship between the amount of carbon and nitrogen present in organic materials is represented by the C/N ratio. Optimum C/N ratios in anaerobic digesters are between 20 to 30. A high C/N ratio is an indication of rapid consumption of nitrogen by methanogens and results in lower gas production. On the other hand, a lower C/N ratio causes ammonia accumulation and pH values exceeding 8.5, which is toxic to methanogenic bacteria. 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.

2.5.4 Retention (or residence) Time

The required retention time for completion of the AD reactions varies with differing technologies, process temperature, and waste composition. The retention time for wastes treated in mesophilic digester range from 10 to 40 days. Lower retention times are required in digesters operated in the thermophilc range. A high solids reactor operating in the thermophilic range has a retention time of 14 days (M. Lakos, May 2001).

2.5.5 Mixing

The purpose of mixing in a digester is to blend the fresh material with digestate containing microbes. Furthermore, mixing prevents scum formation and avoids temperature gradients within the digester. However excessive mixing can disrupt the microbes so slow mixing is preferred. The kind of mixing equipment and amount of mixing varies with the type of reactor and the solids content in the digester.

Sewage Sludge	pH (H_2O)	% C	% N	C/N	% P	%Ca	K $mgkg^{-1}$	Mg $mgkg^{-1}$
1	4.45	48.21	1.67	28.87	0.238	0.627	1205	445
2	3.92	6.13	0.68	9.03	0.321	0.422	1021	521
3	6.43	32.10	1.54	20.84	0.410	1.17	941	1690
4	3.92	11.15	2.70	4.13	0.652	0.323	462	278
5	3.57	56.67	1.52	37.94	0.821	0.160	401	389
6	5.61	41.36	2.27	18.22	0.778	1.12	1209	112
7	5.24	37.41	2.82	13.26	0.634	0.832	728	870
8	5.89	18.28	2.65	6.90	1.20	2.16	621	2062
9	6.02	33.35	2.90	11.50	1.62	0.926	972	2902
10	5.72	41.23	2.64	15.62	0.470	0.640	678	1575
Mean	**5.08**	**32.59**	**2.14**	**16.63**	**0.714**	**0.838**	**824**	**1084**

Sewage Sludge 1, 2, 3,4,6,7 and 10 – domestic type
Sewage Sludge 5, 8 and 9 – mixture of light industry & domestic type

Table 3: Nutrient content and pH (n=3) of sewage sludges taken from 10 different wastewater treatment plants. [22]

2.6 Biogas Recovery

Biogas is formed by the activity of anaerobic bacteria. Microbial growth and biogas production are very slow at ambient temperatures. These bacteria occur naturally in organic environments where oxygen is limited. Biogas is comprised of methane (60%), carbon dioxide (40%) and hydrogen sulfide (0.2 to 0.4%) as shown in Table 3. Biogas is very corrosive to equipment and requires frequent oil changes in an engine generator set to prevent mechanical failure. The heating value of biogas is about 60% of natural gas and about 1/4 of propane (IEA, 2001). Angelidaki et al. (2006) reported that the maximum methane yield (0.43 m^3/kg VS) and the best degradation rate for OFMSW could be obtained from batch experiment at low TS content (1.5%) and under thermoplilic conditions.

The gas produced contains methane, carbon dioxide, some inert gases and sulphur compounds. Typically 100-200 m^3 of gas is produced per ton of organic MSW that is digested. (RISE-AT, 1998)

Type of gas and energy	Quantity
Methane	55-70% by volume
Carbon dioxide	30-45% by volume
Hydrogen Sulphide	200-4000 ppm by volume
Energy Content	20-25 MJ/m^3

Table 4: Typical Biogas composition
Source: RISE-AT, 1998

Generally, there are four options to utilize the energy from Anaerobic Digestion plants but for this particular research the second option which is to burn the methane will be look into:

1) **Clean** the biogas to extract the methane gas, which can then be exported off-site and sold as a substitute for natural gas.
2) **Burn** the methane gas in an internal combustion engine to produce electricity for sale off site while collecting heat from the engine's exhaust and cooling system to produce steam or hot water.
3) **Burn** the methane gas in a boiler to produce steam for use onsite and sale off-site, or
4) **Convert** methane gas into compressed natural gas (CNG) for use as a fuel source for light and heavy-duty vehicles. Vehicles powered by CNG, such as municipal buses, offer a number of positive environmental benefits including reduced noise levels and cleaner emissions compared to diesel-powered vehicles. Operators of CNG-powered vehicles have reported that vehicle maintenance costs are 40-50% lower than diesel fuel.

2.7 Analysis and Purification of the Biogas

Biogas can be used directly to generate power, but the large volume of CO_2 and H_2S reduces the heating value of the gas, increasing compression and transportation costs and limiting economic feasibility to uses that occur at the point of production. Purification allows for a better generation for heat and electricity. Basically H_2S

corrodes vital mechanical components within engine generator sets and vehicle engines if it is not removed. (Q. Zhao, CSANR report 2010)

The water scrubbing process contains two main waste streams. The first waste stream is the exhaust of air which was used to strip the regenerated water. This stream mainly consists of air enriched in CO_2 but also contains traces of H_2S and CH_4. Because H_2S is rather poisonous, this stream needs to be treated. And because CH_4 is far more damaging to the environment than CO_2 the CH_4 in this stream should be burned. The second waste stream consists of water which is purged and replaced with clean water to keep dissolubility as high as possible and avoid accumulations of CO_2 and H_2S. Because most of the CO_2 and H_2S will be absorbed in the stripper during the gas phase the purge stream does not have to be treated.

The chemical reaction involve is shown below for the water scrubbing part, where carbonic acid will form when the CO_2 reacted with water:

$$\begin{array}{ccccc} CO_2 & + & H_2O & \rightarrow & H_2CO_3 \text{ (solution)} \\ \text{(Carbon Dioxide)} & + & \text{(Water)} & \rightarrow & \text{(Carbonic Acid)} \end{array}$$

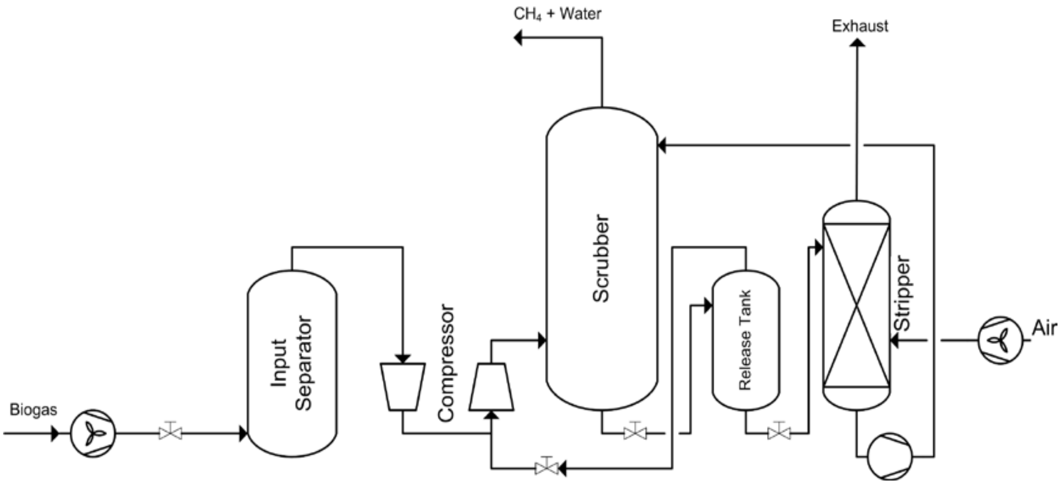


Figure 3: Flow chart of water scrubbing process

To prove the purification system efficiency and to determine the biogas chemical composition, two analysis were required, one before the purification process and other after it. This result is based on the research, from a journal titled “The Production of Sewage Biogas and its Use for Energy Generation” written by

Jönköping, Suécia on 2006. This journal presents an experiment result, where a pilot plant for anaerobic digestion is set up and studied. The project aims to increase the biogas conversion efficiency, by using it as fuel to produce electricity. (Av. Prof. Luciano, 2006)

The tables 2 and 3 present the results of the biogas composition before and after the purification system, respectively:

Chemical Components	**%Vol or ppm**
O2 (Oxygen)	1.23%
N2 (Nitrogen)	15.5%
CO2 (Dioxide Carbon)	4.75%
CH4 (Methane)	75.8%
H2S (Hydrogen Sulphite)	649 ppm
H2O (water)	2.62%

Table 5: Biogas Composition before the Purification Process [7]

Chemical Components	**%Vol or ppm**
O2 (Oxygen)	0.89%
N2 (Nitrogen)	13.2%
CO2 (Dioxide Carbon)	4.07%
CH4 (Methane)	80.8%
H2S (Hydrogen Sulphite)	< 1.0 ppm
H2O (water)	0.98%

Table 6: Biogas Composition after the Purification Process [7]

According to that analysis occurred a significant reduction of H_2S and water in biogas composition, achieving safe values to engine operational conditions, allowing the continuity and for a better energy recovery.

2.8 Storement of Biogas

Due to the low biogas mass flow values, it must be stored before it use as fuel to produce electric energy. The usual range of gas holder that will be suitable for a plant design will be around $500M^3$ and ranging up to 150,000 M^3. The figure below shows an example of gas holder that will be opted to apply in the anaerobic digestion system:

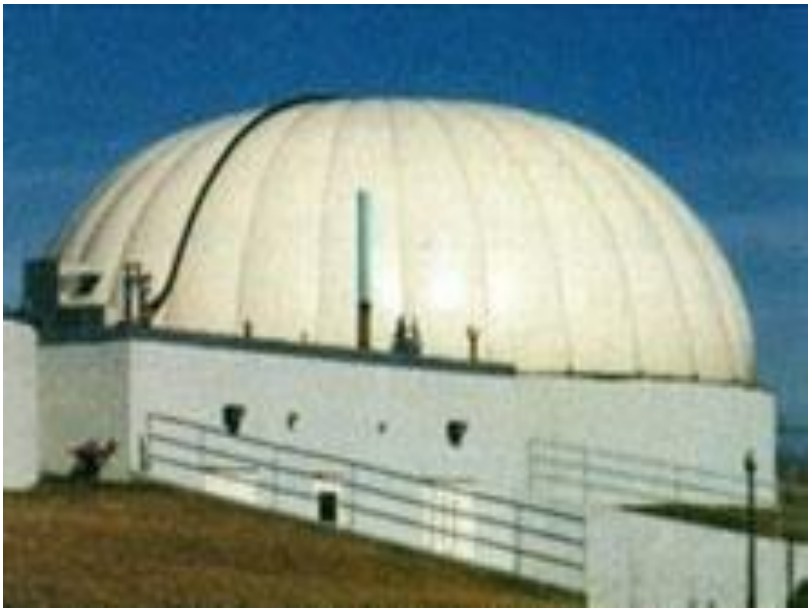


Figure 4: Dystor, Digester Gas Holder Systems
Taken From: [26]

2.8.1 Batch or Continuous

Based on the mode of operation, it can be classified into two processes:

Batch: The reactor vessel is loaded with raw feedstock and inoculated with digestate from another reactor. It is then sealed and left until thorough degradation has occurred. The digester is then emptied and a new batch of organic mixture is added. The sequencing batch concept is generally similar to dry batch digestion, except that leachate from the base of the vessel is exchanged between established and new batches to facilitate start up, inoculation and removal of volatile materials in the active reactor. After the digestion process becomes established inthe solid waste, the digester is uncoupled and reconnected to a fresh batch of MSW in a second vessel.

Continuous*:* The reactor vessel is fed continuously with digestate material;

fully degraded material is continuously removed from the bottom of the reactor. This concept involves a continuously-fed digestion vessel with a digestate dry matter content of 20-40 %. Both completely-mixed and plug-flow systems are available. Plug flow systems rely on external recycle of a proportion of the outgoing digestate to inoculate the incoming raw feedstock. In both cases, the requirement for only minimal water additions makes the overall heat balance favorable for operation at thermophilic digestion temperatures (50-55°C).

2.8.2 Continuous anaerobic digester

The principal objective of developing a continuous AD digestion was to achieve a low initial investment, high efficiency and relatively simple operational and maintenance requirement. The reactor vessel is fed continuously with digestate material; fully degraded material is continuously removed from the bottom of the reactor (RISE-AT, 1998). However, based on RISE-AT 1998 report, the current leading continuous anaerobic plants are:

Dry Continuous Digestion: Continuously fed vessel with dry digestate matter content of 20-40%. Minimal water addition makes the overall heat balance very favorable for operation at thermophilic temperatures.

Wet Continuous Single-Step Digestion: MSW feedstock is slurried with a large amount of water (10% solids). The system leads itself to co-digestion of MSW with more dilute feedstock such as sewage sludge or animal manure. Effective removal of glass and stones is required to prevent rapid accumulation of these in the bottom of the reactor. The digestate requires dewatering to recover liquid, (which can be recycled to mix with incoming waste), to produce a solid digestate for disposal.

Wet Continuous Multi-Step Digestion: MSW feedstock is slurried with water or recycled liquid (10% solids content) and fed to a series of reactors where acetogenesis occurs in a separate reactor from methanogenesis stage.

2.9 Electric Generation Engine

The appropriate purification system contributes to improve the combustion fuel conditions. Other data obtained from biogas analysis is referent to the low heat value that combined to the efficiency and biogas consumption is important to estimate the electric generation potential, as showed in equation below:

$$\eta = \frac{W}{\mathrm{Mb} \times \mathrm{LHV}}$$

W – Estimated Power
Mb – Biogas mass flow consumption
LHV – Low heat value
η - Efficiency

In order to use the calculation above is necessary to admit the efficiency, which depends on technology used in biogas conversion, basically including three different technologies: gas turbines, micro turbines and Otto Cycle engines. Gas turbines have a conversion efficiency of 60-70% while micro turbine has around 80%.

2.9.1 Microturbine

Microturbines are small combustion turbines approximately the size of a refrigerator with outputs of 25 kW to 500 kW. They evolved from automotive and truck turbochargers, auxiliary power units (APUs) for airplanes, and small jet engines. Most microturbines are comprised of a compressor, combustor, turbine, alternator, recuperator (a device that captures waste heat to improve the efficiency of the compressor stage), and generator. Waste heat recovery can also be used with these systems to achieve efficiencies greater than 80%. The figure below illustrates how a microturbine works.

Because of their small size, relatively low capital costs, expected low operations and maintenance costs, and automatic electronic control, microturbines are expected to capture a significant share of the distributed generation market. In addition, microturbines offer an efficient and clean solution to direct mechanical drive markets such as compression and air-conditioning.

Size Range	25-500 kW
Fuel	Natural gas, hydrogen, propane, diesel
Efficiency	20-30% (Recuperated)
Environmental	Low (<9-50 ppm) NOx
Other Features	Cogeneration (50-80°C water)
Commercial Status	Small volume production, commercial prototypes now.

Table 7: Microturbine Overview
(Courtesy of California Distributed Energy Resources Guide on microturbines)

Cogeneration is an option in many cases as a microturbine is located at the point-of-power utilization. The combined thermal electrical efficiency of microturbines in such cogeneration applications can reach as high as 85% depending on the heat process requirements.

Configuration	Efficiency
Unrecuperated	15%
Recuperated	20-30%
With Heat Recovery	Up to 85%

Table 8: Microturbine Efficiency

(Courtesy of California Distributed Energy Resources Guide on microturbines)

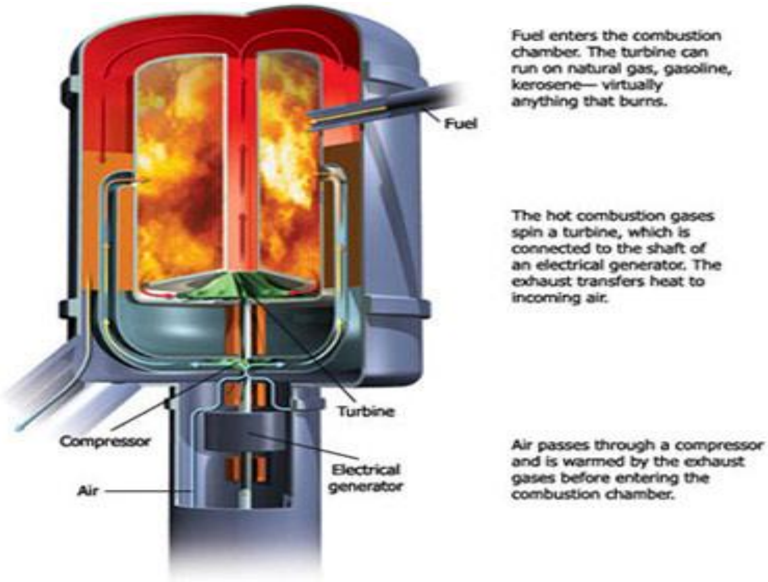


Figure 5: Picture Illustration of a Microturbine [23]

CHAPTER 3

LITERATURE REVIEW

3.1 Literature Review (FYP 1)

The sludge accumulated in a wastewater treatment process must be treated and disposed of in a safe and effective manner. The purpose of digestion is to reduce the amount of organic matter and the number of disease-causing microorganisms present in the solids. The most common treatment options include anaerobic digestion, aerobic digestion, and composting.

For the wastewater sludge processing techniques, the book titled Wastewater Sludge Processing published by Izrail S.Turovskiy and P.K Mathai on (2006) was reviewed. The objective of reviewing the book was to get a clear picture of the typical process involved in treating the sewage sludge. After that, for better understanding of anaerobic digestion process and the potential of extracting methane from dewatered sewage sludge, a journal entitled Principles and potential of the anaerobic digestion of waste-activated sludge was studied, which is written by Lise Appels,Jan Baeyens,Jan Degre`ve, Raf Dewil is reviewed thoroughly.

In this paper, it was said that when treating municipal wastewater, the disposal of sludge is a problem of growing importance, representing up to 50% of the current operating costs of a wastewater treatment plant. Although different disposal routes are possible, anaerobic digestion plays an important role for its abilities to further transform organic matter into biogas (60–70 vol% of methane, $\mathrm{C}H_4$), as thereby it also reduces the amount of final sludge solids for disposal whilst destroying most of the pathogens present in the sludge and limiting odour problems associated with residual matter.

Anaerobic digestion has been touted as the best process for the stabilization of sludge generated from the aerobic treatment of wastewater. Its potential advantages over other stabilization processes include the production of energy as methane (in excess of that required for process operation), a reduction of 30% to 50% of sludge volume requiring ultimate disposal, the production of sludge residue generally free from offensive odors when fully digested and a high rate of pathogen destruction, particularly with the thermophilic process. (I.A.Nges, 2010)

Most high-rate digesters are operated in the mesophilic range, with a temperature between 30 and 38℃ . Anaerobic Digestion can also take place at higher temperatures, in the thermophilic region, where digestion occurs at temperatures between 50 and 57℃ suitable for thermophilic bacteria. Thermophilic digestion is faster than mesophilic digestion since the biochemical reaction rates increase with increasing temperature. Other advantages are an increased solids reduction, improved dewatering, and increased destruction of pathogenic organisms. The use of thermophilic temperatures however has a higher energy requirement, a lower quality supernatant with large quantities of dissolved solids, a higher odour potential and much poorer process stability requiring great care. Taken from a journal titled, Effects of solid retention time on anaerobic digestion of dewatered-sewage sludge in mesophilic and thermophilic conditions, written by (I.A.Nges, 2010)

In order to obtain energy from this biogas in a more productive and cost-efficient way, the gas must be enriched and its pollutants eliminated. This means that all gases except for methane (CH_4) must be removed. The removal of hydrogen sulphide (H_2S) is particularly crucial because it can cause corrosion, which can seriously damage energy co-generation equipment or other installations. Water must also be eliminated because of the accumulation potential of condensate in the pipe line. Finally, CO2 must be removed if the biogas is to be converted into electricity. Taken from a journal titled, Biogas purification from anaerobic digestion in a wastewater treatment plant for biofuel production, written by (F. Osorio, 2009)

It is found that the maximum possible yield of biogas theoretically is around 400m3, but in practice it is nearer to 100m3. This has an energy value of around 21-28 MJ/m3. This produced methane should be burned in an Internal Combustion Engine or this biogas that consists of methane can later be purified and can be extracted to produce pure methane and use it to produce electricity.

Other factors affect the rate and amount of biomethane output. These include pH, water/solids ratio, carbon/nitrogen ratio, mixing of the digesting material, the particle size of the material being digested, and retention time. Pre-sizing and mixing of the feed material for a uniform consistency allows the bacteria to work more quickly. The pH is self-regulating in most cases. Bicarbonate of soda can be added to maintain a consistent pH; for example, when too much "green" or material high in nitrogen content is added. It may be necessary to add water to the feed material if it is too dry or if the nitrogen content is very high. A carbon/nitrogen ratio of 20/1 to 30/1 is best. Occasional mixing or agitation of the digesting material can aid the digestion process. Antibiotics in livestock feed have been known to kill the anaerobic bacteria in digesters. Complete digestion, and retention times, depends on all of the above factors.

3.2 Literature Review (FYP 2)

The main products resulting from the anaerobic digestion process are the biogas, the solid end product (digestate) and water.

3.2.1 Biogas

Biogas is a mixture of various gases. Independent of the fermentation temperature, a biogas is produced which consists of 60%–70% methane and 30%–40% carbon dioxide, whereas trace components of ammonia (NH_3) and hydrogen sulfide (H_2S) can be detected. However, the yield biogas depends on several factors such as temperature, pH and alkalinity, hydraulic and organic loading rates, toxic compounds, substrate type, and total solids (TS)/volatile solids (VS) content (Pavlostathis and Giraldo-Gomez, 1991).

The calorific value of biogas is about 6 kWh/m3 - this corresponds to about half a litre of diesel oil. The net calorific value depends on the efficiency of the burners or appliances. Methane is the valuable component under the aspect of using biogas as a fuel. [18]

Biogas is able to substitute almost the complete consumption of firewood in rural households. [18]

1 m3 Biogas (approximately 6 kWh/m3) is equivalent to:

- Diesel, Kerosene (approx. 12 kWh/kg) 0.5 kg
- Wood (approx. 4.5 kWh/kg) 1.3 kg
- Cow dung (approx. 5 kWh/kg dry matter) 1.2 kg
- Plant residues (approx. 4.5 kWh/kg d.m.) 1.3 kg
- Hard coal (approx. 8.5 kWh/kg) 0.7 kg
- City gas (approx. 5.3 kWh/m3) 1.1 m3
- Propane (approx. 25 kWh/m3) 0.24 m3

The biogas generated from small and medium sized units (up to 6m3) is generally used for cooking and lighting purposes. Large units and/or communal units produce this gas in large quantities and can be used to power engines and generators for mechanical work or power generation. [18] (*ICAR paper)*

According to Symons and Buswell (1933) the yield and composition of the biogas can be estimated from the following equation, when the chemical composition of the substrate is known:

$$\mathrm{CnHaOb} + \left(n - \frac{a}{4} - \frac{b}{2}\right)\mathrm{H2O} \rightarrow \left(n - \frac{a}{8} - \frac{b}{4}\right) CH_4 + \left(\frac{n}{2} - \frac{a}{8} - \frac{b}{4}\right)\mathrm{CO2}$$

Substance	Gas Yield ($m^3 kg^{-1} TS$)	CH_4 Methane content (Vol. %)	CO_2 Carbon Dioxide Content (Vol. %)
Carbohydrates	0.79	50	50
Fats	1.27	68	32
Municipal Solid Waste (MSW)	0.1-0.2	55-65	35-45
Biowaste	0.2-0.3	55-65	35-45
Sewage Sludge	0.2-0.4	60-70	30-40
Manure	0.1-0.3	60-65	35-40

Table 9: Mean composition and specific yields of biogas in relation to the kind of substances degraded (Rilling, 1994)

Most of the biogas is produced during the middle of the digestion, after the bacterial population has grown, and tapers off as the biodegradable material is depleted. The gas is normally stored on top of the digester in an inflatable gas bubble or extracted and stored next to the facility in a gas holder.

3.2.2 Electricity Supply

The mode of operation of a gas engine depends on type of its use e.g. covers peak load, covers basic load, supplies its own needs and only feeds the surplus into the network. The electricity supply mode is determined by the local conditions as well as the price of electricity. Different plant designs are needed for covering a constant basic load and for covering peak loads for certain periods of the day. Peak load covering requires complex and expensive gasholders for longer periods and larger and more expensive power stations. The worldwide ongoing system of promoting renewable energy, as from biogas, does not especially consider whether the power is generated for basic or for peak load and at what time of day the current is fed into the network. Therefore, biogas plants are normally designed to cover the basic load, although the produced power depends on the activity of the microorganism and, as a result, varies. Biogas plants are usually constructed at places, where the power network is not available and special efforts are required to connect the central heat and power to the public power network (Deublin and Steinhouser, 2008)

3.2.3 Heat Supply

Generally, the economics of biogas industry largely depends on the utilization and exploitation of the generated heat from biogas combustion. It must be borne in mind that the heat is produced over the whole year and not only in the winter, when it can be easily used. The heat could be used for the following purposes (Jördening and Winter, 2005):

- heating swimming pools and/or industrial plants
- heating stables
- heating greenhouses
- cleaning and disinfection of the milking equipment
- Transformation of warmth in cold e.g. for milk cooling.

3.2.4 Digestate

Digestate is the solid end product of the process and contains organic compounds which are not susceptible by the anaerobic microorganisms (e.g. lignin). It also consists of the mineralised remains of the dead bacteria from within the digesters (Wastesum, 2006). Digestate can come in three forms; fibrous, liquor or a sludge-based combination of the two fractions depending on the feedstock and the digestion process. In two-stage systems the different forms of digestate come from different digestion reactors. In single stage digestion systems the two fractions will be combined and if desired separated by further processing.

When the digestion is complete, the residue slurry is removed and dewatered to produce a liquid stream and a drier solid. The water content is filtered out and re-circulated to the digester, and the filter cake is cured aerobically, to form compost. The final product is screened for any undesirable materials, (such as glass shards, plastic pieces etc) before being used on the land and sold as organic soil amendment to condition and improve soil (Ostrem, 2004). The digestate may contain ammonia that is phytotoxic as well as pathogenic microorganisms in case where the time temperature regime in not sufficient for their inactivation. However, pathogen destruction can be guaranteed at thermophilic temperatures with a high SRT (Ostrem, 2004). Therefore, the digestate is generally composted after the digestion in order to produce high quality end product. It must be stated that anaerobic digestion does not reduce nutrient content (NPK value), making the digestate more valuable as a fertilizer (Mahony and O'Flaherty, 2002).

3.2.5 Wastewater

This water resulting from the anaerobic digestion process originates both from the moisture content of the produced digestate that is treated (e.g. dewatered) but also includes water produced during the microbial reactions in the digestion systems. This water may be released from the dewatering of the digestate or may be implicitly separate from the digestate. The wastewater is generally recirculated to adjust the water content of the initial substrate, whereas its excess is treated accordingly. Typically, wastewater contains high levels of organic matter which is mainly not biodegradable. As a result, further treatment of the wastewater is often required (Wastesum, 2006).

3.2.6 Energy Generation

The methane in biogas used as an energy source to generate heat and electricity, usually with a reciprocating engine or microturbine often in a cogeneration arrangement where the electricity and waste heat produced are used to system to operate the system in an energy-neutral manner. Excess electricity can be sold to suppliers or put into the local grid. Electricity produced by anaerobic digesters is considered to be renewable energy. Biogas does not contribute to increasing atmospheric carbon dioxide concentrations because the gas is not released directly into the atmosphere and the carbon dioxide comes from an organic source with a short carbon cycle.

Biogas may require treatment to refine it in order to use it as fuel. Therefore, gas scrubbing and cleaning is required when the levels of hydrogen sulfide in the gas are high. The primary challenge associated with the use of biogas as a fuel is the need for gas cleaning to ensure that the gas meets the quality requirements for the utilization equipment. Biogas cleaning is a capital-intensive, multistage operation that can also carry high maintenance costs due to media replacements and/or power costs. However, if the gas impurities are left untreated, they can increase the maintenance requirements of the equipment fueled by the gas and thus reducing equipment duration. Therefore, gas cleaning to reduce condensation, lower H_2S levels, and removal siloxanes is a prerequisite for effective gas utilization. Any foam and sediments entrained in the gas stream are separated using a foam separator in the digester gas piping, while for scrubbing H_2S from biogas the most commonly used methods include the use of iron sponge or chemical scrubbers and the addition of ferric (Fe^{3+}) salts to the feed.

Biogas can be used either for the production of heat only or for the generation of electric power (combined heat and power generation plants). Alternatively, a stirling engine or gas turbine, a micro gas turbine, high - and low - temperature fuel cells, or a combination of a high - temperature fuel cell with a gas turbine can be used. Biogas can also be used to produce steam by which an engine is driven, e.g., in the Organic Rankine Cycle (ORC), the Cheng Cycle, the steam turbine, the steam piston engine, or the steam screw engine (Deublin and Steinhouser, 2008).

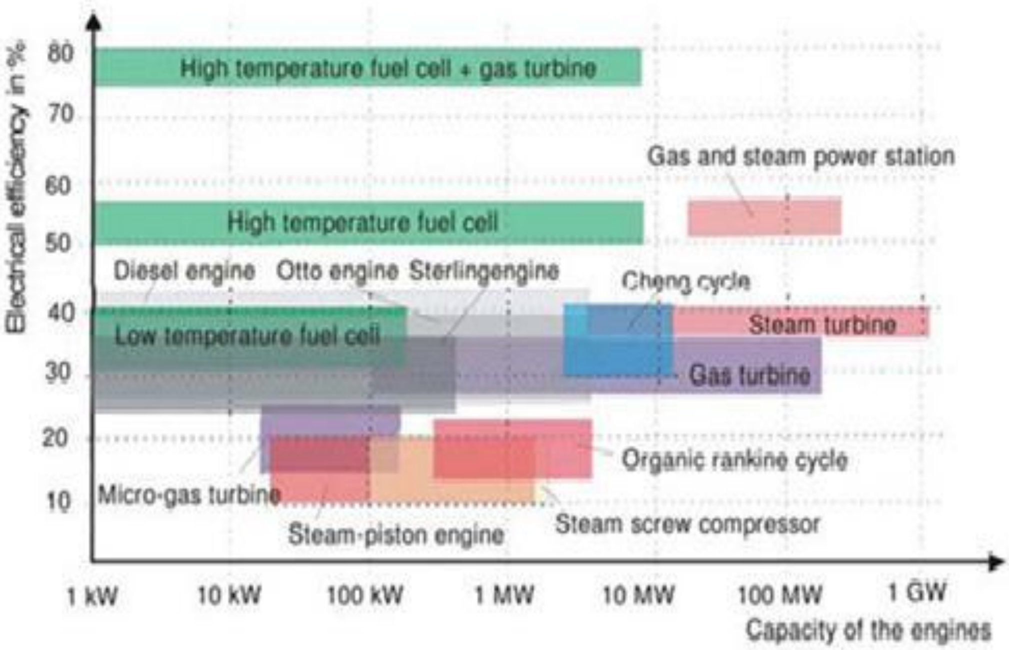


Figure 6: Capacity Range of engines in relation to their electrical efficiency [16]

CHAPTER 4

METHODOLOGY & PROJECT WORK

4.1 Research Methodology

The main target of this research is to identify the best process that can help to yield the optimum amount of energy from the sewage sludge, followed up with evaluation of the design in terms of cost and development aspects of the plant design. HYSYS simulation will be used as a tool to evaluate the energy recovery plant.

The assessment on the optimum choice of process that is needed to set up the anaerobic digestion plant will be constructed into a dynamic simulation by using HYSYS. Finally in order to estimate the energy recovery potential from the sewage sludge produced in Malaysia, a range of experiments will be conducted with the completed HYSYS simulation as different percentage of glucose for the sewage sludge composition will be applied and the power produced for each different composition will be noted.

Prelim Research

- Literature Review on Anaerobic Digestion Process and determine the amount of biogas produced from the process.
- Determine the most highly potential energy recovery system that can be applied in Malaysia.

⇩

Research Work

- Work on Mass Balance and Energy Balance while applying the info in HYSYS.
- Apply the designed energy recovery plant into HYSYS by working on the digester, than the purification part followed up with the energy recovery part.

⇩

Simulation Work

- **Simulation Work 1:** Study on the effect of using single and multi-digesters for the anaerobic digesters.
- **Simulation Work 2:** Study on results of power produced based on different concentrations of glucose in the sewage sludge and compare the changes to other parameters and note the results.

Analysis of Result and Discussion

- Analyze the cost consideration to set up the plant and evaluate the design process.
- Gather and tabulate the data. Discuss the findings from the results obtained and make a conclusion out of the study, determine if the objective has been met.

Report Writing

- Compilation of all research findings, literature reviews, experimental works and outcomes into a final report

4.2 The Energy Recovery System

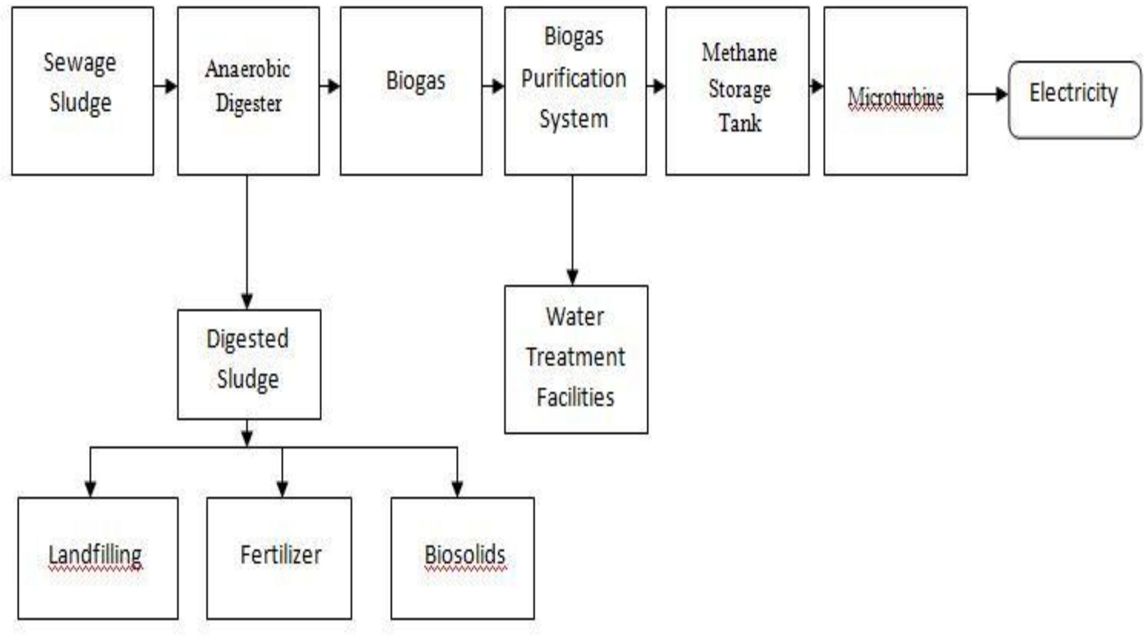


Figure 7: Block Diagram of the Set up Plant for the Energy Recovery System

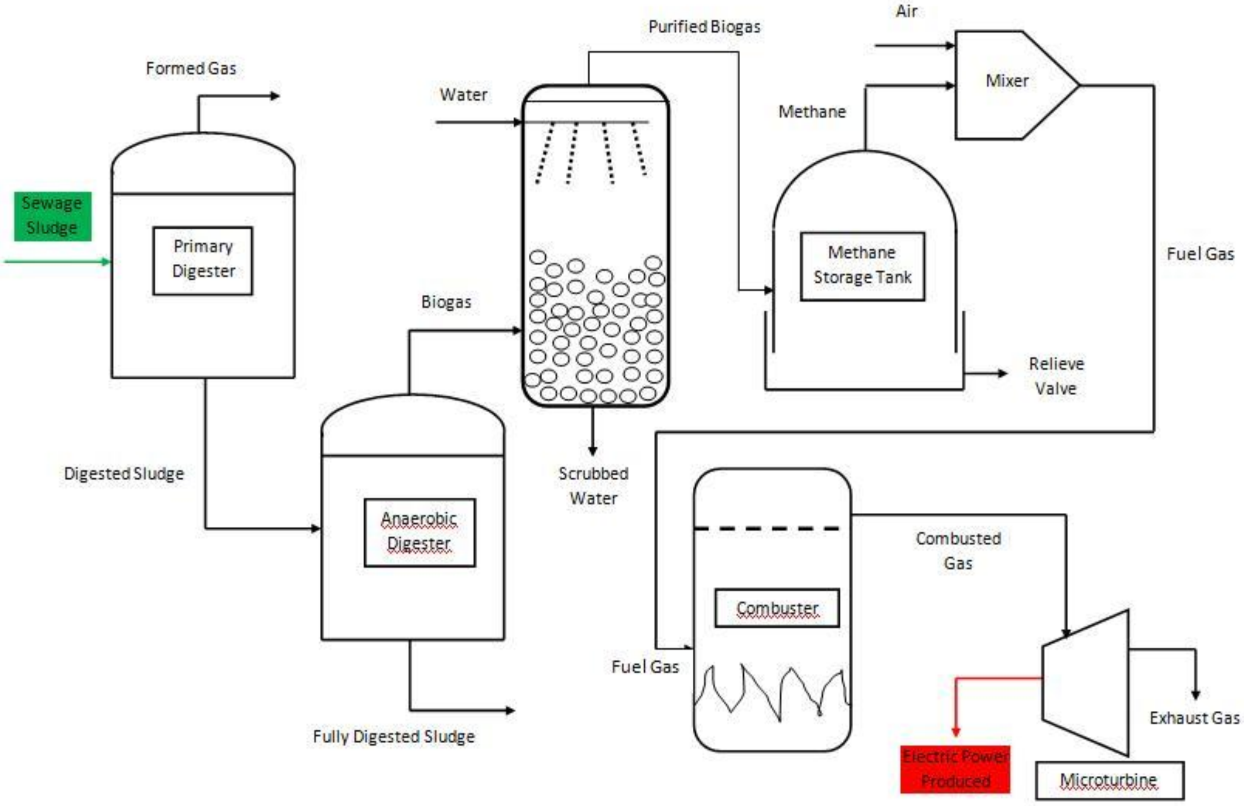


Figure 8: The flow diagram of the total Energy Recovery Plant

4.3 Required Equipment and Software

In order to complete this project, the end product would be modeling of the whole plant using computation software. The software needed to prepare the modeling part is called ASPEN HYSYS.

This software is a chemical software developed by Aspen Technology, Inc. This software offers a comprehensive thermodynamics foundation for accurate calculation of physical properties, transport properties, and phase behavior for the oil & gas and refining industries.

4.4 Project Work

Activities	**Week**														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Work on with the digester in HYSYS	🟪						**MID SEM BREAK**								
Start to work on the mass balance		🟪	🟪												
Complete the mass and energy balance and apply the data in HYSYS				🟪	🟪										
Work on the progress report and absorber column in HYSYS						🟪									
Submission of progress report.								🟥							
Complete the HYSYS simulation									🟪	🟪	🟪				
Experiment with glucose content in sewage sludge and the power produced										🟪	🟪				
Submission of draft report												🟥			
Submission of Dissertation (soft bound) and technical paper													🟥		
Oral Presentation														🟥	
Submission of Project Dissertation (Hard Bound)															🟥

Legend

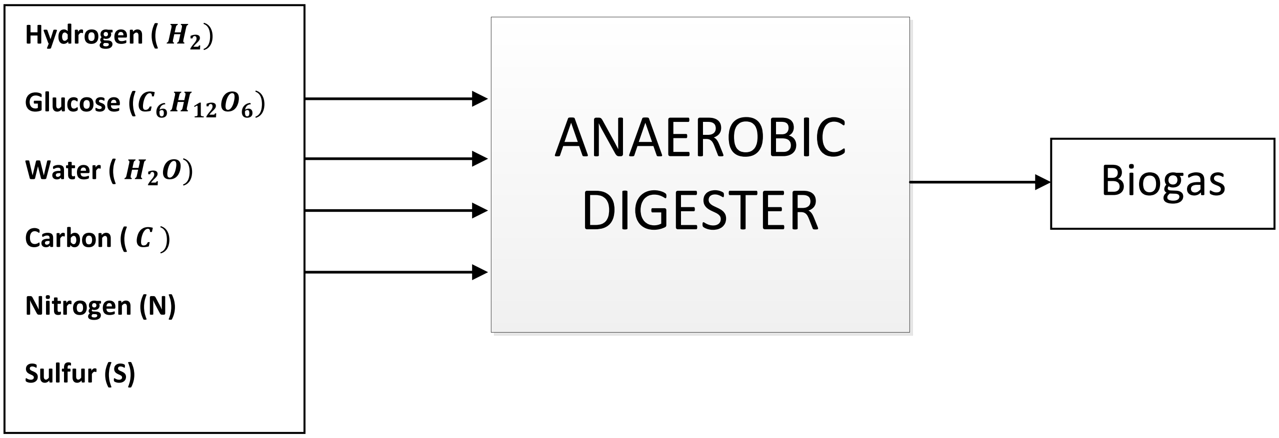
🟥	**Important Milestone**
🟪	**Activity**

Figure 9: Gantt chart

CHAPTER 5

RESULTS & DISCUSSION

5.1 RESULTS



The Digester Condition

- The anaerobic digester will be operated at mesophilic range between 30°C-35°C.
- The design will be consists of double stage processes, the first two stages of anaerobic process occur in one reactor and the methagonesis stage will take place in the second digester. This process is separated in time where one stage occurs after the other.
- The retention time will take approximately around 15-25 days.

The results will be presented in range of glucose concentration as it determines the amount of methane produced which eventually determines the power generated.

5.1.1 SIMULATION RESULTS

Sewage Sludge Composition

Composition	**Percentage (%)**			
Glucose ($C_6H_{12}O_6$)	**10 %**	**20 %**	**30 %**	**40%**
Water (H_2O)	45.32 %	28.77 %	25.32 %	15.32%
Hydrogen (H)	4.97 %	5.64 %	4.97%	4.97%
Carbon (C)	33.01 %	37.51 %	33.01 %	33.01%
Nitrogen (N)	5.22 %	6.27 %	5.52 %	5.52%
Sulfur (S)	1.18 %	1.34 %	1.18 %	1.18%

Feed Rate

Stream Name	**Properties**			
	10 %	**20 %**	**30 %**	**40%**
Temperature (°C)	25°C	25°C	25°C	25°C
Pressure	101.30 kPa	101.30 kPa	101.30 kPa	101.30 kPa
Molar Flow (kgmole/hour)	100 kgmole/hour	100 kgmole/hour	100 kgmole/hour	100 kgmole/hour
Mass Flow (kg/hour)	3217 kg/hour	4884 kg/hour	6460 kg/hour	8081 kg/hour
Actual Volume Flow (m^3/hour)	266.0 m^3/hour	300.5 m^3/hour	264.2 m^3/hour	262.8 m^3/hour

Phase 1 (1/2 Digested Sludge) Composition

Composition	**Percentage (%)**			
	10 %	**20 %**	**30 %**	**40%**
Ethanol (C_2H_5OH)	15.69 %	29.81 %	40.19 %	49.61%
Water (H_2O)	46.46 %	27.23 %	22.02 %	12.38%
Carbon (C)	34.48 %	37.37 %	30.78 %	29.40%
Hydrogen (H_2)	0.0000 %	0.0001%	0.0001%	0.0001%
Nitrogen (N)	0.0003 %	0.0007 %	0.0007%	0.0009%
Sulfur (S)	1.23%	1.33%	1.10%	1.05%
Carbon Dioxide (CO_2)	0.0416%	0.175%	0.30%	0.43%
Glucose ($C_6H_{12}O_6$)	2.08 %	4.07 %	5.60 %	7.12 %

Feed Rate of Phase 1 (1/2 Digested Sludge)

Stream Name	**Properties**			
	10 %	**20 %**	**30 %**	**40%**
Temperature (℃)	32.79 ℃	35.85 ℃	36.43℃	35.85℃
Pressure	101.30 kPa	101.30 kPa	101.30 kPa	101.30 kPa
Molar Flow (kgmole/hour)	95.73 kgmole/hour	100.4 kgmole/hour	107.2 kgmole/hour	112.3 kgmole/hour
Mass Flow (kg/hour)	2290 kg/hour	3109 kg/hour	3941 kg/hour	4714 kg/hour
Actual Volume Flow (m^3/hour)	2.050 m^3/hour	2.829 m^3/hour	3.657 m^3/hour	4.365 m^3/hour

Biogas Formed

Composition	**Percentage (%)**			
	10 %	**20 %**	**30 %**	**40%**
Methane (CH_4)	63.03 %	59.84 %	57.79 %	56%
Carbon Dioxide (CO_2)	29.16 %	30.73 %	31.34 %	31.00 %
Acetic Acid (CH_3COOH)	0.0020 %	0.0066 %	0.0085 %	0.0090 %
Water (H_2O)	3.48 %	3.13 %	2.77 %	1.80 %
Ethanol (C_2H_5OH)	4.0655 %	6.12 %	7.98 %	10.40 %
Nitrogen (N)	0.2585 %	0.15 %	0.0976 %	0.080 %

Properties of Biogas Formed

Stream Name	**Properties**			
	10 %	**20 %**	**30 %**	**40%**
Temperature (℃)	35.61 ℃	37.02 ℃	37.51 ℃	36.81℃
Pressure	101.3 kPa	101.3 kPa	101.3 kPa	101.3 kPa
Molar Flow (kgmole/hour)	9.385×10^{-2} kgmole/hour	0.4259 kgmole/hour	0.8025 kgmole/hour	1.229 kgmole/hour
Mass Flow (kg/hour)	2.395 kg/hour	11.31 kg/hour	21.89 kg/hour	34.38 kg/hour
Actual Gas Flow (m^3/hour)	2.370 m^3/hour	10.80 m^3/hour	20.37 m^3/hour	31.11 m^3/hour
Specific Heat Capacity (kJ/kgmole-C)	38.31 kJ/kgmole-C	39.07 kJ/kgmole-C	39.71 kJ/kgmole-C	40.47 kJ/kgmole-C

- Anaerobic Digestion is a **Exothermic** process
- Digestion rates are optimized by keeping the temperature at 30–60 degrees c, and acidity to 5.5–8.5 pH. The system can be self-powered by the exothermic digestion process itself, though usually with additional heat provided by burning some of the biogas.

Water Scrubber/Absorber Column

Water Properties

- Temperature → 25°C
- Pressure → 100kPa
- Molar Flow → 100 kgmole/hour
- Mass Flow → 1802 kg/hour
- Actual Volume of Water That Flow In → 1.788 m^3/hour

Purified Biogas

Composition	**Percentage (%)**			
	10 %	**20 %**	**30 %**	**40%**
Methane (CH_4)	66.49 %	63.51%	62.26 %	61.7%
Carbon Dioxide (CO_2)	29.15 %	32.23%	33.55 %	34.2%
Water (H_2O)	4.08%	4.08%	4.08%	4.08%
Nitrogen (N)	0.2723 %	0.1618%	0.1051%	0.0872%

- Water seems to scrubbed out all other components such as Acetic Acid and Ethanol, and at the same time increase the concentrations of Methane (CH_4)
- The 29.15 % – 34.2 % range of CO_2 is considered to be manageable, which won't bring much change to the heating value.

Properties of Purified Biogas

Stream Name	**Properties**			
	10 %	**20 %**	**30 %**	**40%**
Temperature (℃)	24.99 ℃	25℃	24.99 ℃	25℃
Pressure	80.0 kPa	80.0 kPa	80.0 kPa	80.0 kPa
Molar Flow (kgmole/hour)	8.897×10^{-2} kgmole/hour	0.4013 kgmole/hour	0.7449 kgmole/hour	1.123 kgmole/hour
Mass Flow (kg/hour)	2.163 kg/hour	10.10 kg/hour	19.01 kg/hour	28.85kg/hour
Actual Gas Flow (m^3/hour)	2.750 m^3/hour	12.40 m^3/hour	23.02 m^3/hour	34.71 m^3/hour
Specific Heat Capacity (kJ/kgmole-C)	36.63 kJ/kgmole-C	36.71 kJ/kgmole-C	36.75 kJ/kgmole-C	36.76 kJ/kgmole-C

- Temperature of the biogas is reduced after the purification process including the pressure.
- Specific heat eventually increased which is good as the heat can be used to generate electricity during combustion process.

RESULTS FOR COMBUSTION PROCESS

Mixed Methane Composition & Properties

Composition	**Percentage (%)**			
	10 %	**20 %**	**30 %**	**40%**
Methane (CH_4)	6.65 %	21.21 %	30.02 %	36%
Carbon Dioxide (CO_2)	4.90 %	12.24 %	17.32 %	20.9%
Water Vapor (H_2O)	0.409 %	1.36 %	1.97 %	2.39%
Oxygen (O_2)	59.55 %	44.07 %	34.27 %	27.5%
Nitrogen (N)	28.47 %	21.10 %	16.42 %	13.2%

- The purified biogas is mixed with air in the mixing chamber, before being combusted in a combustion chamber

<u>Feed Rate</u>

Stream Name	**Properties**			
	10 %	**20 %**	**30 %**	**40%**
Temperature (℃)	29.38 ℃	28.04 ℃	27.26 ℃	26.76℃
Pressure	70.0 kPa	70.0 kPa	70.0 kPa	70.0 kPa
Molar Flow (kgmole/hour)	0.8890 kgmole/hour	1.201 kgmole/hour	1.545 kgmole/hour	1.923 kgmole/hour
Mass Flow (kg/hour)	26.97 kg/hour	34.90 kg/hour	43.81 kg/hour	53.66 kg/hour
Actual Gas Flow (m^3/hour)	31.92 m^3/hour	42.93 m^3/hour	55.05 m^3/hour	68.40 m^3/hour
Specific Heat Capacity (kJ/kgmole-C)	30.17 kJ/kgmole-C	31.89 kJ/kgmole-C	32.98 kJ/kgmole-C	33.73 kJ/kgmole-C
Mass Enthalpy (kJ/kg)	-829.6 kJ/kg	-2317 kJ/kg	-3364 kJ/kg	-4118 kJ/kg

- The table above shows the fuel gas properties and composition of biogas that will be feed into the combusted chamber.
- As expected the Mass enthalpy is found out to be **in negative**, which is prove of exothermic process.
- All the 4 experiments revealed the mass enthalpy ranging from -828.6 kJ/kg to -4118kJ/kg

HIGH TEMPERATURE COMBUSTED GAS PROPERTIES

Stream Name	**Properties**			
	10 %	**20 %**	**30 %**	**40%**
Temperature (℃)	1144 ℃	2375 ℃	2250 ℃	639.1 ℃
Pressure	70.0 kPa	70.0 kPa	70.0 kPa	2.670×10^{-9} kPa
Molar Flow (kgmole/hour)	0.8890 kgmole/hour	1.201 kgmole/hour	1.545 kgmole/hour	1.923 kgmole/hour
Mass Flow (kg/hour)	26.97 kg/hour	34.90 kg/hour	43.81 kg/hour	53.65 kg/hour
Specific Heat Capacity (kJ/kgmole-C)	39.69 kJ/kgmole-C	109.6 kJ/kgmole-C	138 kJ/kgmole-C	49.78 kJ/kgmole-C
Mass Enthalpy (kJ/kg)	−829.6 kJ/kg	−2317 kJ/kg	−3364 kJ/kg	-7338 kJ/kg
Actual Gas Flow (m^3/hour)	149.7 m^3/hour	377.9 m^3/hour	463.1 m^3/hour	1.459 × *1012* m*3*/hour

Combusted Gas Composition

Composition	**Percentage (%)**			
	10 %	**20 %**	**30 %**	**40%**
Methane (CH_4)	1.66 %	5.30 %	12.88 %	22.24 %
Carbon Dioxide (CO_2)	9.89 %	28.15 %	34.45 %	34.63 %
Water Vapor (H_2O)	10.39 %	33.19 %	36.24 %	30.00 %
Nitrogen (N)	28.47 %	21.10 %	16.42 %	13.20 %
Oxygen (O_2)	49.57 %	12.24 %	0.00 %	0.00 %

- The above table shows the properties of high temperature & high pressure gas that will feed into the micro turbine which in HYSYS represented by expander.
- It is also noted that the oxygen is fully reacted with the methane for 30% and 40 % glucose content sewage sludge, after the combustion process.

Properties of Exhaust Gas from the Microturbine

	Properties			
Stream Name	**10 %**	**20 %**	**30 %**	**40%**
Temperature (℃)	268.4 ℃	693.6 ℃	699.7 ℃	639.1 ℃
Pressure	2.405×10^{-2} kPa	2.936×10^{-7} kPa	5.519×10^{-8} kPa	2.670×10^{-9} kPa
Molar Flow (kgmole/hour)	0.8890 kgmole/hour	1.201 kgmole/hour	1.545 kgmole/hour	1.923 kgmole/hour
Mass Flow (kg/hour)	26.97 kg/hour	34.90 kg/hour	43.81 kg/hour	53.65 kg/hour
Specific Heat Capacity (kJ/kgmole-C)	33.29 kJ/kgmole-C	43.46 kJ/kgmole-C	47.76 kJ/kgmole-C	49.78 kJ/kgmole-C
Mass Enthalpy (kJ/kg)	-1898 kJ/kg	-5824 kJ/kg	-7226 kJ/kg	-7338 kJ/kg
Actual Gas Flow (m^3/hour)	1.664 × *105* m*3*/hour	3.289 × *1010* m*3*/hour	2.264 × *1011* m*3*/hour	1.459 × *1012* m*3*/hour

- ❖ Later from the mass enthalpy = h_1 & h_2, and mass flow rate , the total amount of power produced will be calculated

Example Calculations of Power Produced from the Biogas Generated for 20% Glucose

W = mass flow × [mass enthalphy in − mass enthalphy out]

$= \dot{m} \times [h_1 - h_2]$

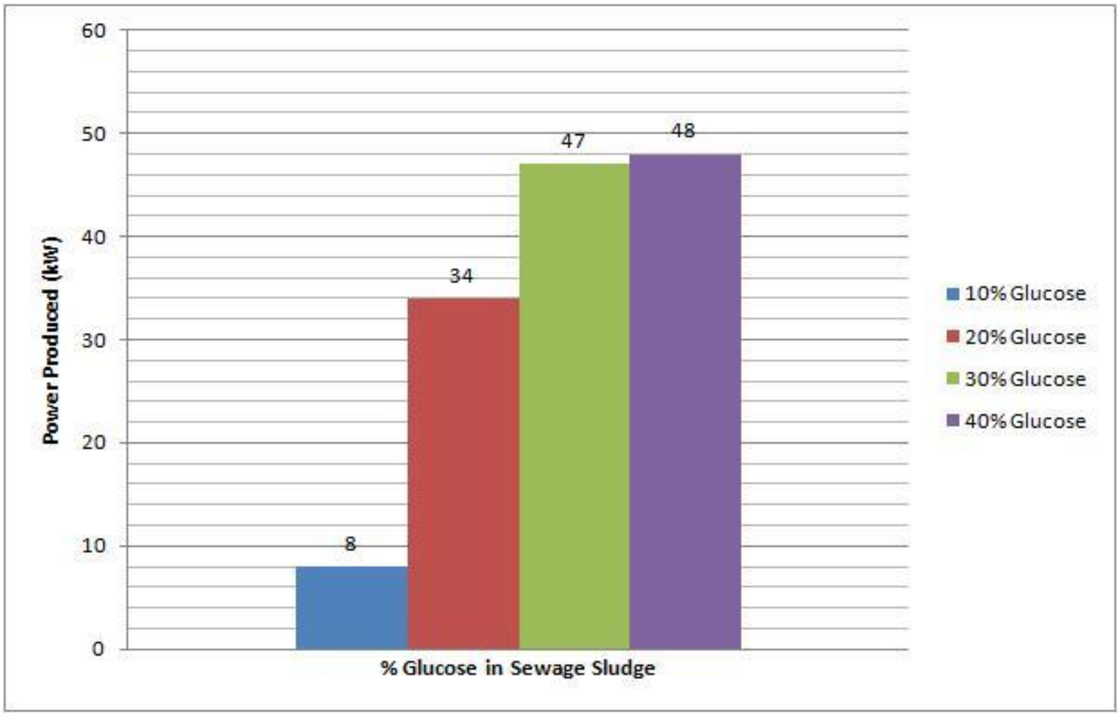
= 34.90 kg/hour $\times \left[\left(-2317 - (-5824)\right)\right]$ kJ/kg

= 122,394.3 kJ/hour $\times$ 1hour/3600seconds

= 33.99 kJ/s

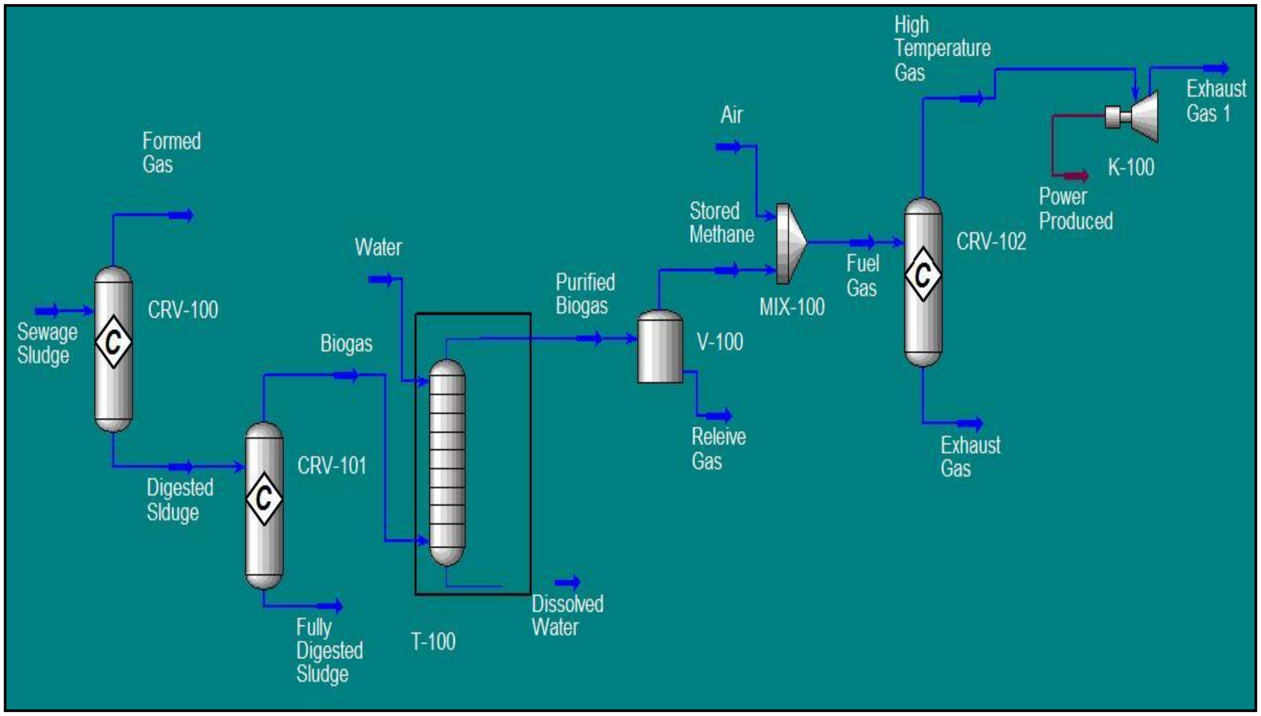
= **34 kW**

- ❖ Results from four different concentration of glucose is concluded in the graph below:



Graph 1: Power Produced (kW) vs. Percentage of Glucose Concentration in Sewage Sludge

5.2 COMPLETED SIMULATION



5.3 COST ESTIMATION

5.3.1 Cost Evaluation for Microturbine

Microturbine capital costs range from RM2198 – RM3455/kW. These costs include all hardware, associated manuals, software, and initial training. Adding heat recovery increases the cost by RM236 – RM1099.40/kW. Installation costs vary significantly by location but generally add 30-50% to the total installed cost.

Microturbine manufacturers are targeting a future cost below RM2041.75/kW. This appears to be feasible if the market expands and sales volumes increase.

With fewer moving parts, microturbine vendors hope the units can provide higher reliability than conventional reciprocating generating technologies. Manufacturers expect that initial units will require more unexpected visits, but as the products mature, a once-a-year maintenance schedule should suffice. Most manufacturers are targeting maintenance intervals of 5,000-8,000 hours.

Maintenance costs for microturbine units are still based on forecasts with minimal real-life situations. Estimates range from RM0.0155 – RM 0.0496 per kWh, which would be comparable to that for small reciprocating engine systems.

5.4 Cost of a Biogas Plant

5.4.1 Cost estimation for Construction of a Whole Plant

Main Digestion Tank Price = RM 1,109,461.50

(Size: 550,000 gallon anaerobic digester)

Construction Costs = RM 237,741.75

Electrical Generation Equipment = RM 475,483.50

Purification Equipment = RM174, 343.95

Total Cost = RM1, 997,030.70

- This cost estimation is taken from a journal name: Financing an anaerobic digester Biocycle December 2007, vol. 48, no. 12, p. 44 [25]
- The values were in USD and it has been converted into ringgit Malaysia.
- The cost evaluation is done for a biogas energy recovery plant that will give an output ranging from 1MW – 2MW.

5.5 Cost Recovery for 34kw of Power Produced at 20% Glucose content

<u>This Calculation Is Done For Sewage Sludge With 20% Glucose Content</u>

Primary Sludge to Digester	2,580 lb/day
Secondary Sludge to Digester	<u>1,193 lb/day</u>
Total	3,773 lb/day

Assume Volatiles are 75%

Volatile Solids to Digestion = 3,773 lb/day x 0.75
= 2,829 lb/day

Assume 50% VSS reduction through digestion

VSS Destroyed = 2,829 lb/day x 0.50
= 1,415 lb/day

Assume 15-C.F. of digester gas produced per pound of volatile solids destroyed.

Gas Production = 1,415 lb/day VSS destroyed x 15 C.F./lb
= 21,225 C.F./day

Gas Production (cfm)

$$= \frac{21{,}225 \text{ C.F./day}}{24 \text{ hr/day} \times 60 \text{ min/hr}}$$

$$= 14.7 \text{ cfm}$$

Each microturbine will generate 30 KW at a digester gas feed rate of 13.13 cfm.

KW Generation Potential

$$= \frac{14.7 \text{ cfm}}{13.13 \text{ cfm}} \times 30\text{KW}$$

$$= \mathbf{34KW}$$

Calculate value of electricity generated at 90% utilization and RM 0.218/KWh, using a 30KW microturbine

30KW x 24 hrs/day x 365 days/yr x 0.90 x RM 0.218/KWh = **RM 51,561.36**

Calculate value of heat recovered while operating the microturbine

$$200{,}000\ \text{BTU/hr} \times 24\ \text{hrs/day} \times 365\ \text{days/yr} \times 0.90 \times \frac{\text{RM}13.70}{1{,}000{,}000\ \text{BTU}} = \textbf{RM21, 602.16}$$

- RM13.20/1million BTU is taken from Suruhanjaya Tenaga report

Annual O&M costs of operating a microturbine:

30KW x 24hrs/day x 365 days/yr x 0.9 x RM 0.0325 KWh = **RM 7698.726**

- RM0.0325 is taken from the average range of operational cost & maintenance as for the table below:

Microturbine Cost	Range
Capital Cost	RM2170 – RM3627/kW
O&M Cost	RM0.0155 – RM 0.0496/kW
Maintenance Interval	5,000-8,000 hrs

(Courtesy of California Distributed Energy Resources Guide on Microturbines)

5.6 Payback Calculation:

RM1, 997,030.70 / [(RM 51,561.36 + RM21, 602.16) – RM 7698.726] = 30.5 years
= **31 years**

- This value is an approximation of total cost if a plant was to be built or constructed in Malaysia.
- The payback value shows the years take to cover the investment cost, if just 30kW of power to be generated.
- This years to recover the investment can be reduced as more power being generated from the digestion plant. It's up to the feed rate of sludge being input and also the amount of glucose available in the sludge.

5.7 Cost Consideration for Construction of a Biogas Energy Recover Plant

5.7.1 Costs of a Biogas Plant

Exact estimations for the construction and operation of biogas plants serve the following purposes:

1) to compare the costs of alternative models (optimal project selection)
2) for the information of the users as far as future financial burdens are concerned
3) the calculation of financing needs including public subsidies (budget planning)

5.7.2 Categories of costs

As far as costs are concerned there are three major categories:

1) Manufacturing or acquisition costs (production costs)
2) Operation and maintenance costs (running costs)
3) Capital costs
4) Production costs

The production costs include all expenses and lost income which are necessary for the erection of the plant e.g.: the land, excavation-work, construction of the digester and gasholder, the piping system, the gas utilization system, the dung storage system and other buildings. The construction costs comprise wages and material.

The production costs of biogas plants are determined by the following factors:

1) purchasing costs or opportunity costs for land which is needed for the biogas plant and slurry storage;
2) model of the biogas plant;
3) size and dimensioning of the biogas unit
4) amount and prices of material
5) labor input and wages
6) the degree of participation of the future biogas user and his opportunity costs for labor.

5.7.3 Total costs

To gain a rough idea of the typical costs of a simple, unheated biogas plant, the following figures can be used: total cost for a biogas plant, including all essential installations but not including land, is between RM 157 –RM236 Malaysian ringgit per m^3 capacity. 35 - 40% of the total costs are for the digester.

The specific cost of gas production in community plants or large plants is generally lower compared with small family plants. The cost for the gas distribution (mainly piping) usually increases with the size of the plant. For communal plants with several end-users of biogas, the piping costs are high and compensate the degression by 'economics of size' partly or wholly. In regions where plant heating is necessary, large-scale plants would be more economical.

To keep the construction costs low, labor provided by the future biogas users is desirable. Often, the whole excavation work is done without hired labor. On the whole, a reduction of up to 15% of the wages can be effected by user-labor. If periods of low farm activities are chosen for the construction of the biogas plant, opportunity costs for labor can be kept low.

5.7.4 Running costs

The operation and maintenance costs consist of wage and material cost for:

1) acquisition (purchase, collection and transportation) of the substrate;
2) water supply for cleaning the stable and mixing the substrate;
3) feeding and operating of the plant;
4) supervision, maintenance and repair of the plant;
5) storage and disposal of the slurry;
6) gas distribution and utilization;

The running costs of a biogas plant with a professional management are just as important as the construction costs, for example for operation, maintenance, expenses for painting, service and repair.

5.7.5 Large-scale biogas plants

Large-scale biogas plants have high water consumption. Investigations are necessary, if the water quantity required causes additional costs in the long run. These could be construction costs for water piping or fees for public water supply. The question of water rights has to be clarified. Steps to be taken to cover the demand for water during dry periods require thorough planning.

5.7.6 Capital costs

Capital costs consist of redemption and interest for the capital taken up to finance the construction costs. For dynamic cost comparison the capital fixed in the plant is converted into equal annual amounts.

5.7.7 Lifetime of plants

In calculating the depreciation, the economic life-span of plants can be taken as 15 years, provided maintenance and repair are carried out regularly. Certain parts of the plant have to be replaced after 8 - l0 years, e.g. a steel gas holder. The steel parts need to be repainted every year or every second year. As a rule, real prices and interest rates should be used in the calculations. For cost calculation inflation rates are irrelevant as long as construction costs refer to one point of time. However, in calculating the cash reserves put aside for servicing and repair the inflation rate must be considered.

5.7.8 Average costs

The cost per cubic meter of digester volume decreases as volume rises. Therefore, the appropriate size of the biogas plant should be estimated. For simple, unheated plants in tropical countries, the digester size is roughly:

1) 120-fold the quantity of substrate put in daily at average expected digester
2) temperatures over 25°C and
3) 180-fold the quantity of daily feeding for temperature between 20 and 25°C.

Since the final method of construction is only determined during the first years of a biogas project, it is impossible to exactly calculate the building costs ahead of the actual implementation. The GTZ computer program called "BioCalc" (produced by BioSystem), can only provide an idea as it is based on only one type of plant. Consequently, the following system is sufficient for a rough calculation:

a. the cost of 6.5 sacks of cement x m3 digester volume plus
b. the cost of 5 days work for a mason x m3 digester volume plus
c. the costs of 100 m gas pipes (1/2"), plus
d. the costs of two ball valves (1/2"), plus

5.8 DISCUSSION

Anaerobic digestion technology has seen remarkable progress in reactor and process design. Earlier, long periods of time were required for complete degradation. In order to provide a constant supply in extracting energy from anaerobic digestion, installing a methane gas holder tank would help to provide a constant supply while the microturbine converts the methane into useful electricity.

Biogas mainly consists of combustible methane (CH4) and non-combustible carbon dioxide (CO_2). Besides CH_4 and CO_2, biogas also contains small amounts of hydrogen sulphide (H2S) and some other pollutants. The composition of biogas strongly depends on its source. Based on the experiments done for the sewage sludge content, it is found out that the Malaysia sewage sludge has Hydrogen (H), Carbon (C), Nitrogen (N), Sulfur (S), Water (H_2O) and Glucose ($C_6H_{12}O_6$) . The amount of power produced is partially depends on the concentrations of glucose content in it, as this will later digested in the anaerobic digester into ethanol and carbon dioxide. This process is continued and acetic acid is produced for the further digestion and later CO_2 itself react with hydrogen to produce methane.

Since the large volume of CO_2 reduces the heating value of the gas, there is a need to purify the biogas by removing the $CO_2\ and\ H_2S$. Purification allows for a better generation for heat and electricity. It also increases the concentration of CH_4 which gives the biogas a higher calorific value allowing for injection in the gas grid or to use as a fuel. H_2S has to be removed because of its corrosiveness.

Water scrubbing is the most applicable CO_2 scrubbing process for use in an agricultural setting because of its simplicity and low cost. On a dairy farm, these factors would be more important than efficiency, reduced footprint, and redundancy. Another advantage of water scrubbing over some other processes is that water is fairly easy to dispose of whereas the chemicals used in some of the other processes may require special handling and disposal when spent.

In future, the best practicable environmental option will be deriving energy from waste. Energy recovery technologies include combustion of waste and anaerobic digestion. However, combustion of the wet stream of municipal sewage sludge does not provide efficient energy recovery. So the advantages offered by anaerobic digestion are worth exploring for the use of Indah Water Konsortum (IWK) in Malaysia.

5.8.2 Why Choose Microturbine

Functional:

- Provides better power reliability and quality, especially for those in areas where brownouts, surges, etc. are common or utility power is less dependable
- Provides power to remote applications where traditional transmission and distribution lines are not an option such as construction sites and offshore facilities
- Can be an alternative to diesel generators for on-site power for mission critical functions (e.g., communications centers)
- Possesses combined heat and power capabilities
- Reduces upstream overload of transmission lines
- Optimizes utilization of existing grid assets—including potential to free up transmission assets for increased wheeling capacity
- Improves grid reliability
- Facilitates faster permitting than transmission line upgrades
- Can be located on sites with space limitations for the production of power

Productive:

- Provides high-quality power for sensitive applications
- Responds faster to new power demands—as capacity additions can be made more quickly
- Facilitates less capital tied up in unproductive assets—as the modular nature of microturbines means capacity additions and reductions can be made in small increments, closely matched with demand, instead of constructing central power plants sized to meet estimated future (rather than current) demand
- Stand-by power decreases downtime, enabling employees to resume working
- Produces less noise than reciprocating engines

Sustainable:

- Produces the lowest emission of any noncatalyzed fossil fuel combustion system
- Has a small footprint, minimizing site disturbance
- Reduces or defers infrastructure (line and substation) upgrades
- For recuperated microturbine, possesses higher energy conversion efficiencies than central generation
- Enables more effective energy and load management.

CHAPTER 6

CONCLUSION

Based on all the studies carried out from FYP 1, the theory had been successfully applied in FYP 2 where the HYSYS simulation have been successfully been designed by using a conversion reactor where the supplied feed is successfully transformed by the digester into biogas. The further process of purification part allows a better yield of methane as it scrubbed out all other impurities which eventually gave a better result of the biogas generated. This water scrubbing method is represented by absorber column in the HYSYS simulation. Final stage of this project will be to convert this produced methane into electrical energy by using a micro turbine in the HYSYS simulation. This microturbine is represented by the combustor and expander in HYSYS.

So based on the output from microturbine, we can estimate the amount of electricity that can be produced from the methane gas that being produced from anaerobic digestion process. From the study and research done, the objectives set are partially been achieved. Firstly, the further development of the HYSYS simulation is done. Compared to FYP 1 there has been more literature review done on the purification part and energy extracting part. Application of absorber column had been identified and it is the most possible method to purify the biogas, as the main purpose is to remove the CO_2 and water is used as the absorbent as these solutions are abundant in nature and also in IWK.

The best model of plant design to extract energy from the sewage sludge are being applied in to the simulation, the completed simulation had been highlighted in the report above. Based on the profound data from journals, an approximation of cost to construct an anaerobic digestion plant has also been calculated and shown in the results above.

The aim of this project are to develop most systematic, reliable, economical, safe, and environmentally friendly plant that can recover energy from the sewage sludge produced in Malaysia. All this result from the simulation and research is enough to conclude the potential to recover energy from the sewage sludge produced in Malaysia.

6.1 Advantage of Anaerobic Digestion Plant

Until now, instruments to reduce the greenhouse effect considered primarily the reduction of CO2-emissions, due to their high proportion in the atmosphere. Though other greenhouse gases appear to be only a small portion of the atmosphere, they cause much more harm to the climate. [25]

Methane is not only the second most important greenhouse gas (it contributes with 20% to the effect while carbon dioxide causes 62%), it has also a 25 times higher global warming potential compared with carbon dioxide in a time horizon of 100 years. The Bio gas plant effectively reduces the amount of methane directly released into the atmosphere, by trapping it and facilitating its use as a green fuel. After burning, methane only releases harmless gases in air. Given below are the figures relating to this:

With anaerobic digestion, a renewable source of energy is captured, which has an important **climatic twin effect**:

1. The use of renewable energy reduces the CO2-emissions through a reduction of the demand for fossil fuels.
2. At the same time, by capturing uncontrolled methane emissions, the second most important greenhouse gas is reduced:

1m3 cattle manure = 22.5 m3 biogas = 146 kWh gross = 36 kg CO2- emissions

Smaller agricultural units can additionally reduce the use of forest resources for household energy purposes and thus slow down deforestation, soil degradation and resulting natural catastrophes like flooding or desertification. [25]

1 m3 biogas (up to 65% CH4) = 0,5 l fuel oil = 1,6 kg CO2
1 m3 biogas = 5,5 kg fire wood = 11 kg CO2

The reduction of 1 kg methane is equivalent to the reduction of 25 kg CO2. The reduction of greenhouse gases with a high global warming potential can be more efficient compared with the reduction of CO2. [25]

Even if there is only one biogas plant in a country - the following valuable assets of biogas use from the environmental point of view can be determined. [25]

As CO2 generation by burned biogas only amounts to 80 per cent of the CO2 generation of fired fuel oil (per kWh electrical energy) and is even more advantageous in relation to coal (about 50 per cent), the environmental benefits of biogas in relation to fossil fuels are indisputable. [25]

Thus, using biogas has a direct and telling effect on local, regional and global atmosphere, by considerably reducing the greenhouse effect.

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