

ENHANCEMENT PRODUCTION BIOGAS FROM  
PALM OIL MILL EFFLUENT (POME)

NURULIANA BINTI ISMAIL

DEGREE OF BACHELOR OF CHEMICAL  
ENGINEERING  
UNIVERSITI MALAYSIA PAHAN

## UNIVERSITI MALAYSIA PAHANG

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EFFLUENT (POME)**

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**Jalan Haji Kosai**

Nama Penyelia

**84000, Muar, Johor**

Tarikh : **20 JANUARY 2012**

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ENHANCEMENT OF PRODUCTION OF BIOGAS FROM PALM OIL MILL  
EFFLUENT (POME)

NURULIANA BINTI ISMAIL

Thesis submitted in fulfilment of the requirements  
for the award of the degree  
in Bachelor of Chemical Engineering

Faculty of Chemical and Natural Resources  
UNIVERSITI MALAYSIA PAHANG

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*Special dedication to my mum and dad that always inspire, love and stand beside me,  
and to my beloved friend.*

*Thank you for all your love, care and support.*

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## ABSTRACT

Energy demand is increasing continuously due to rapid growth in population and industrialization development. The major energy demand is provided from the conventional energy sources such as coal, oil, natural gas, etc. In every country is facing with these conventional fuels, are depletion of fossil fuels and deterioration of environment. Meanwhile, the Malaysian oil palm industry is an important industry but the waste organic from palm oil mill effluent (POME) is a contributed to global warming phenomena. The experiment for capture gas methane will be one of the alternative ways to encounter this problem. It investigated to increase the gas  $\text{CH}_4$  and decrease the gas  $\text{CO}_2$  to a biogas production. The parameters that have been focused throughout identified condition temperature and monitoring optimum day in bioreactor. Gas Chromatography is used to detect the concentration time in weekly for one month. Temperature in the pilot plant is not to control but the result is take for analysis. Meanwhile the pattern of the concentration  $\text{CH}_4$  by a weekly was taken. The study shows, the mesophilic condition is highest concentration methane than thermophilic condition. POME in the bioreactor  $500\text{m}^3$  after a fortnight needed to discharge and uploads a quarter of volume in bioreactor to get optimum condition. As a conclusion, the applicability of temperature and time in bioreactor was enhancement the biogas production and can be used to generate electricity. Biogas capture also has resulted in substantial greenhouse gasses (GHG) reduction.

## ABSTRAK

Permintaan tenaga semakin meningkat secara berterusan disebabkan pertumbuhan pesat dalam jumlah penduduk dan pembangunan perindustrian. Permintaan tenaga daripada sumber-sumber tenaga konvensional seperti arang batu, minyak, gas asli, dan sebagainya memainkan peranan utama. Setiap negara sedang menghadapi permasalahan berkenaan bahan api konvensional ini, kekurangan bahan api fosil dan kemerosotan alam sekitar. Sementara itu, industri kelapa sawit Malaysia merupakan industri utama di Malaysia tetapi sisa organik daripada kilang minyak sawit effluen (POME) menyumbang kepada fenomena pemanasan global. Pengumpulan gas metana merupakan salah satu cara alternatif untuk menangani masalah ini. Dengan meningkatkan  $\text{CH}_4$  gas dan mengurangkan gas  $\text{CO}_2$  dalam proses penghasilan biogas. Parameter yang telah boleh dikenal pasti terdiri daripada suhu dan jumlah hari yang diperlukan semasa berlakunya proses di dalam bioreaktor. Kromatografi gas digunakan untuk mengesan jumlah peratusan gas metana. Suhu dalam loji perintis bukan untuk dikawal tetapi suhu akan diambil untuk di analisis. Sementara itu, corak gas metana dalam seminggu selama sebulan akan di rekod. Kajian menunjukkan, keadaan mesophilic memperoleh peratusan gas metana yang tinggi daripada keadaan thermophilic. Loji perintis yang berisipadu  $500\text{m}^3$  memperlihatkan penurunan peratusan selepas dua minggu. Satu pertiga daripada isipadu lodi perintis akan dilepaskan dan satu pertiga POME yang baharu akan menggantikannya. Secara kesimpulan, penggunaan suhu dan tempoh masa dalam loji perintis memperlihatkan corak peratusan pengeluaran biogas. Biogas boleh digunakan untuk menjana tenaga elektrik. Pengumpulan biogas juga telah mengurangkan kesan terhadap kesan rumah hijau.

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**LIST OF ABBREVIATIONS & SYMBOLS**

%	Percentage
BOD	Biological Oxygen Demand
CH <sub>4</sub>	Methane
CO <sub>2</sub>	Carbon Dioxide
COD	Chemical Oxygen Demand
CPO	Crude Palm Oil
FFB	Fresh Fruit Bunch
GHG	Green House Gasses
POME	Palm Oil Mill Effluent
VFA	Volatile Fatty Acid

## CHAPTER 1

### INTRODUCTION

#### 1.1.1 Introduction

Malaysia is the largest producer of palm oil, the third largest for rubber and fourth for cocoa. There were more than 3.79 million hectares of land, occupying more than one-third of the total cultivated area and 11% of the total land area, under palm oil cultivation in Malaysia in the year 2003 (Yusoff and Hassan 2007).

Effluents from palm oil mills processing plant have been identified as the major cause of the rapid deterioration of the aquatic environment in the 1960s as well as 1970s. There is in fact the largest source of water pollution during the period (DOE 1991). Palm oil mill effluent (POME) is generated mainly from oil extraction, washing and cleaning process in the mill. These contain cellulosic material, fat, oil and grease (Agamuthu 1995). Discharging untreated effluent into water streams may cause considerable environmental problems (Dais and Reilly 1980) due to its high biochemical oxygen demand, BOD ( $25,000 \text{ mg L}^{-1}$ ), chemical oxygen demand, COD ( $53,630 \text{ mg L}^{-1}$ ), oil and grease ( $8,370 \text{ mg L}^{-1}$ ), total solids ( $43,635 \text{ mg L}^{-1}$ ) and suspended solids ( $19,020 \text{ mg L}^{-1}$ ) (Ma 1995,2000). The palm oil mill industry in Malaysia has thus been identified as the one discharging the largest pollution load into rivers throughout the country (Hwabg et al. 1978).

In addition to biomass, palm oil mills also generate large quantities of liquid wastes, known as palm oil mill effluent (POME), which due to its high biochemical oxygen demand (BOD), is required by law to be treated to an acceptable level before it can be discharged into a watercourse. About 0.7tonne of POME is generated for every tonne of FFB processed. Hence in 2001, the palm oil industry generated about 42.7 million tonne of POME. All palm oil mills used anaerobic process to treat their effluents. Biogas is a gaseous product of the anaerobic process. About 28.8 m<sup>3</sup> of biogas are generated from every tonne of POME digested.

Thus in 2001, palm oil industry was generated about 1230 million cubic meters of biogas. The biogas comprising about 65% methane and 35% carbon dioxide is a good source of energy with a heat value of 4740 kcal m<sup>-3</sup>. It was reported that in a gas engine, about 1.8 kWhr of electricity could be generated from 1 m<sup>3</sup> of biogas. Thus in 2001, the biogas produced by the palm oil mills could have generated about 2214 million kWhr of electricity. It was more than sufficient to meet the energy demand by all the palm oil mills. Unfortunately, only a few palm oil mills that need the extra energy for its subsidiary industries harness the biogas for heat and electricity generation. In terms of carbon credit, if all the biogas (instead of diesel) were used to generate electricity, the palm oil industry would have prevented 1040 million kilogrammes of carbon dioxide from being emitted to the atmosphere. This amounts to a carbon credit of US\$ 10.4 million. Both methane and carbon dioxide are GHG that contribute to global warming. Methane is known to be more potent than carbon dioxide. Based on their global warming potential, methane is 21 times more potent than carbon dioxide over a 1000-year period (Tong, 2002). The potency of methane can be reduced if it is burnt.

### 1.1.2 Problem Statement

There are currently about 360 active palm oil mills in Malaysia with a combined annual CPO production capacity of about 15 million tonnes (Malaysian Palm Oil Promotion Council, 2005). On an average, in standard palm oil mills, each tonne of fresh fruit bunch (FFB) processed generates about 0.7 tonne of liquid waste comprising of about 26.3 kg of BOD, 53 kg of COD, 19 kg of suspended solids (SS) and 6 kg of oil and grease. This amounts to a population equivalent of around 60 million in terms of COD (Thani *et al.*, 1999). Also, palm oil mill wastewater treatment systems are one of the major sources of greenhouse gases in Malaysia due to their biogas emission (36 % CH<sub>4</sub> with a flow rate of 5.4 l/min.m<sup>2</sup>) from open digester tanks and/or anaerobic ponds (Yacob *et al.*, 2005). Therefore, palm oil mills in Malaysia face the challenge of balancing environmental protection, their economic viability, and sustainable development after the Department of Environment enforced the regulation for the discharge of effluent from the crude palm oil (CPO) industry, under the Environmental Quality order and regulations, 1997. Thus, there is an urgent need to find an efficient and practical approach to preserve the environment while maintaining the sustainability of the economy.

### 1.3 Objective

The purpose of this thesis is:

- To increase percent of  $\text{CH}_4$  and decrease  $\text{CO}_2$  emission from palm oil mill effluent (POME) for a biogas production.
- To study relevant condition temperatures of maximize biogas production from palm oil mill effluent (POME).
- To obtain the maximum of production  $\text{CH}_4$  based on cycle retention time to enhance the production methane from palm oil mill effluent (POME).

### 1.2 Scope of the research work

In order to achieve the target, extra effort and focus have to be done with the topic of the enhancement of production biogas from palm oil mill effluent (POME).

- Firstly there are should studies the effect of temperature in which value can be obtain to the biogas production. The range temperature that suitable is  $40^{\circ}\text{C}$ - $60^{\circ}\text{C}$  because it will affect the bacteria growth meanwhile to produce the production of biogas.
- In the other hand, the method in the process of biogas that could enhancement/effect the biogas production should be known in order to make a work more efficient. For the most important is a analyse gas and criteria will produce from the palm oil mill effluent (POME) using a gas chromatography.
- Last but not least, the effect of cycle retention time in concentration  $\text{CH}_4$  in weekly will be analysing. The suitable of the retention time should be identified to enhancement the production of biogas from a palm oil mill effluent (POME).

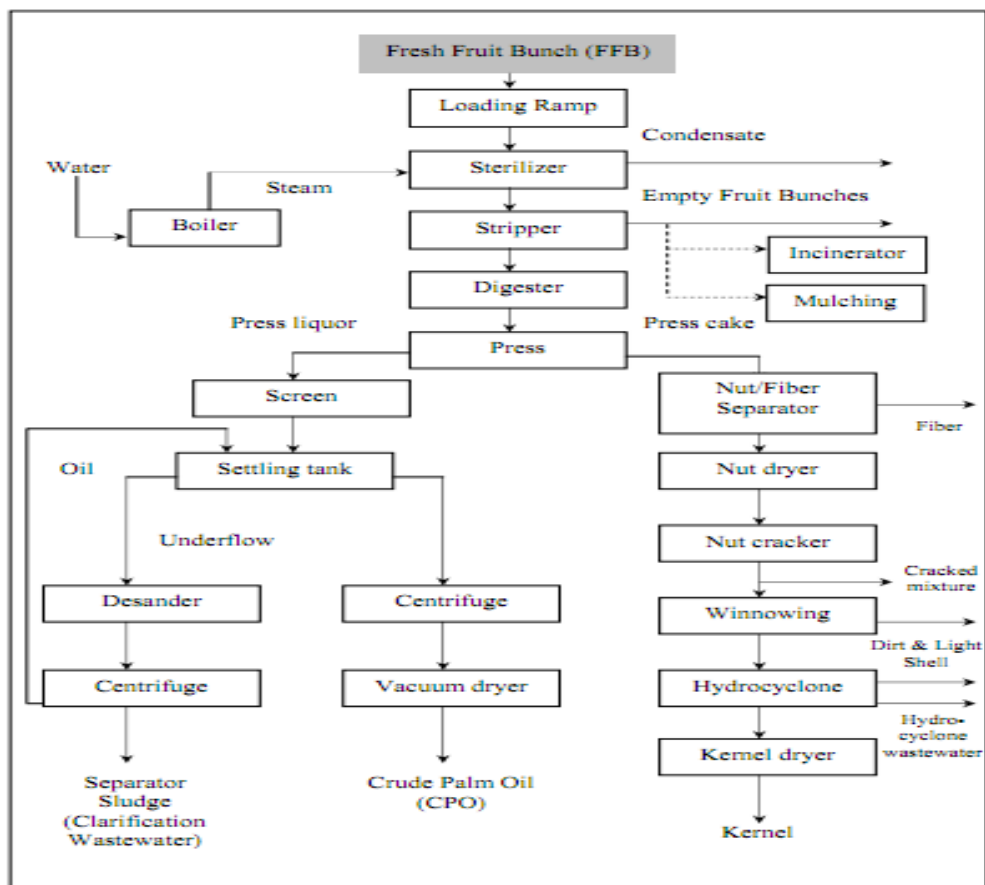
### **Rationale & Significance of Study**

- Section 51 Environment Quality Act 1974 for environmental control of palm oil mills discharge - standards for the emission and discharge or deposits of pollutants into the environment.
- The emission of the methane which partly contributed to global warming phenomena
- Low costs of raw material and renewable alternative energy contribution

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Palm Oil Processing Industry



**Figure 2.1:** Process flow of typical palm oil milling (Industrial Process and The Environment, 1999)

After harvest the palm oil fruit, the fresh fruit bunches (FFB) are transported to the mills for processing. Each FFB consists of hundreds of fruits, each of which containing a nut surrounded by a bright orange pericarp which contains the palm oil. These FFBs are sterilized with steam at a pressure of 3 bars and a temperature of 140°C for 75-90 min. The objectives of this process are to prevent further formation of free fatty acids due to enzyme action, facilitate stripping and prepare the fruit mesocarp for subsequent processing. The steam condensate coming out of the sterilizer constitutes as one of major sources of liquid effluent (Thani et al., 1999).

After sterilization, the FFBs are fed to a rotary drum-stripper where the fruits are stripped from bunches. The detached fruits are passed through the bar screen of the stripper and are collected below by a bucket conveyor and discharged into a digester. In the digester, the fruits are mashed by the rotating arms. In this stage, the mashing of the fruits under heating breaks the oil-bearing cells of the mesocarp. Twin screw presses are generally used to press out the oil from the digested mash of fruit under high pressure. Hot water is added to enhance the flow of the oils. The crude oil slurry is then fed to a clarification system for oil separation and purification. The fibre and nut (press cake) are conveyed to a depericarper for separation (Thani et al., 1999).

The crude palm oil (CPO) from the screw presses consists of a mixture of palm oil (35-45%), water (45-55%) and fibrous materials in varying proportion. It is then pumped to a horizontal or vertical clarification tank for oil separation. In this unit, the clarified oil is continuously skimmed-off from the top of the clarification tank. It is then passed through a high speed centrifuge and a vacuum dryer before sending it to the storage tanks.

The press cake discharged from the screw press consists of moisture, oily fibre and nuts, and the cake is conveyed to a depericarper for nuts and fibres separation. The fibre and nuts are separated by strong air current induced by a suction fan. The fibre is usually sent to boiler house and is used as boiler fuel.

Meanwhile, the nuts are sent to a rotating drum where any remaining fibre is removed before they are sent to a nut cracker. Hydrocyclone is commonly used to separate the kernels and shells. The discharge from this process constitutes the last source of wastewater stream (Chow and Ho, 2000).

## **2.2 The Origin of Palm Oil Mill Effluent**

From the palm oil processing plant, it will produce a waste which is palm oil mill effluent. This oily waste is produced in large volumes and contributes major problem to the palm oil processing mill's waste stream. Thus it has to be treated efficiently because it may have a significant impact on the environment if they are not dealt with properly.

### **2.2.1 Palm Oil Mill Effluent (POME)**

The production of palm oil results in the generation of large quantities of polluted wastewater commonly referred to as palm oil mill effluent (POME). Typically, 1 tonne of crude palm oil production requires 5-7.5 tonnes of water; over 50 % of which ends up as POME (Ma, 1999a). Based on palm oil production in 2005 (14.8 million tonnes), an average of about 53 million m<sup>3</sup> POME is being produced per year in Malaysia (Malaysia Palm Oil Production Council, 2006).

POME comprises a combination of the wastewaters which are principally generated and discharged from the following major processing operations as seen early in figure 2.1.

- Sterilization of FFB - sterilizer condensate is about 36% of total POME;
- Clarification of the extracted CPO - clarification wastewater is about 60% of total POME;

- Clay bath Separation (Hydrocyclone) of separation of cracked mixture of kernel and shell-hydrocyclone wastewater is about 4% of total POME.

There are other minor sources of relatively clean wastewater that may be included in the combined mill effluent POME which is sent to the wastewater stream. These include turbine cooling water and steam condensates, boiler blow-downs, overflows from the vacuum dryers and some floor washings. The volume of the combined POME discharged depends to a large extent on the milling operations.

Distinctive quality characteristics of the individual wastewater streams from the three principal sources of generation are presented in Table 2.1. POME, when fresh is a thick brownish in color colloidal slurry of water, oil and fine cellulosic fruit residues. POME is charged at a temperature of between 80°C and 90°C and it is slightly acidic with a pH between 4 to 5. The characteristics of a usual raw combined POME are presented in Table 2.2. Table 2.2 attests that POME has a very high Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), which is 100 times more than the domestic sewage. POME is a non-toxic waste, as no chemical is added during the oil extraction process.

**Table 2.1** Characteristics of individual wastewater streams (Industrial Processes and The Environment, 1999)

<b>Parameters</b>	<b>Sterilizer Condense</b>	<b>Oil Clarification Wastewater</b>	<b>Hyrocyclone Wastewater</b>
pH	5.0	4.5	-
Oil & Grease	4,000	7,000	300
BOD; 3-day, 30°C	23,000	29,000	5,000
COD	47,000	64,000	15,000
Suspended Solid	5,000	23,000	7,000
Dissolved Solids	34,000	22,000	100
Ammonical Nitrogen	20	40	-
Total Nitrogen	500	1,200	100

\*All units are in mg/l except for pH

However it contains appreciable amounts of N, P, K, Mg and Ca which are the vital nutrient elements for plant growth (Industrial Processes & The Environment, 1999).

**Table 2.2:** Characteristics of combined palm oil mill effluent (POME) (Ma, 2000).

<b>Parameter</b>	<b>Average</b>	<b>Metal</b>	<b>Average</b>
pH	4.7	Phosphorous	180
Oil and Grease	4000	Potassium	2270
BOD5	25000	Magnesium	615
COD	50000	Calcium	439
Total Solids	40500	Boron	7.6
Suspended Solids	18000	Iron	46.5
Total Volatile Solids	34000	Manganese	2.0
Ammonical Nitrogen	35	Copper	0.89
Total Nitrogen	750	Zinc	2.3

\*All in mg/l except pH

### 2.3 Pollution Load and Effect of Discharge

The production of CPO in 2003 increased markedly by 12.1% or 1.4 million tons to 13.35 million tons from 11.91 million tons in 2002 (Malaysian Palm Oil Board, 2004) which is about 46,000 cubic meters per day. Based on this quantity of daily CPO production, the total quantity of effluent generated per day can be averaged up to 161,000 m<sup>3</sup> and the total BOD load of raw effluent generated per day is about 4,025 tons. Finally the population-equivalent of raw effluent BOD<sub>3</sub> load (0.05 kg BOD/Capita/Day) is equal to 64,000,000 persons.

The above pollution statistics indicate that if the entire palm oil industry discharges raw effluent, then the total pollution load of the industry would be equivalent to that of a POME when discharged untreated or partially treated into the river stream undergoes natural decomposition during which the dissolved oxygen of the river or stream is rapidly depleted (Oil Palm & The Environment A Malaysian Perspective, 1999). The palm oil present in the effluent may float to the surface of the waterbody and form a wide-spread film which can efficiently cut-off and avert atmospheric oxygen from dissolving into its waters. Furthermore, when the organic load far exceeds its waste assimilation capacity, the available oxygen in the waterbody is rapidly consumed as a result of the natural biochemical processes that take place. The waterbody may become completely devoid of dissolved oxygen. This will lead to anaerobic conditions in which hydrogen sulphide and other malodorous gases are generated and released to the environment resulting in objectionable odors. Additional damaging effects include the decline and eventual destruction of aquatic life and deterioration in the riverine eco-system. Hence serious measures have to be taken in order to prevent the growing pollution caused by palm oil mill effluents.

## 2.4 Regulatory Control of Effluent Discharge

Oil palm cultivation and processing are regulated by a number of environmental legislations aimed at conserving and protecting the natural environment. These rules and regulations, together with the growing awareness for a clean and pollution-free environment play a significant role in minimizing the degradation of the soil, water and atmospheric environment. The DOE being the government agency acted responsibility in enacting the Environmental Quality Act in 1974 (EQA) and specific regulations for palm oil mill effluent in 1977.

EQA is an enabling act aimed to prevent, abate and control pollution for the protection of public health and the environment. The highlighting agenda of EQA was to set acceptable standards for the emission and discharge or deposits of pollutants into the environment rather than prevention, with an exception given to the necessities on environmental impact measurements. Environmental Quality (Prescribed Premises) (Crude Palm Oil) Regulations 1977 were promulgated under the Section 51 Environment Quality Act 1974 for environmental control of palm oil mills discharge. The regulatory standards for watercourse discharge were made effective from 15th July 1978 (Ma et al, 1982) as shown in Table 2.4.

**Table 2.4:** Regulatory standards for palm oil mill effluent (Source: Ma et al, 1982)

<b>Parameter</b>	<b>Standard A</b>	<b>Standard B</b>	<b>Standard C</b>	<b>Standard D</b>
	<b>1.7.1978</b>	<b>1.7.1979</b>	<b>1.7.1980</b>	<b>1.7.1981</b>
Biological oxygen Demand (BOD)	5000	2000	1000	500
Chemical oxygen Demand (COD)	10000	4000	2000	1000
Total solids (TS)	4000	2500	2000	1500
Suspended solid (SS)	1200	800	600	400
Oil & Grease (O&G)	150	100	75	50
Ammoniacal nitrogen (NH <sub>3</sub> -N)	25	15	15	10
Organic nitrogen	200	100	75	50
pH	5.0-9.0	5.0-9.0	5.0-9.0	5.0-9.0
Temperature °C	45	45	45	45

All except pH in mg/L

## 2.5 Anaerobic Digestion

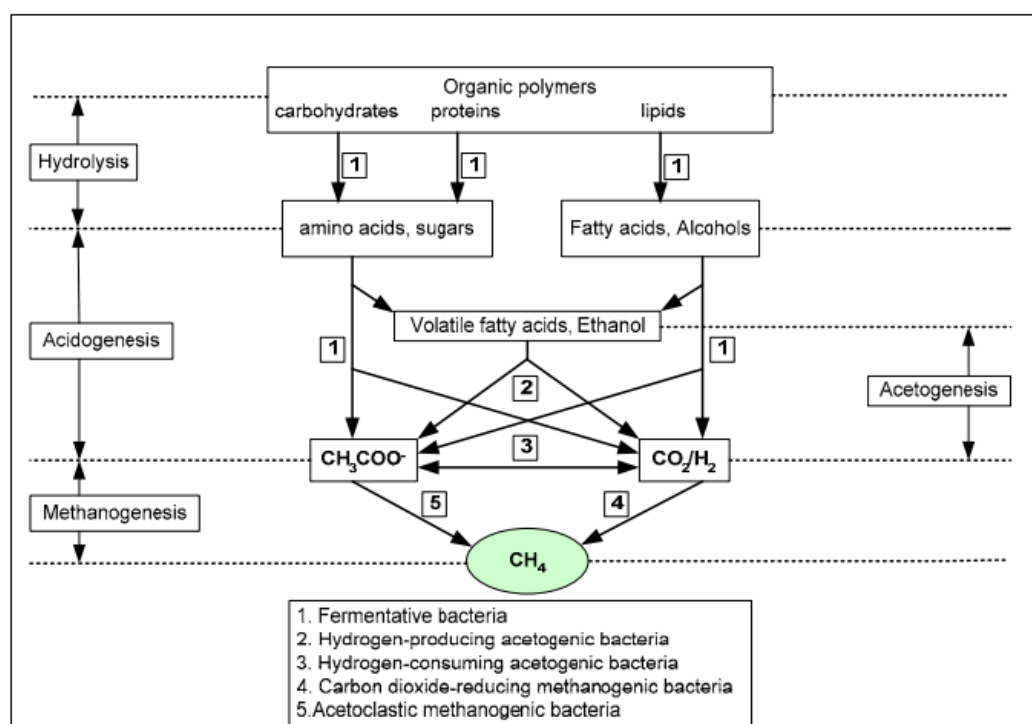
Biological treatment processes are cost effective processes that utilize microbial communities of varying degrees of diversity that interact in a multitude of ways to mediate a myriad of biological reactions (Wise, 1987, Jans and Man, 1988). Anaerobic digestion has been widely accepted as an effective alternative for wastewater treatment and simultaneous fuel gas production. Its successful application arises from the development of new and innovative reactor designs (Surampalli and Tyagi, 2004).

Compared to conventional aerobic methods of wastewater treatment, the anaerobic wastewater treatment concept indeed offers fundamental benefits such as low costs, energy production, relatively small space requirement of modern anaerobic wastewater treatment systems, very low sludge production (10-20% of COD removed) with very high dewaterability, stabilized sludge and high tolerance to unfed conditions (Lettinga, 1995; Droste 1997; Metcalf and Eddy, 2003).

Previously, perceived drawbacks of anaerobic treatment systems such as high susceptibility of microbes (in particular methanogens) to a variety of aenobiotic compounds, low stability of the process and long start-up period, could be attributed to lack of knowledge of the basic principles of the process. As a matter of fact, the anaerobic digestion process is highly stable, provided the system is operated in the proper conditions. It may be needed that optimum operational conditions to be determined for each particular type of wastewater and more importantly, the process must be sufficiently understood by engineers and operators (Lettinga, 1995).

### 2.5.1 Microbiology and Biochemistry of Anaerobic Digestion

In anaerobic digestion, organic matters are degraded to methane and carbon dioxide in discrete steps by the concerted action of several different metabolite groups of microorganism. The main pathways of anaerobic digestion are shown in Figure 2.1 (Pavlostathis and Giraldo-Gomez, 1991). The salient features of those bacteria involved in the stabilization process are as follows:



**Figure 2.2:** Anaerobic conversion of organic matter to methane, (Pavlostathis and Giraldo-Gomez, 1991)

### 2.5.1 (a) Hydrolysis

The first step for most digestion process is hydrolysis during which, particulate matters are converted to soluble compounds that can be hydrolyzed further to simple monomers to be subsequently utilized by fermentative bacteria. The group of nonmethanogenic microorganisms responsible for the fermentation process consists of facultative and obligate anaerobic bacteria (Metcalf & Eddy, 2003). Extra cellular enzymes excreted by the fermentative bacteria catalyze the hydrolysis reactions. As no mineralization of organics is involved, this conversion results in no reduction in COD (Eckenfelder, 2000). Although most of biopolymers are readily degradable, the cellulose of highly lignified plant material (straw, wood, etc.) has been shown to be resistant to hydrolysis (Lynd et al., 2002). The rate of hydrolysis is a function of factors such as pH, temperature, composition and particle size of the substrate (Veeken et al., 2000, Paramsothy et al., 2004). Volatile fatty acids production from the hydrolysis-acidification of the coffee pulp was investigated by Houbroun and his coworkers (2003) and 23% (COD based) hydrolysis were achieved at an organic loading rate (OLR) of 5 g COD/l.d.

### 2.5.2 (b) Acidogenesis

In the acidogenesis step, the hydrolysis products are absorbed by the cells of fermentative bacteria to be fermented or anaerobically converted into compounds such as alcohols, short-chain fatty acids, formic acid, carbon dioxide, hydrogen, ammonia and sulfide. The organic substrates serve as both the electron donors and acceptors. The final products of the metabolic activities of these bacteria depend upon the initial substrate (Figure 2.2) as well as the environmental conditions. As an example, consider the following reactions of glucose metabolism (Mosey, 1983).



The first reaction is the most preferred. It produces acetic acid which is the major precursor of  $\text{CH}_4$ . The other two reactions occur when there is an accumulation of  $\text{H}_2$  in the system. In Equation 2.2, there is a clear utilization of  $\text{H}_2$  while in Equation 2.3, there is also hydrogen production but of lesser quantity (two molecules against four in the first reaction). The increase in the acid load of the system is also lower (one mole butyric acid against two moles acetic acid in the first reaction). Many hydrolyzing microorganisms and acidogens can coexist in anaerobic methanogenic biofilms but little information is available on the characterization of the bacteria involved in the acidogenic phase (Zellner et al., 1999; Bramucci and Nagarajan, 2000). Miyamoto (1997) reported that bacteria belonging to *Clostridium* sp. have been isolated from different types of anaerobic digesters but without specifying the effluent type treated. *Clostridium* sp. is responsible for most of the extra cellular lipase and protease produced, and converts the metabolites into acid products. These strict anaerobic microorganisms are rod-shaped, 2.8-3.0mm long and 0.5-0.6mm wide. The optimal growth temperature and pH vary between 35-37°C and 4.5-7.0, respectively (Zigová et al., 1999).

### 2.5.2 (a)(i) Acetogens, Hydrogen-Producing Bacteria

Propionate and butyrate are thought to be converted to acetate only by syntrophicacetogens in concert with hydrogen-utilizing methanogens (Lowe et al., 1993). *Syntrophobacterwolunii* was the first syntrophic propionate-degrading culture isolated from methanogenic enrichments from an anaerobic municipal sewage digester in association with hydrogen-utilizing bacteria (Lowe et al., 1993). Propionate-oxidizing *Syntrophobacter*-like bacteria have been identified in microcolonies in intimate association with methanogens (De Bok et al., 2004). These bacteria are responsible for converting organic products of fermentative bacterial activity such as alcohols, propionic acid and butyric acid into acetic acid, CO<sub>2</sub> and H<sub>2</sub>O as follows (Rittmann and McCarty, 2001): Acetate is the major intermediate in the bioconversion of organic matter to methane and carbon dioxide. About 70% of the total methane produced in anaerobic digestion originates from acetate. Thus, the production of methane from acetate is an important step in the anaerobic digestion process (Rittmann and McCarty, 2001). A peculiar characteristic of these reactions is that they remain thermodynamically unfavorable ( $\Delta G_0 = +ve$ ) unless the H<sub>2</sub> produced is constantly removed from the system. The utilization of the hydrogen produced by the acidogens and other anaerobes by the methanogens is termed interspecies hydrogen transfer (Metcalf and Eddy, 2003).

### 2.5.2 (b)(ii) Acetogens, Hydrogen-Utilizing Bacteria

The H<sub>2</sub>-utilizing or homoacetogenic bacteria are a group of obligatory anaerobic bacteria that utilize the acetyl coenzyme A (CoA) pathway to synthesize acetate from C1 precursors. These bacteria grow autotrophically on H<sub>2</sub> and CO<sub>2</sub> and/or heterotrophically on a variety of organic compounds, with mixotrophic growth on H<sub>2</sub> and a suitable organic substrate being observed in some species (Breznak and Kane, 1990; Wood and Ljungdahl, 1991). These bacteria also contribute towards the acetic acid pool in anaerobic digestion for subsequent conversion to methane. They are thermodynamically highly efficient because they do not produce H<sub>2</sub> and CO<sub>2</sub> during growth on multi-carbon compounds (Zeikus, 1981) including glucose, fructose, lactose, pyruvate, etc. The reaction is presented as follows:



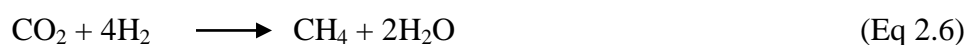
### 2.5.3 (c) Methanogenesis

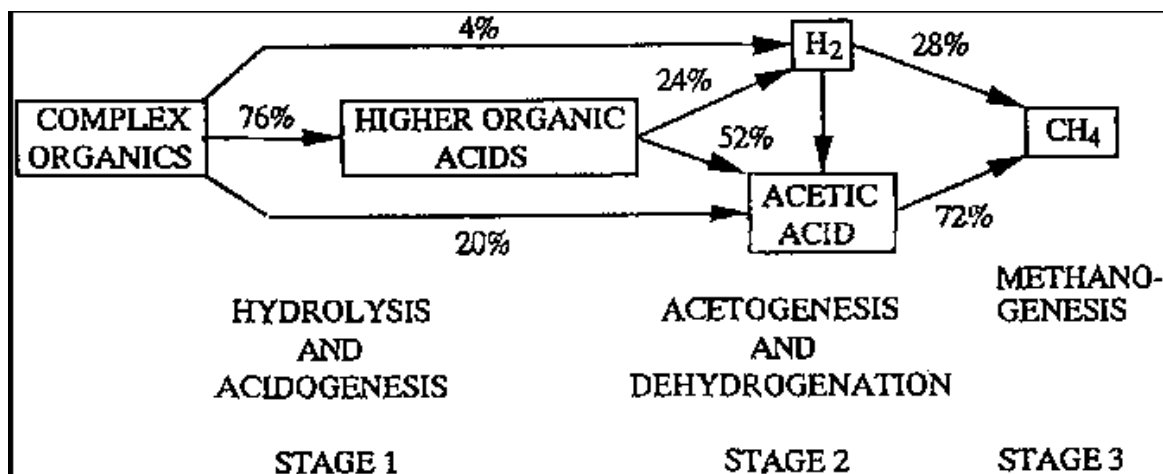
Methanogenesis, is carried out by a group of organisms known collectively as methanogens. Two groups of methanogenic organisms are involved in methane production. One group, termed acetoclastic methanogens, split acetate into methane and carbon dioxide. The second group, termed hydrogen-utilizing methanogens, use hydrogen as the electron donor and CO<sub>2</sub> as the electron acceptor to produce methane. Bacteria within anaerobic processes, termed acetogenesis, are also able to use CO<sub>2</sub> to oxidize hydrogen and form acetic acid. However, the acetic acid will be converted to methane, so the impact of this reaction is minor. As shown in Fig 2.3, about 72% of the methane produced in anaerobic digestion is from acetate formation.

Acetic acid cleavage



Carbon dioxide reduction





**Figure 2.3:** Carbon and hydrogen flow in anaerobic digestion process. The given percentage values are based on COD. (Adapted from Jeris and McCarty, 1963 and McCarty, 1981)

Organic waste stabilisation in anaerobic digestion is accomplished when methane and carbon dioxide are produced. Methane gas is highly insoluble, and its departure from solution represents actual waste stabilisation (Metcalf & Eddy, 1991).

## 2.6 Biogas

Biogas typically refers to gas produced by the biological breakdown of organic matter in the absence of oxygen. Biogas is produced by the fermentation or anaerobic digestion of biodegradable materials such as biomass, waste treatment and crops.

Biogas comprises primarily methane (CH<sub>4</sub>) and carbon dioxide (CO<sub>2</sub>) and may have small amounts of hydrogen (H<sub>2</sub>S). The gases methane, hydrogen, and carbon monoxide (CO) can be combusted or oxidized with oxygen. The composition of biogas varies depending upon the origin of the digestion process.

Compound	Chemical	Percentage %
Methane	CH <sub>4</sub>	50-70
Carbon dioxide	CO <sub>2</sub>	25-50
Nitrogen	N <sub>2</sub>	0-10
Hydrogen	H <sub>2</sub>	0-1
Hydrogen sulfide	H <sub>2</sub> S	0-3
Oxygen	O <sub>2</sub>	0-0

**Table 2.6:** Composition of biogas

### 2.6.1 Production of Biogas

Biogas can be produced using anaerobic digesters. There are two processes of temperature that involve where the mesophilic and thermophilic digestion. Mesophilic digester or mesophilic bio digester that operates in temperatures between 35°C and about 45°C, typically 37°C. This is the most used kind of bio digester. More than 90% of worldwide bio digesters are of this type. Thermophilic digester or thermophilic are less than 10% used of digester in the world. Thermophilic are heat loving, with an optimum growth temperature of 50<sup>0</sup>C or more.

Methanogenic bacteria are converts acetate, and CO<sub>2</sub> + H<sub>2</sub> into methane. Thus methanogens remove the H<sub>2</sub> produced by obligate H<sub>2</sub> producing bacteria, thereby lowering the H<sub>2</sub> partial pressure and enabling the latter to continue producing H<sub>2</sub>. Methanogenic bacteria are the strictest possible anaerobes known. Acetogenic bacteria are the bacteria oxidise H<sub>2</sub> by reducing CO<sub>2</sub> to acetic acid, which is then used up by methanogens to generate methane, CO<sub>2</sub> and H<sub>2</sub>. Thus acetogenic bacteria also remove H<sub>2</sub> and enable the obligate H<sub>2</sub> producing bacteria to continue their function.

The digestion process begins with hydrolysis bacterial process of the input materials to break down insoluble organic polymers, and make them available for other bacteria. Bacteria then convert the sugars and amino into carbon dioxide, hydrogen, ammonia, and organic. Acetogenic bacteria then convert these resulting organic acids into acetic, along with additional ammonia, hydrogen, and carbon dioxide. Finally, methanogens convert these products to methane and carbon dioxide.

Mesophilic species outnumber thermophiles, and they are also more tolerant to changes in environmental conditions than thermophiles. Mesophilic systems are, therefore, considered to be more stable than thermophilic digestion systems. Though thermophilic digestion systems are considered to be less stable and the energy input is higher, more energy is removed from the organic matter. The increased temperatures facilitate faster reaction rates and, hence, faster gas yields. Based on effects of temperature, the bacteria have their limited range on the active process. Methanogens, in particular, are very sensitive to temperature changes. In general, the mesophilic anaerobic digestion of organic sludge is more energy requirements and higher stability of the process. Meanwhile, thermophilic digestion is more efficient in terms of organic matter removal and methane production (Buhr and Andrews, 1977) and (Ahring, 2001).

Biogas is the ultimate waste product of the bacteria feeding off the input biodegradable feedstock, and is mostly methane and carbon dioxide, with a small amount hydrogen and trace hydrogen sulfide. Most of the biogas is produced during the middle of the digestion, after the bacterial population has grown, and tapers off as the putrescible material is exhausted. 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.

### 2.6.2 Factors Affecting Biogas Production

Biogas yield is depends on the type of waste, temperature during digester operation, the retention time and the presence of inhibitors.

Gas yields increase with retention time since a greater proportion of the organic matter will be digested. But increased residence time increases the cost of operation since an increase in retention time reduces the quantity of wastes treated/day

Increasing the biodegradable solids content of the waste would enhance gas production but the solids content should not exceed 10-12% since pumps cannot operate with higher solids content. Toxic components may include ammonia,  $\text{SO}_4^{2-}$ , antibiotics, etc.

Anaerobic digestion is mainly used for pollution control, but its use as an energy source is also important. The estimation of net energy yields is rather complex in view of the factors affecting biogas yields. The total world production of biogas is only a tiny fraction of the total energy requirement. It is thought that the biogas technology will develop as a greater emphasis is placed on organic pollution control.

### **2.6.3 Advantages of Biogas**

- The technology is cheaper and much simpler than those for other biofuels, and it is ideal for small scale application.
- Recovery of the product (methane) is spontaneous as the gas automatically separates from the substrates.
- Dilute waste materials (2-10% solids) can be used as substrate.
- Organic pollutants are removed from the environment and used to generate useful biogas; this helps clean up the environment.
- Aseptic conditions are not needed for operation
- Any biodegradable matter can be used as substrate.
- Biogas is suitable for heating boilers, firing brick and cement kilns, and for running suitably modified internal combustion engines.
- There is reduced risk of explosion as compared to pure methane
- Anaerobic digestion inactivates pathogens and parasites, and is quite effective in reducing the incidence of water borne diseases

### **2.6.4 Disadvantages of Biogas**

- The product (biogas) value is rather low; this makes it an unattractive commercial activity.
- The biogas yields are lower due to the dilute nature of substrates.
- The process is not very attractive economically (as compared to other biofuels) on a large industrial scale.
- Recombinant DNA technology and even strain improvement techniques cannot be used to enhance the efficiency of the process.
- The only improvement in the process can be brought about by optimizing the environmental conditions of the anaerobic digestion.
- Biogas contains some gases as impurities, which are corrosive to the metal of internal combustion engines.

## CHAPTER 3

### METHODOLOGY

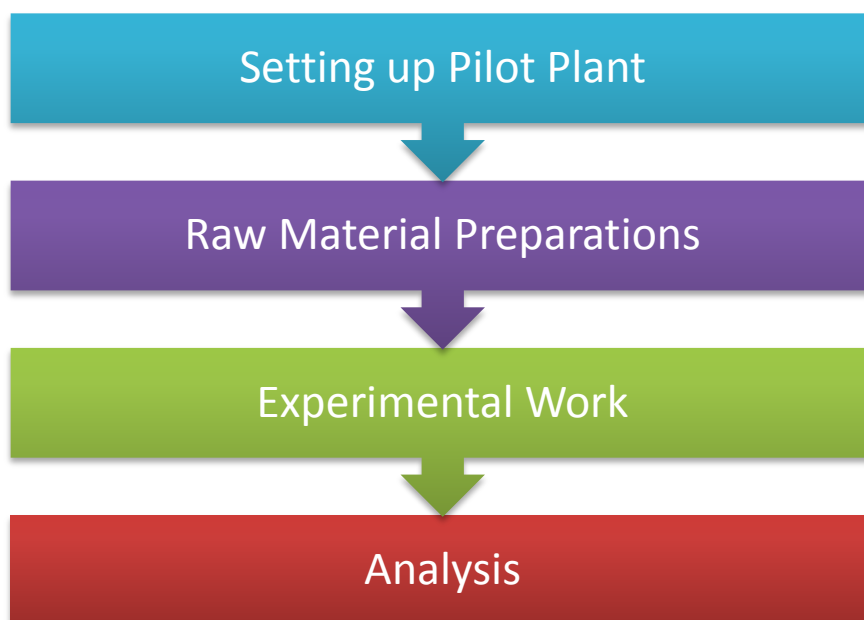
#### 3.1 Introduction

In this study, the anaerobic sludge from 500m<sup>3</sup> closed anaerobic methane digester tank was carried out. The temperature is divided into two categories, where are mesophilic and thermophilic. Mesophilic is the condition temperature at range on 35<sup>0</sup>C until 45<sup>0</sup>C on the inlet of POME pilot plant to pilot plant. Meanwhile the thermophilic is where the condition temperature at ranges on 45<sup>0</sup>C until 55<sup>0</sup>C on the inlet of POME into pilot plant.

The figure shows the process or flow of the production of the methane using a raw material of POME. The raw material of POME is use as sample to test a temperature of the initial of the POME. The average flow of the inlet is 5.41 l/min/m<sup>2</sup>. The mixing pump is used for low viscosity that will mix the entire particle and pump for the inlet the anaerobic digester.

Retention time of the anaerobic digester is between 10-12 days. In the anaerobic digester will produce the bacteria of acetogenic and methanogen based on the temperature and anaerobic conversion of organic matter to produce gas methane. Acetogenic bacteria are the bacteria oxidize H<sub>2</sub> by reducing CO<sub>2</sub> to acetic acid, which is then used up by methanogens to generate methane, CO<sub>2</sub> and H<sub>2</sub>. Foods of the bacteria have been identified that is the POME.

The parameters that have been identified in the pilot plant are temperature, time and volumetric of percentage of methane produced by using these parameters that. It can be determined suitable condition for enhancing the production of biogas from the POME.



**Figure 3.1:** Main Methodology Flow Chart

### 3.2 Setting up Pilot Plant

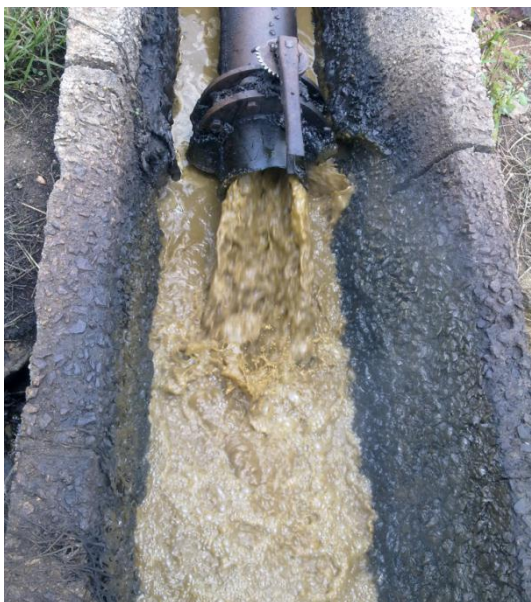


**Figure3.2 :** Flow of Production Biogas

The raw POME was pumped from the mixing pond of the mill into the digester. For the start up operation, 250m<sup>3</sup> of seed sludge was pumped from the existing open anaerobic digester and diluted with POME to give the initial solid content. Mixing was achieved by recirculating the effluent from the bottom to the top of the digester using centrifugal pumps at a rate of 125m<sup>3</sup> per hour. The temperature of the digester was not controlled but it will be recorded (Yacob S. et al, 2005). The process of the bacteria in the process of hydrolysis, acidogenesis and methanogenesis complete will produce methane and carbon dioxide. Methane gases will be collected and transfer into the gas storage. Meanwhile, the carbon dioxide will be released into the environment and gas scrubber will be used to reduce the emission into the environment. Meanwhile, the excess of POME will be recycled by using the settling tank and sludge recycling pump is used. The POME that already threat and used for the process will be flowing back as effluent into the pond near the pilot plant.

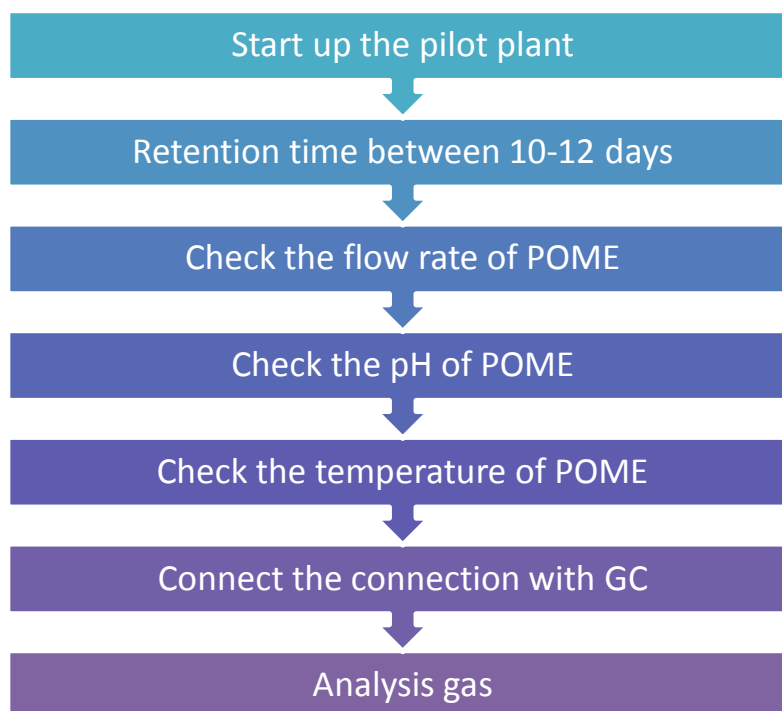
### 3.3 Experimental Materials

Sample of POME (Figure 3.1) was collected from Felda Seriting Hilir Palm Oil Mill, Negeri Sembilan, from their existing sludge at temperature ranging from 80-90 °C and cooled to a suitable temperature of pilot plant before use for experimental study. Freshly discharged POME is viscous and oily with obnoxious odor. POME may vary day to day depending upon the time of sample withdrawal. This might due to the method of the processing, the quality of the fresh fruits and the time of the collection of the POME. The average capacity process fresh fruit bunch (FFB) at 54 tonnes h<sup>-1</sup>. POME is generated from the oil extraction process, with the wastewater treatment which totals 75% of total mill of area. The wastewater treatment facility comprises a few processes, an anaerobic, facultative anaerobic and aerobic stage.



**Figure 3.4:** Palm Oil Mill Effluent (POME)

### 3.4 Experimental Works



**Figure 3.4 (a):** Flow Diagram of experimental work

Pilot plant is switched on of the main switch. The power that use to used pump for the POME into the bioreactor. A 500m<sup>3</sup> closed system digester was constructed to study for the CH<sub>4</sub> fermentation. The digester was designed to treat the daily charge to capture gas methane. The data was taken for one month to see a pattern of the weekly for a time of fermentation and percentage of production methane. The biogas was collected using the silicon tubing that connects to GC for biogas sampling and detection. The concentration CH<sub>4</sub> was detected by using micro gas chromatography Agilent 3000 plugged to the tubing. Silicon tubing is used to connect with the CG to get the result. The connected is checked that suitable with the fitting.



**Figure 3.4 (b):** Fitting connected of Pilot Plant Seriting Hilir



**Figure 3.4 (c):** Gas Analyser



**Figure 3.4 (d):** Site preparation using GC

### 3.5 Analysis

Five samples are run through Gas Chromatography Analysis Equipment and gas analyzer.

#### 3.5.1 Gas Chromatography (GC) Analysis

Gas chromatography is a chemical analysis instrument that for separate chemical in a complex sample. The GC instruments vaporize the sample and then separate and analyze the various components. Each component ideally produces a specific spectral peak that may be recorded on a computer that connects with the instrument. The time elapsed between injection and elution is called the “retention time”. The retention time is taking is less than 180 seconds that can help to differentiate between some compounds. The size of the peak is proportional to the quantity of the corresponding substances in the specimen analyzed. The peak is measured from the baseline to the tip of the peak. The carrier gas use in the analysis is argon. Among the available detectors are the argon ionization detector, flame ionization detector, flame emission detector, cross section detector, thermal conductivity detector, and the electron capture detector. The argon ionization detector does not detect water, carbon tetrachloride, nitrogen, oxygen, carbon dioxide, carbon monoxide, thane or compound containing fluorine. The other carrier gasses can be used is helium, nitrogen, argon, hydrogen and air.

The method that used is a argon carrier gas. The method is used a molecular sieve as a column to detect the concentration gas methane. The sample inlet temperature use is 100°C, injector temperature 100°C, and column temperature 70°C. Meanwhile the sample pump is taken for 10 s. In addition, the inject time use is 10ms, the backflush time is 9.5s, run time is 150s and post run time is 10s. the pressure equilibrium time is taken 10s and the column pressure and post run pressure is 40 psi.

GC is instrument tools for separating and analyzing organic compound that can be vaporized without decomposition. It is use of testing the purity of a substance and separating the components of a mixture. The relative amounts of the components in a mixture can be determined based a right method used to determine the compound by a right carrier gas.



**Figure 3.5:** Gas Chromatography is connected to computer using LAN.

### 3.5.2 Biogas Yield Analysis

Product yield is defined as the weight percentage of the final product (purified methane) relative to the weight of POME in the beginning process. The yield (%wt) calculated by the following equation:

$$\% \text{ Product yield} = \frac{\text{Weight of product}}{\text{Weight of raw material}} \times 100\%$$

## CHAPTER 4

### RESULTS AND DISCUSSIONS

#### 4.1 Introduction

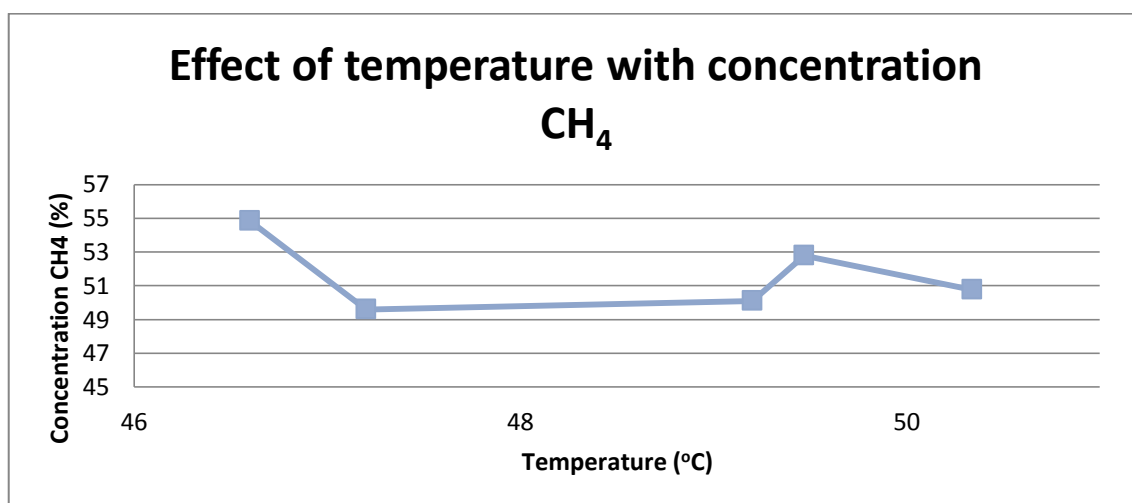
This chapter discusses based on the data from the experimental work that had been carried out. The result is described in the analysis of the concentration  $\text{CH}_4$  from the palm oil mill effluent based on the pilot plant in Seriting Hilir. In this research, the parameter that involved is the effect of condition temperature and retention time. In order to get the higher of concentration of  $\text{CH}_4$ , the analysis has been done using the gas analyzer and gas chromatography (GC).

## 4.2 Effect of temperature

### Thermophilic condition

**Table4.1:** Concentration CH<sub>4</sub> based on thermophilic condition

Concentration CH <sub>4</sub> (%)	Temperature (°C)
54.85	46.6
49.6	47.2
50.09	49.2
52.78	49.47
50.76	50.34



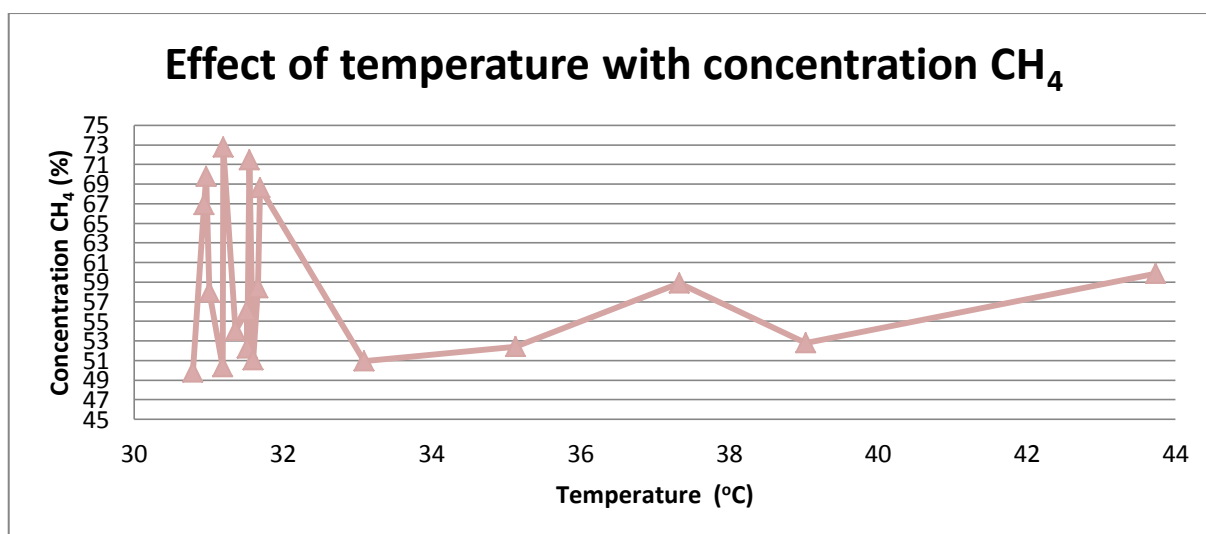
**Figure 4.1:** Effect of thermophilic condition with the concentration CH<sub>4</sub> on 30 Sept

2011

Mesophilic condition

**Table 4.2:** Concentration CH<sub>4</sub> based in mesophilic condition

Concentration CH <sub>4</sub> (%)	Temperature (°C)
49.78	30.79
66.88	30.94
69.77	30.97
57.97	31.01
50.34	31.19
72.74	31.2
54.02	31.36
56.04	31.51
52.24	31.52
71.45	31.55
51.03	31.6
58.42	31.66
68.61	31.69
50.97	33.09
52.42	35.13
43.73	43.73
43.73	43.73
43.73	43.73



**Figure 4.2:** Effect of mesophilic condition with the concentration CH<sub>4</sub> on 30 Sept 2011

Here we can observe the effect of the concentration  $\text{CH}_4$  with the different condition temperature. Based on figure 4.1 and 4.2, the data of temperature in taken in one day (30.9.2011) for collect different condition of mesophilic and thermophilic. The temperature will be categories in two ranges where the mesophilic and thermophilic. The concentration of biogas will be analysis and the result of biogas production was relatively at mesophilic range ( $35\text{-}45^\circ\text{C}$ ) and at thermophilic range ( $45\text{-}55^\circ\text{C}$ ). Mesophilic condition phase is the usual temperature for atmosphere in Malaysia and suitable to get this range of temperature. From the figure 4.1 and 4.2 shows the temperatures of mesophilic condition can product highest percentage concentration gas methane.

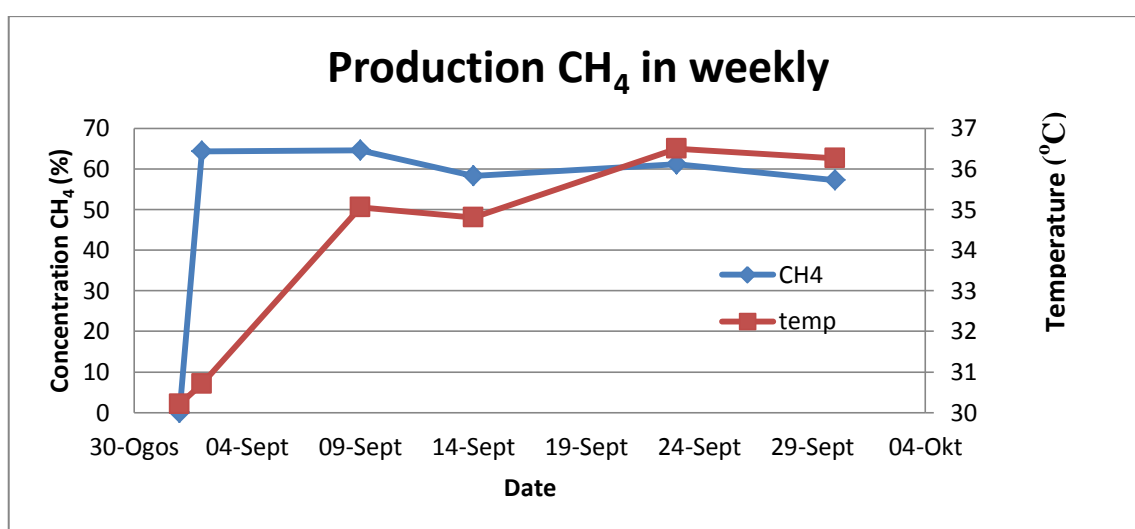
The mesophilic condition gives the highest yield biogas production is 72% was produced at temperature  $31^\circ\text{C}$ . There are many factors that effect to increase the concentration of  $\text{CH}_4$ . The microorganism in the sludge that has been identified both bacteria of *Methanosaeta* sp. and *Methanosarcina* sp. is very important for the production of methane (Robinson et al., 1984; Sekiguchi et al, 1999; Saiki et al., 2002, Yang et al., 2007).

Meanwhile, (Buhr and Andrews, 1977) and (Ahring, 2001), thermophilic digestion is more efficient in terms of organic matter removal and methane production. But in this experiment, the thermophilic is not consistent temperature and will effect of the result concentration of  $\text{CH}_4$ . The mesophilic condition in this study is more consistent at range of temperature. So the process in the sludge is will completely of the process of anaerobic conversion to methane.

## 4.2 Effect production CH<sub>4</sub> in weekly

**Table 4.3:** Effect production CH<sub>4</sub> in weekly

Date	CH <sub>4</sub> (%)	Temp (°C)
01-Sept	0	30.2
02-Sept	64.37	30.71
09-Sept	64.57	35.05
14-Sept	58.26	34.8
23-Sept	61.19	36.5
30-Sept	57.24	36.26



**Figure 4.3 :** Production concentration of CH<sub>4</sub> in weekly with the variables of temperature.

Fermentation leading to the formation of biogas as the main end product of anaerobic fermentation needs special guidance. The anaerobic digestion of palm oil mill effluent (POME) requires large ponds due to long retention times. Closed POME digestion systems were considered uneconomic until recently (Olie & Tjeng, 1972). (Collier & Chick, 1977) considered a thirty-day retention time necessary. Meanwhile at Serting Hilir that is considered the retention time of the digestion system is around 10-12 days. Based on the figure 4.3, when the temperature is increase, the percentage of production gas methane is will increase. Production of gas methane is decrease after day of fortnight.

In order to study the optimum fermentation condition and can reduce the retention time of POME. A shortened retention time will mean a reduced investment in the POME treatment installation. A number of variable affecting retention time were investigated. Refer the advanced technique developed for industrial anaerobic wastewater treatment in The Netherlands (Bellegem & Lettinga, 1976; Bellegem, 1979).

The normal retention time of the 500m<sup>3</sup> bioreactor is average 10-12 days. The retention time that used is different based on the volume of the bioreactor. The data are taken in weekly show the increase and decrease of the yield of concentration CH<sub>4</sub>. The higher concentration is between the retention time between 5-6 days of the retention time. Then after two weeks, the concentration of CH<sub>4</sub> is decrease. About one third of the volume will discharges and the quarter of new POME will upload into the bioreactor to recover back of total volume in bioreactor.

In the initial reading for the concentration of CH<sub>4</sub> it shows the zero of concentration of CH<sub>4</sub> because there are no process is occurring. The bacterial will take time to flow the process until the gas methane was produce. However, when the day is more than the retention time cycle, the concentration of CH<sub>4</sub> will decrease due because the bacteria can be died because several factor of lack of nutrient from POME. Bacteria is survived in the sludge by eat the nutrient that already have in the POME.

The lower concentration CH<sub>4</sub> was attributed by high tendency of oxygen contamination during loading of raw POME. There is a possibility of oxygen transfer from the atmosphere into the raw POME. The presence of oxygen in the system dilutes the gas as well as inhibiting the growth of methanogens. In fact, higher methane concentration could be achieved by implementing a fully controlled reaction in the closed bioreactor and completely anaerobic conditions (Ma et al. 1999). In this study, the bioreactor conditions such as pH and temperature were uncontrolled, is to simulate the semi-commercial closed

anaerobic digester as reported by Yacob et al. (2006) which is governed by factor such as the characteristic of POME. Methane production might effected by a low concentration of hydrogen in the tank which is not sufficient for hydrogen-utilizing homocategons and hydrogen utilizing methanogens. It will produce acetate and methane (Lay et al. 1998). Methanotropic microorganism also possible to produced methane (Bogner et al. 1995).

### **4.3 Effect of the condition**

The study is to enhance the biogas production from palm oil mill effluent (POME). The biogas gasses is  $\text{CH}_4$  gas that can be achieved the maximum production concentration  $\text{CH}_4$  in the range of 70-75%. The average of the pH of the POME in the inlet of the bioreactor is around 4-5 that is acid. When too much acid accumulates the pH will drop below 7 and the fermenting mass in the digester will acidify quickly. The methane production is decreased. The effect of the temperature will relate to growth of bacteria and biological process to produce the production of biogas.

## CHAPTER 5

### CONCLUSION

#### 5.1 Conclusion

From the result we can conclude

- The percentage of concentration  $\text{CH}_4$  is increase when using closed digestion tank design than using open anaerobic pond and at mesophilic condition.
- Based on temperature condition, mesophilic condition temperature will produce more percentage concentration of  $\text{CH}_4$  than thermophilic condition.
- The maximum of production  $\text{CH}_4$  is taken fortnight of reaction POME in reactor. After that, the one quarter of volume is discharged and need to upload to recover back the total volume in bioreactor.

## 5.2 Recommendation

Some recommendations have been made to improve the result are given for future work:

- Check using another parameter to increase the concentration of  $\text{CH}_4$ . The parameter that can be used is Total Alkalinity (TA), pH, Volatile Fatty Acid (VFA), Biological Oxygen Demand (BOD) and Chemical Oxygen demand (COD).
- Total volume that for discharge and upload in bioreactor can be manipulated. Whether to increase or decrease a total volume that to download to upload to know the effect of percent concentration of  $\text{CH}_4$ .
- Installation of electronic for detect of gas production it more easier than using a portable micro GC for checking concentration in every hour.

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*Felda Palm Industries Sdn. Bhd. Felda Palm Industries Sdn. Bhd and Kyushu Institute Of Technology Kyushu Institute Of Technology.*

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## APPENDIX A

Data of Concentration CH<sub>4</sub> on 2 Sept 2011 using GC

Felda Seriting Hilir, Path1 Daily Report

Report day 9/2/2011

Time	LD500 CH4 Conc. Path 1 %	LD500 Light, Path 1 dB	LD500 CH4 Psure P1 kPa	LD500 CH4 Temp P1 °C	LD500 MainFlow Kg/Hralised Kg	LD500 Norm- P1'
00:00	64.37	32.22	101.78	30.71	0.16	0.35
01:00	64.37	32.22	101.78	30.71	0.16	0.35
02:00	64.37	32.22	101.78	30.71	0.16	0.35
03:00	64.37	32.22	101.78	30.71	0.16	0.35
04:00	64.37	32.22	101.78	30.71	0.16	0.35
05:00	64.37	32.22	101.78	30.71	0.16	0.35
06:00	64.37	32.22	101.78	30.71	0.16	0.35
07:00	64.37	32.22	101.78	30.71	0.16	0.35
08:00	64.37	32.22	101.78	30.71	0.16	0.35
09:00	64.37	32.22	101.78	30.71	0.16	0.35
10:00	64.37	32.22	101.78	30.71	0.16	0.35
11:00	64.37	32.22	101.78	30.71	0.16	0.35
12:00	64.37	32.22	101.78	30.71	0.16	0.35
13:00	64.37	32.22	101.78	30.71	0.16	0.35
14:00	64.37	32.22	101.78	30.71	0.16	0.35
15:00	64.37	32.22	101.78	30.71	0.16	0.35
16:00	64.37	32.22	101.78	30.71	0.16	0.35
17:00	64.37	32.22	101.78	30.71	0.16	0.35
18:00	64.37	32.22	101.78	30.71	0.16	0.35
19:00	64.37	32.22	101.78	30.71	0.16	0.35
20:00	64.37	32.22	101.78	30.71	0.16	0.35
21:00	64.37	32.22	101.78	30.71	0.16	0.35
22:00	64.37	32.22	101.78	30.71	0.16	0.35
23:00	64.37	32.22	101.78	30.71	0.16	0.35
Mean	64.37	32.22	101.78	30.71	0.16	0.35
Max	64.37	32.22	101.78	30.71	0.16	0.35
Sum					3.90	8.45
Meas.	24	24	24	24	24	24
Cover.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Values with a star (\*) in front are estimated.

Report created 9/17/2011 12:19:44. Signature:

## APPENDIX B

Data of Concentration CH<sub>4</sub> on 9 Sept 2011 using GC

Report day 9/9/2011

Time	LD500 CH4 Conc. Path 1 %	LD500 CH4 Light, Path 1 dB	LD500 CH4 Psure Pl kPa	LD500 CH4 Temp Pl °C	LD500 MainFlow Kg/Hralised Kg	LD500 Norm- Pl`
00:00	65.46	39.14	101.83	31.65	2.06	0.57
01:00	66.48	38.90	102.02	31.41	0.27	78.60
02:00	68.83	38.93	101.83	31.34	38.78	22.71
03:00	70.43	38.69	101.62	30.95	11.47	3.00
04:00	71.72	38.21	101.59	30.28	1.54	0.41
05:00	72.66	38.09	101.59	30.11	0.21	0.40
06:00	73.42	37.92	101.61	29.85	0.21	0.40
07:00	69.77	37.42	101.64	29.52	0.20	0.39
08:00	69.60	37.80	115.50	31.79	0.20	-5.35
09:00	71.82	41.42	101.67	31.82	-2.75	0.37
10:00	65.38	50.07	101.58	37.25	0.17	0.29
11:00	60.47	50.20	101.52	42.65	0.13	0.24
12:00	59.00	49.13	101.48	45.86	0.10	0.23
13:00	59.53	47.94	101.31	46.87	0.10	0.23
14:00	58.08	47.69	101.25	44.61	0.10	0.26
15:00	57.60	47.43	101.08	43.21	0.11	0.26
16:00	58.95	48.49	114.52	45.32	0.11	-5.25
17:00	64.12	50.40	101.53	39.01	-2.41	69.33
18:00	60.27	43.39	101.61	35.26	29.95	24.55
19:00	58.71	36.13	101.69	31.44	10.33	40.10
20:00	58.97	36.03	101.75	31.17	16.95	13.04
21:00	60.71	35.63	101.90	30.31	5.67	3.03
22:00	62.79	35.55	101.94	29.94	1.37	0.95
23:00	64.90	35.57	101.89	29.53	0.44	0.50
Mean	64.57	41.67	102.75	35.05	4.80	10.39
Max	73.42	50.40	115.50	46.87	38.78	78.60
Sum					115.30	249.28
Meas.	24	24	24	24	24	24
Cover.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Values with a star (\*) in front are estimated.

Report created 9/17/2011 12:19:45. Signature:

## APPENDIX C

Data of Concentration CH<sub>4</sub> on 16 Sept 2011 using GC

Felda Serting Hilir, Path1 Daily Report

Report day 9/16/2011

Time	LD500 CH4 Conc. Path 1 %	LD500 CH4 Light, Path 1 dB	LD500 CH4 Psure P1 kPa	LD500 CH4 Temp P1 °C	LD500 MainFlow Kg/Hralised Kg	LD500 Norm- P1`
00:00	52.29	38.68	101.99	29.40	0.98	3.70
01:00	52.29	38.68	101.93	29.89	1.39	0.54
02:00	52.29	38.68	101.81	30.13	0.20	0.48
03:00	52.29	38.68	101.79	29.98	0.18	0.47
04:00	52.29	38.68	101.74	29.61	0.18	0.47
05:00	52.29	38.68	101.71	29.02	0.18	0.47
06:00	52.29	38.68	101.93	29.44	0.18	19.48
07:00	55.54	29.53	102.01	29.96	7.75	15.55
08:00	56.36	30.99	102.02	30.85	6.28	12.21
09:00	59.66	36.91	102.15	32.95	5.22	61.19
10:00	60.69	44.61	102.04	34.62	26.62	34.33
11:00	60.15	46.43	101.81	39.11	14.80	31.88
12:00	59.07	45.17	101.76	45.98	13.50	78.86
13:00	59.31	43.71	101.61	48.27	33.53	34.28
14:00	59.79	45.32	101.61	48.12	14.69	129.77
15:00	55.70	46.07	101.54	48.07	51.81	157.12
16:00	53.92	46.28	101.51	45.02	60.72	79.75
17:00	58.92	45.56	101.54	40.45	33.68	28.03
18:00	65.82	39.51	101.65	32.88	13.23	10.35
19:00	67.16	36.79	101.64	29.06	4.98	13.68
20:00	69.52	36.87	101.74	28.98	6.81	21.09
21:00	64.54	37.56	102.09	30.64	9.75	163.34
22:00	62.58	38.06	102.04	31.32	73.27	58.92
23:00	63.55	38.43	102.01	31.56	26.84	13.61
Mean	58.26	39.94	101.82	34.80	16.95	40.40
Max	69.52	46.43	102.15	48.27	73.27	163.34
Sum					406.77	969.55
Meas.	24	24	24	24	24	24
Cover.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Values with a star (\*) in front are estimated.

Report created 9/17/2011 12:19:45. Signature:

## APPENDIX D

Data of Concentration CH<sub>4</sub> on 23 Sept 2011 using GC

Felda Seriting Hilir, Path1 Daily Report

Report day 9/23/2011

Time	LD500 CH4 Conc. Path 1 %	LD500 CH4 Light, Path 1 dB	LD500 CH4 Psure P1 kPa	LD500 CH4 Temp P1 °C	LD500 MainFlow Kg/Hralised Kg	LD500 Norm- P1`
00:00	67.13	34.13	101.92	30.63	88.24	187.65
01:00	64.95	34.71	101.82	30.69	87.36	169.28
02:00	62.72	34.77	101.88	31.02	76.11	227.90
03:00	61.09	34.88	101.86	31.85	99.80	256.39
04:00	59.65	35.04	101.78	31.71	109.63	223.49
05:00	58.99	35.32	101.76	31.35	94.50	190.32
06:00	60.01	35.22	101.74	30.80	81.87	143.77
07:00	61.40	35.38	101.79	30.94	63.28	144.97
08:00	62.46	35.41	101.84	31.60	64.90	141.97
09:00	63.43	35.56	101.85	32.90	64.54	145.65
10:00	61.08	33.74	101.72	39.43	63.77	205.80
11:00	58.82	33.35	101.64	48.20	86.77	241.69
12:00	59.02	34.92	101.56	50.18	102.26	224.45
13:00	60.50	36.39	101.44	49.63	97.34	210.59
14:00	62.17	37.41	101.27	48.13	93.84	202.77
15:00	62.56	38.99	101.18	45.91	90.93	187.19
16:00	57.89	40.65	101.07	43.53	77.68	150.05
17:00	62.41	41.65	101.08	40.87	67.13	57.69
18:00	65.35	37.74	101.22	37.44	27.03	5.01
19:00	62.52	34.59	101.32	34.38	2.25	46.61
20:00	36.07	33.86	101.52	32.49	12.05	169.94
21:00	48.78	32.98	101.60	31.43	59.42	83.60
22:00	73.11	32.25	101.52	30.66	43.81	4.12
23:00	76.44	31.92	101.56	30.09	2.26	0.54
Mean	61.19	35.45	101.58	36.50	69.03	150.89
Max	76.44	41.65	101.92	50.18	109.63	256.39
Sum					1656.74	3621.45
Meas.	24	24	24	24	24	24
Cover.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Values with a star (\*) in front are estimated.

Report created 10/1/2011 11:27:10. Signature:

## APPENDIX E

Data of Concentration CH<sub>4</sub> on 30 Sept 2011 using GC

Felda Serting Hilir, Path1 Daily Report

Report day 9/30/2011

Time	LD500 CH4 Conc. Path 1 %	LD500 CH4 Light, Path 1 dB	LD500 CH4 Psure P1 kPa	LD500 CH4 Temp P1 °C	LD500 MainFlow Kg/Hralised Kg	LD500 Norm- P1` Kg
00:00	61.37	39.57	101.70	32.19	89.86	198.54
01:00	58.42	39.32	101.66	31.66	83.13	188.75
02:00	56.04	39.23	101.58	31.51	75.82	182.28
03:00	54.02	39.20	101.58	31.36	70.58	174.26
04:00	52.24	39.29	101.62	31.52	65.25	167.75
05:00	51.03	39.36	101.60	31.60	61.37	153.54
06:00	50.34	39.26	101.61	31.19	55.41	134.39
07:00	49.78	39.18	101.65	30.79	47.96	143.92
08:00	50.97	40.10	101.73	33.09	52.58	208.80
09:00	52.42	40.48	101.69	35.13	78.46	260.49
10:00	52.79	41.98	101.75	39.03	98.58	168.32
11:00	49.60	41.19	101.62	47.20	59.85	250.23
12:00	50.09	40.40	101.49	49.20	89.83	210.01
13:00	50.76	42.51	101.21	50.34	76.41	259.38
14:00	52.78	43.81	100.96	49.47	98.14	314.70
15:00	54.85	43.76	100.85	46.60	123.74	304.52
16:00	59.86	43.65	100.90	43.73	130.66	333.43
17:00	58.91	39.18	101.08	37.33	140.80	325.12
18:00	57.97	34.54	101.04	31.01	135.10	352.92
19:00	66.88	33.91	101.07	30.94	169.18	307.52
20:00	69.77	33.85	101.16	30.97	153.81	331.46
21:00	72.74	33.76	101.26	31.20	172.83	347.71
22:00	71.45	34.08	101.34	31.55	178.07	346.57
23:00	68.61	34.41	101.37	31.69	170.43	342.14
Mean	57.24	39.00	101.40	36.26	103.24	250.28
Max	72.74	43.81	101.75	50.34	178.07	352.92
Sum					2477.83	6006.74
Meas.	24	24	24	24	24	24
Cover.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Values with a star (\*) in front are estimated.

Report created 10/1/2011 11:27:10. Signature:

## APPENDIX F

Data of Concentration CH<sub>4</sub> using gas analyser

LAND INSTRUMENTS INT.  
BOILER TEST  
ON MAIN SITE

SN: 15786991

Version No.: V1.11

Type of fuel:  
Natural Gas  
Dry analysis  
O2 normalisation: off

Date: 03.05.??

Time: 00:59:22

T ambient: 26 C  
T gas : 24 C  
T<sub>g</sub> - T<sub>a</sub> : -2 C

CO : 4327.8 ppm  
5410 mg/Nm<sup>3</sup>  
SO<sub>2</sub> : 0.0 ppm  
0 mg/Nm<sup>3</sup>  
O<sub>2</sub> : 21.6 %  
NO<sub>2</sub> : 1.2 ppm  
2 mg/Nm<sup>3</sup>  
NO : 0.4 ppm  
1 mg/Nm<sup>3</sup>  
CxHy: 0.24 %  
H<sub>2</sub>S : 10.8 ppm  
16 mg/Nm<sup>3</sup>  
CO<sub>2</sub> : 0.00 %  
NO<sub>x</sub> : 1.6 ppm  
3 mg/Nm<sup>3</sup>

efficiency : 0.0 %  
loss : 100.0 %  
excess air : 1253.6 %  
water : 0.0 %  
O<sub>2</sub> norm : 0.0 %

FOR MORE INFORMATION  
TEL: 01246 417691

LAND INSTRUMENTS INT.  
BOILER TEST  
ON MAIN SITE

SN: 15786991

Version No.: V1.11

Type of fuel:  
Natural Gas  
Dry analysis  
O<sub>2</sub> normalisation: off

Date: 03.05.??

Time: 00:57:58

T ambient: 27 C  
T gas : 26 C  
T<sub>g</sub> - T<sub>a</sub> : -1 C

CO : 244.8 ppm  
306 mg/Nm<sup>3</sup>  
SO<sub>2</sub> : 0.0 ppm  
0 mg/Nm<sup>3</sup>  
O<sub>2</sub> : 21.2 %  
NO<sub>2</sub> : 1.5 ppm  
3 mg/Nm<sup>3</sup>  
NO : 0.4 ppm  
1 mg/Nm<sup>3</sup>  
CxHy: 0.01 %  
H<sub>2</sub>S : 9.8 ppm  
15 mg/Nm<sup>3</sup>  
CO<sub>2</sub> : 0.00 %  
NO<sub>x</sub> : 1.9 ppm  
4 mg/Nm<sup>3</sup>

efficiency : 0.0 %  
loss : 100.0 %  
excess air : 1253.6 %  
water : 0.0 %  
O<sub>2</sub> norm : 0.0 %

FOR MORE INFORMATION  
TEL: 01246 417691

LAND INSTRUMENTS INT.  
BOILER TEST  
ON MAIN SITE

SN: 15786991

Version No.: V1.11

Type of fuel:  
Natural Gas  
Dry analysis  
O2 normalisation: off

Date: 03.05.??

Time: 00:58:27

T ambient: 27 C  
T gas : 27 C  
Tg - Ta : 0 C

CO : 102.5 ppm  
128 mg/Nm3  
SO2 : 0.0 ppm  
0 mg/Nm3  
O2 : 25.2 %  
NO2 : 6.2 ppm  
13 mg/Nm3  
NO : 0.6 ppm  
1 mg/Nm3  
CxHy: 0.08 %  
H2S : 38.4 ppm  
58 mg/Nm3  
CO2 : 0.00 %  
NOx : 6.9 ppm  
14 mg/Nm3

efficiency : 0.0 %  
loss : 100.0 %  
excess air : 1253.6 %  
water : 0.0 %  
O2 norm : 0.0 %

FOR MORE INFORMATION  
TEL: 01246 417691

ON MAIN SITE

SN: 15786991

Version No.: V1-11

Type of fuel:  
Natural Gas  
Dry analysis  
O2 normalisation: off

Date: 03.05.??

Time: 00:58:12

T ambient: 27 C  
T gas : 27 C  
Tg - Ta : 0 C

CO : 101.8 ppm  
1265 mg/Nm3  
SO2 : 0.0 ppm  
0 mg/Nm3  
O2 : 21.1 %  
NO2 : 2.9 ppm  
6 mg/Nm3  
NO : 0.6 ppm  
1 mg/Nm3  
CxHy: 0.04 %  
H2S : 18.9 ppm  
29 mg/Nm3  
CO2 : 0.00 %  
NOx : 3.5 ppm  
7 mg/Nm3

efficiency : 0.0 %  
loss : 100.0 %  
excess air : 1253.6 %  
water : 0.0 %  
O2 norm : 0.0 %

FOR MORE INFORMATION  
TEL: 01246 417691

LAND INSTRUMENTS INT.  
BOILER TEST  
ON MAIN SITE

\*\*\*\*\*

SN: 15786991

Version No.: V1.11

\*\*\*\*\*

Type of fuel:  
Natural Gas

Dry analysis

O2 normalisation: off

-----  
Date: 03.05.7>

Time: 00:58:42  
-----

T ambient: 26 C  
T gas : 25 C  
Tg - Ta : -1 C

CO : 614.1 ppm  
768 mg/Nm3  
SO2 : 0.0 ppm  
0 mg/Nm3  
O2 : 23.4 %  
NO2 : 6.8 ppm  
14 mg/Nm3  
NO : 0.6 ppm  
1 mg/Nm3  
CxHy: 0.16 %  
H2S : 42.5 ppm  
65 mg/Nm3  
~~CO2 : 0.00 %~~  
NOx : 7.4 ppm  
15 mg/Nm3

efficiency : 0.0 %  
loss : 100.0 %  
excess air : 1253.6 %  
water : 0.0 %  
O2 norm : 0.0 %  
-----

FOR MORE INFORMATION  
TEL: 01246 417691