PRELIMINARY STUDY FOR METHANE GENERATION OF FELCRA NASARUDDIN USING ANAEROBIC DIGESTION

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

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(Mr. Mohd Faizairi Mohd Nor)

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TRONOH, PERAK

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CERTIFICATION 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.

NURUL FATIMAH ABD RAZAK

ABSTRACT

Utilization of abundant waste by converting them into a useful renewable energy by adopting the third generation of green technology development has attracted much attention from the world as a source of the depleting fossil fuels. Other than awareness towards Carbon Credit and Clean Development Mechanism promoted in Kyoto Protocol to developing countries, development in biochemical transformation of biomass by means of anaerobic digestion to generate methane gas was also one of the enthralling fields.

This project is conducted as a preliminary study with aims to generate methane gas from anaerobic digestion of palm oil mill effluent taken from palm oil mill activity in FELCRA Nasaruddin, situated in Bota, Perak. The purpose of the project is to develop a working prototype of a digester, which will be used to generate methane gas by applying the conceptual of biochemical transformation of anaerobic digestion. A lot of literature studies had been done to support the proposed project. Numerous related equations were used as to support the theory and to proceed with the prototype fabrication and sample testing. The digester was designed using an engineering drawing tool, AutoCAD before it is fabricated. Palm oil mill effluent (POME) is taken from selected pond in FELCRA Nasaruddin, Perak and testing is done under controlled condition.

After that, the prototype is fabricated and experiments were carried out to observe the performance of the digester. Eighteen Litres POME samples taken were digested inside the digester for ten days of retention time and volume of gas captured are taken into record. The result of the experiments were summarized in the graphical representation. Discussions were made to comment and to analyze the results and suggestions to improve the efficiencies of the digester were made.

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First of all, I would like to express my greatest gratitude to Allah S.W.T for giving me the strength, health and patience to successfully complete this project. Not to mention, to my parents and all my family members for supporting and providing fruitful advises that enable me to see this project till the end.

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ABBREVIATIONS

Ammonia Nitrogen	AN
Biochemical Oxygen Demand	BOD
Certified Emission Reduction	CER
Chemical Oxygen Demand	COD
Clean Development Mechanism	CDM
Crude palm oil	CPO
Empty fruit bunch	EFB
Environmental Quality Standard	EQA
Fresh Fruit Bunch	FFB
Green House Gases	GHG
Hydraulic Retention Time	HRT
Organic Loading Rate	OLR
Palm Oil Mill Effluent	POME
Sodium Hydroxide	NAOH
Suspended Solids	SS
Total Nitrogen	TN
Total Solids	TS
Total Volatile Solids	TVS
Up-Flow Anaerobic Sludge Blanket	UASB

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In many components of renewable energy, bio energy is seen to be the most important component. Biomass is divided into three category for the energy conversion; direct combustion, thermo chemical transformation, biochemical transformation and other technology such as bio-diesel. Most of the cases of biomass involves agricultural products such as wood, straw and waste as there were abundant source of waste throughout the world.

In all three famous method of converting biomass into usefull energy, biochemical transformation can be deduced as the most ecological way of converting agricultural waste into useful energy. Biochemical transformation involves numerous microorganisms and the technique could be done naturally. It also helps to improve the quality and quality of the end product. The most suitable material to be transformed under this methodology is organic waste, as biochemical transformation also helps to improve the quality of the end product of the waste after undergone the transformation process.

In Malaysia, the most abundant source for biomass energy is the palm oil tree. Undeniablely, Malaysia has become one of the largest palm oil producer in the world, second after Indonesia. From this large scale of agriculture activity, wastes generated from it also proportional to its products. According to Yacob et. all, in 2004, palm oil mill industry in Malaysia generated about 26.7 million tons of solid biomass and about 30 million tons of Palm Oil Mill Effluent (POME).

POME is an organic waste that can produce significant amount of methane gas. Treatment for POME is mandatory in order to avoid any disturbance in the environment if these waste is discharged to the environment. From biomass and bioenergy perspective of view, these abundant source of waste is seen as abundant source of energy that can be produced naturally via anaerobic digestion, a component in biochemical transformation.

Bioenergy is one of the key options on shorter and medium term to alleviate green house gases (GHG) emission and replacement for fossil fuels. Bioenergy can be used to generate heat or electricity or to produce transport fuel. M.J Taherzadeh et. All in his publication stated that there were around 590-880 millions tons of methane are released to the environment through microbial activity and 90% from them came from biogenic sources.

As a general information, methane (CH_4) is more effective in trapping heat in the atmosphere than carbon dioxide (CO_2) gas for over 100-year period. Thus from this statement, capturing and utilizing methane as a source of renewable energy can prevent from its release to the admosphere, and can be used to obtain Certified Emission Reduction (CER) credit by Clean Development Mechanism (CDM) under Kyoto Protocol.

Renewable energy technologies are seen to be the complements of CDM. With its main objective of producing sustainable energy, renewable energy are contributing to the world energy security as they help to reduce the dependency towards fossil fuel resources, and providing opportunities for mitigating green house effects.

The third generation renewable energy technologies includes advanced biomass gasification, enhanced geothermal system, and marine energy. While the third generations of renewable energy technologies are still being developed, these generation of renewable can be said as having a high potential and comparable to the first two technologies that are widely promoted and adopted globally.

1.2 Problem Statement

Current POME treatment only focused to enhanced effluent quality and reducing harmful organism before discharging it to the environment. Methane gas obtained from anaerobic digestion of POME is often be looked as by product of the treatment. Most of the cases, this abundant gas only been released to the environment without utilizing it. Therefore, a study on designing a digester based on anaerobic digestion concept of treatment to capture methane gas is done.

Improvisation of current POME treatment was necessarily needed. This is because of the high potential value that these abundant waste could be turned into useful energy. By capturing methane gas generated from the organic waste using a biochemical transformation of anaerobic digestion, waste could be turned as a source of energy. Methane gas is a green house gas and with the utilization of methane gas as a source of energy, other than gaining CER and Carbon Credit, this project should be looked as an opportunity to be invested at.

Energy generated from industrial waste is a clean technology and can be a vital component as apprentice for future energy [1, 2]. Out of numerous method of converting these waste into biogas, anaerobic digestion is the process that is most acknowledged. Generations of biogas from anaerobic digestion process is said to be the cleanest technology of converting waste into useful renewable energy. Many studies were conducted in determining the best type of anaerobic digestion for both wastes so that maximum amount of biogas can be generated with the least retention time.

1.3 Objective

Upon completion of this project, some objectives are set to satisfy the scopes of study that have been underlined, which are relevant to the requirement of the project. The objectives of this project are as follows:

i. To conduct a preliminary study on POME production at FELCRA Nasaruddin, Bota, Perak.
ii. To understand the concept of anaerobic digestion for methane gas production from POME as source of feedstock.
iii. To design and fabricate anaerobic digester for methane generation of POME based from pre-determined calculation.
iv. To analyze the quantity and the effectiveness of the digester based from the volume of gas generated.

1.4 Scope of Study

While scope of study will consists of three major points:

i. Studies on current POME production and management system in FELCRA Nasaruddin and the conventional type of anaerobic digester available in current market.
ii. Conduct tests to calculate the methane gas production and analyze results relevancy including influencing factors.
iii. Suggest for digester resizing as preliminary study for methane gas generation for FELCRA Nasaruddin, Bota, Perak.

CHAPTER 2

LITERATURE REVIEW

Precise study on the project is done in order to achieve the objective and the target of the project, as well as to grasp the gist of the project. Literature review on POME and current treatment for POME, FELCRA Nasaruddin palm oil mill activity, and anaerobic digestion types and techniques is done to enquire more insight about the project conducted.

2.1 Palm Oil Mill Effluent (POME)

2.2.1 Palm Oil Mill Processing

POME is one of the by-products generated from several stages during palm oil mill processing. A comprehensive understanding on the palm oil mill processing is vital, with the intention that to relate the process with the composition of POME explained later in next sub topic.

Crude palm oil (CPO) is extracted from the mesocarp of Fresh Fruit Bunch (FFB). Approximately 10 to 35 tons FFB were produced every year from one hectare of palm oil, and 225kg of CPO is obtained from 100kg of processed FFB [3,4,5]. In order to preserve the quality of CPO by maintaining the fatty acid contain, FFB harvested from oil palm plantation have to be processed immediately. FFB are sterilized inside an autoclave using steam about 140℃ for a period of 75-90 minutes [3,4,5]. Sterilization of FFB is done to deactivate hydrolytic enzymes in charge for the breakdown of oil to fatty acids, facilitates in mechanical stripping of FFB, and preconditioning of the nuts to minimize kernel breakage [3,4,5]. Waste generated during this step is condensate steam that coming out from the sterilizer.

After sterilization process, fruits are stripped and separated from the bunch inside a rotary drum stripper. Detached fruits are then fall through the space between the bars on the stripper and being collected in a bucket conveyor and discharged into a digester. Empty fruit bunch (EFB) is the resultant waste from this step. Digestion is a process that involves mashing up fruits under steam condition in a digester with temperature around 90℃ [3,4,5]. This action is done to break the mesocarp oil-bearing cells. Hot water is added to aid the process by enhancing the flow of oil. No residue is generated during this process.

Last but not least is the extraction process. Homogeneous oil mash coming out from the digester is passed through a twin screw press, followed by a vibrating screen, a hydrocyclone and decanters to remove fine solids and water. Twin screw presses are generally used to press out the oil from digested mashed fruits under high pressure. CPO from the presses consists of a mixture of palm oil (35%-45%), water (45%-55%) and fibrous material in varying portions [3,4,5].

The CPO is then pumped to a horizontal or vertical clarification tank to skim the oil from top of the clarification tank and its temperature is maintained about 90℃ to enhance oil separation [3,4,5]. CPO is then passing through a high speed centrifuge and a vacuum dryer before being sent to storage tanks. Temperature in the storage tank is regulated around 60℃ by using steam coil heating [3,4,5]. Major wastes produced in this stage are decanter wastewater and decanter cake.

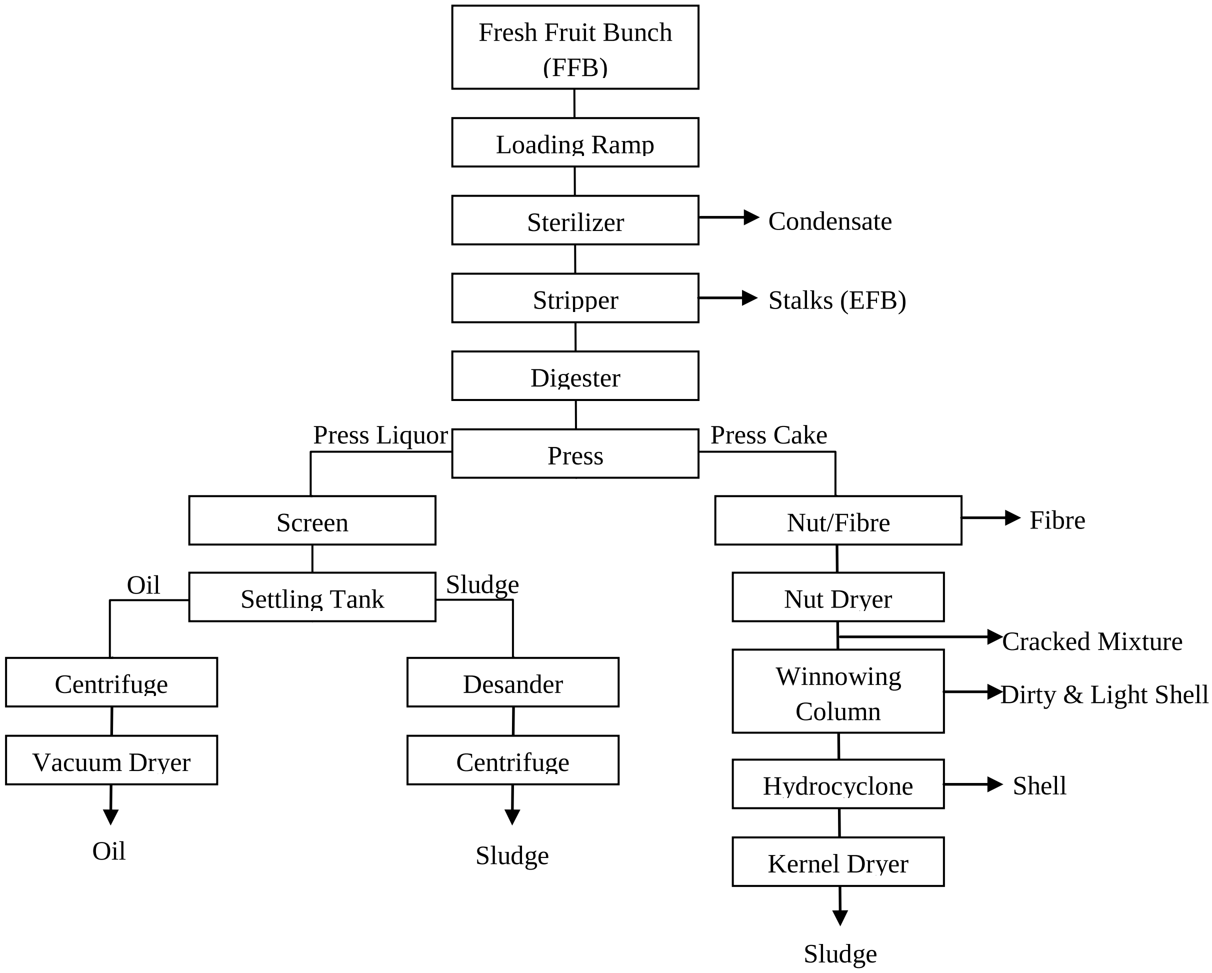


Figure 1 - Processes involved in conventional palm oil extraction [3,4,5].

2.2.2 POME Composition

POME is a type of liquid waste generated from palm oil mill process. This effluent is generated mainly from oil extraction, washing and cleaning process in the mill and therefore it contains cellulosic material, fat, oil, and grease [3]. POME contains organic matter and plant nutrients that are excellent substitutes for organic fertilizers. It can be deduced as the most pollutant organic residues generated from palm oil mills. High composition of organic content mainly oil and fatty acids are able to support bacterial growth to reduce its pollution strength [6].

Citated from Department of Environment, during Sterelization of FFB, the sterilizer condensates is about 36% of total POME. 60% of total POME came from clarification wastewater generated during clarification process of the extracted CPO. The remaining 4% of POME composition came from hydrocyclone separation of cracked misture of kernel and shell-hydrocyclone wastewater.

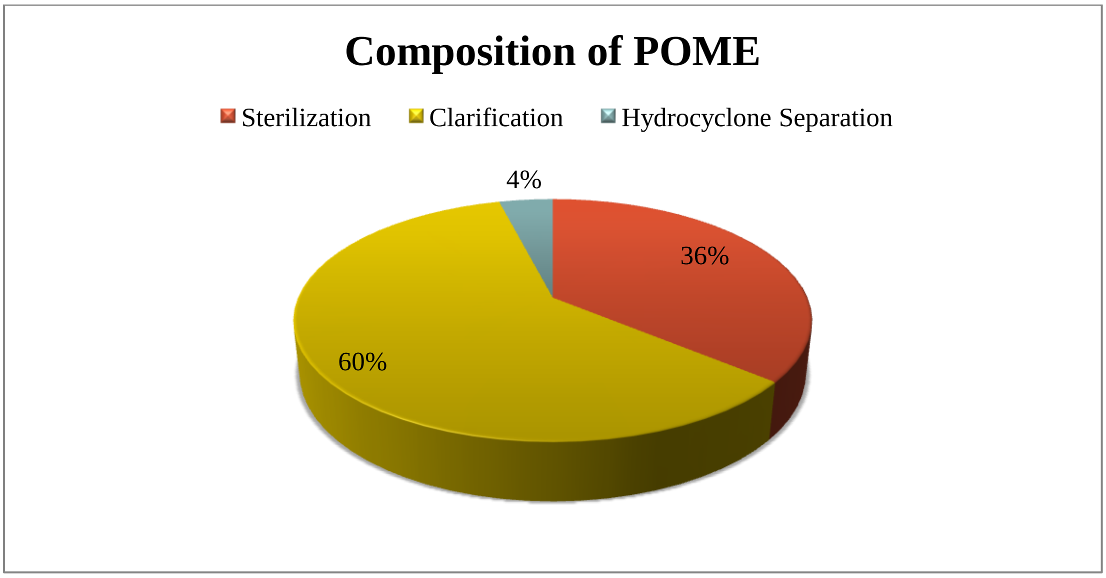


Figure 2 - POME Composition from Palm Oil Mill Processing Activity [x]

Precisely, POME can be categorized as a colloidal suspension thick brownish liquid, discharged at a temperature around 70-80 ºC [7]. It contains about 95-96% water, 0.6-0.7% oil and 4-5% total solids including 2-4% suspended solids originating in the mixing of sterilizer condensate, clarifier and hydrocyclone wastewater [8].

Raw POME have high percentage of Biochemical Oxygen Demand (BOD) and acidic with pH around 4.0 [3]. From the table of POME characteristics, it can bee seen that the ratio of BOD:COD is approximately 1:2. This indicates that POME is suitably to be treated by biological processes.

Table 1 - Characteristic of Raw POME

General Parameters		
Paremeter	**Mean**	**Range**
Percent moisture	98.21	98.01-98.41
pH	4.2	3.5-5.2
Oil & Grease	6,000	150-18,000
Biochemical Oxygen Demand (BOD)	25,000	10,000-14,000
Chemical Oxygen Demand (COD)	50,000	16,000-100,000
Total Solids (TS)	40,500	11,500-79,000
Suspended Solids (SS)	18,000	5,000-54,000
Total Volatile Solids (TVS)	34,000	9,000-72,000
Ammonia Nitrogen (AN)	35	4-80
Total Nitrogen (TN)	750	80-1,400
Composition of Nutrients and Metal Elements		
Phosphorus	180	
Magnesium	615	
Calcium	440	
Boron	7.6	
Iron	47	
Manganese	2.0	
Copper	0.9	
Zinc	2.3	

**all parameters are in mg/L except for pH value and moisture percentage.

Due to high awareness upon this matter, comprehensive environmental control of the crude palm oil industry was commenced. The Environmental Quality (Prescribed Premises) (Crude Palm Oil) Order, 1977 and the Environmental Quality (Prescribed Premises) (Crude Palm Oil) Regulations, 1977 were disseminated under the Environmental Quality Standard (EQA), in order to regulate the discharge of effluent from the crude palm oil industry as well as to exercise other environmental controls [9]. These were the first sets of industry specific subsidiary legislation to be disseminated under the EQA for industrial pollution control.

The following table presented the current effluent discharge standard ordinarily acceptable to crude palm oil mills.

Table 2 - Prevailing Effluent Discharge Standard For Crude Palm Oil Mills

Perameters	Unit	Parameters Limits
Biochemical Oxygen Demand (BOD) (BOD; 3 Days, 30 ºC)	mg/L	100
Chemical Oxygen Demand (COD)	mg/L	*
Total Solids (TS)	mg/L	*
Suspended Solids (SS)	mg/L	400
Total Volatile Solids (TVS)	mg/L	50
Ammonia Nitrogen (AN)	mg/L	150
Total Nitrogen (TN)	mg/L	200
pH	-	5-9
Temperature	ºC	45

2.2 Anaerobic Digestion

Anaerobic digestion is a series of biological treatment process in which microorganisms' aid in breakdown of biodegradable material in absence of oxygen molecules. Most industry are adopting this methodology of managing waste and turn it into useful energy as it is a process to reduce odor, generating energy in terms of biogas (methane gas and carbon dioxide), and improve the characteristic of waste.

The main targets of anaerobic digestion are to biologically demolish an important part of the volatile solids in sludge and to minimize the putrescibility of waste. Major products of anaerobic digesters are biogas and innocuous digested waste solids. Biogas consists mostly of methane (CH_4) and carbon dioxide (CO_2).

Anaerobic process or biological treatment has a considerable advantages compared to other processes. Other than reduction of volume and weight of sludge, anaerobic digester possessed many alluring features such as less energy demands, diminution in number of pathogens, and the generation of methane gas due to the degradation of organic substances by anaerobic bacteria. It has a very great potential for rapid disintegration of organic matter to generate biogas that can be used in electricity generation, and save fossil energy.

2.2.1 Anaerobic Digestion Mechanism

Because of the relatively large quantity of organic wastes placed on the anaerobic digestion process, the study of the bacteria involved, steps and process that builds up the whole process and the operational factors that influenced the efficiency of the process is important.

Numerous microorganisms took part in the process of anaerobic digestion, explicitly acetogens, and methanogens [10]. For the most part, bacteria were divided into two category; mesophilic and thermophilic bacteria. Mesophilic are bacteria that can live optimally between 35 and 40℃ , while thermophilic are the stroger bacteria that can live under hostile condition around 55 to 60℃.

In anaerobic system mentioned above, with no presence of oxygen, anaerobic bacteria gain oxygen from the organic material itself. The results of deriving oxygen from the existed material produced intermediate products such as alcohols, aldehydes and organic acids, not to be forgotten carbon dioxide. In the presence of methanogens, the intermediates are then converted into the final end products of methane, carbon dioxide, and traces of hydrogen sulphide.

While the definition suggests anaerobic digestion as a series of bacterial events that convert organic compound into methane, carbon dioxide and new bacterial cells, the event occurred in four major stage-process; hyrdolysis, acidogenesis, acetogenesis, and methanogenesis [10].

Hyrdolysis is the solubilization of particulate organic compound such as cellulose (2.1) and colloidal organic compounds such as protein (2.2) into simple soluble compounds (simple sugars, amino acids and fatty acids) that can be absorbed by bacterial cells.

$$\text{cellulose} + H_2O - \text{hydrolysis} \rightarrow \text{soluble sugars} \qquad (2.1)$$

$$\text{proteins} + H_2O - \text{hydrolysis} \rightarrow \text{soluble amino acids} \qquad (2.2)$$

Next stage is acidogenesis. Acetate and hydrogen produced during first stages can be used directly by methanogens. Other molecules such as fatty acids with a chain length greater than that of acetate acid must be catabolized into compounds that can be directly used by methanogens [5, 10]. The biological process of acidogenesis results in further breakdown of the remaining components by fermentative bacteria (acidogenic) [5, 10]. Products during this stage are volatile fatty acids (VFA) such as ethanol and propionate, ammonia, carbon dioxide, and hydrogen sulphide [5, 10].

In the third stage, products from previous stage are further digested by acetogens to produce acetate, as well as carbon dioxide and hydrogen [5, 10]. Methanogenesis, the last stage is the use of methanogens to convert intermediate products generated earlier to form methane gas, carbon dioxide and water. Methane gas can be generated from the degradation of acetate (2.3) and reduction of carbon dioxide by hydrogen gas (2.4). Methanogenesis is a sensitive process that it can only occur at pH range of 6.5 and 8.

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

$$CO_2 + 4H_2 \rightarrow CH_4 + CO_2 \qquad (2.4)$$

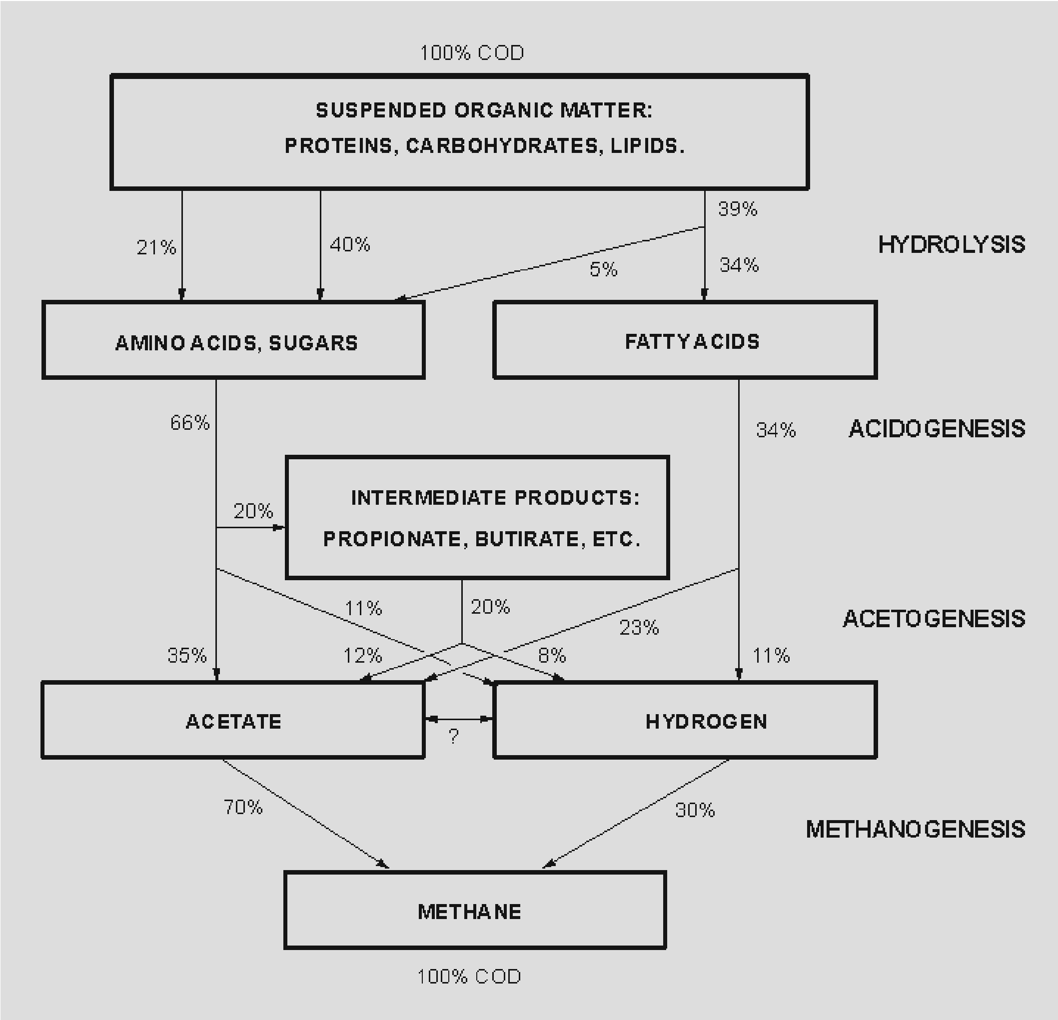


Figure 3 - Flow Diagram Representation of The Decomposition Pathways by Anaerobic Digestion [11]

2.2.2 Current Anaerobic Digestion Treatment Methods for POME

In order to comply with the standard commenced by EAQ, research and technology on POME treatment was introduced and enhanced. Across the country, there were numerous of technology implied by palm oil mill industry. Few of them were studied and their advantages and benefits as well as their limitations were listed in this sub- topic.

As an overview, the conventional treatment technology of POME employed in most of the palm oil mill in Malaysia is the combination of physical and biological treatment. While physical treatment caters POME screening, sedimentation, and oil removal processes, biological treatment are the seocndary level of treatment involving biodegradation of organic matters by microorganism digestion. Ponding System, Anaerobic Filtration, Up-Flow Anaerobic Sludge Blanket (UASB) Reactor and Fluidized Bed Reactor will be the current POME treatment method discussed further.

Ponding System [12]

The ponding system is the most widely used biological teratment for POME as 85% of Malaysia palm oil mills are applying this system. Ponding system is a combination of anaerobic, aerobic and facultative ponds of lagoons. Main components of the system includes de-oiling tank, acidification ponds, methanogenic ponds, facultative ponds and sand beds.

The number of ponds varies according to the capacity of the palm oil mill. Facultative or aerobic ponds are necessary to further reduce BOD concentrations in order to produce effluents that complies the discharge standards. A typical size of an anaerobic pond in a palm oil mill which has a processing capacity of 54 tons per hour is 60.0 × 29.6 × 5.8m (length × width × depth) [13].

Anaerobic pond has a relatively long treatment periods up to 200 days. Due to large system and large aquiring area, ponding system has one of the highest maintenance required. Further investigations [13] showed that anaerobic pond had a higer emission of methane with an average methane composition of 54.4% compared to open digester tank.

Anaerobic Filtration

Other than palm oil wastewater treatment [14], anaerobic filtration methodology for wastewater treatment has been employed by various type of substance, including soybean processing wastewater, landfill lechate, municipal wastewater, municipal wastewater, drug wastewater, brewery wastewater, distillery wastewater, and wastewater from ice-cream manufacture.

Anaerobic filter is selected for wastewater treatment because;

i. It requires a smaller reactor volume which operates on a shorter Hydraulic Retention Times (HRTs).
ii. It has high substrate removal efficiency.
iii. It has the ability to maintain high concentration of biomass in contact with the wastewater without affecting treatment efficiency.
iv. It capables to tolerate to shock loadings.

Other than that, construction and operation of anaerobic filter is less expensive and small amount of suspended solids in the effluent eliminated the need for solid separation or recycle. However, clogging is a major problem in hte continuous operation of anaerobic filters.

In general, anaerobic filter is capable of treating wastewaters to give good effluent quality with at least 70% of COD removal efficiency with methane composition of more than 50%. In terms of POME treatment, the highest COD removal efficiency recorded was 94% with 63% or methane at an Organic Loading Rate (OLR) of 4.5 kg COD/m^3/day, while overall COD removal efficiency was up to 90% with an average methane gas composition of 60% [14].

Up-Flow Anaerobic Sludge Blanket (UASB) Reactor

The fundamental principle of UASB reactor is to have an anaerobic sludge which exhibits good settling properties [15]. Up to now, UASB has been applied for the treatment of potato wastewater, slaughterhouse wastewater, ice-cream wastewater, pharmaceutical wastewater, instant coffee wastewater, and sugar-beet wastewater. UASB has a relatively simple design where sludge from organic matter degradation and biomass settles in the reactor. Organic matter from wastewater that comes in contact with sludge will be digested by the biomass granules. UASB reactor has ability to tolerate high OLR.

In most cases, UASB is successful in COD removal of more than 60% for most wastewater. POME treatment has been successful with UASB reactor, achieving COD removal efficiency up to 98.4% with the highest operating OLR of 10.63 kg COD/m^3/day [14]. Despite that, UASB has drawbacks as well. The reactor might become unstable after 15 days when overload conditions due to increase in concentration of volatile fatty acids. The reactor was design to comply with high amount of POME discharged daily from milling process, which recommends the system operation at high OLR.

Fluidized Bed Reactor System

Fluidized bed reactor exhibits several advantages that make it useful for treatment of high-strength wastewater. It has a very large surface areas for biomass attachment, enabling high OLR and short HRTs during operation [16]. In addition, fluidized bed has minimal problems of channeling, plugging or gas hold-up [16]. Higher up-flow velocity of raw POME is maintained for fluidized bed reactor to enable expansion of the support material bed. Therefore, biomass can be retained in the reactor.

Fluidized bed reactor has also been widely used to treat cutting-oil wastewater, real textile wastewater, wine and distillery wastewater, brewery wastewater, ice-cream wastewater, slaughterhouse wastewater, pharmaceutical wastewater, as well as POME.

Anaerobic fluidized bed can typically remove at least 65% and up to more than 90% of COD. Inverse flow fluidized anaerobic bed is capable of tolerating higher OLRs compared to up-flow configuration [4] . It was found that in general , anaerobic fluidized bed is able to operate at higher OLRs, implying that less reactor volume will be required to operate at lower OLRs.

In POME treatment, fluidized bed was found to be a better treatment method compared to anaerobic filter due to its ability to tolerate higher OLRs and its better methane gas production. Shorter HRT (6 hours) also proved to be a plus point of fluidized bed over anaerobic filter (1.5-4.5 days) in POME treatment.

2.3 Design Theory

Prior to the designing stage of the prototype by using AUTOCAD, studies and calculation was made for the design sizing. Influencing factors including temperature, pH value, and retention time were included.

According to Adrianus van Haandel and Jeroen van der Lubbe in their book [11], the empirical expression following is suggested for calculating retention time in a high rate anaerobic digester.

$$\text{Retention Time, } T_r = (20 \times 1.1^{(20-T)}) + 5 \qquad (2.5)$$

Since the temperature range of POME can be regarded as in a range of mesophilic temperature, the above formula was used to find the suitable retention time for the POME. Meanwhile, the volume of the digester can be calculated by multiplying the volume of feed rate needed with the retention time calculated earlier.

pH value is needed to be maintained near the neutral value of 7 for a stable operation of the anaerobic digester. Methanogenesis might occur at slower rate if pH value is outside the range of 6.5 to 7.5 [11]. However, if the acid formation during acidogenesis stage is more rapid than methanogenesis, change of pH value to be as low as 4.5 to 5.0 can happen. Once this happens, the methanogenesis reaction can become very slow as the ractor become more acidic. The reactor can only become normal by inducing external alkalinity [11].

For a complete-mix, high rate digester without recycle, the mass of biological solids synthesized daily (P_x), in mg/day was calculated using equation below [17];

$$P_x = \frac{Y[S_0 - S]8.34Q}{1 + k_d T_r} \qquad (2.6)$$

Y= yield coefficient (lb/lb)

k_d = endogenous coefficient, (day^{-1})

T_r = retention time (day)

Q = flow rate, (Mgal/day)

S_o = ultimate BOD in influent (mg/l)

S = ultimate BOD in effluent (mg/l)

The kinetic coefficient (endogenous coefficient) recommended in the literature for substrate similar in composition to vinasse (fatty acid) was 0.04 d^{-1} and the yield coefficient was 0.05 lb of cell/lb of BOD. With assumption 30% of total BOD in influent (S_0 = 25,000 mg/L) will be digested during the digestion process, final S value will be 17,500 mg/L. Further calculation on finding the volume of methane gas produced is based on the following formula [17].

$$V_{CH_4} = 5.62\,[8.34Q(S_0 - S) - 1.42P_x] \qquad (2.7)$$

The value 5.62 is a theorotical conversion factor for the amount of methane produced from the complete conversion of one pound of BOD to methane and carbon dioxide, cu ft CH_4/lb BOD oxidized.

CHAPTER 3
METHODOLOGY

3.1 Flow Chart

Figure 4 below shows a flow chart consisting of the planned process workflow for this project.

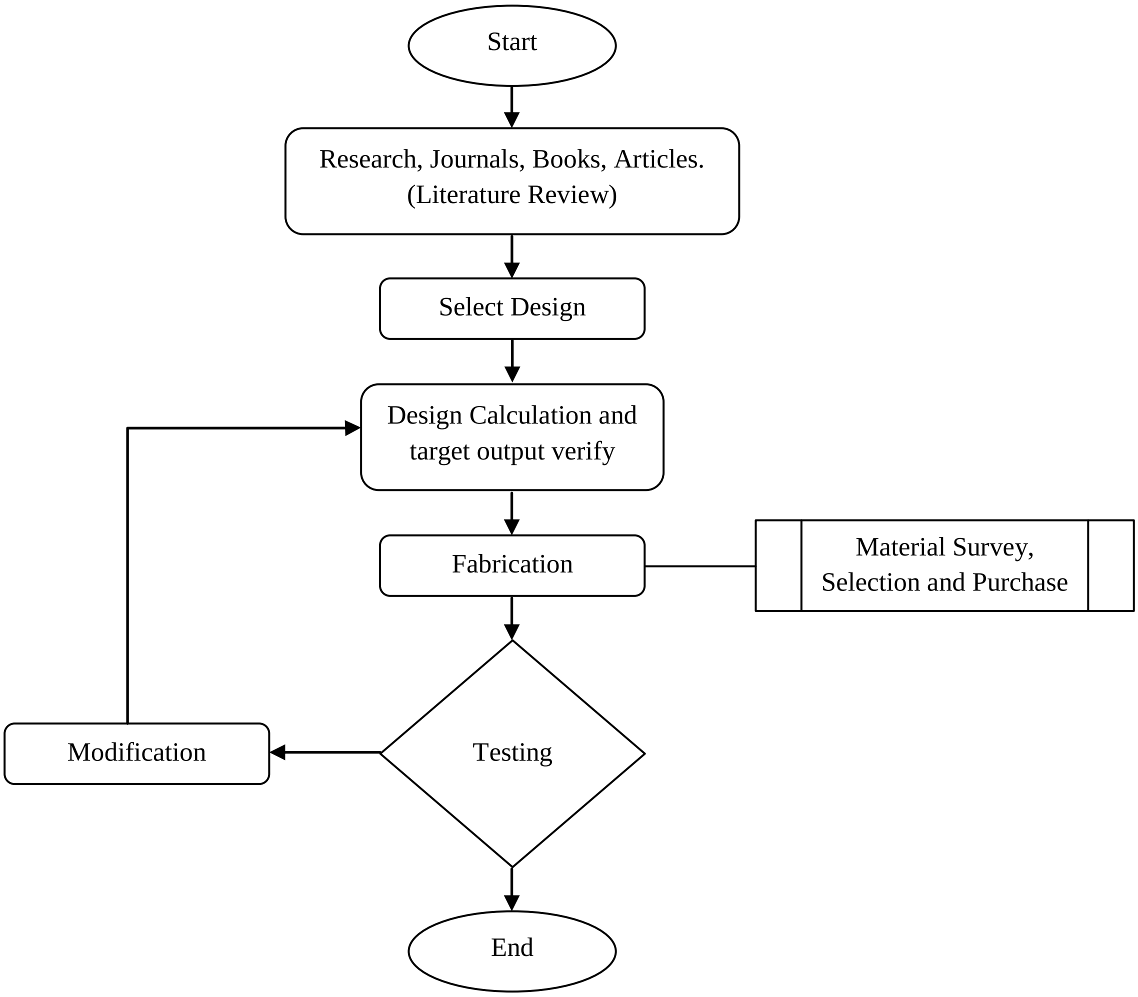


Figure 4: Process Workflow of Design and Fabrication of Anaerobic Digester.

3.2 Project Workflow

In order produce a digester with a high performance rate, the process of designing and fabricating must be done explicitly. The basic steps and procedures involved in this project are specified in a Gantt Chart in Appendix A. Key milstones on the project is also attached together in Appendix B. The relevant steps for this project are as follow:

i. Identify need

To come up with a design and a digester that can generate maximum volume of methane gas with lowest retention time as per calculated in before.

ii. Define problem

Renewable energy is much encouraged as to reduce the dependency towards the depleting source of fossil fuels. Vast amount of POME generated from palm oil mill activity significants with biogas generation technology that can be seen as an opportunity to generate methane gas can be used in order to support CDM and obtain CER, as well as saving the environment by improving the quality os wastewater discharged to the environment.

iii. Research

A lot of researches are conducted by surfing the internet, journals, conference papers science webpage about the concept of methane gas generation from anaerobic digestion. The mechanism of anaerobic digestion, theory and calculations to design a digester were studied in order to produce a digester.

iv. Set constraint

The target of this project is to complete the fabrication and testing of the digester within the time given. Budget for this project is around RM500 which is allocated to cover all the material use for this project.

v. Set criteria

Among the criteria set for this project include, cost effective, efficient and reliable, practical and safe for usage.

vi. Analysis

All pros and cons of the proposed ideas are considered. The performance of the digester must be monitored to inspect for any error and to monitor the product performance. Alternative ideas are considered as back-up plans if problems would arise unexpectedly in the future.

vii. Decision

A final decision is made by choosing the most practical design considering the objective and other constraint that has been set to ensure the project can be realized.

viii. Specification

The specification of the design must be set beforehand as it represent the desired outcome expected from the project. Among the specification of this project includes:

Design → Reliable

Quality →Digester performance in term of output (methane gas) generated

Material → Affordable

Performance → Efficiency of the prototype

3.3 Design Theory and Calculations

Before designing stage of the prototype by using AUTOCAD, studies and calculation was made for the design sizing. Influencing factors including temperature, pH value, and retention time were included.

Data given:

POME composition in digester	= 100%
Moisture content	= 98.21%
Volatile solid	= 85%

Assumption:

Feed Rate	= 5kg/week (7.2×10^{-4} ton/day)
Temperature Range of POME	= 28 ºC
Digester Height	= 0.7 m
Retention Time, T_r	= 15 Days

Below are the calculation to find the suitable digester volume :

Composition × Feed Rate $= \frac{100\%}{100\%} \times (7.2 \times 10^{-4})$

$= \mathbf{7.2 \times 10^{-4}}\ \boldsymbol{ton/day}$

Moisture × 7.2×10^{-4} ton/day $= \frac{98.21}{100} \times (7.2 \times 10^{-4})$

$= \mathbf{7.015 \times 10^{-4}}$ **ton/day**

Density of water = 1000 kg/m^3

= 1 ton/m^3

$\therefore$ 1t = 1 m^3

$$\therefore 7.015 \times 10^{-4}\, ton = \mathbf{7.015 \times 10^{-4}\, m^3}$$

Digester Volume = 7.015 × 10^{-4} ton/day × 15 days

= 10.6 × 10^{-3} m^3 (10.6 Liter)

Multiplying with safety factors of 1.70, the volume of digester is finallized to be 18 liter with height of 0.7 meter. Next, from this values the digester area and diameter is calculated in order to design the digester in a cylinder shape.

Digester area, A_D $= \frac{Digester\ Volume}{Height}$

$= \frac{0.021\, m^3}{0.7\, m} \rightarrow \mathbf{0.03\, m^2}$

Diameter, d_D $= \sqrt{\frac{4\,(0.03)}{\pi}}$

$$d_D = 0.1348\, m \sim \mathbf{0.2\, m}$$

The value for mass of biological solids synthesized daily (P_x) is calculated as below:

$$P_x = \frac{Y[S_0 - S]8.34Q}{1 + k_d T_r}$$

Y= yield coefficient (lb/lb)

k_d = endogenous coefficient, (day^{-1})

T_r = retention time (day)

Q = flow rate, (Mgal/day)

S_o = ultimate BOD in influent (mg/l)

S = ultimate BOD in effluent (mg/l)

$$P_x = \frac{0.05[25\,000 - 17\,500](8.34)(0.185 \times 10^{-6})}{1 + 0.04(18)}$$

$$\mathbf{P_x = 3.36 \times 10^{-4}\ mg/day}$$

Volume of methane gas expected to be produced in this project is determined as follows;

$$V_{CH_4} = 5.62\,[8.34Q(S_0 - S) - 1.42P_x]$$

$$V_{CH_4} = 5.62\,[8.34(0.185 \times 10^{-6})(25\,000 - 17\,500) - 1.42(3.36 \times 10^{-4})]$$

$$= 0.0625\, ft^3/day$$

$$= \mathbf{0.00177\ m^3/day}$$

3.4 Prototype Design

Prior to fabrication of the prototype, AUTOCAD, engineering software is used to design the structure of the digester base on the concept and idea that have been identified earlier. The top view, side view and overall view of the prototype's drawing is shown in figure below.

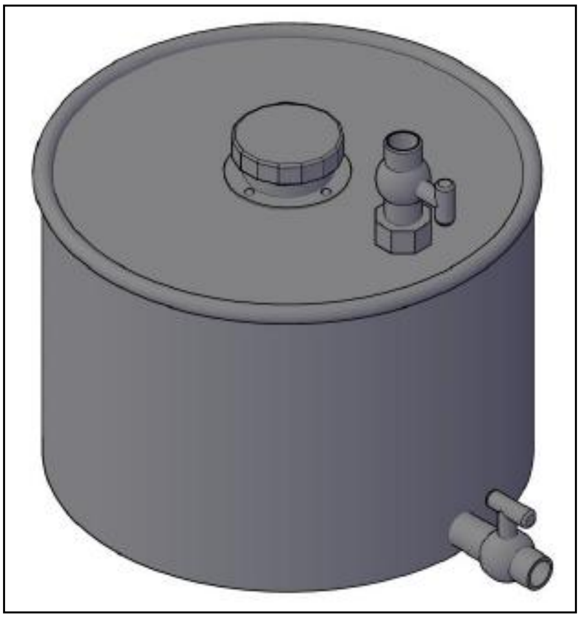


Figure 5 - Prototype Design of POME Anaerobic Digester

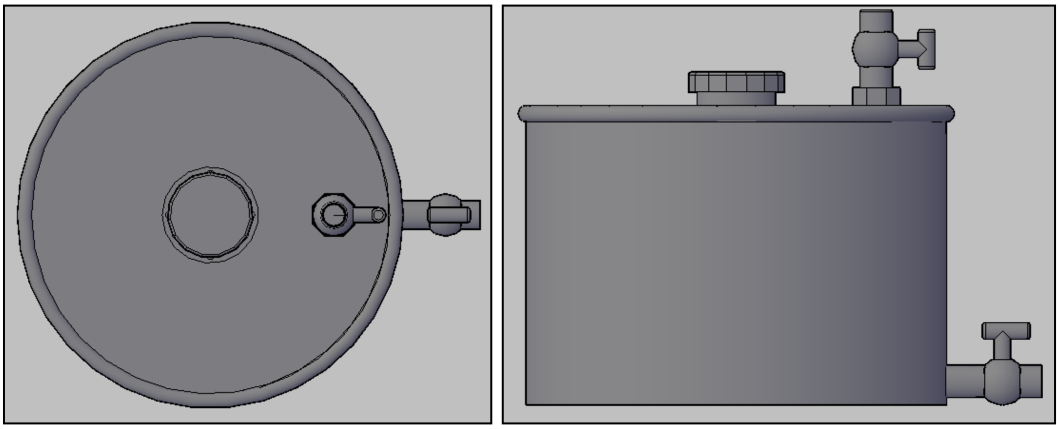


Figure 6 - (Left) Top View and (Right) Front View of the Prototype

3.5 List of Material

Based from the design made, materials to fabricate the digester were listed and best material were chosen. Mainly, the digester was fabricated from a plastic based material while other material like PVC pipes and tubes are used.

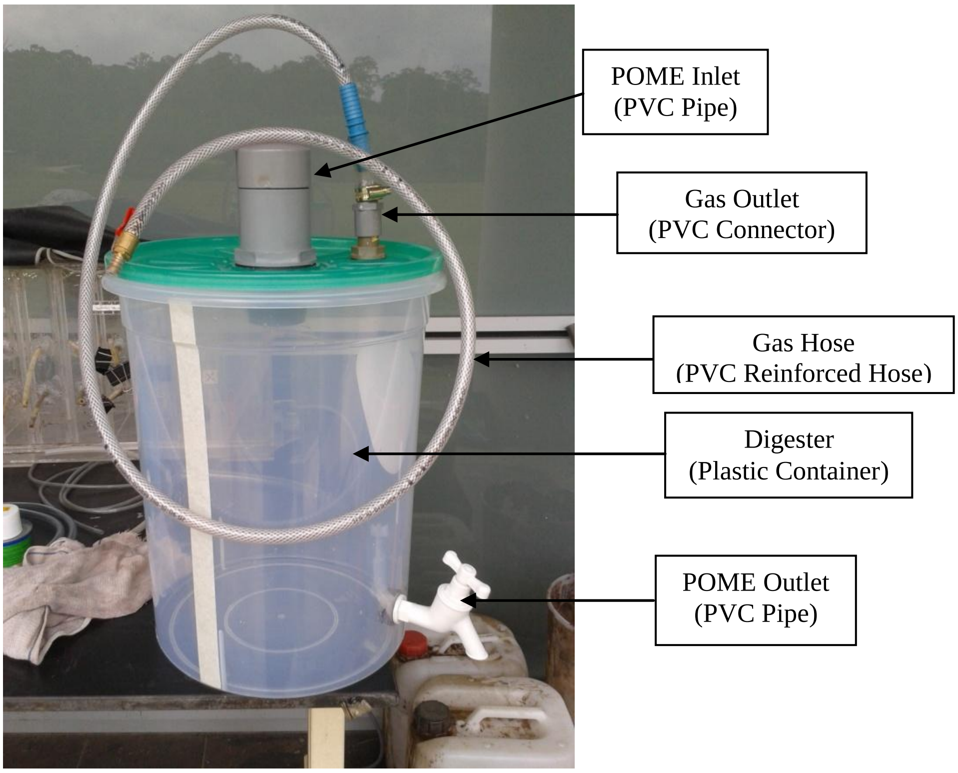


Figure 7 - Design Material Composition

Table below enlisted the material used to fabricate the digester.

Table 3 - List of Material

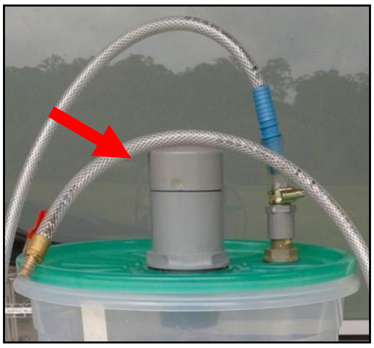
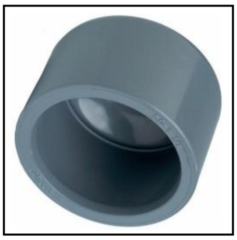
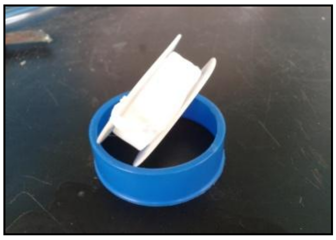
Parts	Material Used	Measurement
 POME Inlet	 Ø 50mm PVC Pipe (1)	Length: 50 mm
	 Ø 50mm Thread Connector (1)	Standard Size Available in Market for Ø 50mm PVC Pipe
	 Ø 50mm End Cap (1)	Standard Size Available in Market for Ø 50mm PVC Pipe
	 Rubber Washer (1)	Standard Size Available in Market for Ø 50mm PVC Pipe
	 PTFE Tape	Standard Size Available in Market (Ø 15mm)

Table 4 - List of Material

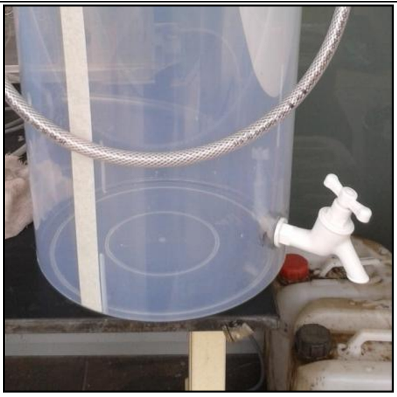
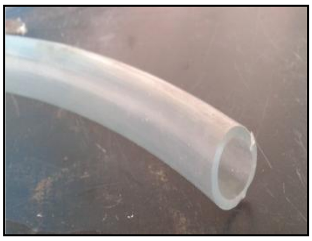
Parts	Material Used	Measurement
Digester Tank	 Plastic Container	• 0.7 m height with Ø 0.2 m (can fill up to 18 L POME)
 POME Outlet	 Plastic tap	Standard Size Available in Market (Ø 15mm)

Table 5 - List of Material

<table>
<tr><th>Parts</th><th>Material Used</th><th>Measurement</th></tr>
<tr><td rowspan="6">
Gas Outlet</td><td>
PVC Nylon Braided Hose Pipe</td><td>10 mm OD x 1 m length</td></tr>
<tr><td>
Transparent Hose Pipe</td><td>12 mm OD x 0.3 m length</td></tr>
<tr><td>
Steel Fastener</td><td>Standard Size Available in Market (Ø 15mm)</td></tr>
<tr><td>
PVC Connector</td><td>Standard Size Available in Market (Ø 15mm)</td></tr>
<tr><td>
PVC Tank Connector (1)</td><td>Standard Size Available in Market (Ø 15mm)</td></tr>
<tr><td>
Rubber Washer (1)</td><td>Standard Size Available in Market for Ø 15mm PVC Pipe</td></tr>
</table>

3.6 Experimental Procedure

After the fabrication of the prototype is completed, the digester is tested in order to observe its performance. All tests are done in laboratory using POME sample taken at FELCRA Nasaruddin. Tests were conducted in batches, as one batches comprises of 10 days of retention time. Although earlier in the literature review it is stated that the retention time would be depending on the temperature of POME sample, the fluctuating ambient temperature and initial temperature of POME sample is different. Therefore, a constant batch volume of 18 liter of POME with 10 days retention time is chosen.

The experiment lay out can be seen as shown in figure on the next page. The digester is connected with a gas chamber by using a transparent pipe in order to channel the methane gas generated from the digestion process. The gas chamber is made up from perspect and cylinder in shape, with two holes in the bottom and one hole at the top. It is taped with a measuring scale to record the volume of gas captured during the retention time. Inside the gas chamber, sodium hydroxide (NAOH) solution is used to vaccuumized the gas chamber, and to purify the gas captured, allowing only pure methane gas is contained inside the chamber. The captured gas will eventually push down the solution to the tank prepared through one of the bottom outlet of the chamber.

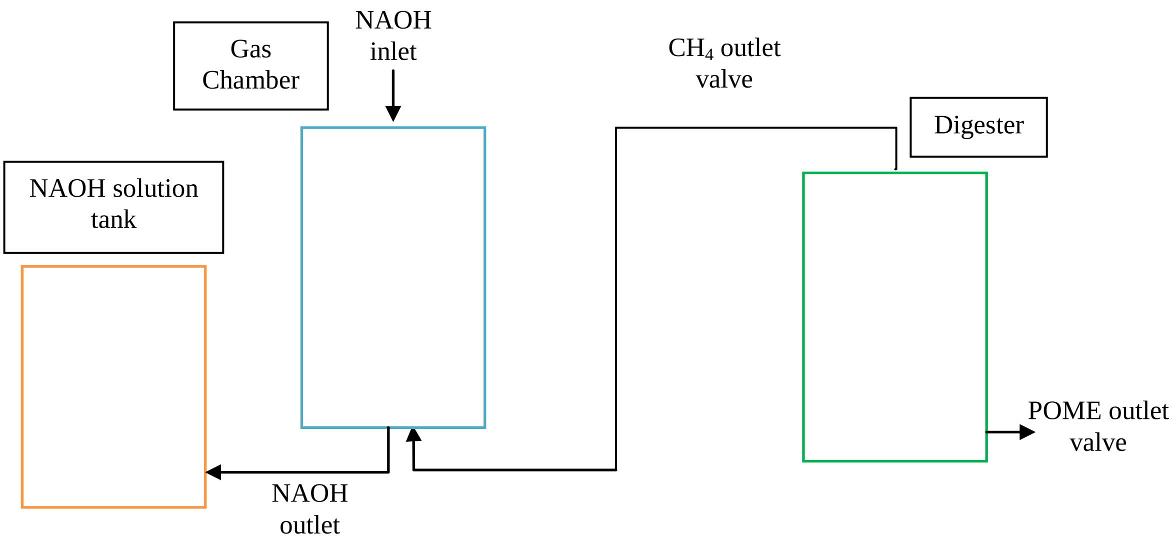


Figure 8 - Experiment Setup Diagram

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Testing Results

Three tests were conducted to verify the calculated performance of the digester. In the earlier state before proceed with the tests, several parameters tabulated below are identified as manipulating variables.

Table 4.1 - Testing Parameters

Test	POME Initial Temperature (°C)	pH value
1	26.6	4.7
2	45.6	4.78
3	46.5	7.05

Test 1 and 2 are designed in order to compare and to define the relationship of initial temperature of POME against volume of methane gas generated, while Test 2 and Test 3 are designed so as the relationship between POME initial pH value and volume of methane gas generated as 10 days of retention time takes place is analyzed.

The POME samples for all three tests were taken directly from palm oil mill factory, before POME is channelled to the first pond for treatment, or can be said as a raw POME. This discharged POME are actually high in temperature, with range around 70-80 ºC [7]. Therefore, in order to obtain low temperature of POME as required for Test 1, POME is stored in a cool room for one night before the experiment was conducted. The temperature of 26.6 ºC is an annotation that the experiment is conducted at ambient temperature, as the experimental setup is done at the outside of the laboratory.

As for both Test 2 and Test 3, the POME samples are taken directly from the discharge pipe and the experiment is done subsequently. Heat is loss along the way, however as the temperature difference between Test 1 and both Test 2 and 3 are high, these temperature drop is negligible.

Initial pH value for Test 3 is increased by adding concentrated Sodium Hydroxide into the digester tank filled with POME. Sodium hydroxide has alkali characteristic, which will help to reduce the acidity of POME and neutralizes it. From the literature review made previously, increasing pH value of POME towards near neutral condition will help providing the ample condition for microorganism or digestive bacteria to digest the waste more efficiently [10]. By adding an alkaline characteristic solution, this neutral state of POME pH value can be achieved. Therefore, the relationship between pH value and volume of methane gas generated can be identified and analyzed by having these two different pH value tested.

Inside the gas chamber, it is explained that there are NAOH solutions with functions as a purifier to extract all carbon dioxide gas generated together during the digestion process, allowing only pure methane gas is trapped inside the chamber. The reactions between NAOH and gas generated from the anaerobic digestion activity are as follows:

$$CO_2(g) + NAOH(l) \rightarrow NA_2CO_3(s) + H_2O(l) \qquad (4.1)$$

Nett Ionic Equation: $$OH^- + CO_2 \rightarrow CO_3{}^{2-} + H_2O \qquad (4.2)$$

These following tables and graphs are the findings gained from all tests conducted. Further analysis and discussion on the results are done consecutively after the comparison is done.

Table 7 - Calculated Data for Test 1

Day	Height (cm)	Volume (m^3)	Volume (l)	Time (hr)	Gas Flow Rate, (l/hr)	Cumulative Volume, (l)
0	0	0	0	0	0	0
1	0.7	0.00009292	0.09292465	24.08	0.003858	0.09292465
2	0.7	0.00009292	0.09292465	25.17	0.003692	0.18584930
3	0.5	0.00006637	0.06637475	23.58	0.002814	0.25222405
4	0.3	0.00003982	0.03982485	24.17	0.001648	0.29204890
5	0.4	0.00005310	0.05309980	21.00	0.002529	0.34514870
6	0.3	0.00003982	0.03982485	26.17	0.001522	0.38497355
7	0.2	0.00002655	0.02654990	24.33	0.001091	0.41152345
8	0.2	0.00002655	0.02654990	23.25	0.001142	0.43807335
9	0.5	0.00006637	0.06637475	24.58	0.002700	0.50444810
10	0.2	0.00002655	0.02654990	23.50	0.001130	0.53099800

Table 8 - Calculated Data for Test 2

Day	Height (cm)	Volume (m^3)	Volume (l)	Time (hr)	Gas Flow Rate, (l/hr)	Cumulative Volume, (l)
0	0	0	0	0	0	0
1	13.6	0.000185849	0.1858493	23.00	0.0080804	0.18584930
2	12.3	0.000172574	0.1725744	24.00	0.0071906	0.35842365
3	11.2	0.000146024	0.1460245	24.83	0.0058802	0.50444810
4	10.3	0.000119475	0.1194746	22.17	0.0053898	0.62392265
5	9.3	0.000132750	0.1327495	23.92	0.0055505	0.75667215
6	8.6	0.000092925	0.0929247	25.33	0.0036681	0.84959680
7	7.8	0.000106200	0.1061996	24.08	0.0044097	0.95579640
8	6.8	0.000132750	0.1327495	19.83	0.0066933	1.08854590
9	6.1	0.000092925	0.1858493	26.00	0.0035740	1.18147055
10	5.5	0.000079650	0.1725744	24.25	0.0032845	1.26112025

Table 9 - Calculated Data for Test 3

Day	Height (cm)	Volume (m^3)	Volume (l)	Time (hr)	Gas Flow Rate, (l/hr)	Cumulative Volume, (l)
0	0	0	0	0	0	0
1	2.5	0.000331874	0.331874	20.83	0.015930	0.331874
2	2.3	0.000305324	0.305324	25.75	0.011857	0.637198
3	1.9	0.000252224	0.252224	23.58	0.010695	0.889422
4	1.6	0.000212399	0.212399	24.92	0.008524	1.101821
5	1.3	0.000172574	0.172574	21.08	0.008185	1.274395
6	1.0	0.000132750	0.132750	25.08	0.005292	1.407145
7	1.1	0.000146024	0.146024	25.75	0.005671	1.553169
8	0.9	0.000119475	0.119475	23.00	0.005195	1.672644
9	0.6	0.000079650	0.079650	24.58	0.003240	1.752293
10	0.7	0.000092925	0.092925	23.00	0.004040	1.845218

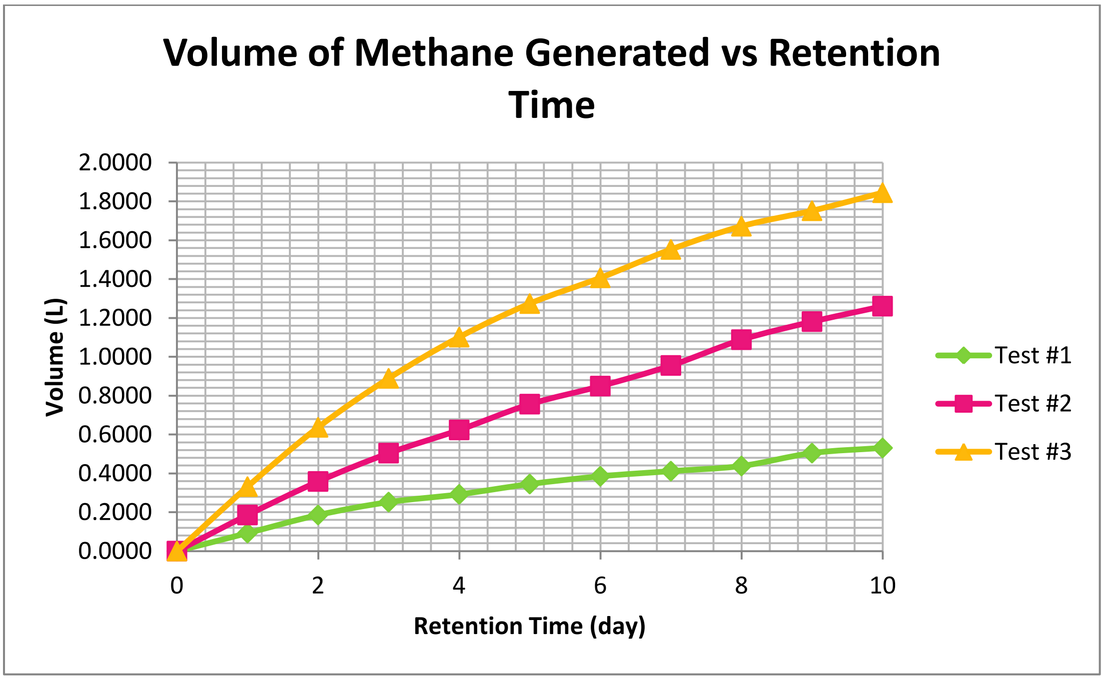


Figure 10 - Graph of Volume of Methane Gas Generated versus Retention Time

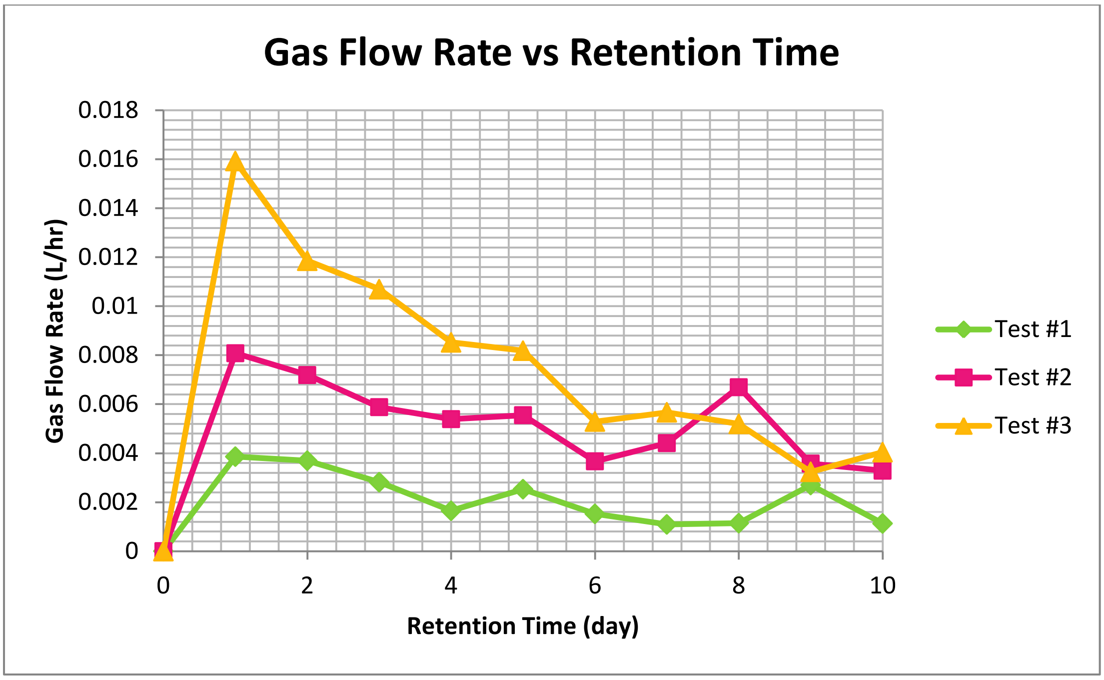


Figure 11- Graph of Gas Flow Rate versus Retention Time

The graphs show the relationship between cumulative volumes of methane gas generated versus ten days of retention time, and the relationship between rate of methane gas generated versus ten days retention time for all test. Based from the graphs, the general pattern of increasing volume of methane gas for all three tests is seen clearly. However, the difference in gradient of all three tests shows that, Test 3 is the one with highest volume of methane gas generated, following by Test 2 and Test 1.

Meanwhile, the pattern for rate of methane gas formation versus retention time is comparatively the same for all three tests. During the beginning stage of retention days, it can be seen that all three tests are having their peak rate of biogas generated. Obviously the rate of methane gas generated is the highest on Test 3, followed by Test 2 and Test 1. Further comparison on the rate of methane generated will be explained by comparing Test 1 and Test 2 to identify the influence of initial temperature, and Test 2 with Test 3 to identify the role of pH value.

Comparing Test 1 and Test 2 in terms of initial temperature of POME, Test 2 gives a better yield for rate of methane gas generated than Test 1. Higher initial temperature of POME is contributing to an optimum condition for microorganism to digest POME and generate methane gas. As anaerobic digestion consists mainly of 4 stages namely hydrolysis, acidogenesis, acetogenesis and methanogenesis, the influence of high temperature would actually helping the bacteria to complete these four stages faster.

From the relationship between rate of biogas generated and retention days, the same pattern can be seen, with Test 2 yielding a higher rate than Test 1. The influence of initial temperature also affecting the rate or biogas generated, the reason of this to happen is the same as mention previously. From the same graph, there were some inconsistencies on the rate of gas formation. This might due to the change of ambient temperature during the retention time takes place. As been mentioned previously, the test is conducted at uncontrolled ambient temperature (environment temperature). As current treatment of POME at FELCRA Nasaruddin is also done under uncontrolled environment temperature, this factor is omitted from the consideration due to its small influence towards the biogas formation rate.

In general, the initial temperature solely, is not the contributing factors of methane gas generation. The ability of the digester to preserve or keeping the temperature constant at high temperature is the factor that matter most in this experiment. From the table, one can see that the volume of methane generated each day is fluctuating, and reducing; i.e. day by day the formation of methane gas becomes lesser. This is because of the inability of the digester fabricated to preserve the temperature, maintaining POME at high temperature so that the volume of methane gas generated is constantly high. This applies to all the tests done, especially Test 1 and 2 as the influence of temperature is being observed and analyzed from both tests.

Moving on to comparison between Test 2 and Test 3 in terms of volume of methane gas generated. Definitely from the graph of methane volume against retention time, Test 3 is overall having a higher volume compared to Test 2. Test 2 and 3 are both having more or less the same initial temperature. However, the difference in initial pH value, especially for Test 3 which is having an optimum initial pH value influenced the overall volume of methane gas generated. Optimum pH value for the optimum methane gas formation is around 6-7. This will provide suitable neutral condition for the microorganisms especially methanogen in methanogenesis stage to digest and to produce methane gas faster.

In Test 2, the initial pH value is maintained to be around 4.78 during the retention days and 7.05 for Test 3. However during the test, the pH value is decreasing, due to formation of Volatile Fatty Acids (VFA) during acidogenesis stage. This decrement in pH value by some means had influenced the rate of methane gas generated. This is because there are indications that the acidity of POME is increasing. By having acidogenesis stage controlled, the acidity of the waste as whole can be controlled. This effect of acidity will be explained further during the comparison between Test 2 and Test 3.

The pattern in rate of methane gas generated against time for both Test 2 and 3 is observed. It shows quite the same pattern as in Test 1 and 2. The fluctuating rate is due to the surrounding temperature, which is negligible. Despite that, Test 3 still is having a higher rate of methane production compared to Test 2. The microbial activity in Test 3 is more active than one in Test 2. The microorganisms are able to digest the waste at their optimum condition, resulting higher yield of methane gas generated.

From the beginning of this discussion part, the importance of serving the bacteria an optimum condition for them to digest the waste is often been mentioned. This is because, anaerobic digestion are solely depending on the bacteria to decompose the material, minerals and nutrient inside the POME to produce methane gas. When this happens, the quality of POME as an effluent is increased and simultaneously energy from this waste is harvested in terms of biogas. Optimum conditions are mainly important to make sure that the bacteria are able to stay alive and decomposing POME successfully. Such care and tedious work need to be done in order to maintain the bacteria condition as it will contribute to the performance of the digester in terms of volume of methane gas generated.

Other than having pH value maintained at neutral condition and temperature controlled during the retention time, inducing mixing as providing some mechanism that will helps to mixed up the POME inside the digester would also helps to improve the digester performance as it helps to generate methane gas more. This is because POME tends to settle down after few days, having this darker sedimentation at the bottom side of the digester, and lighter coloured solution at the upper side of the digester.

After completion of the retention time, there is also formation of thin layer of fungus at the upper part of POME wastewater observed. This uneven layer of POME inside the digester might as well affect the microbial activity of decomposing the waste. As pH value is obtained by opening the valve at the bottom of the digester, this uneven layer of POME might be having different concentration, as well as different pH value and it might affect the volume of methane generated.

In order to calculate the efficiency of the digester, the following formula is used:

$$\eta_{digester} = \frac{volume\ generated}{calculated\ volume} \times 100\% \qquad (4.3)$$

Based from the three tests conducted, the best test that is selected to find the digester efficiency is Test 3 with total volume of 1.845 Litre for 10 days, with average volume of gas generated of 0.1845 Litre gas per day. Thus, the equation of finding the efficiency of the digester is as follows:

$$\eta_{digester} = \frac{0.1845}{1.77} \times 100\% \rightarrow \mathbf{10}\%$$

The percentage of efficiency is rather low and identification of factors that are contributing to this low value of efficiency is determined. The main factor of this low efficiency is the ability of microorganism or bacteria to work at the manipulated unstable condition. As been mention above, the designated prototype does not equipped with mixing mechanisms allowing a formation of oil layer on top of the effluent. When this happen, the gas generated is trapped inside the solution.

Also, the setup experiment might not be air-tight enough to prevent outside air from entering the system, disallowing the anaerobic digestion principle to be performed. This might explain the uneven concentration of pH value of effluent layers. Due to this inconsistency, the bacteria digesting activity is not happening as a same rate. Another contributing factor is that, POME sample taken directly from the outlet valve of mill process contains low amount of oil. Although it is low, it is enough to trap the biogas generated from flowing into the gas chamber. This might be another reason for the oil formation on top of the layer.

The design of the digester itself, are most likely the main contributor to its low efficiency. It does not helping to improve the condition of the POME. Although studies and reviews on related papers for this project are done, the development of the digester is still lacking. There are insufficient technologies, or mechanism induced by the digester in order to provide the best condition for the methane gas to be digested optimally. Other than manipulating the initial temperature and initial pH value of the effluent, maintaining and providing appropriate circulation inside the digester itself are actually vital to produce optimum volume of biogas. Further studies related to treating POME with intention to optimize the characteristics of BOD and COD is required.

In terms of the experimental procedure, delicately having the experiment conducted is an obligation. Tubes that were connected from the digester to the gas chamber need to be secured tightly so that biogas captured is channelled to the chamber. Also, the top inlet of the chamber need to be always closed, to prevent biogas escaping to the environment, and to provide vacuum condition inside the chamber. If the NAOH solution inside the chamber requires refill, the gas valve is switch off manually. Then only the top inlet of the chamber can be opened to refill the solution.

During the experiment, any samples that must be taken to be tested can only be taken from the outlet pipe designated at the bottom part of the digester. The upper part is sealed throughout the retention days as to allow anaerobic digestion activity takes place. Also, it is assumed that only pure methane gas is inside the chamber after completing the retention days. There are possibilities that the gas might escape to ambient air during refill of NAOH solution. These explain the low value of the digester efficiency.

Based from the volume of methane gas generated from the designed digester, further discussion relating the potential volume of methane gas generated, and volume of POME discharged from FELCRA Nasaruddin is studied. It was stated that for $1m^3$ of POME discharged will produce around $28m^3$ volume of biogas which methane yield from the gas is around 54-70%.

FELCRA Nasaruddin production of CPO is approximately around 72 ton/day. Based from this production of CPO, around 216 ton/day of POME is discharged. From this value, it is estimated that 216 m^3/day volume of POME discharged to the environment will emit biogas with volume approximately around 6, 048 million m^3/day. This biogas volume generated will yield methane gas production around 3, 265 million m^3 volume.

According to the theoretical calculation made earlier in the project, 18 Litre per day of POME digested inside the fabricated digester will generate 0.00177 m^3 volume of methane gas per day. Based from this theoretical calculation, 20.24 m^3 of pure methane gas is generated if the digester is functioning with 100% efficiency. However, in this project, 1.845×10^{-5} m^3/day volume of pure methane is generated when 0.018 m^3/day of POME is been digested inside the fabricated digester. If FELCRA Nasaruddin were to utilize this digester, this 216 m^3/day volume of POME discharged will result an approximate volume of 0.022 m^3/day of methane generated.

It is expected that the volume of methane gas generated from the fabricated digester is rather low. Discussions on the efficiency of the digester have been made in earlier page of the chapter. However, the potential of having all POME discharged from FELCRA Nasaruddin digested and harvesting of methane gas from this anaerobic digestion activity is very high. If there are chances to improvise the current design and specifications of the digester, it has to be made tediously in order to ensure optimum volume of POME could be digested, resulting optimum volume of pure methane gas will be obtained.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As a conclusion, a preliminary study on methane gas generation for Palm Oil Mill Effluent (POME) of FELCRA Nasaruddin using anaerobic is done using a digester designed and fabricated based on calculated formula and identified theory. The designed prototype is able to digest POME and generate methane gas suggested as a biomass energy source in electricity generation for co-firing biomass boiler. Basic characteristics of POME and factors affecting the performance of the digester have been studied. Tests were conducted to analyze the performance of digester fabricated in terms of volume of methane gas generated. Digester efficiency is calculated by comparing the theorotical value of methane calculated and the actual value of methane obtained during the test.

There are some important findings gained from this study. Based from the tests conducted, it can be concluded that when initial temperature of POME is higher, the volume of methane gas generated also is higher. Other than factors of intial temperature that influence the rate of methane gas production, the pH value of POME also affects the rate of methane gas production. This projects proves that despite higher initial temperature, POME with pH value nearest with neutral value produce higher value of methane gas production. The digester is having only 10% efficiency as compared to the theorotical value calculated earlier. Therefore, the discussions made earlier was done to analyze the results and come with further suggestions to improve the digester efficiency.

Based from the tests conducted, volume of methane generated and comparison in terms of the digester efficiency, it can be concluded that this current design of digester is looked as small step towards harvesting alternative, environmental friendly energy from abundant waste to replace the depleting source of existing energy for human good. Further recommendations and suggestions to improve the digester characteristics and performance are writen on the next subtopic.

5.2 Recommendation

There a many improvements that can be made in order to produce a more desirable output. For example, introducing thermal insulation to the digester would be helpful in maintaining high temperature of POME. Plastic container are tough and transparent. However, by adding this thermal insulation outside the digester container, any changes experienced by POME during the retention time takes place cannot be seen visibly. Therefore, a meterial that can withstand high temperature and transparent such as perspex is more suitable. There are also consideration to replace plastic with metal sheets, provided a visible part of the digester body and appropriate insulation to the digester.

Also, inducing mixing mechanism or heating element to the prototype would also be one of the recommendation to improve the performance of the digester to achieve the desired output. Inducing heating element will help to cope with loss of heat to the surrounding, allowing the digester to work under thermophilic conditions. This will helps capturing higher volume of methane gas.

More features can be added to the existing design in order to increase the product marketability. Apart from its main objective to develop an anaerobic digestion concept of digester to generate optimum output of methane gas, this project is also intended to raise people awareness about green technology and the importance of utilizing the energy available in the surrounding, especially this abundant agricultural waste. The prototype can further be improved by reducing its size while maintaining its capability to produce the same or greater amount of output. The digester can be further improvised to be used for other types of wastewater, such as sewage sludge.

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APPENDIX A

Project Gantt Chart

No	Details / Week	FYP 1 Timeline														
		1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Topic	■							Mid Semester Break							
2	Preliminary Reseach Work		■	■	■	■										
3	Submission of Extended Proposal					■	■									
4	Estimation of Project Performance					■	■	■								
5	Preliminary Design stage							■		■	■					
6	Proposal Defence									■	■					
7	Material Survey and Purchasing									■	■	■				
8	Preliminary Fabrication Stage									■	■	■	■	■		
9	Submission of Interim Draft Report														■	
10	Submission of Interim Report															■

No.	Details / Week	FYP 2 Timeline														
		1	2	3	4	5	6	7	8		9	10	11	12	13	14
1	Project Work Continues									Mid Semester Break						
2	Progress Repost Submission															
3	Project Work Continues															
4	Pre SEDEX															
5	Draft Report Submission															
6	Dissertation Submission (Soft Bound)															
7	Technical Paper Submission															
8	Oral Presentation (Viva)															
9	Dissertation Submission (hard bound)															