ENHANCE SUSTAINABLE METHANE PRODUCTION FROM ANAEROBIC CO-DIGESTION OF POME USING UASB (HYDRAULIC RETENTION TIME)

TAN JIA XIANG

BACHELOR OF ENGINEERING TECHNOLOGY
(INFRASTRUCTURE MANAGEMENT)
UNIVERSITY MALAYSIA PAHANG

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TAN JIA XIANG

Report submitted in partial fulfillment of the requirements
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(Supervisor's Signature)

Full Name : DR. NURUL ISLAM SIDDIQUE

Position : SUPERVISOR

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____

(Co-supervisor's Signature)

Full Name : IR. AHMAD TAMIZI BIN ALI

Position : CO-SUPERVISOR

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Dedicated to my parents

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ABSTRACT

Palm Oil Mill Effluent (POME) is a waste of palm oil mills. This material is highly biodegradable and produces tremendous amount of methane gases when it is being digested. Most palm oil mill treats this material by leaving it in an open environment pond. The POME left in the pond will decompose and release methane gas into the environment. Methane gas is 20 times stronger than carbon dioxide to cause greenhouse effect as it destroys the atmosphere rapidly. In order to prevent the release of methane gas into the environment, the decomposition of POME must occur in a closed environment. Anaerobic digestion is a method that allows material to decompose without the presence of oxygen. Anaerobic co-digestion can improve the methane yield when different type of material are mix together. In this study, cow manure is mixed with POME for the co-digestion process at a ratio of 50:50. Upflow Anaerobic Sludge Blanket (UASB) reactor allows waste mixture to decompose within an enclosed environment. The sludge blanket consist of microorganism that digest the waste as it passes through it. During digestion the waste will produce methane gases which will then be collected by the equipment for other purposes. In this paper, we will be studying the effects of Hydraulic Retention Time (HRT) on the yield of methane gas. Hydraulic retention time are known as the average length of time that a compound remains within a storage unit before it is being discharge. HRT is important since the growth of anaerobic bacterial depends on the quantity of time needed and subsequently converting organic material to biogas. Hydraulic retention time is dependable on the flow rate of the effluent into the reactor. For this study, three retention time of 5, 10 and 15 days are conducted based on flow rate of 200, 100, 66.67 mL/day. The flow rate is based on how many days is required for 1000 mL of effluent to pass through the reactor. At the end of the study, the results showed that HRT 15 days showed the highest amount of methane yield with a flow rate of 66.67 mL/day. This shows that the waste material needed more time in order for it to digest entirely to produce high amount of methane gas.

ABSTRAK

Efluen kilang kelapa sawit (POME) adalah pembaziran kilang kelapa sawit. Bahan ini sangat biodegrasi dan menghasilkan banyak gas metana apabila ia dicerna. Kebanyakan kilang minyak kelapa merawat bahan ini dengan meninggalkannya di kolam persekitaran terbuka. POME yang tersisa di dalam kolam akan mengurai dan melepaskan gas metana ke dalam alam sekitar. Gas metana adalah 20 kali lebih kuat daripada karbon dioksida untuk menyebabkan kesan rumah hijau dan ia memusnahkan atmosfera dengan cepat. Untuk mengelakkan pelepasan gas metana ke alam sekitar, penguraian POME mesti berlaku dalam persekitaran tertutup. Pencernaan anaerobik adalah satu kaedah yang membolehkan bahan mengurai tanpa kehadiran oksigen. Pencernaan anaerobik boleh meningkatkan hasil metana apabila jenis bahan yang berlainan bercampur bersama. Dalam kajian ini, tahi lembu dicampur dengan POME untuk proses pencernaan pada nisbah 50:50. Reaktor Upflow Anaerobic Blanket (UASB) membolehkan campuran sisa untuk mengurai di dalam persekitaran tertutup. Selimut kumbahan terdiri daripada mikroorganisma yang mencerna sisa yang melepasinya. Semasa penghadaman, sisa akan menghasilkan gas metana yang akan dikumpulkan oleh peralatan untuk tujuan lain. Dalam makalah ini, kita akan mengkaji kesan Waktu Pengekalan Hidraulik (HRT) terhadap hasil gas metana. Waktu pengekalan hidraulik dikenali sebagai panjang purata masa yang sebatian kekal di dalam unit simpanan sebelum ia dilepaskan. HRT adalah penting kerana pertumbuhan bakteria anaerobik bergantung pada kuantiti masa yang diperlukan dan seterusnya mengubah bahan organik kepada biogas. Waktu pengekalan hidraulik adalah bergantung kepada kadar aliran efluen ke dalam reaktor. Untuk kajian ini, tiga masa pengekalan 5, 10 dan 15 hari dijalankan berdasarkan kadar aliran 200, 100, 66.67 mL / hari. Kadar aliran adalah berdasarkan berapa hari diperlukan untuk 1000 mL efluen untuk melepasi reaktor. Pada akhir kajian, hasil menunjukkan bahawa HRT 15 hari menunjukkan jumlah tertinggi metana hasil dengan kadar aliran 66.67 mL / hari. Ini menunjukkan bahawa bahan buangan memerlukan lebih banyak masa supaya ia dapat dicerna sepenuhnya untuk menghasilkan jumlah gas metana yang tinggi.

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LIST OF ABBREVATIONS

AD	Anaerobic Digestion
POME	Palm Oil Mill Effluent
UASB	Upflow Anaerobic Sludge Blanket
WWTPs	Waste Water Treatment Plants
COD	Chemical Oxygen Demand
UASBR	Upflow Anaerobic Sludge Blanket Reactor
ADM1	Anaerobic Digestion Model Number 1
MPOB	Malaysian Palm Oil Board
FFB	Fresh Fruit Bunch
HRT	Hydraulic Retention Time
BOD	Biochemical Oxygen Demand
VS	Volatile Solids
SS	Suspended Solids
TS	Total Solids
C:N	Carbon/Nitrogen Ratio
FELDA	Federal Land Development and Authority
ASB	Activated Sludge Biomass

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Anaerobic digestion (AD) is a process that allows organic matter to be broken down by microorganism in the absence of oxygen. AD can be used to treat various organic waste to produce bio-energy such as biogas which consists mainly of methane, CH4 and carbon dioxide, CO2. Anaerobic digestion have four stages in its operation; Hydrolysis, Acidogenesis, Acetogenesis, and Methanogenesis.

Anaerobic co-digestion involves two or more types of waste in the process. Theoretically by combining different types of waste, the yield of bio-gas will be higher making this method more effective in treating waste materials. Although co-digestion may produce higher efficiency in methane production, different types of materials used have different impact on the yield of methane gas. This is because the difference in reactivity and compatibility between different materials.

Palm oil mill effluents, which are also known as POME are liquid waste product that are produced from palm oil milling factory. These liquid wastes have high polluting properties in which they release methane gas into the atmosphere and are often treated before it can be discharged into water body such as river and streams. POME are highly biodegradable due to its organic properties.

Upflow Anaerobic Sludge Blanket (UASB) is a technology that is normally used for wastewater treatment. This anaerobic digester utilizes anaerobic microorganism to form blanket of granular sludge by breaking down the organic waste that was feed into the reactor. The type of reactor used by UASB is well known for its capability to collect biogas such as methane that is produced during digestion process within the reactor. The collected biogas can then be stored and use for various purposes.

1.2 PROBLEM STATEMENT

Contaminations of soil and water body by POME have serious impact to the environment due to the large amount of methane gas that is released into the atmosphere. Methane gas has known to be 20 times stronger than carbon dioxide to cause greenhouse effect. Due to the high yield of methane gas by this waste material, anaerobic digestion method was adapted to serve as a waste management for this material.

To prevent POME from directly discharged into the natural elements, many palm oil mills and refineries have their very own method to treat these waste material. Open pond system was widely adapted as waste treatment system for POME as it is relatively cheap and easy to install. But due to the open air properties of this method, methane gas is being released directly into the atmosphere when decomposition of POME is occurring within the pond.

Methane has variable uses ranging from cooking gas to natural gas for vehicles. In order to utilize the methane gas produced by digesting POME, Upflow Anaerobic Sludge Blanket (UASB) technology can be used. This system comprise of a UASB reactor that provides a closed environment for anaerobic digestion of POME. By doing so, the methane gas released from the digestion can be captured effectively and transported for storage for further use. This method will also help in preventing harmful methane gas from entering into the atmosphere, in which will reduce greenhouse effect.

Anaerobic digestion has proven effective in treating POME. This qualitative study will explore the performance of UASB reactor in methane production yield when co-digestion of POME with other waste materials is being adapted. This paper will study the feasibility of co-digestion of POME with other materials by obtaining methane gas production yield.

In this study, we will determine how hydraulic retention time affects the yield of methane gas from anaerobic co-digestion of POME. Hydraulic retention time measures the average of a compound stay within a confined space. This study will show the productivity of anaerobic co-digestion with the influence from hydraulic retention time. We will study the rate of yield of methane gas using anaerobic co-digestion of POME with Upflow Anaerobic Sludge Blanket method based on the hydraulic retention time of the digesting materials.

1.3 OBJECTIVE

The objectives of the research are:

i. To study the effects of hydraulic retention time on the yield of methane in anaerobic co-digestion of POME using UASB.

1.4 SCOPE

The scopes of the research are:

i. The source of POME obtained will be consistent throughout the research.
ii. The temperature and pH value of in the UASB tank will be consistent throughout the research.
ii. Different hydraulic retention time will be studied to obtain the best methane yield.

1.5 THESIS ORGANIZATION

This thesis consists of 5 chapters. Chapter 1 describes the introduction of the research. Chapter 2 discusses the literature reviews which explain existing problem or solution and compare related works on the research. Chapter 3 discusses the methodology used in this research. Chapter 4 describes the implementation process of the technique and the analysis of result in the project. Chapter 5 contains the conclusion of the research findings.

CHAPTER 2

LITERATURE REVIEW

In Chapter 1, we have discussed on the research introduction consisting of the problem statement, objective and scope. In this chapter, we will discuss on the relevant literature review to understand the application of anaerobic digestion and co-digestion, properties of UASB reactor, nature of biogas, properties of POME and effect of hydraulic retention time in AD process.

2.1 OVERVIEW

Anaerobic Digestion can bring new energy source by harnessing the biogas that is produce during the process. POME is an abundant source to serve as material for this technique as it is a by-product from manufacturing of palm oil. In Malaysia, palm oil manufacturing is one of the major production industries, making more POME to be generated from each production. UASB is the technology that can carry out this technique effectively. Further research such as co-digestion suggested that more waste can be combined with POME for effectiveness in digesting these materials, acquiring more energy for shorter period of time. Thus, co-digestion through UASB is the new technology in handling waste and also producing alternative energy at the same time.

2.2 ANAEROBIC DIGESTION AND CO-DIGESTION

Anaerobic digestion (AD) is the reaction of decaying organic matter without the presence of oxygen, it can happen either in a controlled system of naturally. In natural state, anaerobic digestion occurs when organic matter degrades and decays, by-product such as gases are released into the atmosphere, which in turn worsen the greenhouse effect. A control state of anaerobic digestion is an old technology that is used to stabilize organic material waste in a closed environment, and recently energy production is adapted by harnessing its by-product such as biogas (Sevda et al, 2013). Anaerobic digestion that is being used for bioenergy production through treatment of organic wastes often uses agricultural residues and animal manure (Nizami et al, 2013). The main products produced by anaerobic digestion are methane and carbon dioxide. The processes include hydrolysis, acidogenesis and methanogenisis. Methane CH4, are produced through the process of methanogenis. Through anaerobic digestion, large amount of organic material waste can be reduced and alternative energy can be obtained at the same time.

Anaerobic digestion is well known for its low cost solution in treating organic matter waste. Many countries around the world had been using this method to deal with the large amount of waste produced every day. Wastewater treatment plants (WWTPs) can adapt this technology in waste management and energy production. In China, more than 8 million anaerobic digesters are operating and Nepal has more than 50,000 units to reduce the amount of waste (IEA, 2005). In some countries, the biogas produced are being upgraded by removing the excess carbon dioxide and other contaminants, leaving only ‘biomethane’ that can be used for multiple purposes such as electrical generation and heating. Compressed biomethane can be used for vehicular fuel (Korres et al, 2010).

Anaerobic digestion is extremely useful both economically and environmentally. The treatment of organic material waste using AD system reduces the amount of waste that is left in the environment. By doing so, contamination of soil and groundwater can be reduced and greenhouse effect can also be reduced by minimizing the amount of high energy gases in the atmosphere. Economically, this system provides alternative inexpensive energy. Biogas such as methane is a valuable energy source in the electric generation industry. Biogas is used by combustion engines that powers electrical generator through mechanical energy of the combustion engine .The low cost technology of AD system can help underdeveloped countries to obtain energy at minimal expenses with high energy output.

Anaerobic co-digestion refers to the used of two or more type of organic substrates in an AD system. By carefully selecting the proper feedstock to be combined with a based substrate in an AD system, the production of biogas per unit mass can be increased significantly. The basic principle of co-digestion is to produce a higher yield of biogas than treating one type of organic substrate in the AD system through addition of other biodegradable substrate. According to Tasnim et al (2017), it is believed that by using effective combination of organic matter waste materials and controlled condition, a better result can be obtained. However, there are chances for improper combinations of waste material to produce hazardous by-product. It is advised to evaluate all the materials before use.

The physical and chemical properties of feedstock need to be considered carefully for maximum output of biogas. In many cases, long chain woody molecules such as lignin are hard to be broken down by anaerobic microorganism (Wastesum, 2006). The theoretical methane yield for a given feedstock depends on the chemical oxygen demand (COD) value (Owen et al, 1979). For a hundred percent conversion efficiency, one gram of substrate COD will result in 350mL of methane at standard temperature and pressure (Korres and Nizami, 2013).

The physical properties of organic material wastes are also one of the key contributions to the yield of methane during anaerobic digestion. Sizes of solid are one of the factors that determine the yield of methane. Smaller particle size would provide more surface area for increased microbial activity to take place (Lusk et al, 1996). Large feedstock size will cause clogging within the reactor, slowing down the digestion process. According to K. Aboudi et al (2017), it is proven that digestion of organic material with higher total solid concentrations (8%) produces higher methane yield as compare to digestion of the same material at with lower total solid concentrations (5%). Their result shows a significant difference of 1.5 folds in specific methane production.

Not only biogas are produced using AD system that are able to provide resource for electric and heat generation, AD system will also produce semi-solid by product called digestate that are not digested during the process. Most digestate contains high level of macro and micro nutrients that are environmentally safe to be used for alternative mineral fertilizer than can potentially improve soil fertility and quality (Muscolo et al, 2017). This by-product further enhances the performance of AD system in disposing organic material waste product.

2.3 UPFLOW ANAEROBIC SLUDGE BLANKET REACTOR (UASBR)

An UASBR is an enclosed tank that allows anaerobic digestion to take place. There are many types of UASB reactor used for AD. In general, wastewater is fed into the tank from below, promoting an upward motion of the wastewater. A suspended sludge blanket within the reactor filters and treats the wastewater as the wastewater flows upward and passes through it. The upstream velocity within the tank must be controlled along with the sludge settling speed as to allow steady growth of the sludge blanket which is made up of anaerobic bacteria. The upstream velocity must also be kept constant in order to prevent the active sludge from washing out. Mixing device is not required for UASB reactor.

The main characteristic of a UASB reactor is its three phase separator function. This ability allows UASB reactor to separate three states of matter which is solid, liquid and gas. The UASB must be able to retain the solids (sludge blanket) within the reactor, preventing it from washing out whilst allowing liquid (wastewater) to pass through the sludge blanket and flow out through an outlet above the tank (Naturgerechte et al, 2001). The UASB must also be able to collect gases that are produced by AD through a specific outlet for transferring gas to another section.

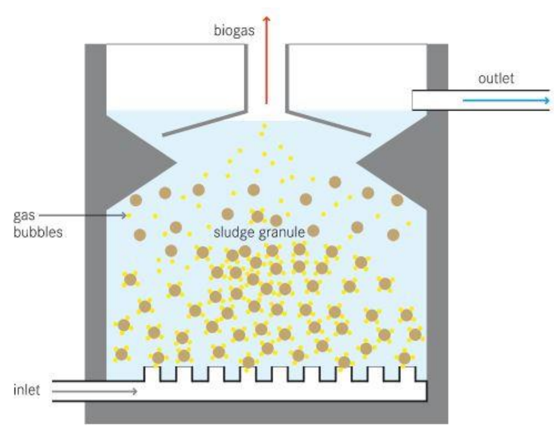

Figure 2.1: Typical structure of UASB reactor (Tilley, 2008)

Referring to Figure 1, wastewater influent is fed into the reactor via inlet pipe located at the bottom of the tank. The pressure from inlet pipe pushes the wastewater into an upward motion. As anaerobic bacteria build up with time, a sludge blanket is formed. Deflector at the side of the wall helps to maintain the sludge, preventing it from washing out through the outlet pipe. Wastewater that passes through the sludge will then be transfer out from the tank via outlet pipe that is located at the top of the tank. A special funnel is built at the top center of the tank to collect and provide passage for biogas that is produce by AD.

The microbial granules that form the sludge blanket are typical range in size of 1 to 3mm diameter. The weight of these micro granules resists being washed out from the tank by the upflow motion. The main purpose of the bacteria within the sludge blanket is to degrade the organic waste material that passes through it. Anaerobic digestion takes place within the sludge blanket. Gases such as methane and carbon dioxide are the end result of this process. Clarified effluent will be extracted via outlet pipe to allow more space for influent to enter into the tank. After several weeks, large chunk of granular sludge are formed. These large sludge blankets help to accumulated smaller particles to form a larger sludge blanket that can filter more influent that passes through it.

There are a few factors to consider when designing a UASB reactor. Sludge retention and transfer are the most important aspect to consider for designing the reactor. To accommodate different organic substrates at related operational conditions, different types of AD models have been developed (Lohani, 2016). In 2002, a general benchmark for anaerobic digestion modeling was developed by The International Water Association (IWA) task force. The model developed is called Anaerobic Digestion Model Number 1(ADM1). Conducted by 7 bacterial groups, the ADM1 involves 19 chemical processes for substrates decomposition, hydrolysis, acidogenesis, acetogenesis and methanogenesis. The initial purpose of this model is to monitor the sludge digestion at different temperature conditions. But recent studies are using it for various type of organic waste including blackwater and high strength CO2 capture amine waste at varied temperature.

2.4 BIOGAS

Conventional energy sources such as petroleum, natural gas, coal are used to fulfill demands in many sectors. But the extractions of these natural resources are exhausting them rapidly with the advancement of countries all over the world (Kadam and Panwar, 2017).

Developing countries without natural energy resource faced difficulties in advancing their technology energy demand. With worldwide energy consumption growing at a rapid pace, alternative renewable energy source like biogas, biomass, wind and solar are needed to accommodate the increasing demand of energy sources.

Biogas is a mixture of gases produced during digestion of organic matter in absence of oxygen. The organic matters that produce these gases are mostly agricultural waste, manure, sewage or food waste. Biogas can be obtained through the method of anaerobic digestion. Two of the main substances that are found in the biogas are methane, CH4 and carbon dioxide, CO2. Some impurities such as hydrogen, ammonia and other substances can be found in very small portion within the biogas. Biogas such as methane has the same chemical properties as natural gas, making it an alternative energy source for electric generation. Methane gas is 20 times stronger than carbon dioxide to cause greenhouse effect. By harnessing methane and using it as an alternative energy source, this help the environment by eliminating methane from the atmosphere while replacing non-renewable energy source such as fossil fuels.

Biogas extracted from AD system can be upgraded to be used for vehicular fuel by elimination of unwanted impurities and compression of methane gas. Renewable methane gas that are extracted and upgraded are called biomethane. Production of biomethane from anaerobic digestion is receiving increasing attention as one of the most important biofuels (Monlau et al., 2014). However, traces of hydrogen in biogas must be removed as the corrosive properties of hydrogen on metal surface. Water vapor will lower the heating value of methane gas as well. Thus biogas that is extracted from AD system requires extensive post treatment before it is being transferred into any pipeline system for energy distribution.

Table 2.1: Typical Composition of Biogas and Natural Gas (Kadam and Panwar, 2017)

Component	**Biogas**	**Natural Gas**
	Compositions	
Methane (%)	40-75	87-97
Carbon dioxide (%)	25-55	0.1-1.0
Hydrogen sulfide (ppm)	50-5000	NA
Ammonia (%)	0-1	NA
Nitrogen (%)	0-5	0.2-5.5
Water (%)	0-10	NA
Hydrogen (%)	0-1	Trace-0.02
Oxygen (%)	0-2	0.01-0.1

As can be seen in Table 1, the composition of methane from biogas is 40-75% which is relatively low compared to 87-97% of methane yield in natural gas. It can also be observed from the table that biogas contains more impurities than natural gas. Biogas contains traces of ammonia, water and hydrogen sulfide which are not found in natural gas. Some of these impurities can cause maintenance problem when it is passed down through pipeline. Hydrogen sulfide and water must be removed completely from biogas as it can cause chemical corrosion which will damage the pipeline or any container. Therefore, biogas must be cleaned before it can be fed into other pipeline.

2.5 PALM OIL MILL EFFLUENT (POME)

Palm oil mill effluent is a type of wastewater generated from the process of palm oil milling. It is often found from oil extraction, washing and cleaning processes in the mill. During anaerobic process, POME produces tremendous amount of methane gas which is harmful to the environment as methane gas is 20 times stronger than carbon dioxide to cause greenhouse effect. Data shows that about 2.5 m3 of raw POME will be generated for 1.13 m3 of crude palm oil processed (Ma and Ong, 1988). However, methane is a renewable energy source for alternative energy to replace conventional energy source such as natural gas. By using anaerobic digestion, methane gas can be harness from biogas collected from the anaerobic digester.

In many palm oil mills in Malaysia, POME is treated using lagoons and open ponds. This method highly allows the methane gas generated during anaerobic process to escape into the atmosphere, increasing the greenhouse effect. In Sarawak, methane gas had been collected and burned to power gas turbine which then generates energy to be sent to Sarawak energy. According to Malaysian Palm Oil Board (MPOB), 0.65m3 of POME is generated from each ton of processed fresh fruit bunch.

Table 2.2: Parameters for estimating CH4 from POME adopted from Sarawak Energy (2013)

Parameters	**Value**	**Unit**
Fresh Fruit Bunch	9,288,000	ton/year
POME yield	6,037,200	m^3/ton
Biogas yield from POME	25	m^3-biogas/m^3
CH_4 gas fraction in biogas	0.625	m^3-CH_4/m^3
CH4 emitted	0.94×10^8	m^3
Electricity equivalent (38% efficiency)	3.6×10^8 or 41	kWh

From Table 2, we can observe that the annual fresh fruit bunch (FFB) is obtained at an amount of 9,288,000 ton. 6,037,200 tons of POME is generated from the amount of FFB. 65% of FFB will be turned into POME. The tremendous amount made POME fairly abundant in Malaysia palm oil industry. With the amount of POME produce each year in Malaysia palm oil industry, biogas utilization can bring upon new alternative energy source for the country, saving cost of electric generation. Although anaerobic digestion can bring upon solution to treating this number of organic waste and providing alternative energy source, only a few biogas utilization applications can be found on Peninsular Malaysia. One of the few biogas refineries in Malaysia that captures biogas to produce electricity can be found in Rompin, Pahang.

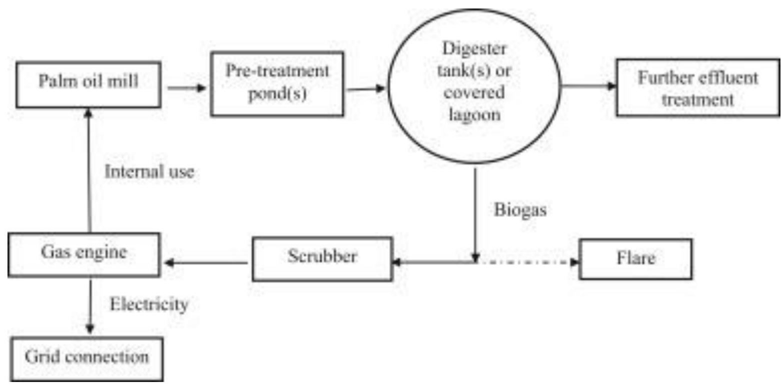

Figure 2.2: Process flow of capturing biogas to produce electricity for grid-connection or internal use. (NKEA, 2014)

Capturing Biogas for alternative energy use helps generate economic return from energy value of POME. The Malaysian Government encourages the harnessing biogas from POME as alternative fuel for electric generation (Loh et al, 2017). Palm oil mills in Malaysia are receiving extra revenues in treating POME and reduce methane emissions to the environment. High global concerns over the environment produce strict standards by palm oil importing countries. Capturing and utilizing of biogas will help to ease the current predicament sustained by the environment.

2.6 HYDRAULIC RETENTION TIME

Hydraulic retention time (HRT) can be defined as the average amount of time that a compound remains within a storage unit before it is being discharge. Hydraulic retention time is an important aspect to be considered when designing a digestion system as it influence the economics of digestion and methane yield (Anonymous, 2009). HRT is important since the growth of anaerobic bacterial depends on the quantity of time needed and subsequently converting organic material to biogas. The most common problem faced by many wastewater treatment plant are the variations in HRT and it is normally caused by changes in wastewater characteristic and production with HRT often significantly affects the treatment performance of biological treatment system(Eker and Kargi, 2006; Han et al., 2010).

In general, longer retention time provide better methane yield as the anaerobic bacteria is fully grown, allowing more waste to be digested. Shorter retention time might cause washout of bacterial sludge which is not fully formed within the reactor. The size of sludge blanket must be large enough for the deflector to hold it in place. Longer retention time requires larger digester which causes higher capital cost (Sreekrishnan et al, 2004).
Hydraulic retention time (HRT) is defined as the average length of time of a compound remains within a storage unit before it is being discharge. It can be calculated by the volume of storage over influent flow rate.

$$\text{HRT} = \frac{\text{Volume of storage}}{\text{Influent flow rate}}$$

Units: Volume (m3)
Flow Rate (m3/day)

There are several aspects to be considered when reducing the HRT in AD process. Buekens (2005) stated that the aspects are:

i. Separating the digestion stages to assist the growth of bacteria in order to optimize their performance.
ii. Improvements in the mixing ratio of different waste in anaerobic co-digestion process.
iii. Introducing surface materials such as foam or other porous carriers to allow bacteria to colonize and grow permanently on as washout of bacteria is reduced.
iv. Choosing the appropriate feedstock pre-treatment to increase the digestibility.

CHAPTER 3

METHODOLOGY

3.1 SAMPLE COLLECTION AND CHARACTERIZATION

Table 3.1: Characteristics of raw POME (Krishnan, 2016)

Parameter	**Concentration (mg/L)**
Palm Oil Mill Effluent (POME)	
pH	5.1 ± 0.2
Biochemical oxygen demand (BOD)	3500 ± 500
Chemical oxygen demand (COD)	56,500 ± 300
Total carbohydrate	16,400 ± 200
Total nitrogen	960 ± 100
$NH_4^+ - N$	810 ± 100
Total phosphorus	110 ± 1
Phosphate	22 ± 1
Oil	109,000 ± 20
Total solids (TS)	32,000 ± 300
Volatile solids (VS)	26,000 ± 400
Suspended solids (SS)	8300 ± 200
Ash	4500 ± 200
Fe	2 ± 0.1

Table 3.2: Characteristics of cow manure (Khairuddin, 2015)

Parameter	Value
Cow Manure	
pH	7.5
Total solids (%)	15.2
Volatile solids (%)	13.8
Moisture content (%)	50.4
C:N	11.2
Ammonia (g/L)	26.88

3.2 PRE-TREATMENT OF ACTIVATED SLUDGE

Activated sludge is made with mixing ratio 50:50 of POME and cow manure. Pre-treatment of activated sludge by thermal can efficiently enhance CH4 generation by 20% and decrease stringy particle sizes (Angelidaki and Ahring., 2000). Therefore, activated sludge were heated up to 100-145 °C before AD to improve CH4 yield and volatile solids loss (Mladenovska et al., 2006).

3.3 SEEDING

The reactor will be seeded with a combination of waste activated sludge (0.5L), partially granulated waste activated sludge consisting of cow manure (0.5L). Both of the waste activated sludge were obtained from FELDA, Pahang, Malaysia. 1L of waste activated sludge comprising 18.9 g of total solids (TS), 0.5L of waste activated granulated sludge comprising 41.5 g of TS was mixed and preserved at 4 °C in cold room. The mixed anaerobic microbial culture was filtered by passing through a 0.05 inch mesh size screen and thickened by settling for 2.5 hours before to be used as inoculum. The TS content of the UASBR was 66.3 g. A 64 and 39 g/L of total suspended and volatile suspended solids were fed to the UASBR (Siddique et al., 2015). Combined activated sludge biomass (ASB) formation was executed according to the procedure of (Ahmad et al., 2010). The mixture below is added as an energy resource for ASB cultivation 3.0 g/L K_2HPO_4, 0.1 g/L $MgSO_4$ .7 H_2O, 0.3 g/L $CaCl_2$. 2 H_2O, 0.01 g/L $FeSO_4$. 7 H_2O. The initial pH of the medium was 4.5. Subsequently, pH at 7.0 was maintained using 1N NaOH throughout incubation period.

3.4 UASB SETUP AND OPERATION

A schematic drawing of the UASB reactor on the total experimental setup is shown in Figure 3.1. Conventional UASBR design is not able to maintain the pH and temperature in an appropriate way. pH, temperature sensor and digital pressure display are installed in order to obtain a good control over the system. The reactor was fabricated in university workshop. The UASB reactor used in this study was measured with a dimension determining the reactor's total (3.5 L) with working volume of (1 L). The main reactor is constructed of glass and stainless steel. Steel plate capping in conjunction with 6 nuts is used to completely seal the reactor to prevent any air contact. Deflectors were installed within the reactor to help retaining the sludge blanket. Heater has also been installed in the system to maintain the temperature within the reactor. Feeding tank has also been added to serve feeding. Biogas generated within the reactor will be collected through a biogas collection tank passing through a digital gas flow meter that will measure the amount of gas collected. The UASBR was operated at mesophilic condition of 37 °C with an electric heater. The effectiveness of the UASBR was examined by studying the biogas generation. The operational design for the experimental runs in schematic drawing was shown in Figure 3.1.

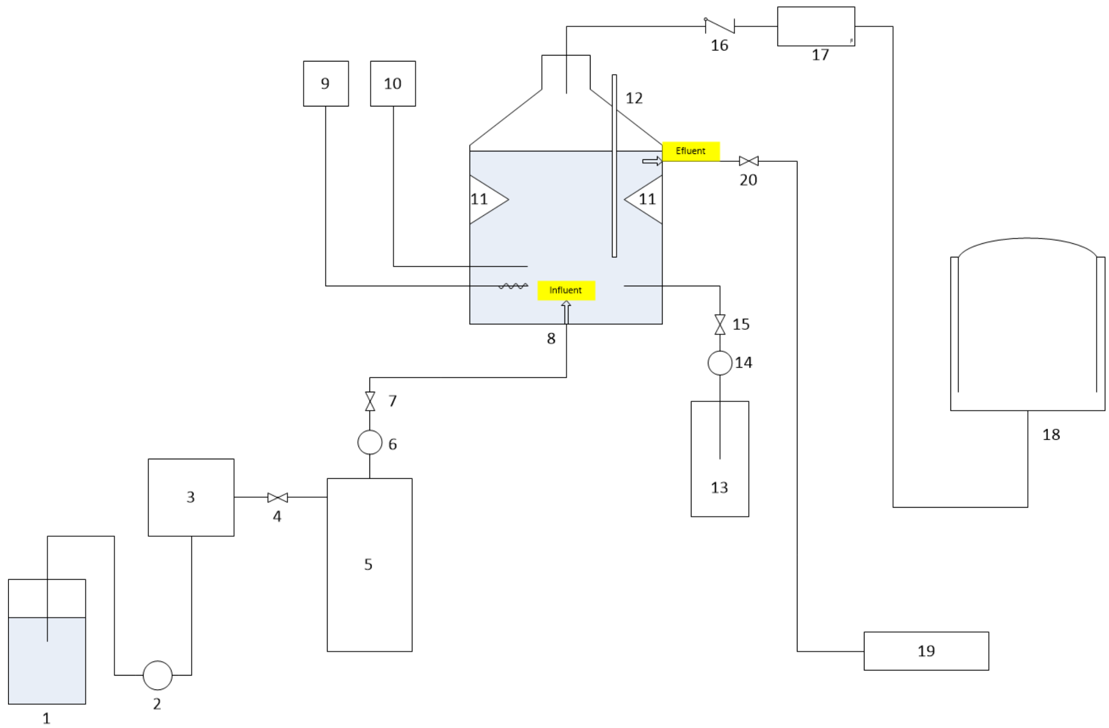

Figure 3.1: Schematic drawing of the UASB reactor on the total experimental setup.

Table 3.3: Legend entries for Figure 3.1

No.	Item	No.	Item	No.	Item
1	Dosing zone	8	UASB reactor	15	Control valve
2	Peristaltic pump	9	Heater	16	Check valve
3	Power generator	10	Temperature sensor	17	Biogas flow meter
4	Control valve	11	Deflectors	18	Biogas collection tank
5	Feeding tank	12	pH sensor	19	Drain
6	Peristaltic pump	13	Acid base control tank	20	Control valve
7	Control valve	14	Peristaltic pump		

3.5 COMPUTING HYDRAULIC RETENTION TIME USING FLOW RATE

Throughout the AD process, the amount of biogas will be recorded at different HRT. 5, 10, 15 days HRT will be recorded. The hydraulic retention time is manipulated by changing the flow rate of influent to the UASB reactor. The flow rate is determined by how many days it would take for 1000 ml of effluent is injected into the reactor. By injecting certain amount of untreated effluent into the reactor, we expect the same amount of treated effluent is discharged from the reactor itself. The amount of biogas collected is recorded at the end of experiment. Due to co-digestion method, shorter retention time is needed to achieve the same methane yield as conventional AD. The average AD process with one type of feeding material requires up to 30 days of HRT.

Table 3.4: Flow rate for 1000 ml to pass through the reactor resulting in HRT

Days	Flow Rate (ml/Day)	HRT
5	200	5
10	100	10
15	66.7	15

3.6 ANALYSIS

Liquid displacement was used to determine the amount of biogas generated, this ensures atmospheric temperature and pressure corrections. Shimadzu Class-GC 14B gas chromatography apparatus armed with a Porapak N column and thermal conductivity detector will be used to analyze the biogas constitution. The results of the biogas constitution are obtained from UMP central lab.

3.7 FUNCTIONAL AND PERFORMANCE PARAMETERS

The functional and performance parameters of this study constitute of HRT. The parameters were calculated by the relationship below:

i. Flow Rate

The ratio of working volume of reactor and HRT can be defined as flow rate. The smaller the diameter of tube hose, the smaller the flow rate of the influent flow and vice versa.

$$\text{Flow Rate} = \frac{\text{Volume of Influent}}{\text{Days}} \quad (1)$$

ii. Hydraulic Retention Time

HRT can be defined as the mean time that a fluid retain within a reactor. In other words, HRT is the time consumed by a liquid entering from inlet to the outlet until all soluble matter could be degraded.

$$\text{HRT} = \frac{V}{Q} \quad (2)$$

3.8 FLOW CHART

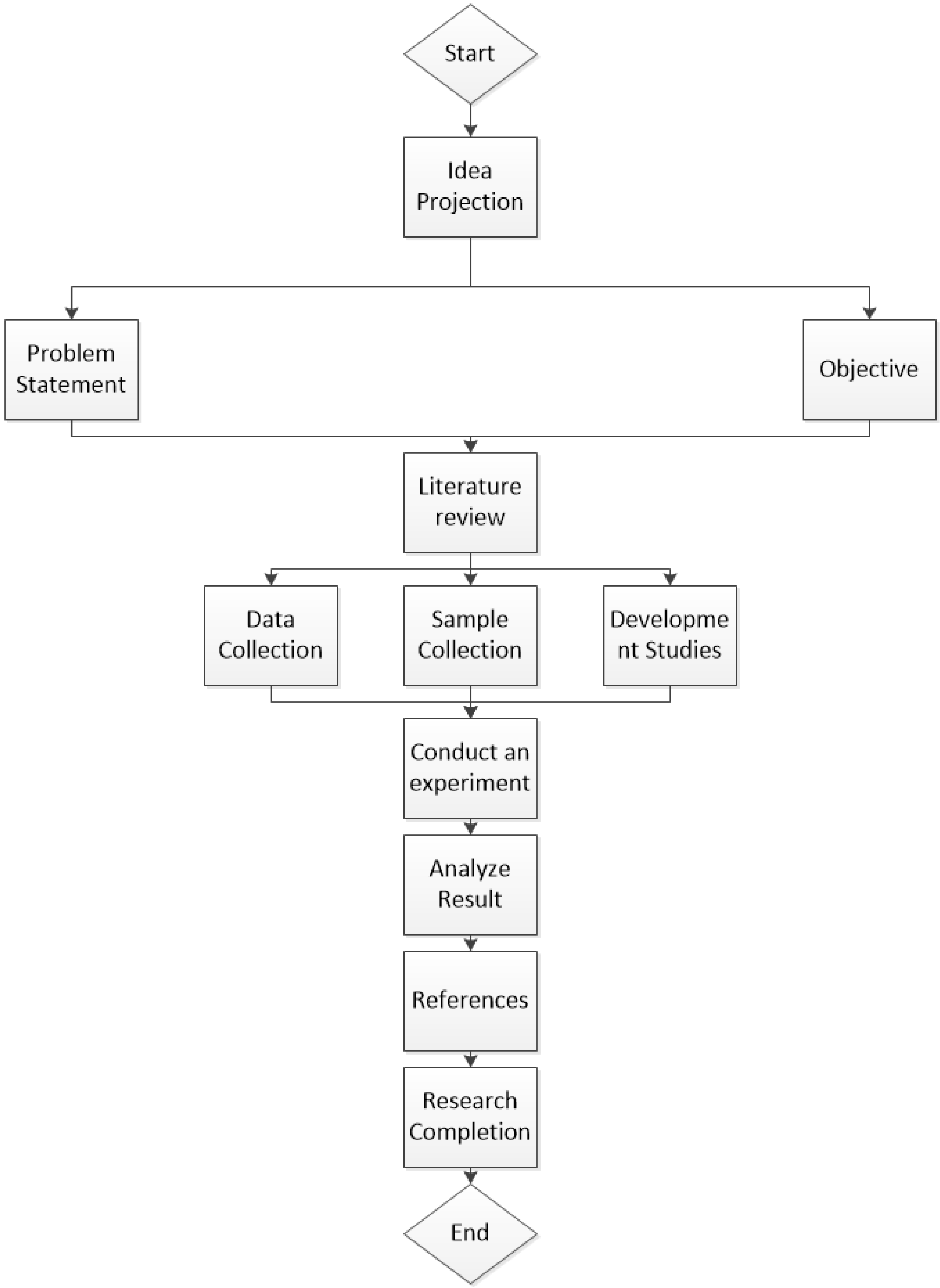

Figure 3.2: Flow Chart

3.9 GANTT CHART

Table 3.5(a): Gantt Chart Senior Design Project 1

No	MONTH / ACTIVITIES	February			March				April				May				Jun			
		2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	SDP1 Briefing	■	■						MID SEMESTER BREAK							REVISION WEEK	EXAMINATION WEEK			
2	Proposal Preparation			■	■	■	■	■		■	■	■	■							
3	Progress Report Preparation			■	■	■	■	■		■	■	■	■							
4	Proposal Presentation													■						
5	Proposal Submission														■					
6	Log Book Submission														■					

Table 3.5(b): Gantt Chat Senior Design Project 2

No	ACTIVITIES / MONTH	September 1	September 2	September 3	September 4	October 1	October 2	October 3	October 4	November 1	November 2	November 3	November 4	December 1	December 2	December 3	December 4	January 1	January 2	January 3	January 4
1	SDP2 Briefing	■						MID SEMESTER BREAK								REVISION WEEK	EXAMINATION WEEK				
2	Collecting Sample		■	■	■																
3	Experiment					■	■		■	■	■	■	■	■							
4	Progress Report Preparation					■	■		■	■	■	■	■	■							
5	Proposal Presentation														■						
6	Report Submission																	■			
7	Log Book Submission																	■			

3.10 EXPECTED OUTCOME

The expected outcome of this study is that with longer HRT, higher methane yield can be obtained. This is due to the longer time for bacteria to form a stable sludge blanket to accelerate AD process. Co-digestion method will also show significant decrease in HRT retention time to produce better methane yield.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter describe the experimental outcomes and discussion of anaerobic co-digestion of POME using UASB reactor. In this part, results are described in terms of effect of hydraulic retention time on the methane generation performance. Purpose of this implementation is to show how hydraulic retention time affects the methane production from anaerobic co-digestion of POME in UASB reactor. The mixing ratio, temperature and pH in this experiment are kept constant in order to obtain accurate result.

4.2 CHARACTERIZATION OF PALM OIL MILL EFFLUENT

The characterized parameters of POME are pH, BOD, COD, total solids, total nitrogen etc. The POME characterization were summarized in Table 4.1.

Table 4.1: Composition and Characteristics of POME

Parameters	**POME**
pH	7.3
BOD	378
COD	1828
Total solids	8662
Total Nitrogen	203
Ammoniacal Nitrogen	260
Oil and Grease	4
Total Phosphorus	79.88

Except pH all parameters in mg/L and Phosphorus in ppm

Values are the mean + S.D. of the 3 determinations

Table 4.2 shows the filtered values obtained for each parameter determined for filtered mixture.

Table 4.2: Composition and Characteristics of filtered mixture

Parameters	**Raw POME**	**Filtered Solution**
pH	7.3	8.4
BOD	378	374
COD	1828	1278
Total solids	8662	2332
Ammonical Nitrogen	203	250
Nitrate	260	304
Oil and Grease	4	<1
Total Phosphorus	79.88	75.27

Except pH all parameters in mg/L and Phophorus in ppm

Values are the mean + S.D. of the 3 determinations

4.3 EFFECT OF HRT ON UASB REACTOR PERFORMANCE

In order to study the methane production, the pH and temperature are kept constant throughout the experiment period. In order to stimulate the growth of bacteria, I have selected the temperature of 37^{o}C allowing the reactor to operate at mesophilic condition. This stimulates an environment inside a living organism. The temperature of the mixture is maintained using a heater and thermometer installed along with the reactor. The pH of the mixture is kept at 7.0 to enhance the growth of bacteria. The pH value of the mixture is maintained by an acid-base control tank that are installed along with the reactor.

Table 4.3: An anaerobic UASB Bioreactor performance operated at (mesophilic condition) 37˚c at varying HRT under steady state condition

Parameters	HRT (d)		
	5	10	15
Total biogas production (m^3/Kg)	0.398	0.578	0.808
Total methane (m^3/Kg)	0.26	0.41	0.62
Methane production (%)	65.3	70.9	76.7
pH	7.0	7.0	7.0

From the table above, it can be seen that the total biogas production for 5 days HRT is relatively low compared to HRT of 10 days and 15 days. This is due to the reduced time in order for the sludge blanket to digest the effluent that passes through it. This proves that the same amount of effluent needed more time in order for it to be digested entirely to production that amount of methane gas. Furthermore, 15 days HRT has the highest percentage of methane exist within the biogas. This reading shows that the UASB is the most efficient with a 15 days HRT as the total methane production and percentage is the highest.

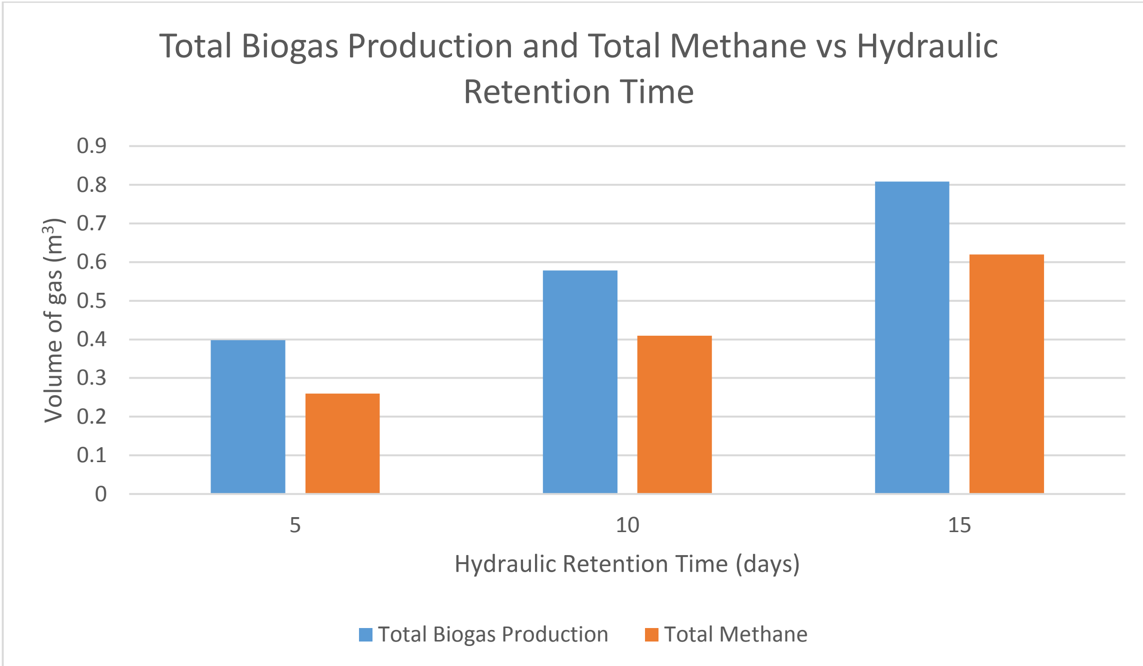

Figure 4.1: Table representing total biogas production and total methane versus hydraulic retention time

As can be seen from figure 4.1, the generation of biogas and methane increase as the amount of HRT increases. This shows that longer HRT is required to allow more effluent to be completely digested. Low HRT results in rather low amount of methane production. The composition of biogas collected mainly comprised mainly of Methane, Nitrogen, Hydrogen and other gases.

4.4 OPTIMAL OPERATING FLOW RATE

The hydraulic retention time is determined by changing the flow rate of the effluent flowing into the UASB reactor. This is due to the formula of HRT.

$$\text{HRT} = \frac{\text{Volume of storage}}{\text{Influent flow rate}}$$

The flow rate is the amount of effluent in ml flow into the UASB reactor per day.

Table 4.4: Results of total biogas and methane by flow rate affecting HRT.

Trial	**Flow rate (mL/d)**	**HRT (days)**	**Total Biogas (m^3/kg)**	**CH4 (m^3/kg)**	**pH**	**Methane Production (%)**
1	200	5	0.398	0.62	6.5	65.3
2	100	10	0.578	0.71	6.5	70.9
3	66.67	15	0.808	0.85	6.5	76.7

The flow rate indicates the amount of effluent is pumped into the UASB resulting in the HRT indicating the amount of days needed to inject 1000 ml of effluent into the UASB reactor. In this case, the optimal flow rate is 66.67 mL/day. The particular flow rate requires 15 days to pump 1000 ml of effluent into 1000ml working volume of the reactor. The results of total amount of CH4 resulted in the highest of all. This shows that the 1000 ml of effluent produces more CH4 with a slightly longer retention time in the UASB reactor.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

The previous chapter discussed the outcome of anaerobic co-digestion of POME using UASB reactor. This episode will explain the significance of the results obtained. Recommendation and future works will be explained based on the analyzed methane production rate and effectiveness of co-digestion of POME with cow manure.

5.2 CONCLUSIONS

As of the intensive growth in technology, UASB has not been the most extensively practiced anaerobic reactor strategy treating of wastewaters. Many palm oil mill are still using the regular ponding system for treating POME. This research investigates the combined effect of POME with cow manure on anaerobic co-digestion strategy to determine the significant enhancement in bioenergy production.

Co-digestion of POME with cow manure in proportion of (50:50) successfully increased methane production up to 50-60% compared to conventional treatment systems. From the operational trials conducted, it is suggested that the optimum HRT might be 15 days. The reason is due to the extent amount of time allowed the waste to be fully digested by the sludge blanket. Additionally, the amount of energy produced may be utilized in a boiler to for heating purposes. It can also be harnessed and stored as long term combustion fuel for internal combustion engine that are used by power generation factory which uses this technique. The novelty of this research is that the retention time of this study is significantly shorter compared to previous studies with this type of reactor. The POME was digested almost entirely by co-digestion with cow manure, the final slurry can be expected to be used as some form of soil improvement material for reformative properties. This shows a novel conversion, but some industries might find it essential as a municipal wastewater network.

This research provide the following novel contributions: The major contribution of the research is the success of combination with two type of municipal waste utilizing framework of chemical and biological coupled treatment technology. The second contribution is it successful implementation treating POME along with the compliance to the environmental regulations.

The key finding of anaerobic co-digestions of POME with cow manure is:

Optimum HRT was an important operating parameter that improved the COD degradation and methane production efficiency. Longer HRT (15 days) improved bioconversion of POME to methane.

5.3 FUTURE WORKS

The successful application of this technology can be expanded by recommending further research below:

1. The utilization of anaerobic co-digestion with UASB reactor has shown its effectiveness in converting wastewater into methane. The accumulated methane gas can further be collected and be used as form of combustion material for various type of energy generators.

2. UASB reactor is currently successful in application for treating wastewater containing non-inhibitory substrate at high concentration, e.g., distillery waste,

brewery waste, and sugar industry waste. Complex industrial wastewater which consist of some inhibitory compounds can be counter with proper modification on the system. With further development and research in this direction will lead to successful application of UASB for treating food processing waste, gelatin manufacturing plant waste, slaughterhouse waste, etc.

3. Cow manure and POME are great source of methane gases as they decompose. Palm oil mill industry can utilize this method to further increase their profit by collecting the methane gas produced by the decomposition of POME and sell it to other parties that can use it to generate electricity to the public. This also help improve the environment condition by preventing the release of methane gas into the atmosphere.

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APPENDIX A

Basic Calculations of Reactor Performance Parameters

Sample Calculation

$$\mathrm{HRT} = \frac{V_W}{Q}$$

- Flow rate, Q = 1000mL / 5d

  = 200mL/d

- Working Volume, V_W = 1000 mL

  HRT = V_W / Q

  = 1000 mL / 200 mL /d

  = 5 days

APPENDIX B1

Measuring the pH of POME.

APPENIDX B2

Preparation of activation sludge.

APPENDIX B3

Comparison between POME and mixture of POME and cow manure after experiment.

APPENDIX B4

Activation treatment of sludge.