EVALUATION OF PALM OIL MILL EFFLUENT (POME) BY MEMBRANE ANAEROBIC SYSTEM (MAS)

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RAJALETCHUMY A/P VELOO KUTTY

A thesis submitted in fulfillment
of the requirements for the award of the degree of
Bachelor of Chemical Engineering (Biotechnology)

Faculty of Chemical & Natural Resources Engineering
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APRIL 2010

I declare that this thesis entitled “Evaluation of Palm Oil Mill Effluent (POME) by Membrane Anaerobic System (MAS)” is the result of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date	: 30 APRIL 2010

Dedicated especially to my beloved Father, Mother, Siblings, Friends, Lecturers and the ones who give me inspiration and support that made this work possible.

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ABSTRACT

The evaluation of anaerobic digestion process of palm oil mill effluent (POME) was carried out in a laboratory-scale membrane anaerobic system (MAS). The MAS consists of a cross-flow Ultra-filtration membrane for solid-liquid separation and operational pressure of 1.5 to 2 bars. An enrichment mixed culture of methanogenic bacteria was developed and acclimatized in the digester for three days when the POME is fed into the 30 L digester combining Ultrafiltration (UF) membrane MAS is a modern bioreactor and was used for the rapid biotransformation of organic matter to Methane gas with the help of Methanogenic bacteria. Two concentration ratios of 50% and 100% of the raw POME were studied. The hydraulic retention time (HRT) ranged between 1 and 4 days. Throughout the experiment, the removal efficiency of COD was between 78.81% and 81.44%. The methane gas production rate was 0.673 L/g COD/d to 0.974 L/g COD/d. The effluent flow rates for the two ratios were found as 10.31 L/d and 21.75 L/d respectively. The pH was between 6.8 and 7.7. The membrane anaerobic system, MAS treatment efficiency was greatly affected by solid retention time, hydraulic retention time and organic loading rates. In this study, membrane fouling and polarization at the membrane surface played a significant role in the formation of the strongly attached cake layer limiting membrane permeability.

ABSTRAK

Evaluasi proses pencernaan anaerobik sisa kilang kelapa sawit (POME) dilakukan dalam skala makmal membran sistem anaerob (MAS). MAS terdiri daripada Ultra-penapisan membran untuk pemisahan pepejal-cecair dan tekanan operasi 1.5 hingga 2 bar. Kultur campuran bakteria metanogen dibangunkan dan dibiarkan menyesuaikan diri dalam Digester selama tiga hari untuk menyesuaikan diri dengan persekitaran POME dimasukkan ke dalam Digester 30 L menggabungkan Ultrafiltrasi (UF) membran Bioreaktor moden dan digunakan untuk merawat bahan organic dan menukarkan kepada metana dengan bantuan bakteria metanogen. Sample POME yang mempunyai dua jenis kepekatan yang berlainnan telah dikaji iaitu kepekatan sebanyak 50% dan 100%. Masa penahanan hyroulik (HRT) berkisar antara 1 dan 4 hari. Sepanjang percubaan, kecekapan penyisihan COD adalah antara 78.81% dan 81.44%. Tingkat pengeluaran gas metana adalah 0,673 L / g COD / hari untuk 0,974 L COD / g / hari. Aliran sisa cecair untuk kedua-dua kepekatan dijumpai sebagai 10.31 L / hari dan 21.75 L / hari. pH adalah antara 6.8-7.7. Sistem anaerobik membran, MAS kecekapan perubatan sangat dipengaruhi oleh masa penahanan hyroulik pepejal, masa penahanan hyroulik dan tahap beban organik. Dalam kajian ini kerosakan membran dan polarisasi pada permukaan membran memainkan peranan penting dalam pembentukan lapisan pejal yang mempengaruhi ketelapan membran.

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LIST OF SYMBOLS / ABBREVIATIONS

BOD	Biological Oxygen Demand (mg L^{-1})
COD	Chemical Oxygen Demand (mg L^{-1})
CO_2	Carbon Dioxide
CUF	Cross flow Ultra filtration Membrane
CH_4	Methane gas
DOE	Department of Environment
EFB	Empty Fruit Bunches
ETP	Effluent Treatment Bunches
FFB	Fresh Fruit Bunch
HRT	Hydraulic Retention Time (day)
H_2	Hydrogen gas
MAS	Membrane Anaerobic System
MRE	Mixed Row Effluent
MWCO	Molecular Weight Cut Off
NaOH	Sodium Hydroxide
NH_3	Ammonia gas
POME	Palm Oil Mill Effluent
SS	Suspended Solids
TSS	Total Suspended Solid (mg L^{-1})
UF	Ultra-Filtration membrane

CHAPTER 1

INTRODUCTION

1.1 Background of research.

Malaysia is a major producer of palm oil in the world. The production of crude palm oil reached 17.73 million tonnes in the year 2008, increases to 19.64million tonnes in year 2009 (MPOB, 2009). This amount will continuously increase in proportion to the world demand of edible oils seeing as palm oil already is bio-diesel product. Although the palm oil industry is the major revenue earner for our country but it has also been identified as the single largest source of water pollution source due to the palm oil mill effluent (POME) characteristic with high organic content and acidic nature.

In palm oil mills, liquid effluent is mainly generated from sterilization and clarification processes in which large amounts of steam and hot water are used (zinatizadeh *et al*., 2006). For every ton of palm oil fresh fruit bunch, it was estimated that 0.5-0.75 tones of POME will be discharged (Yacob *et al*.,2006) . In general appearance, palm oil mill effluent (POME) is a yellowish acidic wastewater with fairly high polluting properties, with average of 25,000 mg/L biochemical oxygen demand (BOD), 55250 mg/L chemical oxygen demand (COD) and 19610mg/L suspended solid (SS). This highly polluting wastewater can cause several pollution problems and also create odor problems to the neighborhoods of the mills such as a nuisance to the passers- by or local residents and river pollution. Thus, there is need to prevent environmental pollution due to the increase of crude palm oil production.

Over the past 20 years, the technique available for the treatment of POME in Malaysia has been basically biological treatment, consisting of anaerobic, facultative and aerobic pond systems (Chooi, 1984; Ma, 1999). The pond system has been applied in our country for POME treatment since 1982 (Ashhuby *et al*.,1996). Most of the pond system that has been applied for the treatment of POME in Malaysia was classified as waste stabilization pond. The configuration of this system consists of essentially a number of ponds of different functions such as anaerobic, facultative and aerobic ponds. Thus, anaerobic ponds are one of the most effective treatments that are being applied in Malaysia either in pond system or close digesting tank systems to treat highly concentrated POME wastewater. This is because the anaerobic process has considerable advantages such as (a) it demands less energy, (b) sludge formation is minimal, (c) unpleasant odors are avoided, and (d) anaerobic bacteria efficiently break down the organic substances to methane (Rincon *et al.,* 2006).

Anaerobic digestion is the breakdown of organic material by micro-organisms in the absence of oxygen. Although this takes place naturally within a landfill, the term normally describes an artificially accelerated operation in closed vessels, resulting in a relatively stable solid residue. Biogas is generated during anaerobic digestion which mostly methane and carbon dioxide and this gas can be used as a chemical feedstock or as a fuel. The digestion process begins with bacterial hydrolysis of the input materials in order to break down insoluble organic polymers such as carbohydrates and make them available for other bacteria. Acidogenic bacteria then covert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. Acetogenic bacteria then convert these resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. Methanogens finally are able to convert these products to methane and carbon dioxide.

Throughout this research, a membrane anaerobic system (MAS) at steady state was operated continuously at different hydraulic retention time (HRT) and waste concentration in order to evaluate the performance of the reactor in term of biogas production.

1.2 Problems statement.

As mentioned earlier, large quantities of POME wastewater are produced from the crude palm oil extraction process. This large amount of wastewater if discharged untreated into freshwater, estuarine and marine ecosystems may alter aquatic habitats, affect aquatic life and adversely impact human health. However, the treatment of wastewater is always a burden and costly for many industrialists. Therefore, a new and effective approach in wastewater treatment technology should be developed to comply with stringent environmental regulations on the quality of the effluent entering receiving waters.

In relation to that, several POME wastewater treatment plants have been successfully operated but majority of the plants are still struggling to observe the Malaysian discharge standards under Environmental Quality Act (EQA 1974) (Prescribed Premises) (Crude Palm Oil) Regulations in 1977. Most of the palm oil mill industries are facing a common problem; an under designed wastewater plant to cope with ever growing production. Though installation of higher capacity plant and new alternative treatment system such as membrane technology will be an alternative but it always involves a high cost. In practice, it has been observed that all industries prefer simple, low cost wastewater treatment technology.

Throughout this research study, the studies would be focused on the Anaerobic digestion is considered to be an effective treatment process for (POME). This involves a consortium of microorganisms catalyzing a complex series of biochemical reactions that mineralize organic matter producing methane and carbon dioxide. The key factors to successfully control the stability and efficiency of the process are reactor configurations, hydraulic retention time (HRT), waste concentration, pH, and temperature. In order to avoid a process failure and low efficiency, these parameters require an investigation so that they can be maintained at or near to optimum conditions.

Generally, these anaerobic digestions are conducted at either mesophilic (30ºC - 37ºC) or thermophilic (50ºC - 60ºC) temperatures. In a palm oil mill processing system, the wastewater is discharged at relatively high temperatures (70ºC - 90ºC) (Najafpour *et al*. 2006), making it feasible to treat the POME at either mesophilic or thermophilic temperatures. Therefore, this research study is required to investigate the efficiency of MAS to treat POME.

1.3 Objectives of the study

This research aims to examine the performance of POME wastewater in the anaerobic reactor which works under room temperature. The specific objectives are:

- To evaluate the efficiency of Membrane Anaerobic System in term of Methane gas production.
- To experimentally assess the influence of waste concentration and retention times on the parameters (COD, TSS, Turbidity, Manganese and Iron).

1.4 Scope of the research

The treatment of POME wastewater is in demand due to the pollution problems created from the high volume of wastewater generated by the palm oil mill industry. The anaerobic digestion process is the main focus in this study. To accomplish these objectives, a laboratory scaled membrane anaerobic system (MAS) with an effective 20 liter volume used to treat Palm Oil Mill Effluent (POME). The laboratory digester is completely semi-continuous process followed steady state operation. There also some limitations of these studies to ensure all results are base on parameters. The limitations are:

- Using optimum temperature for anaerobic digestion in the mesophilic range at 25°C-45°C
- The pH of the reactor content maintain at 6.8-7.7
- Using 0.5 M NaOH as a solvent to absorb the carbon dioxide, CO_2
- The operating pressure is maintain at 1.5-2.0 bar
- Using two different waste concentration (50% and 100%) and Hydraulic retention times (HRT) is 4 days
- Volume of Methane gas was measure daily, using J-Tube analyzer.
- The COD, TSS, Turbidity, Manganese, Iron and pH of feed's and permeate are measure every day.

1.5 Rationale and significant.

Rationally, this research can help to develop another environmental friendly alternative to overcome the emission of green houses gases such as methane and carbon dioxide to the atmosphere. This is because anaerobic digestion produces biogas from biodegradable waste that can be burnt to generate heat or electricity or also can be used as a vehicle fuel.

Anaerobic digestion technology serves dual-function that is as wastewater treatment and energy generation (organic conversion to methane gas). This technique offer fundamental benefits such as low costs, energy production, and relatively small space requirement of modern wastewater treatment systems.

CHAPTER 2

LITERATURE REVIEW

2.1 Palm Oil Industry in Malaysia

2.1.1 History and Development of Palm Oil Industry

The oil palm tree (*Elaeis guineensis*) originated from West Africa where it was grown wild and later developed into an agriculture crop. It was first introduced to Malaysia in the early 1870’s as an ornamental plant. In the year 1917, the first commercial planting took place at Tennamaran Estate in Selangor, laying the foundation for the vast oil palm plantations and palm oil industry in Malaysia. Today, 3.88 million hectares of land in Malaysia is under oil palm cultivation producing 14 million tonnes of palm oil in 2004. Malaysia is the largest producer and exporter of palm oil in the world, accounting for 30% of the world’s traded edible oils & fats supply. (MPOC, 2009).

Oil palm is a crop that bears both male and female flower on the same tree, meaning they are monoecious. Each tree produces compact bunches weighing between 10 and 25 kilograms with 1000 to 3000 fruitlet per bunch. Each fruitlet is almost spherical or elongated in shape. Generally the fruitlet is dark purole, almost black and the colour turns to orange red when ripe. Each fruitlet consists of hard kernel (seed) inside a shell (endocarp) which is surrounded by thea fleshy mesocarp Palm trees may grow up to sixty feet and more in height. The trunks of young and adult plants are wrapped in fronds which give them a rather rough appearance. The older trees have smoother trunks apart from the scars left by the fronds which have withered and fall on off.

A normal oil palm tree will start bearing fruits after 30 months of planting and will continue to be productive for the next 20 to 30 years thus ensuring a consistent supply of oil. Each ripe bunch is commonly known as Fresh Fruit Bunch (FFB). In Malaysia, the trees planted are mainly the *tenera* variety, a hybrid between the *dura* and *pisifera*. The *tenera* variety yields about 4 to 5 tonnes of crude palm oil (CPO) per hectare per year and about 1 tonne of palm kernels. The oil palm is most efficient, requiring only 0.25 hectares to produce one tonne of oil while soybean, sunflower and rapeseed need 2.15, 1.50 and 0.75 hectares respectively (MPOC,2009).

Figure 2.1 Empty Fruit Bunches (FFB)

www.flickr.com/photos/9496861@N02/1840425900

Figure 2.2 cross section of fruitlet

http://www.oilsvegetable.com/palmoil.htm

2.1.2 Palm Oil Mill Process

Palm Oil Milling Process involve the physical extraction of palm products namely, crude palm oil and palm kernel from the FFB. The process begin with sterilization of FFB. The fruit bunches are steamed in pressurized vessel up to 3 bars to arrest the formation of free fatty acids and prepare the fruits for subsequent sub-processes. The sterilized bunches are then stripped of the fruitlets in a rotating drum thresher. The stripped bunches or empty fruit bunches (EFB) are transported to the plantation for mulching while the fruitlets are conveyed to the press digesters.

In the digesters, the fruits are heated using live steam and continuously to loosen the oil-dearing mesocarp from the nuts as well as to break open the oil cells present in the mesocarp. The digested mash is then pressed, extracting the oil by means of screw presses. The press cake is then conveyed to the kernel plant where the kernels are recovered. The oil from the press is diluted and pumped to vertical clarifier tanks. The clarified oil is then fed to purifiers to remove dirt and moisture before being dried further in the vacuum drier. The clean and dry oil is ready for storage and dispatch.

The sludge from the clarifier sediment is fed into bowl centrifuges for further oil recovery. The recovered oil recycled to the clarifiers while the water or sludge mixture which is referred to as Palm Oil Mill Effluent (POME) is treated in the effluent treatment plant (ETP). The press cake is conveyed to the depericarper where the fiber and nuts separated. Fiber is burned as fuel in the boiler to generate steam.

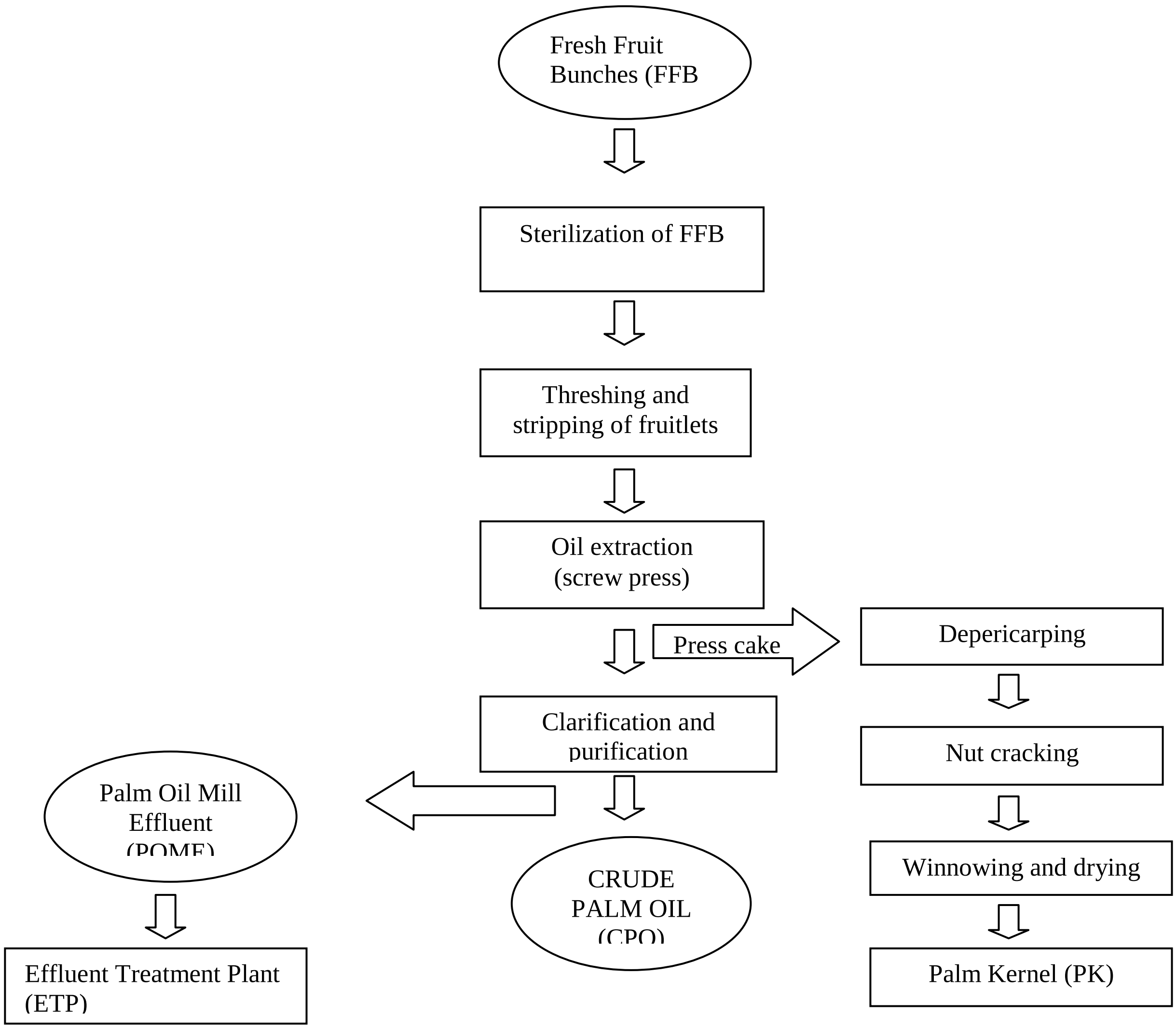

Figure 2.3 Palm Oil Milling Process

Source : T.Cheng(2002)

2.1.3 Palm Oil Mill Effluent (POME)

Based on the process of oil extraction and the properties of FFB, POME is made up of about 95% - 96% water, 0.6% - 0.7% oil, and 4% - 5% total solid, including 2% - 4% suspended solids, which are mainly debris from mesocarp. No chemical are added during the production of palm oil; thus I is nontoxic waste. Upon discharge from the mill, POME is in the form of highly concentrated dark brown colloidal slurry of water, oil, and fine cellulosic materials. Due to introduction of heat (from the sterilization stage) and vigorous mechanical processes, the discharge temperature of POME is approximately $80^{o}C$ - $90^{o}C$. the chemical properties of POME vary widely and depend on the operation and quality control of individual mills. The general properties of POME are indicated in Table 2 (Lawrence *et al*) .

Apart from the organic composition, POME is also rich in mineral content, particularly Phosphorus (18mg/L), Potassium (2270mg/L), Magnesium (615mg/L) and Calcium (439 mg/L). Thus most of dewatered POME dried sludge (the solid end product of the POME treatment system) can be recycled or returned to the plantation as fertilizer (Lawrence *et al*).

Table 2.1 Chemical Properties of Palm Oil Effluent (POME)

Chemical property	Average	Range
Ph	4.2	3.4-5.2
BOD (mg/L)	25000	10250-43750
COD (mg/L)	50000	15000-100000
0il and grease (mg/L)	6000	150-18000
Ammonia (mg/L)	35	4-80
Total nitrogen (mg/L)	750	180-1400
Suspended solid (mg/L)	18000	5000-54000
Total solid (mg/L)	40000	11500-78000

Source : Lawrence *et al*

2.2 Palm Oil Mill Effluent Wastewater Treatment

The choice of POME wastewater treatment system is largely influenced by cost of operation and maintenance, availability of land, and location of the mill. The first factor plays a bigger role in the selection of the treatment system. In Malaysia, the final discharge of the treated POME must follow the standards set by the Department of Environment (DOE) of Malaysia, which is 100 mg/L of BOD or less (Table 2.3) regardless of which treatment system is being utilized.

Table 2.2: Environment Regulation for watercourse Discharge for Palm Oil Mill Effluent (POME)

Parameters	Level
BOD (mg/L)	100
Suspended Solid (mg/L)	400
Oil and Grease (mg/L)	50
Ammonia cal Nitrogen(mg/L)	150
Total Nitrogen (mg/L)	200
Ph	5-9

Source: Industrial process and the environment (Handbook No.3)

2.2.1 Pretreatment

Prior to the primary treatment, the mixed raw effluent (MRE), a mixture of wastewater from sterilization, clarification, and other sources) will undergo a pretreatment process that includes the removal of oil and grease, followed by a stabilization process. The excess oil and grease is extracted from the oil recovery pit using an oil skimmer. In this process, steam is continuously supplied to the MRE to aid the separation between oil and liquid sludge. The recovered oil is then reintroduced to the purification stage. The process will prevent excessive scum formation during the primary treatment and increase oil production. The MRE is then pumped into the cooling and mixing ponds for stabilization before primary treatment. No biological treatment occurs in these ponds. However, sedimentation of abrasive particle such as sand ensures that all pumping equipment is protected. The retention time of MRE in the cooling and mixing ponds is between 1 and 2 days (Lawrence *et al*)

2.2.2 Pond Treatment System

The pond system is comprised of a series of anaerobic, facultative, and algae (aerobic) ponds. These systems require less energy due to the absence of mechanical mixing, operation control, or monitoring. Mixing is very limited and achieved through the bubbling of gases; generally this is confined to anaerobic ponds and partly facultative ponds. On the other hand, the ponding system requires a vast area to accommodate a series of ponds in order to achieve the desired characteristics for discharge. For example, in the Serting Hilir Palm Oil Mill, the total length of the wastewater treatment system is about 2 Km, with each pond about the size of a soccer field (Figure 2.3). Only a clay lining of the ponds is needed, and they are constructed by excavating the earth. Hence, the pond system is widely favored by the palm oil industry due to its marginal cost.

In constructing the ponds, the depth is crucial for determining the type of biological process. The length and width differ based on the availability of land. 1m - 1.5m deep. For anaerobic ponds, the optimum depth ranges from 5m - 7m, while facultative anaerobic ponds are 1m - 1.5m deep. The effective hydraulic time (HRT) of anaerobic and facultive anaerobic systems is 45 and 20 days, respectively. A shallower depth of approximately 0.5m - 1m is required for aerobic ponds, with an HRT of 14 days. The POME is pumped at a very low rate of 0.2Kg to 0.35Kg BOD/m^3 . day of organic loading. In between the different stages of the pond system, no pumping is required, as the treated POME will flow using gravity or a sideways tee-type subsurface draw-off system. Under these optimum conditions, the system is able to meet the requirement of DOE. The number of ponds will depends on the production capacity of each palm oil mill.

One problem faced by pond operators is the formation of scum, which occurs as the bubbles rise to the surface, taking with them fine suspended solids. This results from the presence of oil and grease in the POME, which are not effectively removed during the pretreatment stage. Another disadvantage of the pond system is the accumulation of solid sludge at the bottom of the ponds. Eventually the sludge and scum will clump together inside the pond, lowering the effectiveness of the pond by reducing the volumetric capacity and HRT. When this happens, the sludge may be removed by either using submersible pumps or excavators. The removed sludge is dewatered and dried before being used as fertilizer. The cleanup is normally carried out every 5 years or when the capacity of the pond is significantly reduced.

Figure 2.4 A series of ponds for POME treatment occupying a large land area. (courtesy of Felda Palm industries).

2.2.3 Facultative Ponds

Facultative ponds are generally aerobic; however these ponds do operate in facultative manner and have an anaerobic zone. Facultative organisms function with or without dissolved oxygen. Treatment in a facultative pond is provided by settling of solids and reduction of organic oxygen demanding material by bacteria activity. Dissolved oxygen is supplied by algae living within the pond and atmospheric transfer through wind action. Facultative ponds are usually 4-8 feet in depth and can be viewed as having three layers. The top six to eighteen inches is aerobic where aerobic bacteria and algae exist in a symbiotic relationship. Aerobic stabilization of BOD by aerobic bacteria occurs in the upper oxygenated layer. The aerobic layer is important in maintaining an oxidizing environment in which gases and other compound leaving the lower anaerobic layer are oxidized.

The middle two to four feet is partly aerobic and partly anaerobic, in which facultative bacteria decompose organic material. The bottom one to two feet is where accumulated solids are decomposed by anaerobic bacteria. BOD can be converted to methane by methane bacteria in the lower anaerobic layer. Maintaining a balance between the depth and surface area is important for facultative ponds to function properly. Aerobic reactions in facultative ponds are limited because they do not have mechanical aeration. Facultative and anaerobic reactions need more time than aerobic reactions to provide the same degree of treatment (Lagoon system in Maine). The disadvantage of this system is the requirement of a relatively large land area (Lim *et al*.,2006)

Figure 2.5 Facultative pond of Sewage Treatment Plant

Source : Indah Water Kuatan

2.2.4 Anaerobic Ponds

Anaerobic ponds are deep treatment ponds that exclude oxygen and encourage the growth of bacteria, which break down the effluent (figure 2.5). It is in the anaerobic pond that the effluent begins breaking down in the absence of oxygen.The anaerobic pond act like an uncovered septic tank. Anaerobic bacteria break down the organic matter in the effluent, releasing methane and carbon dioxide. Sludge is deposited on the bottom and a crust forms on the surface. Anaerobic ponds commonly 2m - 5m deep and receive such a high organic loading (usually 100g

BOD/m^3 d equivalent to 3000 Kg/ha/d for depth of 3 m). They contain an organic loading that is very high relative to the amount of oxygen entering the pond, which maintains anaerobic conditions to the pond surface. Anaerobic ponds do not contain algae, although occasionally a thin film of mainly *Chlamydomonas* can be seen at the surface.

Anaerobic ponds reduce Nitrogen, Phosphorus, Potassium and pathogenic microorganisms by sludge formation and the release of ammonia into the air. As a complete process, the anaerobic ponds serve to:

- Separate out solid from dissolved material as solids settle as bottom sludge
- Dissolve further organic material
- Break down biodegradable organic material
- Store undigested material and non-degradable solids as bottom sludge
- Allow partially treated effluent to pass out

This is a very cost effective method of reducing BOD. Normally, a single anaerobic pond in each treatment train is sufficient if the strength of the influent wastewater is less than 1000 mg/L BOD (McGarry and Pescod, 1970).

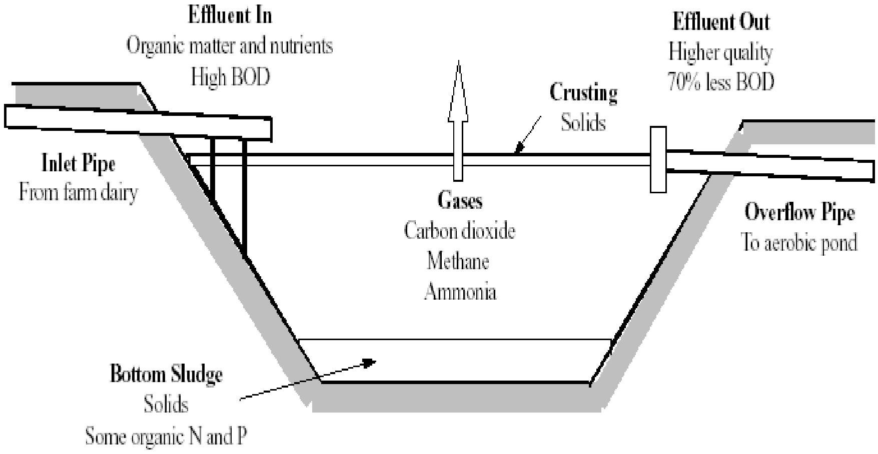

Figure 2.6: Anaerobic Pond

(source: P.S Navaraj,2005)

2.2.5 Aerated Ponds

The aerated ponds are used as tertiary treatment process for improving the effluent quality from secondary biological process (Grady et al., 1999). Effluent quality is improved by removing the suspended solids, ammonia, nitrate, phosphate concentration and also the number of enteric microorganisms. There are two types of aerated ponds exist: the aerobic pond and the aerobic-anaerobic pond. In the aerobic pond, all the solids are in suspension so that the concentration of the effluent suspended solids will be equal to the suspension of solid in the basin. On the other hand, in aerobic-anaerobic pond, the degree of turbulence maintained insures uniform distribution of oxygen throughout the basin but is usually insufficient to maintain all the solids in suspension so that some solids are settled at the bottom of the basin to undergo anaerobic decomposition.

For the fact that the deposited solids undergo anaerobic decomposition, the net sludge is not too much and is required only for periodic de-sludging. About 70% to 90% of BOD removal efficiency will be achieved for aerobic pond system but the effluent may contain relatively high concentration of suspended solids which gave the turbid appearance. Therefore the installation of settling tank or shallow pond for removal of solids should be carried out after aerobic pond system. The aerated pond used in the treatment of POME in Malaysia could be described as aerobic-anaerobic pond system. The current aerated pond contained high concentration of suspended solids and the turbid appearance of the effluent from the pond have to undergo to the next settling pond before final discharge. However, some of the aerobic ponds of POME treatment are equipped with mechanical surface aerators for oxygen supply.

The hydraulic retention times for recovery tank, acidification, anaerobic, facultative and aerobic ponds are 1, 4, 45, 8 and 8 days respectively (Ashhuby *et al.*, 1996; Ma, 1999). For the purpose of cost minimization, many oil palm mills in Malaysia do not apply the aerated pond because of energy consumed in operating the aeration pump. In these cases, the HRT for the facultative pond system was increased to 16 days. He pond system has however been reported to be reliable, stable and capable of producing good final quality effluent (Chan and Chooi, 1982; Chooi, 1984).

2.3 Anaerobic Digestion Process

Anaerobic digestion is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen. It is widely used to treat wastewater sludge and organic wastes because it provides volume and mass reduction of the input material (anaerobic digestion website). As a part of an integrated waste management system, anaerobic digestion reduces the emission of landfill gas into the atmosphere. Anaerobic digestion is a renewable energy source because the process produces a methane and carbon dioxide rich biogas suitable for energy production helping replace fossil fuels. Also, the nutrient-rich solids left after digestion can be used as fertilizer.

Biogas production involves complex interactions between various micro organisms such as enzymes and bacteria. There are four phases in its production;

- Hydrolysis – during this phase the long chain organic compounds (e.g. proteins, fats, carbon hydrates) are split into more simple organic compounds (e.g. amino acids, fatty acids, sugars) through bacteria action.

- Acidogenesis – the products of hydrolysis are subsequently metabolized in the acidogenesis phase by acidogenic bacteria and broken down into short chain fatty acids (e.g. acetic acid, propionic acid, butyric acid, valeric acid) and alcohol. Acetic acid, hydrogen and carbon dioxide are also created and act as initial products for methane formation. The relationship between the products depends on the hydrogen partial pressure, i.e. the concentration of hydrogen. The lower the partial pressure the higher is the amount of acetic acid.

- Acetogenesis – the organic acids and alcohols are broken down from acetogenic bacteria into acetic acid, hydrogen and carbon dioxide which are the source compounds for biogas production.

- Methanogenesis – the product from the previous phases are converted into methane and carbon dioxide by methanogenic micro organisms (Archaea). The end product is a combustible gas called biogas.

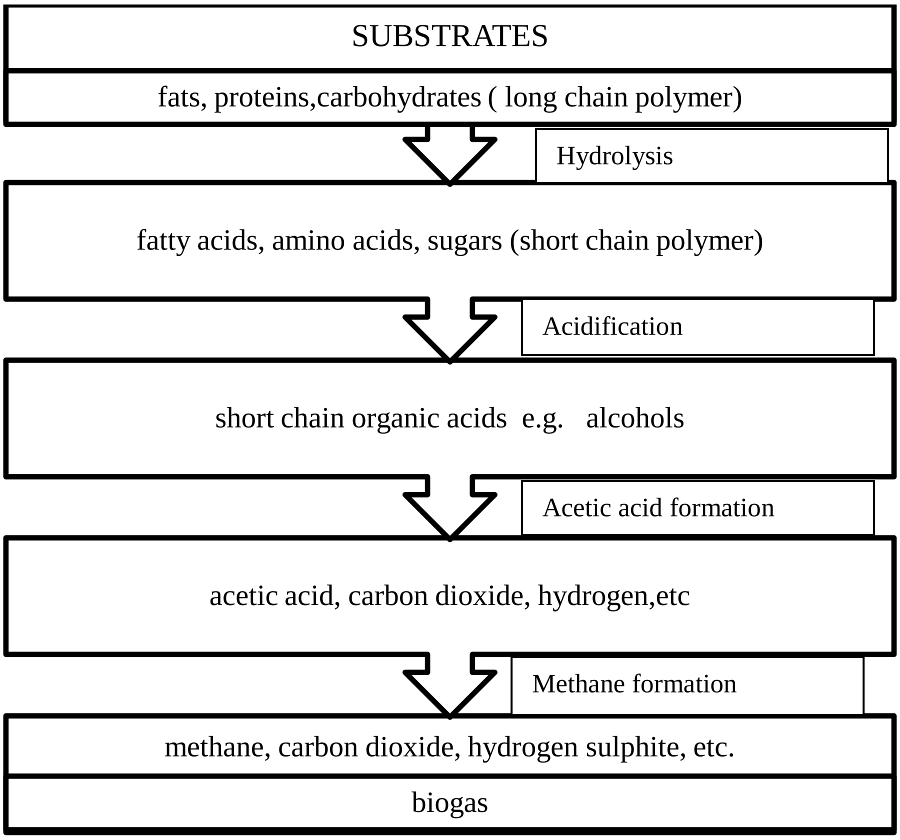

Figure ***2.7*** Stages in Anaerobic Digestion

Source: sustainable energy Ireland

2.3.1 Acidogenic Bacteria

Acidogenic is a acid-forming bacteria convert sugars, amino acids, and fatty acids to organic acids, alcohols and ketones, acetate, CO_2, and H_2. Acetate is the main product of carbohydrate fermentation. The products formed vary with the type of bacteria as well as with culture conditions such as temperature, pH, redox potential.

2.3.2 Methanogenic Bacteria

Methanogens are usually coccoid or rod shaped. This bacteria carry anaerobic reaction which cannot function under aerobic conditions they can sustain oxygen stresses for prolonged times. This group is composed of both gram-positive and gram-negative bacteria. Methanogenic microorganisms grow slowly in wastewater and their generation times range from 2 days at 35 ^{o}C too as high as 50 days at 10 ^{o}C. About two thirds of methane gas is derived from acetate conversion microorganisms. The other third is the result of carbon dioxide reduction by hydrogen.

2.3.3 Hydrolytic Bacteria

Consortia of anaerobic bacteria break down complex organic molecule into soluble monomer molecules such as amino acids, glucose, fatty acids, and glycerol. The monomers are directly available to the next group of bacteria. Hydrolysis of the complex molecules is catalyzed by extracellular enzymes such as celluloses, proteases, and lipases. However, the hydrolytic phase is relatively slow and can be limiting in anaerobic digestion of waste such as raw cellulolytic wastes, which contain lignin.

2.4 Factor Influencing Anaerobic Digestion Process

2.4.1 Effect of Temperature

Methane production has been documented under a wide range of temperatures. In municipal wastewater treatment plants, anaerobic digestion is carried out in the mesophilic range at temperatures from 25°C to up to 40°C with the optimum at approximately 35°C .Thermophilic digestion operates at temperature ranges of 50°C - 65°C .It allows higher loading rates and is also conductive to greater destruction of pathogens. One drawback is its higher sensitivity to toxicants. Because of their slower growth as compared with acidogenic bacteria, methanogenic bacteria are very sensitive to small changes in temperature, which leads to a decrease of the maximum specific growth rate while the half-saturation constant increases. Thus, a mesophilic digester must be designed to operate at temperatures between 30°C and 35°C for their optimal functioning.

2.4.2 Effect of Retention time

The hydraulic retention time (HRT), which depends on wastewater characteristics and environmental conditions, must be long enough to allow metabolism by anaerobic bacteria in digesters. Digesters based on attached growth have a lower HRT (1-10 days). The retention times of mesophilic and thermophilic digesters range between 25 and 35 days but can be lower.

2.4.3 Effect of pH

Most methanogenic bacteria function in a pH range between 6.7 and 7.4, but optimally at pH + 7.0-7.2, and the process may fail if the pH is close to 6.0. Acidogenic bacteria produce organic acids, which tend to lower the pH of the bioreactor. Under normal conditions, this pH reduction is buffered by the bicarbonate that is produced by methanogens. Under adverse environmental conditions, the buffering capacity of the system can be upset, eventually stopping the production of methane. Acidity is inhibitorier to methanogens than of acidogenic bacteria. An increase in volatile acid levels thus serves as an early indicator of system upset. Monitoring the ratio of total volatile acids (as acetic acid) to total alkalinity (as calcium carbonate) has been suggested to ensure that it remains below 0.1.

2.4.4 Effect if Toxicants

A wide range of toxicants is responsible for the occasional failure of anaerobic digesters. Inhibition of methanogenesis is generally indicated by reduced methane production and increased concentration of volatile acids.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this research methodology, will be explained on the specification and the properties of raw waste which is Palm Oil Mill Effluent (POME) and its properties. In addition, this chapter also will be focused on the specification of the Membrane Anaerobic System (MAS) reactor. Included the experimental rig set-up and the procedures involve in POME treatment and methane gas determination.

3.2 Membrane Anaerobic System (MAS) reactor setup

To accomplish the objective of this research, the Palm Oil Mill Effluent (POME) is treating by using 30 Liter volume Membrane Anaerobic system (MAS) reactor. The culture is enriched to increase the concentration of methanogens in digesters. The laboratory digester is completely mixed-semi continuous in order to maintain the volume in digester.

A schematic representation of laboratory of Membrane Anaerobic System (MAS) which consists of hollow fiber ultra filtration membrane (CUF) apparatus, a centrifugal pump, and an anaerobic reactor is shown in Figure 3.1.

The feed system is design to provide continues addition of feed solution (POME wastewater) by gravity flow, from feeder tank which is on top of the reactor. The volume of biogas produce will be measure by 20 Liter water displacement bottle. The optimum temperature for anaerobic in the mesophilic range is between 25^{o} C- 40^{o}C. The pH of the reactor content in the range between 6.8 to 7.7.

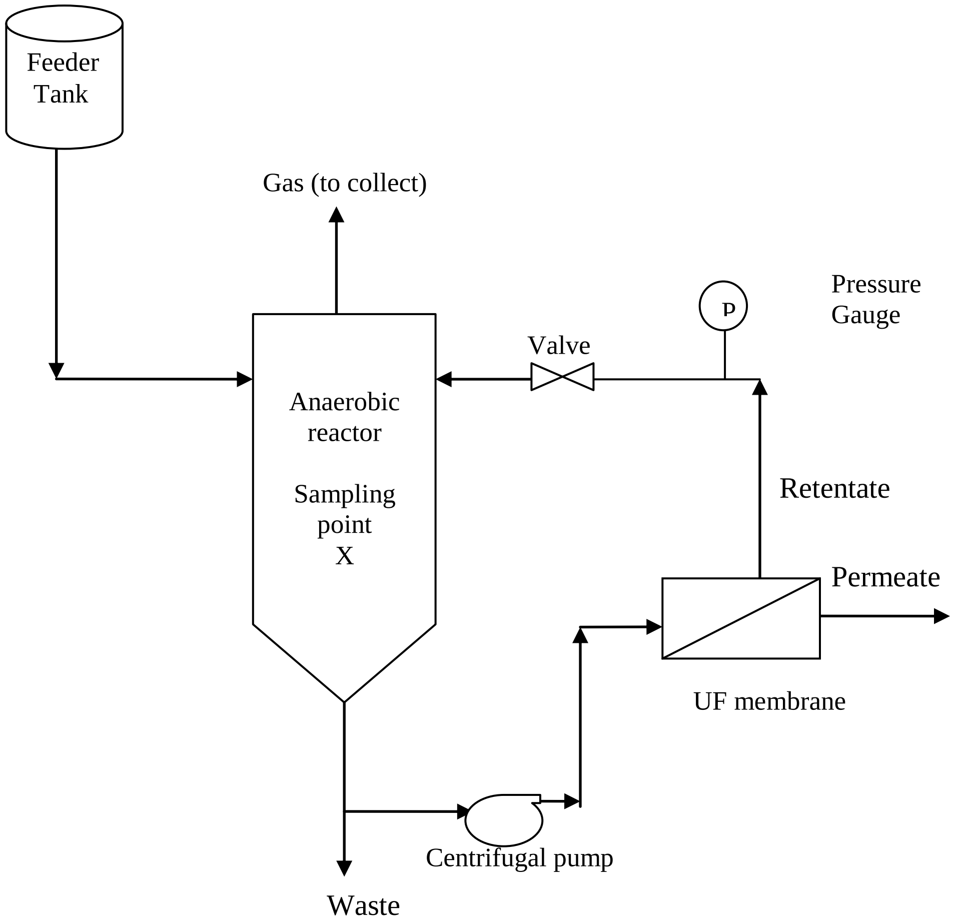

Figure 3.1: Experimental set-up

3.3 Sampling of Palm Oil Mill Effluent

The raw POME samples were collected from the Felda Palm Industries Sdn. Bhd, in Gambang. The cooperation from the palm oil mill and the people in-charge, Mr. Anuar Mat lead to smooth sampling frequency and time. The sample was screened through strainer to remove coarse particles in order to avoid clogging in membrane and pump damage. Then, samples were freshly preserved at 4°C in the cooler. Figure 3.2 and Figure 3.3 showed the front view of Palm oil mill and the sampling pond of raw POME. The POME sample was taken from anaerobic pond where this pond contains bacteria.

Figure 3.2: Front view of Felda Palm Industries Sdn. Bhd.

Figure 3.3 Sampling anaerobic pond of raw POME

3.4 Characterization of Palm Oil Mill Effluent

The characteristic of the raw POME, such as pH, turbidity, chemical oxygen demand (COD), Manganese content, Iron content, and total suspended solids (TSS) were determined according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2000) and DR2400 Spectrophotometer Procedures Manual.

About 100 L of raw POME were collected freshly and determined in the laboratory at two different concentration rations of 50% and 100% respectively. The initial characteristics of these two concentration ratios of raw sewage samples were illustrated in Appendix A.

3.5 Screening

Screening devices were used to remove coarse solids from wastewater. Corse solid consist of soil particle, residual oils and other large objects that often and, inexplicably, from their way into pond system. Screening was performed as first operation to protect pumps and other mechanical equipment and to prevent clogging of valves and especially membrane ultrafiltration and other appurtenances in digester. Screened solids were coated with organic material of a very objectionable nature. Hence it should be promptly disposed of to prevent a health hazard or nuisance condition.

3.6 Microbiological Cultures

Microbiological cultures utilize Petri dishes that have a thin layer of universal agar based growth medium in them. Once the growth in the Petri dish is inoculated with the desired bacteria medium (POME sample which was diluted to 10^1), the agar plates were incubated in the incubator at 30°C for three days. After three days, the growth bacteria were suspended in universal liquid broth, a nutrient medium and were incubated again for another two days at 30°C and 150rpm in the shaker for uniform growth. The cultured plate and broth is shown in Figure 3.4 and Figure 3.5, respectively.

Figure 3.4 cultured agar plate with Growth

Figure 3.5 cultured broth with bacterial Bacterial growth

3.7 Membrane Cleaning

In the course of this study, there were two ways that the membrane were cleaned, in order to improve the permeate flux and permeate flow rate. The two methods, which were followed in this study, the first method is mild brushing, flush with water for 20 to 30 minutes. The second method is soaking the membrane in 0.1M NaOH for a day (24 hours) rigorous brushing, with water. In both methods, the membranes have been taken out from membrane housing. The membrane soak in NaOH is shown in Figure 3.6.

Figure 3.6 Hollow Fiber Ultrafiltration membrane
In NaOH solution

3.8 Crossflow Ultrafiltration Membrane (CUF) Unit

The CUF consists of four tubular Polysulphone membranes, which put inside steel membrane housing. The length of polysulphone is 30cm and its diameter was 1.25cm. The total areas of the four membranes were 0.048m^2 and the average pore size of 0.1µm. the molecular cut-off weight of 200000.

The membrane can be operated at a maximum pressure of 55bar at 70°C or at 70bar at 20°C. The operating pressure in this study was maintained at 1.5-2.0bar, by manipulating the gate valve at the retentate line after the CUF unit. The CUF unit is shown if Figure 3.7 below.

Figure3.7 Crossflow Ultrafiltration membrane (CUF) unit

3.9 Analytical Techniques

3.9.1 Chemical Oxygen Demand (COD)

A 100 ml of homogenized sample was blended for 30 seconds. Meanwhile the COD reactor was turned on to 150 ^{o}C. The cap o COD digestion reagent via was removed and the vial is held at a 45-degree angle to pipette 2ml of sample into the vial. After the vial is recapped tightly, the outside of the COD vial is being rinsed wit deionized water and the vial is wiped until it is clean with a paper towel. The vial is inverted gently several times to mix the contents. The vial is placed in the preheated COD reactor and is heated for 2 hours, as shown in Figure 3.8. After that, the reactor is turned off and is left for 20 minutes for the vials to cool to 70 ^{o}C or less. Each vial was inverted several times while there were still warm and places the vials in the rack. The calorimetric method technique is used to measure the COD with the aid of Spectrophotometer DR2400 HACH.

Figure 3.8: Digital Reactor Block for COD Measurement

3.9.2 Suspended Solid Analysis

A well-mixed measured sample of raw POME, sample at 50% and 100% concentrations, reactor content and permeate were filtered through a weighed standard glass-fiber filter and the residue retained on the filter is dried to a constant weight at 103°C to 105°C. The increase in weight of the filter represents the total suspended solids. If the suspended material clogs the filter and prolongs filtration, it may be necessary to increase the diameter of the filter or decrease the sample volume. TSS apparatus is shown in Figure 3.9 as below.

Figure 3.9 Glass fiber filter Apparatus

3.9.3 Turbidity Analysis

The turbidity value of raw POME, sample at 50% and 100% concentrations, reactor content and permeate was determined by using turbidity meter. The sample filled into cell about 10ml. the sample cell is placed in the instrument cell compartment and the lid is closed. Turbidity meter is shown in Figure 3.10.

Figure 3.10 Turbidity meter

3.9.4 pH analysis

The sample is poured in a beaker. The sample is being swirled and the electrode is placed in the beaker. The entire sensing end is submerged and then the results is recorded when the pH value is stable. The pH meter is shown in Figure 3.11.

Figure 3.11 pH meter

3.9.5 Manganese analysis

In Manganese test, the procedures of Method 8034 were followed. Manganese in the sample is oxidized to the purple permanganate state by sodium periodate, after buffering the sample with citrate. The purple color is directly proportional to the manganese concentration. Test results are measured at 525 nm.

3.9.6 Iron Analysis

In Iron test, the procedures of Method 8008 were followed. For iron test, FerroVer Iron Reagent converts all soluble iron and most insoluble forms of iron in the sample to soluble ferrous iron. The ferrous iron reacts with the 1, 10 phenanthroline indicator in the reagent to form an orange color in proportion to the iron concentration. Test results are measured at 510 nm.

3.9.7 Methane gas measurement

The gas volume is measured daily by using a 20 litre displacement bottle as shown in Figure 3.12. The gas method used to perform this analysis was a J-tube gas analyzer as shown in Figure 3.13 (Yau, 1983; H.N. Abdurahman, 2000). The method assuming that the biogas produced composed only of two gases, CO_2 and CH_4. Then sodium hydroxide (NaOH) was added to the composition. Sodium hydroxide will absorb CO_2 and the remaining volume is CH_4.

The J-tube device was consisting of a glass tube connected by a flexible hose to a syringe. Initially, the device is filled with 0.5 NaOH solution and the the glass tube was inserted into the gas line, where a column of biogas is drawn into the glass tube until a certain mark. The end of the glass tube was then immersed in water.

By manipulating the syringe for many times, the NaOH solution will absorb CO_2, and the remaining gas will be CH_4. The final length of the biogas column is measured as an evidence of reduction in the length of the biogas column. The percentage of methane in the biogas is measured as (Abdurahman *et al.,* 2010):

$$\frac{\text{Final length of gas column}}{\text{Initial length of gas column}} \text{ X } 100\%$$

Figure 3.12: 20L Displacement Bottle

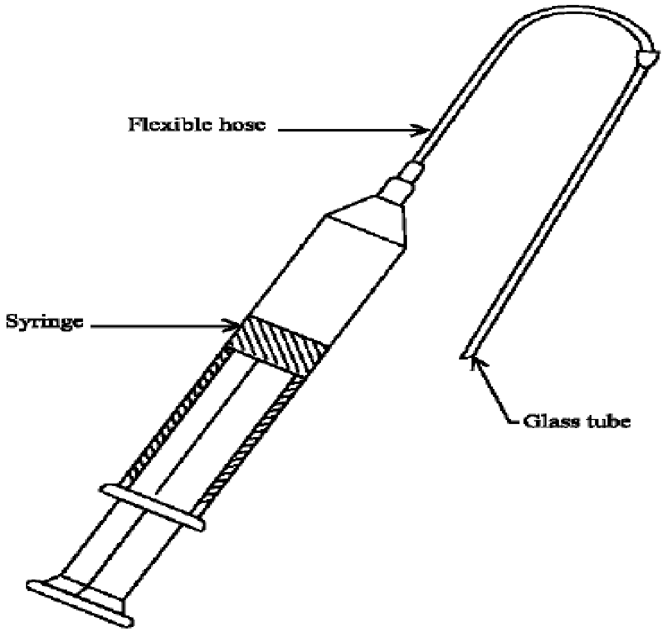

Figure 3.13 J-tube Gas Analyzer

3.10 Design of Experiments

In this study, the reactor pump was operated for a total of 8 hours per day. The initial sample test was done on the reactor content (influent) in order to measure the initial reading of pH, temperature, turbidity, COD, Manganese, Iron and TSS. Some gas bubbles were found in the reactor on the first day. The parameters were measured daily for reactor content on every morning, reactor content after 8 hours and permeate (effluent). To maintain the level of the reactor (30 liter), some of the treated sludge was recycled back to the reactor. The sample was acclimatized with bacteria for the first three days, and then it was run for four days for 50% and 100% concentration of sample respectively. The Methane gas produced was measured daily by using J-Tube gas analyzer.

CHAPTER 4

RESULT & DISCUSSION

4.1 Introduction

The results obtained from experiment were tabulated and then will be plotted to graphs. The calculation of MAS reactor efficiency on COD, Turbidity, TSS, Manganese and Iron data are show in Appendix B.

4.1.1 Design of Experiments

The parameters such as pH, temperature, turbidity, COD, Manganese, Iron and TSS were measured in every morning, and after the membrane treatment. The data collected for two different concentration ratios of 50% and 100% of raw POME, were tabulated in the Table 4.1 and 4.2, respectively. In additional the sample of raw POME and permeate are shown in Figure 4.1 and 4.2 respectively.

Table 4.1 Summary of experimental result for 50% concentration of POME

Parameters	**Initial**	**4th day**	**5th day**	**6th day**	**7th day**
Turbidity, (NTU)	503	10.7	5.62	3.97	3.62
Total Suspended Solid, (mg/L)	2450.67	333.33	250.0	246.67	100.0
Manganese, (mg/L)	44.5	25	23.0	22.0	20.5
Iron, (mg/L)	15.0	0.9	0.64	0.46	0.31
(COD),(mg/L)	17700	13800	10700	6300	3750.67
Methane Gas, (L/day)	0	0.521	0.565	0.632	0.673

Table 4.2 Summary of experimental result for 100% concentration of POME

Parameters	**Initial**	**4th day**	**5th day**	**6th day**	**7th day**
Turbidity, (NTU)	547	560	454.28	323.23	256.4
Total Suspended Solid, (mg/L)	7600	5766.67	4422	4300	3200
Manganese, (mg/L)	46	30	27	23	23.4
Iron, (mg/L)	22	18.2	11.3	9.8	7.2
COD,(mg/L)	45800	27100	19400	10300	8500
Methane Gas, (L/day)	0	0.926	0.936	0.95	0.974

Figure 4.1 Sample of treated POME for 50% concentration

Figure 4.2 Sample of treated POME for 100% concentration

4.2 Discussion

All data will be collected and interpreted into graph. The graph results will be discussed in order to understand all the effects of parameters.

4.2.1 pH

The pH value of the system is just maintained between 6.8 to 7.7. Most methanogenic bacteria function in a pH range between 6.7 and 7.4, but optimally at pH 7.0-7.2, and the process may fail if the pH is close to 6.0. Acidogenic bacteria produce organic acids, which tend to lower the pH of the bioreactor. Under normal conditions, this pH reduction is buffered by the bicarbonate that is produced by methanogens. At pH above 8.0, most of the bacteria are washed out from the digester and this might reduce production of methane gas and the efficiency of the digester. Thus it's very important to maintain the pH level of the system (Biogas Chemistry).

4.2.2 Turbidity and TSS

The concentration of TSS in the influents that supplied into the MAS reactor during startup period found to be 2450 mg/L to 7600 mg/L. After acclimatization period it was increases to 3000 mg/L to 8000 mg/L. The increment due to the solids and particulate organic matters that not accumulated in the reactor at early stage but they were hydrolyzed and fermented into soluble form (T.Y.Wu *et al*). During acclimatization period the solids start to settle down formed activated sludge. Figure 4.3 indicates the highest reduction of turbidity up to 99% while the removal efficiency of total suspended solid (TSS) is up to 95% as shown in Figure 4.. The color of treated POME after UF was significantly different before being treated. At the 50% concentration, the color of permeate was light yellow, whereas at the 100%

concentration, the color of permeate was dark yellow, corresponding to the values obtained from turbidity analysis. This indicates that the ultrafiltration membrane had effectively retained solid particles within the membrane and hence produced a clearer permeate. The removal of TSS also will reduce the concentration of metals in POME. Ultrafiltration is a pressure driven membrane separation process which able to remove particulate from digester. However, further treatment required for color removal.

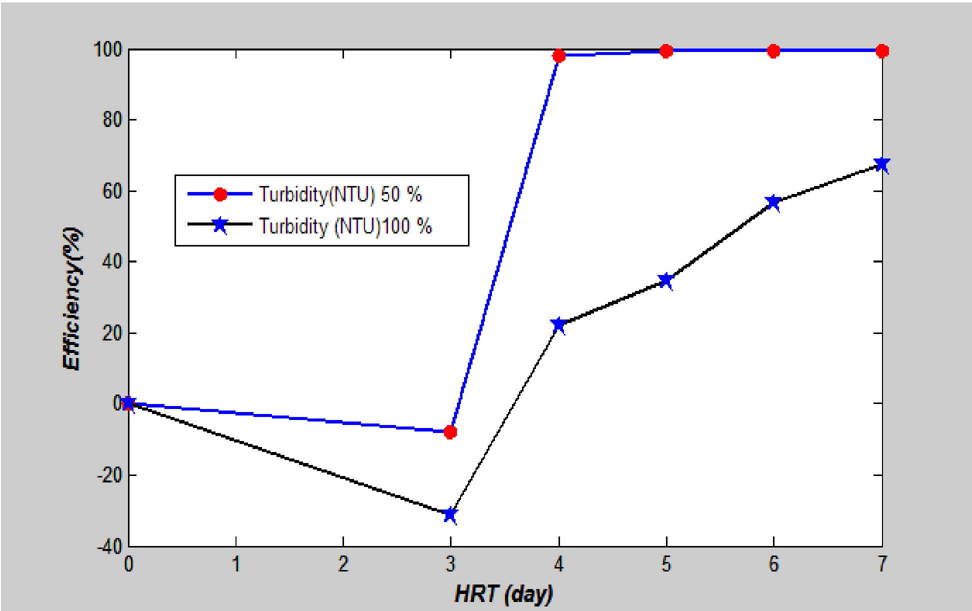

Figure 4.3 Efficiency (%) of Turbidity removal vs HRT (day)

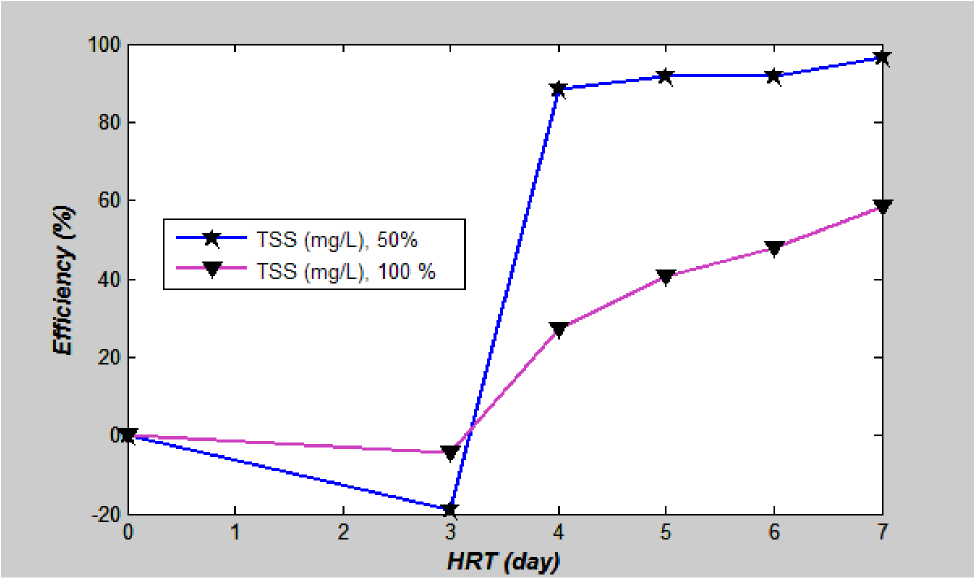

Figure 4.4 Efficiency (%) of TSS removal vs HRT (day)

4.2.3 Manganese and Iron

Iron and Manganese normally exist in reduce form that is Fe^{2+} and Mn^{2+}, respectively. Both metals undergo oxidation in order to form insoluble compounds such as Fe^{3+} and Mn^{3+} The overall oxidation of Manganese and Iron can be expressed as shown in Eq 1 and Eq 2, respectively.

$$4\ H_2O(l) + Mn^{2+}(aq) \rightarrow MnO^{-}{}_4(aq) + 8\ H^{+}(aq) + 5\ e^{-} \qquad \text{(eq. 1)}$$

$$2\ Fe^{2+} + H_2O_2 + 2\ H^{+} \rightarrow 2\ Fe^{3+} + 2\ H_2O \qquad \text{(eq 2)}$$

In this research, the removal of iron is more efficient compare to the manganese. From Figure 4.5 the removal of iron was up to 98% , whereas the removal of manganese within range of 40% to 50% as shown in Figure 4.6. The removal of manganese is less than iron because ion manganese is not easily oxidizes compare to iron. The Oxidation of manganese by oxygen alone is slow but the reaction is catalyzed by the presence of previously oxidized manganese. The ion in its reduced form is adsorbed by the manganese dioxide which allows the normally slow oxidation reaction to go to completion. The presence of Iron bacteria enhance the removal of iron and also manganese, iron bacteria naturally exist in raw POME which gives brown color which is hard to treated. Iron bacteria growth well at temperature range from 5°C to 50°C, while the pH between 6 to 8 (Tamura *et al.*,1999). The precipitate will filter out by Ultrafiltration membrane. The black precipitate retain on membrane required backwashing. During backwashing the manganese oxide particle deposit inside the pores, rather than its accumulation on top of the membrane skin layer. The accumulation of the metal oxide particles on the membrane surface form thick cake layer which reduce the permeability. Thus, oxidized manganese claimed a greater responsibility for membrane fouling and polarization at the membrane surface during UF (Kwang *et al*.,2005).

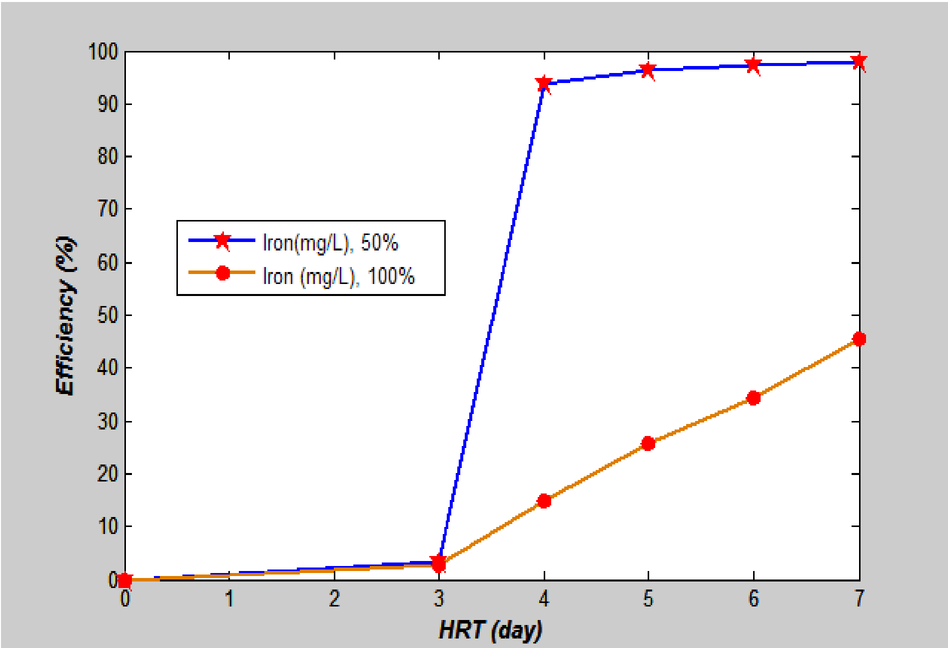

Figure 4.5 Efficiency (%) of Iron removal vs HRT (day)

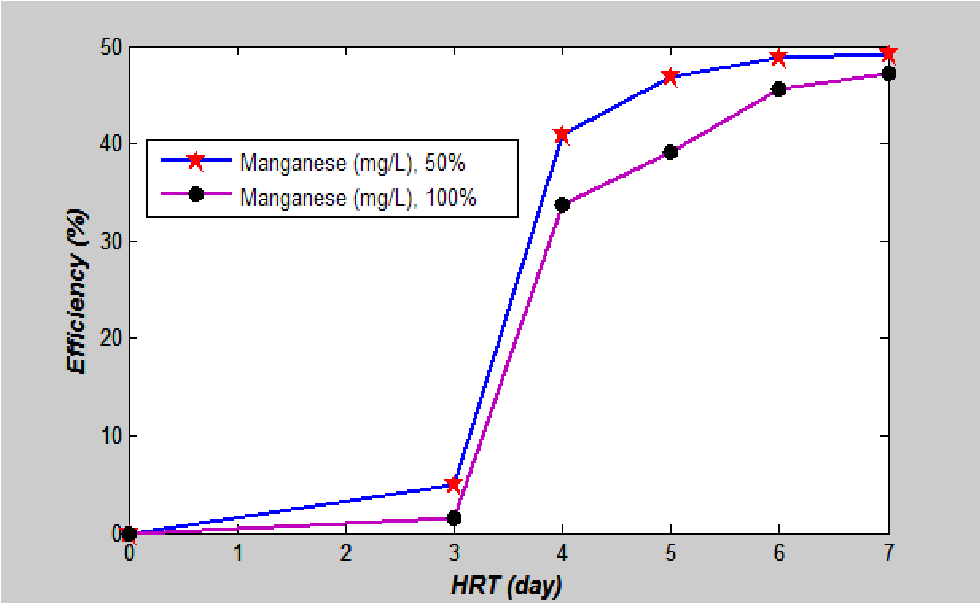

Figure 4.6 Efficiency (%) of Manganese removal vs HRT (day)

4.2.4 Chemical Oxygen Demand (COD)

The start-up period of this digester takes only from day 0 to day 3. This was largely due to the usage of seed sludge from anaerobic pond of POME and hence reducing the acclimatization period by sustaining high microbial activity. The digester was operated for 4 days HRT with an average COD removal efficiency was between 78.81% and 81.44%. The main factor that had significant effect on removal of COD was pH and HRT. It's important to maintain the pH of the system between 6.8 to 7.7, because higher level of pH might be toxic to biomass. This would cause the low bioactivity and treatment efficiency.

The organic compounds will be degraded into carbon dioxide, acetate, and hydrogen by acidogenesis bacteria thus a high alkalinity is needed to assure pH near neutrality. Sludge digestion provide sufficient alkalinity is produced by the breakdown of protein and amino acids to produce NH_3, which combines with CO_2 and H_2O to form alkalinity as $NH_4(HCO_3)$ (Biogas Chemistry). The changes in COD removal and effluent COD values with time for each of the three HRT settings are illustrated in Figure 4.7. On the first day, the COD in permeate has been removed to 13800mg/L to 27100 mg/L which is 20% to 30% of the COD, although the influent COD fluctuated from 17400 mg/L to 38900 mg/L. However, the COD removal efficiency was increased up to 70% of the COD which are ranging from 3750mg/L to 8500 mg/l on the fourth day.

Ultrafiltration membrane increases the removal of COD; this is probably because the organic of Molecular Weight (MW) higher than 200kDa are susceptible to being absorbed into membrane hole, which leads high removal rate of organic within certain time (Lin *et al*.,2010). For more concentrated wastewater, the efficiency of COD removal less as more organic matter have been partially blocked the membrane holes and become smaller where higher HRT required to remove more COD.

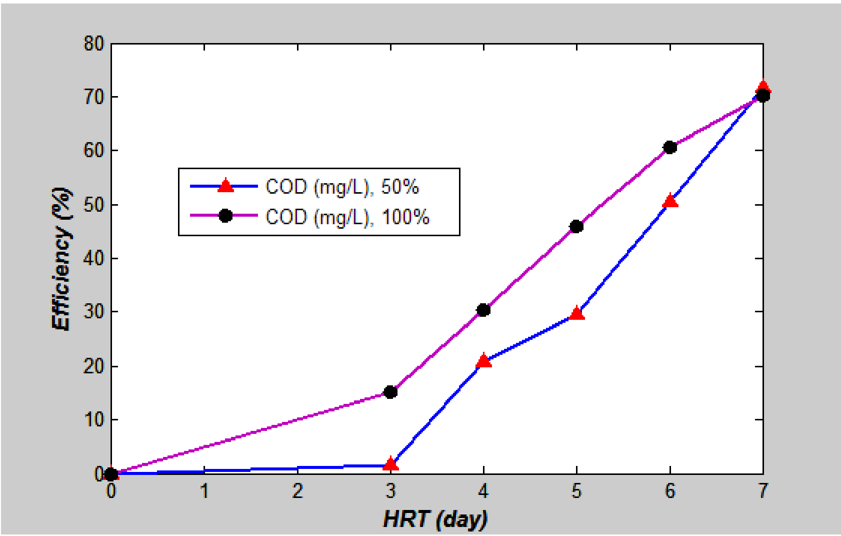

Figure:4.7 Efficiency (%) of COD removal vs HRT (day)

4.2.5 Methane gas Production and its composition

Many factors govern the performance of anaerobic digesters where adequate control is required to prevent reactor failure. The few major factors that greatly influence digester performances in POME treatment are pH, mixing, operating temperatures, nutrients for bacteria and organic loading rates into the digester. In this regards, the microbial community in anaerobic digester is sensitive to pH changes, in this study, the pH is maintained to the optimum (6.8-7.7) to avoid methanogens affect which cause reduction of biogas production. The methanogenesis is strongly affected by pH. As such methanogenic activity will decrease when pH in the digester deviates from the optimum value. Mixing also provides good contact between microbes and substrates reduces resistance to mass transfer, minimizes build-up of inhibitory intermediates and stabilizes environmental conditions (Abdurahman *et al.,* 2010). In this study, mechanical mixing and recirculation of biogas adopted to improve contact between active microbes and organic material. Results have shown that mixing improved the performance of anaerobic digester. Figure 4.8 shows the gas production rate and methane content of biogas produced by MAS. The biogas production of methane content registered a general incline with increasing HRT. However gas production will increase with HRT until a stage when methanogens can only convert acetic acid in diluted substrate to methane in a small amount as the sludge particulates amount decreasing. In this regards, the gas yields with increasing HRT. It increased from 0.673 L/g COD/d to 0.974 L/g COD/d.

Thus, the production of biogas will increase when HRT increases. This is due to the longer time contact between substrate and activated sludge. The longer the time contact between substrate and activated sludge, the higher the degradation of biomass to biogas by methanogenic bacteria, and hence the higher the production of methane. The operating temperature was 42°C and found that the substrate degradation rate and biogas production was higher than operating at 37°C. Higher temperature increases the rate of biological transformation and degradation of substrate as it take advantage of the fact that almost all microbial metabolism doubles in rate for each 10°C rise in temperature.

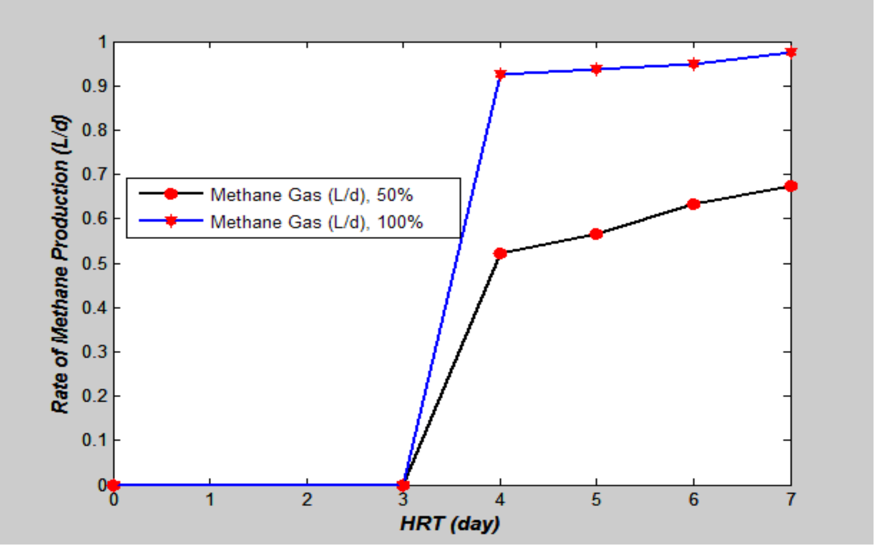

Figure 4.8 Production rate of Methane gas vs HRT (day)

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

Based on the results of this study, it can be concluded that the MAS had provided good treatment of the POME waste. The UF membrane was able to sustain good solid-liquid phase separation and adequate flux rates to give a sound performance for the MAS. The total methane gas yield obtained range from 0.673 L/g COD/d to 0.974 L/g COD/d. The removal efficiency of COD was between 8.81% and 81.44%. The overall removal efficiency for concentration of 50% was 95.92% for TSS, 99.28% for turbidity, 97.93% for iron, and 53.93% for manganese. For concentration of 100%, the removal efficiency about 57% for TSS, 53% for turbidity, 67.27 for iron and 49.13% for manganese.

In this study, membrane fouling and polarization at the membrane surface played a significant role in the formation of the strongly attached cake layer limiting membrane permeability. The two methods of membrane cleaning (mild brushing, flush with water and soak in 0.1M NaOH for a day (24 hours)), is very important to increase the permeate flux and flow rate. The effluent flow rates for the two ratios were found as 10.31 L/d and 21.75 L/d respectively.

The MAS was found to be a successful biological treatment system to achieve a high COD removal efficiency in a short period of time. The membrane anaerobic system, MAS treatment efficiency was greatly affected by solid retention time, hydraulic retention time and organic loading rates. The MAS was able to operate at very high POME concentration to variations in influent COD loadings. Thus, it makes MAS a good alternative for treating high strength wastewater and for recovery of energy as methane would be a value added product for this process.

5.2 Recommendation

- Carry the experiment in steady state in order to develop kinetic model equations
- Fix T-junction on digester in order to backwash the Ultra filtration membrane instead of open it and wash
- Increase the height of Aluminum con in order to prevent any leakage.

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APPENDIX A

METHODOLOGY

Initial chemical composition in raw POME

Sample: 50% Concentration

CHEMICAL PROPERTIES	INITIAL
Temperature, C^{O}	25 ^{O}C
pH	7.340
Turbidity, NTU	503
TSS,mg/L	2450.67
Manganese, mg/L	44.5
Iron, mg/L	15
COD,mg/L	17700
Methane gas, cm^3/day	0

Sample: 100% Concentration

CHEMICAL PROPERTIES	INITIAL
Temperature, C^{O}	27.8 ^{O}C
Ph	7.436
Turbidity, NTU	547
TSS,mg/L	7600
Manganese, mg/L	46
Iron, mg/L	22
COD,mg/L	45800
Methane gas, cm^3/day	0

APPENDIX B

RESULT & DISCUSSION

RESULTS FOR 50% CONCENTRATION

DAY 1

CHEMICAL PROPERTIES	INITIAL	INFLUENT	EFFLUENT	EFFICIENCY (%)
Temperature, C^{O}	29 ^{O}C	35 ^{O}C	27.7 ^{O}C	-
pH	7.356	7.422	7.323	-
Turbidity, NTU	542	486	10.7	98..02583
TSS,mg/L	2916.67	1500.00	333.33	88.57156
Manganese, mg/L	42.3	35.0	25	40.89835
Iron, mg/L	14.5	14.967	0.9	93.7931
COD,mg/L	17400	16300	13800	20.68966
Methane gas, L/day	0.5214			

DAY 2

CHEMICAL PROPERTIES	INITIAL	INFLUENT	EFFLUENT	EFFICIENCY (%)
Temperature, C^{O}	27.9 ^{O}C	37.3 ^{O}C	29.8 ^{O}C	-
pH	7.454	7.319	7.321	-
Turbidity, NTU	799	793.33	5.62	99.29662
TSS,mg/L	3033	2970	250	91.75734
Manganese, mg/L	43.3	37.33	23	46.88222
Iron, mg/L	18.1	17.7	0.64	96.46409

COD,mg/L	15200	1300	10700	29.60526
Methane gas, L/day	0.5653			

DAY 3

CHEMICAL PROPERTIES	INITIAL	INFLUENT	EFFLUENT	EFFICIENCY (%)
Temperature, C^O	29.3 ^OC	35.1 ^OC	28.2 ^OC	-
pH	7.483	7.533	7.321	-
Turbidity, NTU	705	711.33	3.97	99.43688
TSS,mg/L	2930.34	2233.35	246.67	91.58221
Manganese, mg/L	43.000	35.70	22.00	48.8721
Iron, mg/L	16.3	15.63	0.46	97.17791
COD,mg/L	12700	13100	6300	50.3937
Methane gas, L/day	0.6327			

DAY 4

CHEMICAL PROPERTIES	INITIAL	INFLUENT	EFFLUENT	EFFICIENCY (%)
Temperature, C^O	28.7	39.1	29.1	-
pH	7.567	7.633	7.363	-
Turbidity, NTU	704	701	3.62	99.4858
TSS,mg/L	2831	2644	100	96.46768
Manganese, mg/L	40.3	39.0	20.5	49.13151
Iron, mg/L	15.7	14.5	0.31	98.02548
COD,mg/L	13300	11500	3750.67	71.79947
Methane gas, L/day	0.6734			

RESULTS FOR 100% CONCENTRATION

DAY 1

CHEMICAL PROPERTIES	INITIAL	INFLUENT	EFFLUENT	EFFICIENCY (%)
Temperature, C^{O}	26.2 ^{O}C	32.1 ^{O}C	28.9 ^{O}C	-
pH	7.475	7.515	7.267	-
Turbidity, NTU	718	652	560	22.00557
TSS,mg/L	7940.8	7738.5	5766.67	27.37923
Manganese, mg/L	45.3	42.33	30	33.77483
Iron, mg/L	21.4	20.4	18.2	14.95327
COD,mg/L	38900	34500	27100	30.33419
Methane gas, L/day	0.9255			

DAY 2

CHEMICAL PROPERTIES	INITIAL	INFLUENT	EFFLUENT	EFFICIENCY (%)
Temperature, C^{O}	26.9 ^{O}C	34.1 ^{O}C	27.4 ^{O}C	-
pH	7.493	7.584	7.332	-
Turbidity, NTU	695.65	623	454.28	34.6971
TSS,mg/L	7466.67	5890	4422	40.7768
Manganese, mg/L	44.3	39.4	27	39.0932
Iron, mg/L	15.2	13.7	11.3	25.6579
COD,mg/L	35966.67	32005.54	19400	46.0612
Methane gas, L/day	0.9359			

DAY 3

CHEMICAL PROPERTIES	INITIAL	INFLUENT	EFFLUENT	EFFICIENCY (%)
Temperature, C^{O}	29.3 ^{O}C	35.1 ^{O}C	28.2 ^{O}C	-
pH	7.593	7.682	7.453	-
Turbidity, NTU	742	711.33	323.23	56.43801
TSS,mg/L	8266	7833.35	4300	47.97968
Manganese, mg/L	42.33	41.70	23.00	45.66501
Iron, mg/L	14.9	13.63	9.8	34.2282
COD,mg/L	26100	23100	10300	60.5364
Methane gas, L/day	0.9501			

DAY 4

CHEMICAL PROPERTIES	INITIAL	INFLUENT	EFFLUENT	EFFICIENCY (%)
Temperature, C^{O}	28.7	39.1	29.1	-
pH	7.687	7.559	7.313	-
Turbidity, NTU	784.8	701	256.4	67.3293
TSS,mg/L	7665.4	5344	3200	58.2540
Manganese, mg/L	44.3	39.0	23.4	47.1783
Iron, mg/L	13.2	12.5	7.2	45.4546
COD,mg/L	28700	11500	8500	70.3833
Methane gas, L/day	0.9743			

APPENDIX C

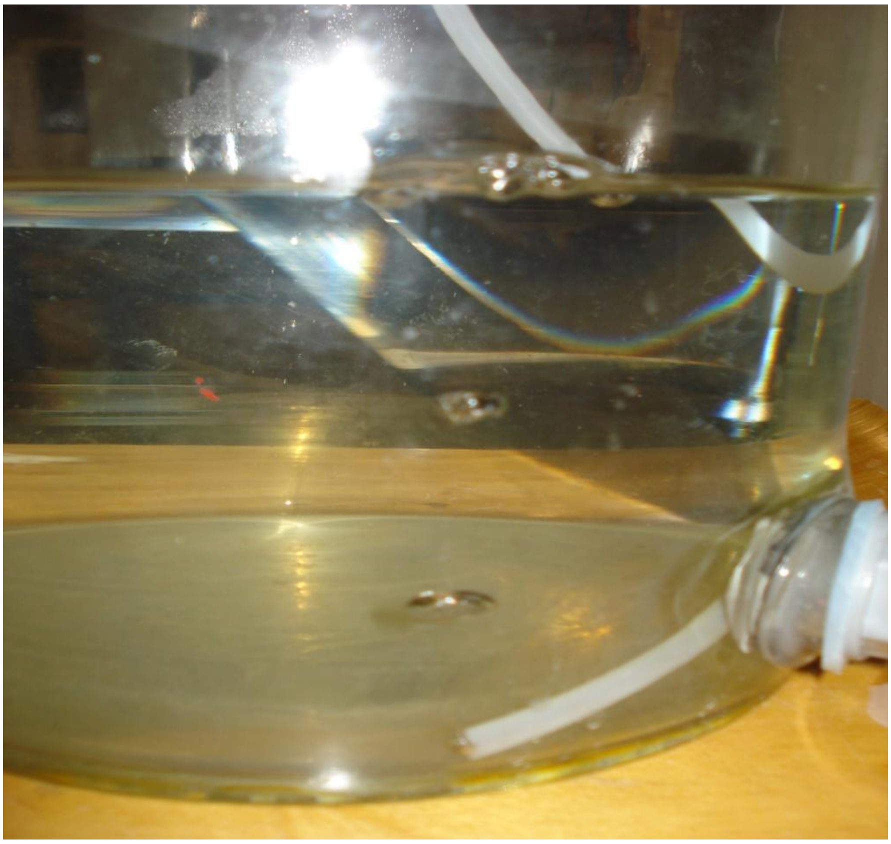
Research team with supervisor I

After collect the sample

Bacteria Culture

Membrane Anaerobic System (MAS) reactor

Permeate collection



Formation of Bubble in displacement bottle