SEWAGE SLUDGE TREATMENT BY MEMBRANE ANAEROBIC SYSTEM (MAS)

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"I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Chemical Engineering"

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I declare that this thesis entitled "Sewage Sludge Treatment by Membrane Anaerobic System (MAS)" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any degree.

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To my beloved Mother, Father, and brother and the ones who give me inspiration and support that made this work possible.

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ABSTRACT

The performance of Membrane Anaerobic System (MAS) was investigated in treating raw sewage sludge. Certain parameters were investigated such as Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Suspended Solid (TSS) and pH. MAS consist of Ultrafiltration membrane for solid-liquid separation with 1.5 – 2.0 bar of operational pressure. An enrichment culture of methanogenic bacteria was developed in the digester when seed sludge was feed into 50 L digester. The raw sewage sludge was obtained from the Indah Water Municipal Treatment Plant at Taman Seri Mahkota Aman KUN 112. The digester operates 5 hours per day for 11 days. The conventional method to treat raw sewage sludge is by using Aerobic and Anaerobic digestion. Aerobic digestion is expensive method since it used oxygen and anaerobic digestion required large area and slower process. As an alternative method, MAS was being invented and offer great advantages. In this study, 70 % of methane gas was produce and removal efficiency of COD was up 60.74% to 97.24%.MAS treatment efficiency is greatly affected by pH, temperature, organic loading rate (OLR) and hydraulic retention time (HRT).MAS was found to be the biological treatment system to achieve a high COD removal in a short period of time and the effluent colour is more clear. Thus make MAS is a good alternative for treating wastewater.

ABSTRAK

Prestasi Membran anaerobik System (MAS) telah diselidiki dalam merawat kumbahan sisa mentah. Parameter tertentu telah diteliti seperti Permintaan Oksigen Kimia (COD), Permintaan ooksigen Biokimia (BOD), Keseluruhan Tahanan pepejal (TSS) dan pH. MAS terdiri daripada membran ultrafiltrasi untuk pemisahan padat-cair dengan 1,5-2,0 bar tekanan operasi. Bakteria metanogen dikultur pada reaktor ketika lumpur benih dimasukkan ke dalam reactor 50L. Lumpur sisa baku diperolehi daripada Indah Water Treatment Plant Bandar di Taman Seri Mahkota Aman KUN 112.Reaktor beroperasi selama 5 jam sehari untuk 11 hari. Kaedah konvensional untuk merawat lumpur sisa baku adalah dengan menggunakan aerobik dan pencernaan anaerobik. Pencernaan Aerobik adalah kaedah mahal kerana menggunakan oksigen dan pencernaan anaerobik memerlukan kawasan yang luas dan prosesnya lebih lambat. Sebagai kaedah alternatif, MAS telah dicipta dan menawarkan banyak kelebihan. Dalam kajian ini, 70% gas metana telah dihasilkan dan kecekapan removal COD dari 60.74% menjadi 97.24%.Kecekapan rawatan MAS sangat dipengaruhi oleh pH, suhu, laju beban organik (OLR) dan masa retensi hidrolik (HRT) .MAS telah dibuktikan menjadi sistem pemprosesan biologi yang baik dan dapat mencapai COD tinggi dalam masa yang singkat dan warna efluen lebih jelas. Jadi,MAS adalah alternatif yang baik untuk memproses sisa cair.

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LIST OF ABBREVIATION / SYMBOLS

MAS	Membrane Anaerobic System
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
TSS	Total Suspended Solid
CH_4	Methane Gas
H_2O	Water
CO_2	Carbon Dioxide
NH_3	Ammonia
VFA	Volatile Fatty Acid
HCO_3	Bicarbonate
HRT	Hyraulic Retention Time
PVC	Polyvinylchloride
CH_3OH	Methanol
CH_2O	Formaldehyde
CH_3NO_2	Nitromethane
CH_3Cl	Chloroform
CCl_4	Carbon Tetracholide
CUF	Cross Flow Ultrafiltration
NaOH	Sodium Hydroxide
MWCU	Molecilar Weight Cut-Off
OLR	Organic Loading Rate
pKa	Dissociation Constant

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The sewage sludge treatment by Membrane Anaerobic System (MAS) currently used to treat the organic waste from any treatment plant. This kind of waste treatment presents the great advantages since it not used any chemicals like strong acids that can be harmful to people and animals and also it can reduce the amount of organic matter which might otherwise be destined to be land filled. The process is also simple, less expensive and it will produce useful by-products which is methane gas, a valuable gas nowadays. Methane gas are use to generate electricity, produce cooking gases, and also it can replace the energy derived from fossil fuels, and hence reduce emissions of greenhouse gasses.

The first discovery was reported in the seventeenth century by Robert Boyle and Stephen Hale, who noted that flammable gas was released by disturbing the sediment of streams and lakes. Through scientific research anaerobic digestion gained academic recognition in the 1930s and it lead the discovery of anaerobic bacteria. As the time goes by, anaerobic digestion are widely use. It is not only to treat manure but also the waste from treatment plant.

Anaerobic digestion is a process in which microorganisms digest biodegradable material with little or in the absence of oxygen. The mesophilic bacteria were place into the reactor which temperature is between 35^0C-45^0C. Then the sewage sludge is entering the reactor, and the digestion process occurs. 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 convert 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. The final product is methane, carbon dioxide and also the treated sewage sludge (Metcalf &Eddy.Inc, 2003)

When a liquid sludge is produced, further treatment may be required to make it suitable for final disposal. Typically, the water in the sludge is been remove to reduce the volumes transported off-site for disposal. Processes of removing water content include lagooning in drying beds to produce a cake; pressing, where sludge is mechanically filtered, often through cloth screens to produce a firm cake; and centrifugation where the sludge is thickened by centrifugally separating the solid and liquid. Sludge can be disposed of by liquid injection to land or by disposal in a landfill. In certain country, after centrifugation, the sludge is then completely dried by sunlight (Howard S. Peavy et al, 1985). The nutrient rich biosolids are then provided to farmer free-of-charge to use as a natural fertilizer (M. H. Wonga et al, 1995). This method can reduce the amount of landfill generated by the process each year.

1.2 PROBLEM STATEMENT

- The conventional techniques take times to accomplish.
- Expensive and high cost for raw materials treatment.
- High demand.
- Limited resources.

1.3 OBJECTIVE

In this research, there are few objectives to be fulfilled. Those are:

- To evaluate the anaerobic transformation of sewage sludge to methane gas in a membrane anaerobic system (MAS).
- To experimentally assess the factors influencing anaerobic digester performance such as pH, chemical oxygen demand(COD),biological oxygen demand(BOD), and total suspended solid(TSS).
- Overall performance of membrane anaerobic system (MAS).

1.4 SCOPE OF STUDY

To accomplish the objectives of this study, these are the scopes to be focused on:

- A laboratory digester was scaled membrane anaerobic system (MAS) with an effective 50 litre volume was designed and used to treat raw sewage sludge.

- Enrichment cultures of methanogenic bacteria were developed in the digester.

- To study the parameters that affects the performance of MAS such as pH, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and Total Suspended Solid (TSS).

- Last but not least, to measured the percentage of methane gas production by using J-Tube gas Analyzer.

1.5 RATIONAL& SIGNIFICANCE

- Energy saving.

- Less expensive treatment.

- Environmental friendly.

- Can reduce the organic matter in the sewage sludge.

- Production of methane gas (CH_4) from waste.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

There are mainly two ways to treat raw sewage sludge. First with aerobic process and second is anaerobic process. Aerobic process is the process in which the microorganisms breakdown all the biodegradable materials with presence of oxygen. This process is quite expensive treatment because it uses oxygen in the process of treating sewage sludge. Since the percentage of raw sewage sludge disposal is increasing daily so this technique is not convenient anymore. People started to find other alternative ways to treat their raw sewage sludge and found that, anaerobic process is the best way to treat their raw sewage sludge.

Anaerobic process is the process in which microorganisms will breakdown all the biodegradable materials with little or absence of oxygen. This process used anaerobic bacteria. Not much country used this process, only a few countries like German used this process. This process offers several advantages and also disadvantages, which are:

- Less energy required
- Less biological sludge produced
- Lower nutrient demand
- Methane production: Providing potential energy source with possible revenue both from sale of the energy, and benefit from government tax, and (Kyoto agreement) CDM etc. payments arising from renewable fuels/non-fossil fuel incentives
- Methane production: Anaerobic digestion contributes to reducing greenhouse gases by reducing demand for fossil fuels
- Smaller reactor volume required
- Biomass acclimatisation allows most organic compounds to be transformed
- Rapid response to substrate addition after long periods without feeding
- End product can be potentially saleable products biogas, soil conditioner and a liquid fertiliser.
- Process more effectively provides sanitisation/removal of diseases.

Several disadvantages of anaerobic process:

- Longer start-up time to develop necessary biomass inventory
- May require alkalinity and/or specific ion addition
- May require further treatment with an aerobic treatment process to meet discharge requirements
- Biological nitrogen and phosphorus removal is not possible
- Much more sensitive to the adverse effect of lower temperatures on reaction rates
- May need heating (often by utilisation of process gas) to achieve adequate reaction rates
- May be more less stable after ‘toxic shock’(eg after upsets due to toxic substances in the feed)
- Increased potential for production of odours and corrosive gases.
- Hazards arise from explosion. (In the EU, such additional Health & Safety Regulations as the ATEX Directive, and possibly also Gas Institute Regulations will require various compliance measures to be applied for AD.)

- Anaerobic treatment is not effective for treatment of methanogenic landfill leachate, it may (rarely) be efficacious for the early stage leachate production period while the waste is still Acetogenic.

All those weaknesses drive people to find an alternative ways to improve the system. Recently, there have an alternative ways to treat sewage, which is Membrane Anaerobic System (MAS).This system is a combination of membrane separation technology and anaerobic process. This system has overcome several problem that face before such as it is only required small treatment area and the most important is it is only takes a short period of time to treat sewage sludge compared with conventional technique and this process can produce methane gas (CH_4) .

2.2 RAW SEWAGE SLUDGE

Raw sewage sludge is a muddy like, yellowish colour and has a bad smell. It is slurry with water content and rich in nutrient such as organic matter derived from human, animal and food wastes. Other constituents are trace contamination mainly from industrial effluents and bacteria. (B.R.Gurjar,2001). Since raw sewage sludge contain hazardous materials to human, so it has to treat before it can dispose to the landfill site. Basically, there are 2 methods to treat the sewage sludge which are aerobic process and anaerobic process than only it can be dispose. Before dispose, it will undergo thickening and dewatering process to increase the solid concentration of sludge and decrease its volume by removing a portion of the water. (IzrailS.Turovskiy et al, 2006).

2.3 AEROBIC DIGESTION

Aerobic digestion is the conventional technique to treat a wide range of sludge. It is a process of oxidation and decomposition of the organic part of the sludge by microorganism in special open or enclosed tank with the presence of oxygen (IzrailS.Turovskiy et al, 2006).The process produce stable product. The stable product means the sludge is reduce in mass, volume, pathogenic organisms and does not have bad smell. This process has advantages and disadvantages. The major advantages of this process are odourless and easier to operate. The major disadvantage is the operating cost higher since it used oxygen in this process. So, people start to find alternative method in order to reduce the cost for sludge treatment.

2.3.1 PROCESS THEORY

Aerobic digestion is a continuous process. When the soluble substrate is completely been consumed by the bacteria, the bacteria begin to consume their protoplasm to obtain the energy for cell maintenance. This phenomenon is called *endogenous respiration*. This is the major reaction in aerobic process. The cell is oxidized aerobically to produce carbon dioxide (CO_2), water (H_2O) and ammonia (NH_3) (IzrailS.Turovskiy et al,2006).

2.3.2 CONVENTIONAL AEROBIC DIGESTION

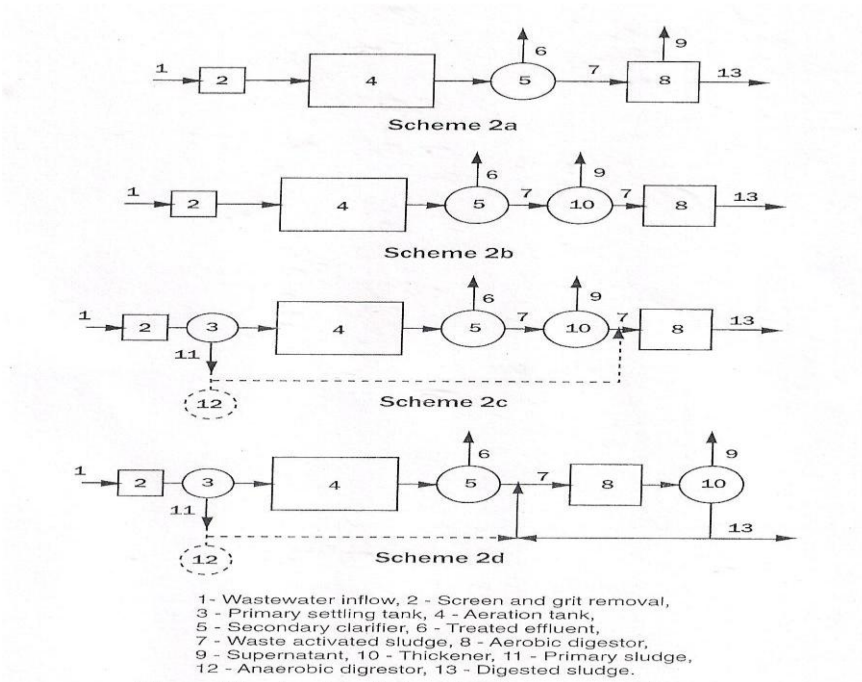

Figure 4.2 Aerobic sludge digestion process schemes.

Figure 2.1: Aerobic Sludge Digestion Process Scheme Taken from (IzrailS.Turovskiy et al, 2006)

For wastewater treatment plant without primary settling tank, scheme 2a and 2b is recommended. In scheme 2a, the activated sludge goes to the aerobic digester directly from secondary clarifier. The sludge goes to the digester after preliminary concentration in a sludge thickener. Scheme 2c and 2d are the common process used to treat raw sewage sludge from small to medium size wastewater treatment plant. In 2c, thickened secondary sludge is combined with primary sludge and discharged to the digester. For 2d, combined primary and unthickened secondary sludge is digested first and thickened in a thickener. (IzrailS.Turovskiy et al,2006)

2.4 ANAEROBIC DIGESTION

Anaerobic digester has been used as an alternative way to treat raw sewage sludge. It is the process by which organic materials in this case is raw sewage sludge is fermented or has been breakdown by bacteria in the absence of oxygen (LudovicoSpinosa et al,2001) This process basically do the same this as aerobic process did, like produce stable sewage sludge, but the different between this 2 methods is the by-products. In anaerobic process, it will produce methane gas (CH_4) as it by-product but in aerobic process not. So, anaerobic process is a preferable method to treat raw sewage sludge in the industry. The stable sewage sludge can be used as a soil conditioner or fertilizer (LudovicoSpinosa et al, 2001). There have two types of anaerobic digestion which are mesophilic and thermophilic digestion.

2.4.1 MESOPHILIC DIGESTION

Mesophilic digestion operates at ambient temperature at 35-45^{0}C. The optimum temperature of the mesophilic methane bacteria is 37^{0}C. For simplicity of the operation and to avoid the need to heat the reactor, most anaerobic digestion plants are operated at mesophilic temperatures that at temperatures between 3°C and 35°C and require 15 to 20 days of mean retention time in the digestion reactor, but it is not so efficient in reducing the total suspended solid and deactivation of pathogenic microorganisms.(Young-Chae Song et al,2004)

2.4.2 THERMOPHILIC DIGESTION

Thermophilic digestion using higher metabolic rate of thermophilic microorganisms has become a favourable technique recently. (Aoki N, Kawase M, 1991). Theoretically, the reaction rate of thermophilic digestion is double than mesophilic rate. The operation temperature of thermophilic process is between 55^0C to 60^0C. Although better performance of reduction of volatile solid and deactivation of pathogen organism can be obtained from thermophilic digestion, the effluent quality and ability of dewatering the residue is poor and required heat energy to heat the digester (FangHHP, ChungDWC, 1999; Maibaum C, Kuehn V.,1999; Kim M,2002). Moreover, the thermophilic digestion suffer from high amount of free ammonia, which plays an inhibiting role for the microorganisms; but the increasing pKa of the volatile fatty acid (VFA) will make the process more susceptible to inhibition(Boe K.,2006), thus make the thermophilic is very sensitive process than mesophilic process.

2.4.3 PROCESS THEORY

The anaerobic digestion process is composed of four stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis (ZhijunWanga et al, 2008). Hydrolysis is the process where the sewage sludge is breakdown to their simple form. Acidogenesis or fermentation is the process where the acid-forming bacteria concert the simple form to short chain of organic acid. Acetogenesis is the process where the acetate is produce by the bacteria and the methanogenesis is the process where the process that produce methane gas and carbon dioxide (IzrailS.Turovskiy et al, 2006). The schematic below is the general reaction in anaerobic digestion.

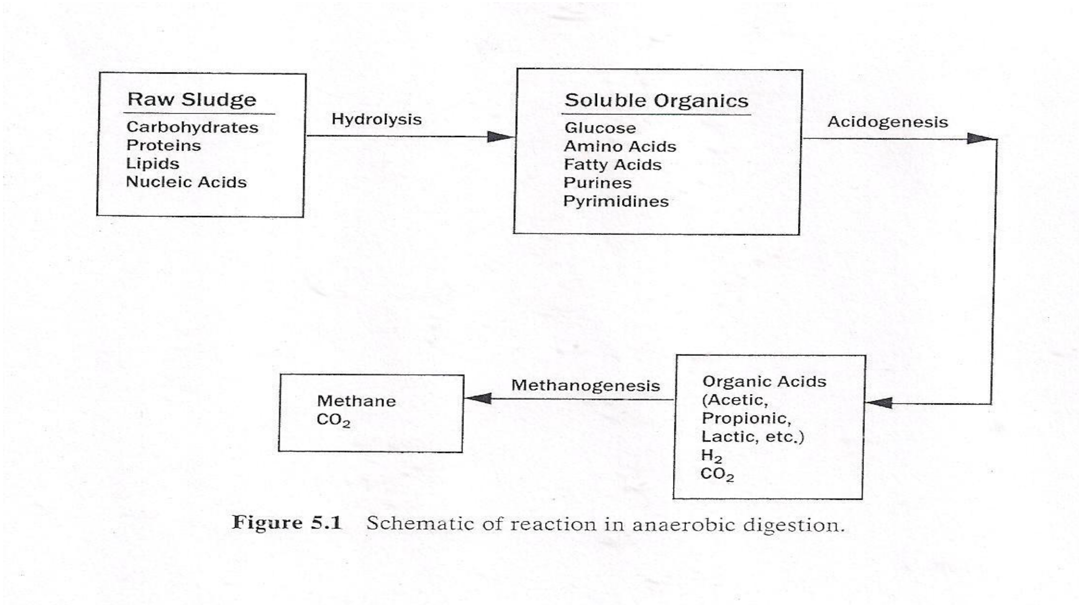

Figure 2.2: Schematic Of Reaction in Anaerobic Digestion Taken from (IzrailS.Turovskiy et al, 2006)

2.5 ANAEROBIC MICROORGANISM

2.5.1 ACIDOGENIC BACTERIA

The essential organics in wastewater are proteins, lipids and hydrocarbon. All of it can be breakdown into simple monomer by acidogenic bacteria. Proteins are hydrolyzed into amino acid by protease enzyme. Lipids are converted from glycerin by lipase enzyme and the polymeric hydrocarbon are converted into glucose and other sugar via exo-enzyme (UdoWiesman et al,2007)

2.5.2 ACETOGENIC BACTERIA

Most of acetate is formed by synthrophic reaction, and only little of acetate is formed through direct fermentation (UdoWiesman et al, 2007). This bacterium is able to converted carbon dioxide into acetate via the acetylcoenzyme A (acetyl-CoA).

2.5.3 METHANOGENIC BACTERIA

There are 2 types of bacteria which are Methanosacina and methanothrix. It can grow using acetate. 70% of methane gas (CH_4) is formed in digester process. Methanosacina can produce ATP from acetate and water. Methanol and methyl amine are intermediate product that can be degraded down to methane gas (CH_4) and carbon dioxide (CO_2) (UdoWiesman et al, 2007)**.**

2.6 FACTORS AFFECTING ANAEROBIC DIGESTION

As known, in the anaerobic process, it contains bacteria to consume all the organic matter in the raw sewage sludge. In order to run this process, it is necessary to provide optimum condition to bacteria to react with the sewage sludge. The factors that may affect the optimum condition are temperature, pH, nutrients and toxicants concentrations (LudovicoSpinosa et al, 2001). Table 2.1 shows the optimum operating conditions for anaerobic sludge digestion:

Table 2.1: Optimum Condition for Anaerobic Digestion Taken from (LudovicoSpinosa et al, 2001)

Table 13.1. Optimum and extreme operating conditions for anaerobic sludge digestion

Variable	Optimum	Extreme
pH	6.8–7.4	6.3–7.9
Oxidation reduction potential (mV)	–520 to –530	–490 to –550
Volatile acids (mmol/L)	0.8–8.0	>35.0
Alkalinity (mg/L as $CaCO_3$)	1300–3000	1000–5000
Organic loading rate (as volatile solids)		
Mesophilic (kg/m^3/d)	0.8–2.0	0.4–6.4
Thermophilic (kg/m^3/d)	1.5–5.0	1.0–7.5
Temperature		
Mesophilic (°C)	32–37	20–42
Thermophilic (°C)	50–56	45–65
Hydraulic retention time (days)	12–18	7–30
Biogas composition		
Methane (% vol)	65–70	60–75
Carbon dioxide (% vol)	30–35	25–40

2.6.1 pH

pH is one of the important factor that can affect the performance of the anaerobic process since methane bacteria is sensitive to pH. Methane bacteria will growth at all pH values between 6.5 and 7.2 (Boe K,2006) but the optimum condition of methane bacteria to growth is at 7.0 – 7.2. The acidogenesis organism is less sensitive and can live in wide range of pH between 4.0 and 8.5(Hwang MH et al,2004).At low pH the main product are acetic and butyric acid while at pH of 8.0, acetic and propionic acid are produced (Boe K.,2006). The volatile fatty acid produce during the process tend to reduce pH of the system. Normally, the activity of methanogenic bacteria countered the system pH by produced alkalinity in a form of carbon dioxide, ammonia and bicarbonate (Turovskiy IS, Mathai PK, 2006; Hwang MH et al, 2004).The system pH are controlled by CO_2 concentration in gas phase and HCO_3 alkalinity in liquid phase (Lise Appels et al , 2008). If concentration of CO_2 is remain constant in the digester, the HCO_3 may be added to the system to maintained the alkalinity of the system.

2.6.2 TEMPERATURE

The most importance factor that affects the digestion performance and the production of biogas is temperature. Anaerobic bacteria can stand temperature ranging from below freezing to above 57^0C but the desired temperature for mesophilic is at 37^0C and for thermophilic is at 54.4^0C. The bacteria activity and the production of gas are fall off significantly between temperatures of $39\text{-}51.7^0C$.

In the thermophilic range, the production of biogas and decomposition occur more rapidly than in the mesophilic range but it is highly sensitive to the changes in temperature or composition of the feed materials. All the anaerobic digestion reduces the organic matter and pathogens but in the thermophilic digestion the rate of destruction is high. Although the mesophilic process is slower than thermophilic, the process is less sensitive to changes and produces more methane gas (Ivo Achu Nges and Jing Liu, 2010).

The temperature of the digester must be keep at the consistent temperature to optimize the digestion process because the rapid changes will upset bacterial activity. In United state, digester vessel required some level of insulation or heating to maximize the production of gas.

2.6.3 HYRAULIC RETENTION TIME (HRT)

Hydraulic retention time (HRT) is a measure of the average length of time that microorganism needs to digest the biodegradable material in the reactor. HRT is depending on the sewage sludge characteristics and environmental condition. The digester must reach suitable HRT in order to achieve better process. The poor degradation of colloidal particles has resulted in long retention times (20-30 days) in anaerobic processes (Parawira et al,2004) and above 35 days in some full-scale operations primarily designed for wastes stabilization. Sludge digestion at shorter SRT has been reported by Appels et al (2008) in thermophilic digestion.. However, a major drawback that comes with shortening of the SRT could be the poor destruction of volatile solids (Appels et al, 2008), a condition which will lead to an increase in the volume of residual sludge for further disposal.

2.7 MEMBRANE ANAEROBIC SYSTEM

Membrane Anaerobic System (MAS) is a combination of anaerobic process and membrane separation process. It consists of anaerobic reactor that coupled with cross flow ultrafiltration modules. The maximum operating pressure on the membrane is 55 bar at 70^0C and it can be used in the pH range from 2 to 12. The anaerobic reactor is made of clear PVC which has a dimension of 30 cm diameter and a total height of 100 cm. The total effective liquid volume of the reactor is 50 L.

As compared with conventional method, it offer a lot of advantages such as clear final effluent, less usage of chemical, low energy consumption, small foot print and low maintenance cost.(A.G. Liew Abdullah et al, 2005). Several studies have conducted on anaerobic process for wastewater treatment and shows that, the membrane anaerobic process had retained all the particulates matter and liquefied and decomposing them in long solid retention time (A. Fakhru'l-Razi, 1992; V.L. Pillay, B. et al, 1994; W.R. Ross et al, 1994; K. Strohwald and W.R. Ross, 1992)

2.8 ULTRAFILTRATION MEMBRANE

Ultrafiltration membrane has a fine pore with pore sizes in the range of 0.1 to 0.001 micron. Ultrafiltration will remove high molecular-weight substances, colloidal materials, and organic and inorganic polymeric molecules. The low molecular weight and ion such as sodium and calcium will not be removed. This membrane is suitable for low pressure and has high reflux. Flux of a membrane is defined as the amount of permeate produced per unit area of membrane surface per unit time.

2.9 BY-PRODUCT

2.9.1 METHANE GAS (CH_4)

Methane gas is the chemical compound that has chemical formula of CH_4. It is a simple alkane compound because it has only one atom of carbon. It is colourless, odourless and less dense than air. It is a part of natural gas which is inexpensive, burns cleanly and is easy to transport through pipes (Russo silver, 2007). Methane gas can be explosive in a confined area if composition of methane gas is 5% and 15% in air (low concentration). In high concentration, methane gas can be flammable. Methane gas is mainly produce by breakdown of organic matter by bacteria in absence of oxygen.(Hyunhee Lee et al, 2008)

2.9.2 METHANE GAS USAGE

Methane is mainly used as a fuel. The combustion of methane is highly exothermic. The energy released by the combustion of methane, in the form of natural gas, is used directly to heat homes and commercial buildings. It is also used in the generation of electric power by burning it as a fuel in a gas turbine or steam boiler.

In the chemical industry, methane is a raw material for the manufacture of methanol (CH_3OH), formaldehyde (CH_2O), nitromethane (CH_3NO_2), chloroform (CH_3Cl), carbon tetrachloride (CCl_4), and some freons (compounds containing carbon and fluorine, and perhaps chlorine and hydrogen). The reactions of methane with chlorine and fluorine are triggered by light. When exposed to bright visible light, mixtures of methane with chlorine or fluorine react explosively.

2.9.3 DIGESTATE

Besides producing methane gas, MAS also produce final biological stable and partially hygienic organic product which is digestate (Tambone et al., 2009).Digestate is differences from compost and also ingestates. It can act as carbon storage in soil and organic fertilizer (Møller et al., 2009). Digestate have high nutrient contain (N,P,K) in available form, thus make it suitable to replace inorganic fertilizer and contribute to the short-term soil organic matter turnover.

2.10 OVERVIEW SEWAGE SLUDGE TREATMENT IN MALAYSIA

In Malaysia, the system used to treat sewage sludge are different, it is depends on types of communities. The most common system that they used is activated sludge, aerated lagoons, rotating biological contactors and trickling filters. In urban area which has large communities, more complex treatment systems are evolved. In small communities, where the population is less dense, they used “package plan” to treat the sewage sludge. The “package plan” is shown below. In Malaysia, only aerobic process is popular and the anaerobic process is not yet developed. But Malaysia starts to look other alternative way to treat their sewage sludge. The local university was doing the research about anaerobic process so that Malaysia can use this process widely to treat their sewage sludge.

Table 2.2: Commonly Used Treatment Systems for Small Communities

Primary Treatment	Individual Septic Tanks Communal Septic Tanks Imhoff Tanks
Secondary Treatment	Package (pre fabricated) Plants - activated sludge systems - sequencing batch reactors - contact stabilization - rotating biological contactors Individually Designed Plants - activated sludge systems - oxidation ponds - sequencing batch reactors - rotating biological contactors - trickling filter - facultation lagoons - aerated lagoons

2.11 THE ANAEROBIC PROCESS IN OTHER COUNTRY

In United Kingdom, the anaerobic digestion is only limited for small on- farm digester. However, anaerobic digestion is widely used across Europe. For example, Denmark has several farms co-operative anaerobic digestions plant that produce electricity and district heating for local villages. Other country like Sweden produce vehicles fuel for busses town used. Austria and Germany also have on –farm digester treating energy crops, mixture of manure and restaurant waste to produce electricity. (Greenfinch Ltd, 2006)

Anaerobic digestion also was being used in other part of world like Thailand and India. They have thousands of small scale plant. In developing countries like Malaysia, anaerobic digestion is the way to produce biogas in a cheap and low cost energy required

CHAPTER 3

MATERIALS AND METHODS

3.1 MATERIALS

In this research, the raw material which is sewage sludge was obtained from Indah Water Municipal Treatment Plant at Taman Seri Mahkota Aman KUN 112. The cooperation from person-in-charge, Mr. Zul was lead to smooth the sampling process. The sewage sludge were undergoes screening process to remove the coarse particles in order to avoid failure in the system. After that, it will be freshly store in the chiller at 4^0C.

3.2 INTRODUCTION

In this research, MAS operation is 5 hours per day for 11 days. Initially, the sample was acclimatized with bacteria for the first 3 days. Every day before the process begin, the sample analysis was done to the reactor content (influent) in order to measure the pH, COD, BOD, and TSS. Then, after 5 hours, the sample analysis was done again for permeate (effluent) and for sample at the bottom of the reactor.

The volume (30 Litre) of the sewage sludge must be maintain by recycled back some of the treated sludge. The pressure of the system is maintained to 1.5-2.0 bars by controlling gate valve. The methane gas production was being analyzed by using J-Tube Analyzer. The illustration of the membrane anaerobic reactor is shown below. It is equipped with a feed tank, reactor (digester), centrifugal pump, cross flow Ultrafiltration Membrane unit (CUF).

Figure 3.1: Membrane Anaerobic Reactor

3.3 EXPERIMENTAL START-UP

There are 2 methods in treating the sewage sludge. The conventional method is aerobic process and the preferable is anaerobic process. In this experiment methodology, it consists of 5 major processes which are:

- Screening process
- Parameter measurement
- Anaerobic process
- Separation process
- Sample analysis

In this process, the sewage sludge must undergo screening process. The purpose of this process is to eliminate all the coarse materials to avoid damages at the centrifugal pump. After that, the raw materials was placed into feed tank.After placing the raw sewage sludge into feed tank with an adaquate amount, then the initial analysis of certain parameter such as pH, Chemical Oxygen Demand(COD), Biochemical Oxygen Demand(BOD), and Total Suspended Solid(TSS) were done on the sludge and the data was being recorded.

After that, the raw sewage sludge will flow to the anaerobic reactor that contain methanogenic bacteria. An enrichment mix culture of methanogenic bacteria was cultured. The bacteria was developed and acclimatized in the digester for three days when the seed sludge was feed into the digester.Bacteria is used to breakdown all the biodegradable materials in sewage sludge. As the process continue, the methane gas(CH_4) was produced and will be collect by a 20 L of water displacement bottle that connected at the top of the reactor. The total volume of methane gas produced was being measured by using J-Tube Gas Analyzer that shown in Figure 3.4.

Once again, that sewage sludge was been analysis. Then, the sludge will go through separation process. Membrane ultrafiltration module was being used in separation process. Then, the sludge will be filtered. After it has been treated, there will be two conditions for the results which are fully treated (permeate) and partially treated. For the partially treated sludge, it will flow back to the reactor through the recycle path. The used of the recycle path is to maintain the pH to avoid failure of the system.

For the last step, the analysis of permeate and the sludge waste at the bottom stream of the reactor were done on pH, COD, BOD and TSS. The data that taken before the treatment and permeate will be compared. The illustration of raw sewage sludge before, during (permeate) and after the treatment and also flow of the sludge was shown in the figure below.

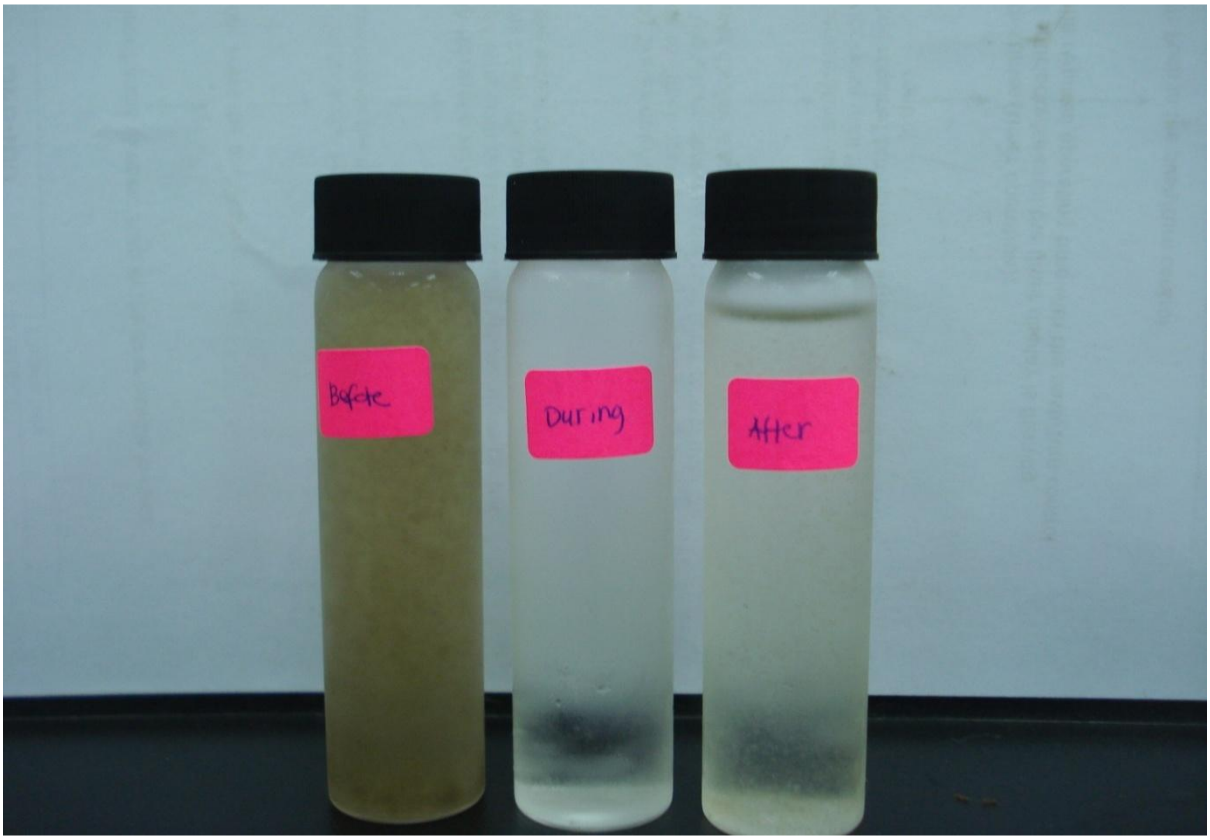

Figure 3.2 : The Raw Sewage Sludge Before, During(Permeate) And After The Treatment

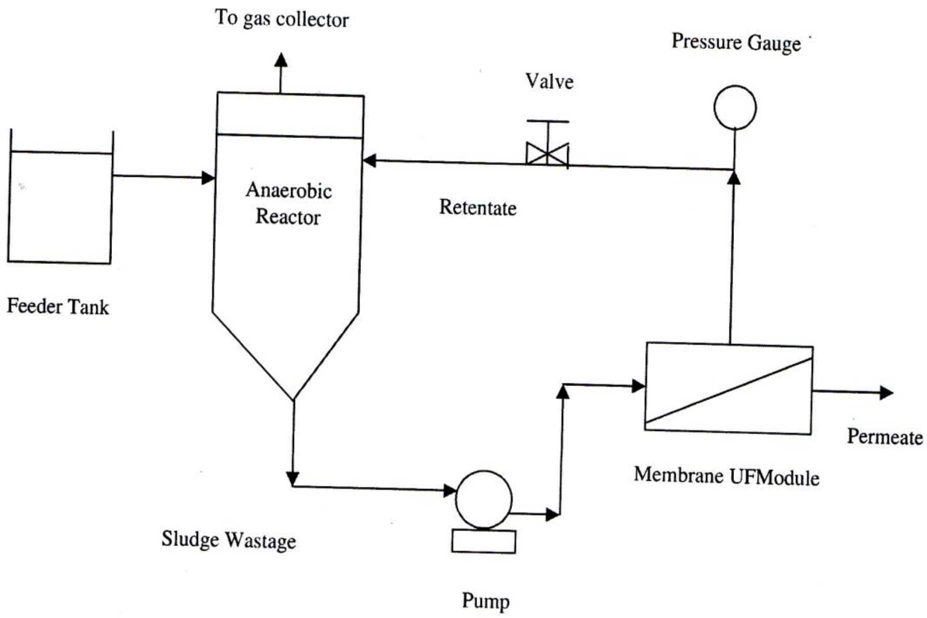

Figure 3.3 : Experimental Set-Up

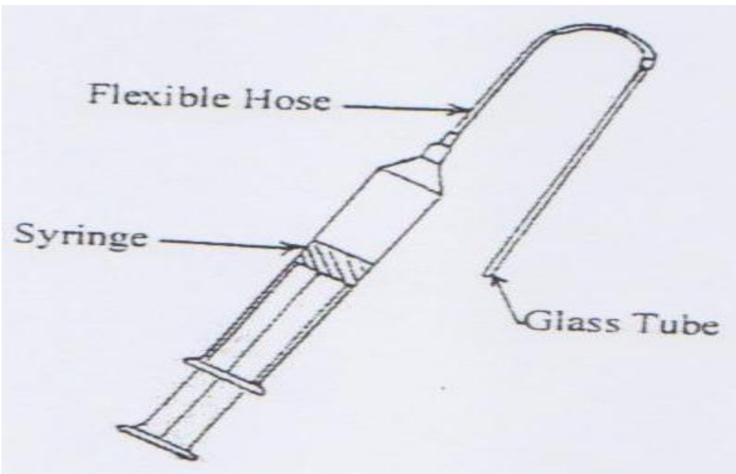

Figure 3.4: J-Tube Gas Analyzer

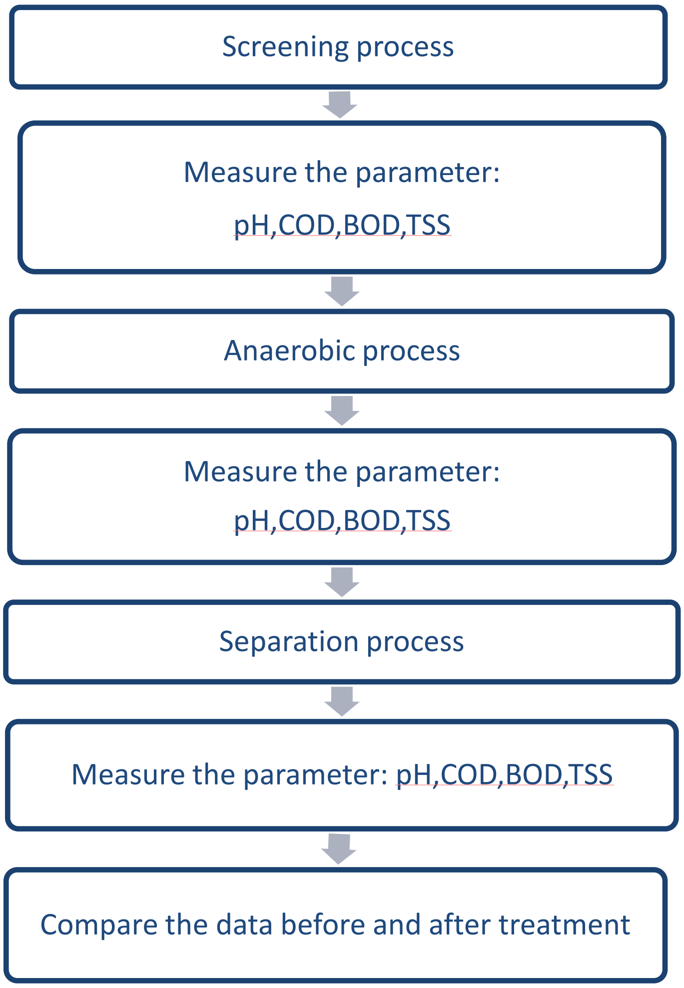

Figure 3.5: Brief Experimental Method

3.4 SCREENING AND FEED PROCESS

Screening process is performing to remove coarse particles present in the sample. Coarse particles may contain waste from home, papers, plastics, and organic waste. This process was being performed to avoid failure in the system such as blockage at the valve and UF membrane. Then, the sample was feed to the feed tank daily and it will flow by gravity through hose to the reactor. The screening process and feed tank are shown in Figure 3.6 and 3.7.

Figure 3.6: Screening process

Figure 3.7: Feed Tank

3.5 BACTERIA CULTURES

The bacteria culture is the method to produce more bacteria by letting them to reproduce in a thin layer of universal agar based growth medium. In this research, the bacteria cultures utilize Petri dishes that have a thin layer of agar based growth medium in them. Once the growth medium in the Petri dish is inoculated with the sewage sludge sample bacteria, the plates are incubated in an incubator usually set at 30^0C and for 24 hours. Then, a few loops of 24 hours-incubated cultures were being placed into the sterilized 500 mL Erlenmeyer flask which contains 150 mL nutrient broth by following the aseptic technique. Then, place the flask in the incubator at 30°C and 150 rpm, respectively. The culture was being incubated for 24 hours.

3.6 ANALYSIS OF SEWAGE SLUDGE

Analysis process such as pH, chemical oxygen demand (COD), biochemical oxygen demand (BOD) and total suspended solid (TSS) were done on sewage sludge. Standard methods were being used for analysing the samples in the laboratory. The analysis data of these samples was illustrated in Appendix A.

3.7 ANALYTICAL TECHNIQUE

3.7.1 pH

The pH of sludge that contain in the feed tank, permeate and at the bottom of the rector was determined by using Mettler Toledo pH meter. The pH meter is shown in Figure 3.8.

Figure 3.8: pH meter

3.7.2 CHEMICAL OXYGEN DEMAND (COD)

Chemical oxygen demand (COD) is used to measure the oxygen requirement of a sample that is susceptible to oxidation by strong chemical oxidant. The dichromate reflux method is preferred over procedures using other oxidants because of its superior oxidizing ability, applicability to a wide variety of samples. Oxidation of most organic compounds is 95-100% of the theoretical value. 2 mL of homogenize samples were pipette to the high range

(HR) vials and is heated for 2 hours at 150^{0}C in COD digestion reactor. Then, wait for 20 minutes for vials to cool to 120^{0}C or less and place it into the Spectrophotometer, HACH DR/2400 to analyze the COD content. The COD digestion reactor and Spectrophotometer are shown in Figure 3.9 and 3.10.

Figure 3.9: COD Digestion Reactor

Figure 3.10: Spectrophotometer, HACH DR/2400

3.7.3 BIOCHEMICAL OXYGEN DEMAND (BOD)

Biochemical oxygen demand (BOD) test measures the ability of naturally occurring microorganisms to digest organic matter by analyzing the depletion of oxygen. BOD is the most commonly used parameter to determining the oxygen demand on the receiving water of a municipal discharge. The sample was being dilute and place into the incubation bottles. Then, it will be incubated at 20^{0}C in the BOD Incubator. After 5 days, the BOD content is analyzed by using Dissolved Oxygen Meter. The illustration of Incubation Bottle, BOD Incubator and Dissolved Oxygen Meter is shown in Figure below:

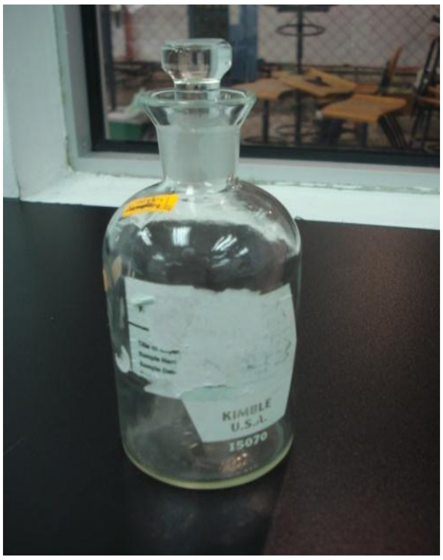

Figure 3.11: Incubation Bottle

Figure 3.12: BOD Incubator

Figure 3.13: Dissolved Oxygen Meter

3.7.4 TOTAL SUSPENDED SOLID

Solid suspended in water may consist of inorganic and organic particles or of immiscible liquid. The suspended solids parameter is used to measure the quality of wastewater influent, to monitor several treatment processes, and to measure quality of the effluent. The 50 mL well-mixed samples are filtered through a weighed standard glass-fibre filter and the residue retained on the filter is dried to a constant weight at 103^0C to 105^0C. The increase in weight of the filter represents the total suspended solid. The TSS apparatus is shown in Figure 3.14.

Figure 3.14: TSS Apparatus

3.7.5 METHANE GAS (CH_4) MEASUREMENT

During the process, some biogas was being produce that contain methane gas (CH_4) and carbon dioxide (CO_2).The volume of methane gas produce is measured at day 11 using J-Tube Gas Analyzer. J-tube device consist of a glass tube that connected to a syringe by a flexible hose. Firstly, the device is filled with 2 molar of Sodium hydroxide (NaOH) solution. The purpose of NaOH solution in this measurement is to adsorb CO_2 that contain in the biogas. Then, the glass tube was being inserted to the top reactor for 20 minutes and after that, the end of the glass tube was immersed in water. The initial length was being marked. By manipulating the syringe for several times, the length is reduce and it shows that, all CO_2 is being absorbed by NaOH and the remaining gas was being assumed to be a methane gas. Then, the percentage of methane gas produce id measured as:

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

3.8 CROSS FLOW ULTRAFILTRATION MEMBRANE (CUF) UNIT

The UF membrane module has molecular weight cut-off (MWCO) of 200,000 and a tube diameter of 1.25 cm and an average pore size of 0.1 μm. The length of each tube is 30 cm. The total effective area of the two membranes is 0.024 m^2. The maximum operating pressure on the membrane is 55 bars at 70 ºC and it can be used in pH range from 2 to 12. The CUF unit is shown in Figure 3.15.

Figure 3.15: Cross flow Ultrafiltration Membrane (CUF) Unit

CHAPTER 4

RESULT AND DISCUSSION

4.1 RESULT

The results obtained from 11 days of experiment were tabulated and plotted in graph form. All the result of Membrane Anaerobic System (MAS) efficiency on Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Suspended Solid (TSS) and methane gas yield are shown in Appendix A.

4.1.2 OVERALL RESULT

The parameter such as pH, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Suspended Solid (TSS) were analyzed for the raw sewage sludge before, during (permeate) and after (influent) the treatment. Before the experiment, each parameter was measured for the raw sewage sludge. Then, after 5 hours the permeate and the reactor content after the treatment sample were analyzed for each parameter mention above. The experiment was done for 11 days of hydraulic retention time (HRT). The result and picture obtained from the experiment is shown in Table 4.1 and Figure 4.1.

Table 4.1: Overall Result obtained from the experiment

Day	pH	% COD Removal	$BOD_{Reduction}$	$TSS_{Reduction}$
1	7.90	98.76	293.4	68.0
2	7.44	88.55	219.3	48.0
3	8.05	60.74	279.0	8.0
4	8.15	89.13	78.6	2.0
5	8.11	92.17	581.1	8.0
6	8.14	84.26	423.3	18.0
7	7.70	88.89	293.4	2.0
8	8.20	83.80	420.9	36.0
9	8.01	97.24	191.4	20.0
10	8.20	83.00	469.8	2.0
11	8.15	92.86	48.0	10.0

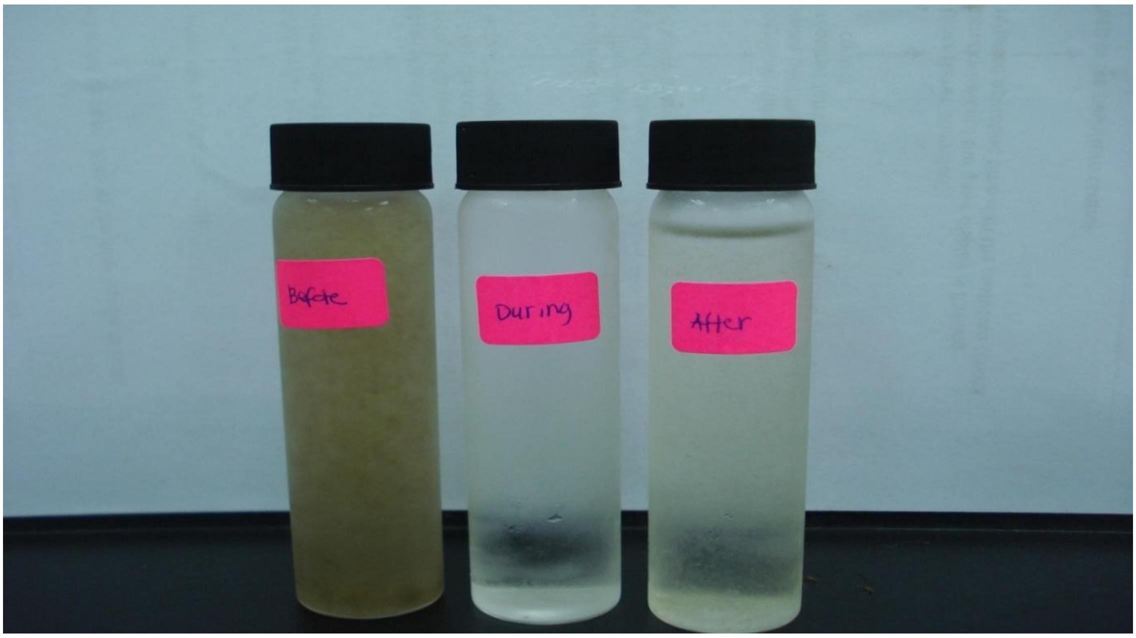

Figure 4.1: Raw sewage sludge, effluent (permeate), influent

4.2 DISCUSSION

4.2.1 pH

Each group of bacteria has their own optimum pH range. The methanogenic bacteria optimum pH is between 6.5 -7.2. In the result, it shows that, the pH of permeate range is fall between 7.44 – 8.20. At this range of pH, the methanogenesis process is slow and acidogenesis process is more dominant. pH has becomes an inhibitory for the process since methanogenic bacteria is extremely sensitive to the changes of pH. The microbe activity is highly depending on the pH of the system thus affecting the yield of biogas.

4.2.2 EFFICIENCY (%) OF CHEMICAL OXYGEN DEMAND(COD) REMOVAL

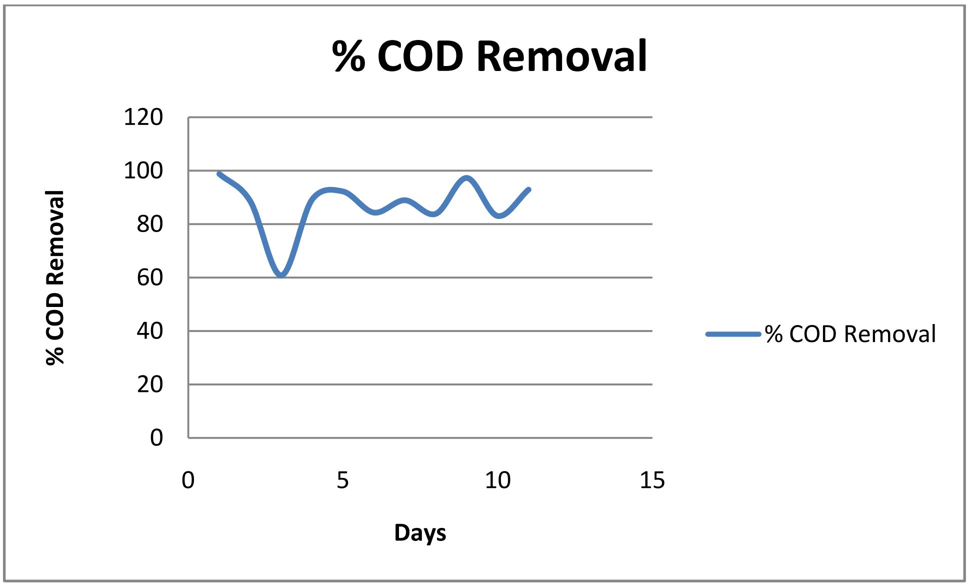

Figure 4.2: Graph of Efficiency of Chemical Oxygen Demand (COD)

Table 4.2: Efficiency of Chemical Oxygen Demand (COD)

Day	$COD_{Influent}$	$COD_{Effluent}$	% COD Removal
1	980.0	12.0	98.76
2	358.0	41.0	88.55
3	326.0	128.0	60.74
4	276.0	30.0	89.13
5	217.0	17.0	92.17
6	235.0	37.0	84.26
7	27.0	3.0	88.89
8	216.0	35.0	83.80
9	181.0	5.0	97.24
10	100.0	17.0	83.00
11	42.0	3.0	92.86

The initial COD content of the raw sewage sludge was found to be at 980 mg/L which was 98.76 % of the COD removal and gradually drop to 326 mg/L which was 60.74% of the COD removal at third day. During these three days, the methanogenic bacteria is adapting new environment and digest the organic particulates in order to produce new cells. On the day 4 till day 9, the COD in permeate has been remove from 276 mg/L to 31 mg/L which was 89.13% to 92.86% of the COD removal. The efficiency of COD removal was increased and slightly decreased over these five days. At day 9, the high efficiency of COD removal has been achieved. The overall result shows that, the high efficiency of COD removal has been achieved in a short period of time, but the graph shows this system is not in a steady state yet. This system needs longer hydraulic retention time (HRT) in order to digest more organic matter in the sewage sludge. By providing the optimum temperature (37-40^{0}C), pH (6.5-7.2) and suitable HRT, it can increase the methanogenic bacteria activity in decomposing biodegradable material thus increases the yield of methane gas.

4.2.3 BIOCHEMICAL OXYGEN DEMAND (BOD) REDUCTION

Table 4.3: Biochemical Oxygen Demand (BOD) Reduction

Day	$BOD_{Influent}$	$BOD_{Effluent}$	$BOD_{Reduction}$
1	324.0	30.6	293.4
2	237.0	17.7	219.3
3	306.0	27.0	279.0
4	102.0	23.4	78.6
5	600.0	18.9	581.1
6	474.0	50.7	423.3
7	345.0	51.6	293.4
8	480.0	59.1	420.9
9	276.0	84.6	191.4
10	606.0	136.2	469.8
11	120.0	72.0	48.0

The initial biochemical oxygen demand (BOD) content of raw sewage sludge was found to be at 324 mg/L. The overall BOD in the sample is somehow low. It indicates that, not much biodegradable organic matter in the sample. Only at day 5, 6, 8 and 10, the BOD content is high and the BOD reduction is also high. The overall results shows that, there have some reduction of the sample from day by day and it shows that anaerobic process is occur in the Membrane Anaerobic System (MAS) and the organic matter was been consumed by the anaerobic bacteria.

4.2.4 TOTAL SUSPENDED SOLID REDUCTION

Table 4.4: Total Suspended Solid (TSS) Reduction

Day	$TSS_{Influent}$	$TSS_{Effluent}$	$TSS_{Reduction}$
1	180.0	112.0	68.0
2	56.0	8.0	48.0
3	46.0	38.0	8.0
4	28.0	26.0	2.0
5	10.0	2.0	8.0
6	48.0	30.0	18.0
7	4.0	2.0	2.0
8	46.0	10.0	36.0
9	24.0	4.0	20.0
10	10.0	8.0	2.0
11	20.0	10.0	10.0

This table above shows that, the overall degradation efficiency of the organic matter in the sewage sludge is low. The low reduction of Total suspended solid (TSS) are generally associated with the hydrolysis stage (Tiehm A et al, 2001). During hydrolysis, cell walls are ruptured and the intercellular which contain glycan strands cross linked by peptide chain (Lise Appels et al, 2008) are degrade and release in the readily available organic matter which being relatively unfavourable substrate for bacteria degradation. This mechanism leads to reduce the degradation of organic matter hence reducing the production of methane gas.

4.2.5 METHANE GAS PRODUCTION

The biogas production in Membrane Anaerobic digester was been measured by using 20 L water displacement bottle. The Composition of the biogas is methane gas and carbon dioxide. The percentage of methane gas at day 11 was determined by using a J-tube gas analyzer (A.G. Liew Abdullah et al, 2005) as mentioned in chapter 3.

From the experiment, the percentage of methane gas was found to be at 70%. This methane gas production is somehow low and many factors govern the performance of Membrane Anaerobic digester. These factors include pH, operating temperature, mixing, nutrient availability and organic loading rates (OLR) into the digester.

The bacteria community in the anaerobic digester was extremely sensitive to pH changes. Therefore, the pH must be maintained at their optimum condition (6.5-7.2) to avoid the inhibitory in biogas production. Since the pH of the system in this study is deviates from their optimum range which is between 7.44-8.20, the methanogenic activity will decrease thus lowering the production of methane gas.

The temperature also plays an importance role in the performance of digester. It can affect the physicochemical properties of the components found in the digester. It also influences the growth rate and metabolism of the bacteria in the digester. At higher temperature (thermophilic condition) the solubility of organic compound increase, enhances the biological and chemical reaction rate and increase the death pathogen rate (Lise Appels et al, 2008). The percentage of methane gas produced in thermophilic is higher than mesophilic condition. It is important to maintain a stable operating temperature in the digester since frequent fluctuation in temperature affect the bacteria activity especially methanogenic bacteria.

Mixing provide good contact between bacteria and substrate, thus reduces the resistance to mass transfer, minimizes the build-up of inhibitory intermediates and stabilizes environmental condition (N.H Abdurahman et al , 2010). The methane content also depends on the organic loading rate (OLR) into the digester. The methane content generally declined with increasing OLRs. The higher OLR favoured a higher growth rate of acid forming bacteria over methanogenic bacteria (A.G. Liew Abdullah et al , 2005). Thus affect the methane content in the biogas production.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Based on the result of this study, it can be concluded that, the Membrane Anaerobic System (MAS) was found to be a successful biological treatment system to achieve a high COD removal efficiency in a short period of time. About 60.74% to 92.86 % of COD removal was achieved. The system still not achieved it steady state condition, longer HRT are needed to allow more decomposition of organic matter occur in the digester.

The $TSS_{Reduction}$ and $BOD_{Reduction}$ is somehow low but there still have some reduction and indicated that there are anaerobic process occur in the system that convert the organic matter into soluble form. Furthermore, the sludge effluent was being filtered by an average pore size 0.1µm of membrane, that produce very low concentration of effluent suspended solid.

In this study, the methane gas produce from laboratory digester is being analyzed by using J-tube gas analyzed at day 11. The total percentage of methane gas yield is only 70%. Hydrolysis step is found to be a general rate limiting in this study. The pH of the system effect decomposing process by methanogenic bacteria. The acidogenesis process is dominant in this system thus; conversion of substrate to methane gas is low.

5.2 RECOMMENDATION

Based on the finding and observation during this study, it should be possible to re-examine the factor which influences the design and operation condition of Membrane Anaerobic System (MAS) treatment. The following suggestions are subjected for future work.

- Use steady state condition in order to get good conversion of Acidogenic to Methanogenic stage.

- Do pre-treatment such as thermal, mechanical or chemical pre-treatment to the raw sewage sludge before run the experiment to increase the rate of methanogenesis bacteria activity.

- Study on kinetic reaction of the reactor by varying the Organic Loading Rate.

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APPENDIX A

SAMPLE RESULT

Table A.1: Result obtain at Day 1

Parameter	Before	During	After
pH	7.70	7.90	7.74
COD(mg/L)	980.00	12.00	188.00
BOD(mg/L)	324.00	30.60	261.00
TSS(mg/L)	0.182	0.106	0.15

Table A.2: Result obtain at Day 2

Parameter	Before	During	After
pH	7.45	7.44	7.56
COD(mg/L)	358.00	41.00	204.00
BOD(mg/L)	237.00	17.70	153.00
TSS(mg/L)	56.00	0.00	8.00

Table A.1: Result obtain at Day 3

Parameter	Before	During	After
pH	7.46	8.05.00	8.07.00
COD(mg/L)	326.00	128.00	129.00
BOD(mg/L)	306.00	27.00	264.00
TSS(mg/L)	46.00	0.00	38.00

Table A.2: Result obtain at Day 4

Parameter	Before	During	After
pH	7.64	8.15	8.03
COD(mg/L)	276.00	30.00	43.00
BOD(mg/L)	102.00	17.00	23.40
TSS(mg/L)	28.00	0.00	26.00

Table A.2: Result obtain at Day 5

Parameter	Before	During	After
pH	7.63	8.11	8.16
COD(mg/L)	217.00	17.00	38.00
BOD(mg/L)	600.00	18.90	309.00
TSS(mg/L)	10.00	0.00	2.00

Table A.1: Result obtain at Day 6

Parameter	Before	During	After
pH	7.89	8.14	8.17
COD(mg/L)	235.00	37.00	55.00
BOD(mg/L)	474.00	50.70	414.00
TSS(mg/L)	48.00	0.00	30.00

Table A.2: Result obtain at Day 7

Parameter	Before	During	After
pH	7.47	7.70	7.32
COD(mg/L)	27.00	3.0	3.00
BOD(mg/L)	345.00	51.60	276.00
TSS(mg/L)	4.00	0.00	2.00

Table A.2: Result obtain at Day 8

Parameter	Before	During	After
pH	7.76	8.20	7.91
COD(mg/L)	216.00	35.00	63.00
BOD(mg/L)	480.00	59.10	350.00
TSS(mg/L)	10.00	0.00	46.00

Table A.1: Result obtain at Day 9

Parameter	Before	During	After
pH	7.50	8.01	8.06
COD(mg/L)	181.00	5.00	7.00
BOD(mg/L)	276.00	84.60	93.00
TSS(mg/L)	24.00	0.00	4.00

Table A.2: Result obtain at Day 10

Parameter	Before	During	After
pH	7.83	8.20	8.29
COD(mg/L)	100.00	17.00	20.00
BOD(mg/L)	606.00	136.20	492.00
TSS(mg/L)	8.00	0.00	16.00

Table A.2: Result obtain at Day 11

Parameter	Before	During	After
pH	7.75	8.15	8.13
COD(mg/L)	42.00	3.00	4.00
BOD(mg/L)	120.00	72.00	90.00
TSS(mg/L)	20.00	0.00	10.00

Percentage Production of Methane Gas (CH_4)

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

$$\frac{4.0\ \text{cm}}{5.70\text{cm}} \times 100\% = 70\%\ \text{yield of } CH_4$$

Formula

1. **Efficiency of COD Removal**

$$COD_{Removal} = \frac{COD_{Influent} - COD_{Effluent}}{COD_{Influent}} \times 100\%$$

2. $$BOD_{Reduction} = \frac{BOD_{Influent} - BOD_{Effluent}}{BOD_{Influent}} \times 100\%$$

3. $$TSS_{Reduction} = \frac{TSS_{Influent} - TSS_{Effluent}}{TSS_{Influent}} \times 100\%$$

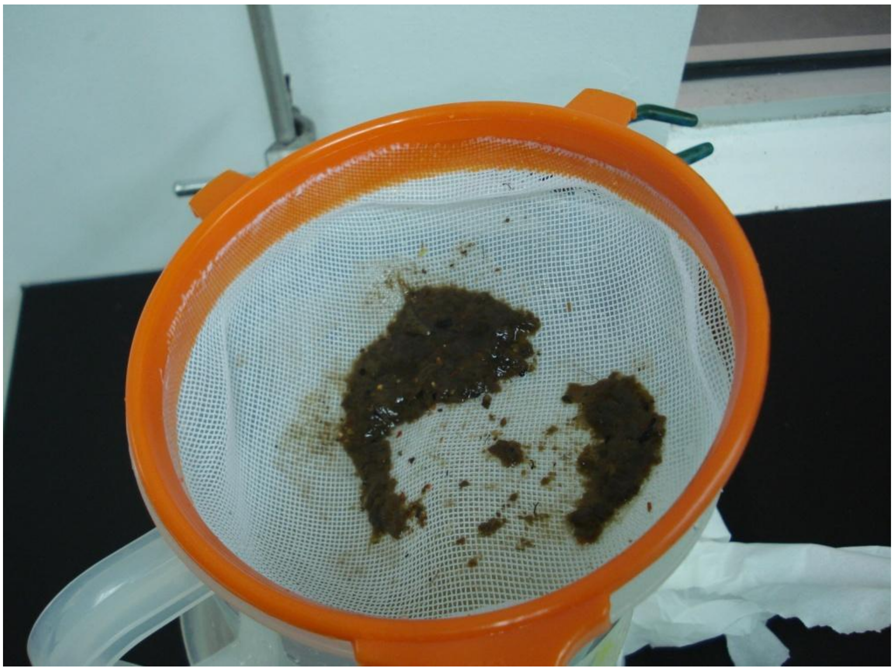
APPENDIX B

PICTURES

The author and her supervisor are beside the Membrane Anaerobic System (MAS).

The crystal clear effluent that was collected.

Sewage sludge storage.



Coarse particles that has been removed from sewage sludge.

Centrifugal pump