BIOMETHANATION OF SEWAGE SLUDGE BY USING ULTRASONIC MEMBRANE ANAEROBIC SYSTEM (UMAS) USING SEWAGE SLUDGE AS SUBSTRATE

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NUR SARAFINA BINTI SAMSUDIN

Thesis submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Chemical Engineering (Gas Technology)

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JANUARI 2015

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Chemical Engineering (Gas Technology).

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Date	: 20 JANUARI 2015

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :
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Date : 20 JANUARY 2015

Dedication

Especially for Supervisor, family and friends. Thank you for your support and encouragement.

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ABSTRACT

This study is going to introduce Ultrasonic Membrane Anaerobic System (UMAS) as an alternative to current conventional methods to solve the problem of membrane fouling. Raw sewage sludge was treated by UMAS which consists of a cross flow ultra-filtration membrane (CUF) apparatus, while pH, pressure, and temperature parameter were kept constant during this experiment with the value of 7.0-7.6, 1.5 bars, and 32^{O}C respectively. Samples has been analyzed for several parameters such as chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), pH, volatile suspended solids (VSS), turbidity and colour, by controlling volatile fatty acids (VFA) and pH parameters. The initial value of COD recorded was 1040 mg/L; BOD was 98.7 mg/L, while TSS and VSS recorded the values of 98.6 mg/L, and 65.8 mg/L respectively. After 28 days of experiment, the final value of COD became 92 mg/L, BOD value dropped to 4.1 mg/L, TSS had final value of 6.0 mg/L while VSS dropped to 4.2 mg/L. The findings are this ultrasonicated-membrane technology has overcome fouling membrane, shorten the retention time of the sewage sludge treatment, reduce the treatment area, and high removal efficiency of Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS). The complete treatment reduced the COD content to 92 mg/L equivalent to a reduction of 91% reduction from the original, while TSS and VSS removal efficiency have reached up to 93%. The final product is Methane (CH_4) biogas, ranged from 79% to 96% which become a highly-demand in energy resource, at the same time this technology can reduce the greenhouse effect and global warming caused by the methane gas.

Key words: UMAS, wastewater, methane, membrane fouling, sludge

ABSTRAK

Kajian ini akan memperkenalkan Ultrasonik Membran Sistem Anaerobik (UMAS) sebagai alternatif kepada kaedah konvensional sedia ada bagi menyelesaikan masalah pengotoran membran. Enapcemar kumbahan mentah telah dirawat oleh UMAS yang terdiri daripada aliran merentas membran ultra-penapisan (CUF) radas, manakala pH, tekanan, dan parameter suhu telah dimalarkan dalam eksperimen ini dengan nilai 7,0-7,6, 1.5 bar, dan masing-masing $32^{O}C$. Sampel telah dianalisis untuk beberapa parameter seperti permintaan oksigen kimia (COD), permintaan oksigen biokimia (BOD), jumlah pepejal terampai (TSS), pH, pepejal terampai meruap (VSS), dengan mengawal asid lemak meruap (VFA) dan parameter pH. Nilai awal COD yang dicatatkan adalah 1040 mg / L; BOD adalah 98.7 mg / L, manakala TSS dan VSS masing-masing mencatatkan nilai 98.6 mg / L, dan 65.8 mg / L. Setelah 28 hari eksperimen dijalankan, hasil terakhir ialah nilai COD menjadi 92 mg/L, BOD jatuh kepada 4.1 mg/L, TSS mempunyai hasil terakhir 6.0 mg/L sementara VSS jatuh kepada 4.2 mg/L. Hasil kajian adalah teknologi ultrasonic-membran ini telah mengatasi masalah pengotoran membran, memendekkan masa tahanan rawatan enapcemar kumbahan, mengurangkan kawasan rawatan, dan kecekapan penyingkiran yang tinggi keperluan oksigen kimia (COD), Pepejal Biokimia Oxygen Demand (BOD) dan Jumlah Terampai (TSS). Rawatan yang lengkap telah mengurangkan kandungan COD kepada 92 mg / L bersamaan dengan 91% pengurangan daripada nilai asal, manakala kecekapan penyingkiran TSS dan VSS telah mencapai sehingga 93%. Produk akhir adalah Metana (CH4) biogas, adalah di antara 79% hingga 96% yang menjadi permintaan tinggi dalam sumber tenaga, pada masa yang sama teknologi ini boleh mengurangkan kesan rumah hijau dan pemanasan global yang disebabkan oleh gas metana.

Kata Kunci: UMAS, air kumbahan, metana, pengotoran membran, kumbahan

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LIST OF ABBREVIATIONS/SYMBOLS

MAS	Membrane Anaerobic System
UMAS	Ultrasonic Membrane Anaerobic System
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
TSS	Total Suspended Solid
VSS	Volatile Suspended Solid
CH4	Methane Gas
H2O	Water
CO2	Carbon Dioxide
NH3	Ammonia
VFA	Volatile Fatty Acid
HCO3	Bicarbonate
HRT	Hyraulic Retention Time
PVC	Polyvinylchloride
CH3OH	Methanol
CH2O	Formaldehyde
CH3NO2	Nitromethane
CH3Cl	Chloroform
CCl4	Carbon Tetracholide
CUF	Cross Flow Ultrafiltration
NaOH	Sodium Hydroxide
MWCU	Molecular Weight Cut-Off
OLR	Organic Loading Rate
pKa	Dissociation Constant

CHAPTER 1

INTRODUCTION

1.1 Background

Sludge contains large amounts of pathogenic organisms and heavy metals, which are harmful to human health and the environment (US EPA, 2007). Therefore, useful and effective methods are needed to remove pollutants, such as organic micro-pollutants and heavy metals (Xu et al.,2013). Anaerobic digestion can regenerate electricity and heat by using the methane produced by sewage sludge. Sewage sludge (SS) from wastewater treatment plant, which is accompanied with unpleasant odors, pathogens, and heavy metals (HMs), has been deemed as a common pollution source (Huang et al.,2011;Li et al.,2012).Besides, accompanied with the high water content and large production, conventional treatment processes (e.g. agricultural application, landfilling) of SS are becoming increasing complex. Furthermore, the rigorous requirement of environmental protection has limited the application of conventional treatment processes and gives rise to the treatment of SS an urgent issue to tackle. On the other hand, due to the high contents of organic matter, nitrogen and phosphorus, SS has been viewed as a promising alternative source of energy (Zhai et al., 2014).The anaerobic degradation of complex organic matter to methane (CH_4) and carbon dioxide (CO_2), which involves the interaction of four different metabolic groups of bacteria, namely hydrolytic, acidogenic, acetogenic and methanogenic bacteria, (Kataoka et al.,1992) offers, in general, some significant advantages when compared to aerobic treatment. These are: less production of sludge, low nutritional requirements, ability to deal with high organic loads, low cost and finally biogas (CH_4) production (Kappell et al.,2005) .In this case, Anaerobic digestion is one of the most important processes used for various industrial wastewaters as well as sewage treatments because it combines pollution reduction and energy production. (Lin et al., 2013). An improvement in the efficiency of anaerobic digestion can be brought about by either suitably modifying the existing digester design or by incorporating appropriate advanced techniques. Thus, UMAS is found to be superior to the conventional processes due to low concentrations of VFA in the effluent, a high degree of sludge retention and stable reactor performance. UMAS which the membrane is ultrasonicated, it is designed to create high energy compared to normal Membrane Anaerobic System (MAS) to clean the waste of filter. Besides, the ultrafiltration membrane which has high permeability and porosity properties, is important for the membrane to filter waste easily. In recent times biomethanation technology has become more attractive source of renewable energy due to reduced technological cost and process efficiency. Different variety of substrates are extensively used in this anaerobic technology. Methane production through biomethanation technology has been evaluated as one of the most energy-efficient and environmentally benign way of producing vehicle biofuels and can provide multiple benefits to the users. In biomethanation process the organic waste is converted into energy (methane) (Weiland, 2012). It is also now a well-accepted fact that methane is a powerful greenhouse gas, each molecule of methane causes about 25 times more global warming than a molecule of CO_2 (IPCC,2007). If we do not process organic waste and recover methane from it but, instead, allow the waste to rot in the open we will let the methane escape into atmosphere to cause global warming (Abbasi et al.,2010). However, this issue could be resolved by applying membrane separation in anaerobic processes as the membrane can retain biomass (methane) effectively, producing a solids-free effluent and prevent unintended sludge wasting. Short HRT coupled with long solids retention time (SRT) to achieve high biomass concentration in a bioreactor is now possible through the use of membrane for solids-liquid separation (Huang et al.,2010).

1.2 Problem Statement

The sewage sludge wastewater will be treated using Membrane Anaerobic System (MAS) under anaerobic digestion method. Still, the main problem that always occurs in this system is membrane fouling. Membrane fouling is a process where solute or particles deposit onto a membrane surface or into membrane pores in a way that degrades the membrane's performance. The quality of the water produced will be affected and severe flux declined will occur when membrane fouling happens. To overcome this problem, membrane replacement or chemical cleaning will take place, but these will increase the operating costs of a treatment plant. Therefore, another economic solution to overcome this problem is by adding ultrasonicated-device into the MAS system. This is a new design that was proposed by NH Abdurahman *et.al*, (2012) in treating POME and producing methane. Still there are few things that have to be upgraded to improve the Ultrasonic Membrane Anaerobic System (UMAS) to produce methane gas. Furthermore, other problems that related to the conventional methods are:

i) The conventional techniques take times to accomplish and are costly.
ii) Expensive and high cost for raw materials treatment.
iii) High demand of energy.
iv) Limited resources.
v) Lack to retain the biogas

1.3 Objectives

The following are the objectives of this research:

i) To experimentally evaluate the removal of COD, BOD, TSS, and VSS.
ii) To evaluate the performance of UMAS in treating raw sewage sludge.
iii) To evaluate the effect of organic loading rate (OLR) in UMAS performance.

1.4 Scope of Study

The following are the scope of this research:

i) Design a 100 L UMAS to treat sewage sludge wastewater.
ii) To analyze the parameters such as BOD, COD, TSS, VSS, pH and colour.
iii) To measure the percentage of methane gas production by using J-Tube Gas Analyzer.
iv) To determine the amount of methane gas produced by the volume of permeates

1.5 Rational and Significance

The following are the contributions of this study:

i) Energy saving.
ii) Less expensive treatment.
iii) Environmental friendly (comply with standard issue).
iv) Can reduce the organic matter in the sewage sludge.
v) Reduce retention time.
vi) Overcome membrane fouling problem.
vii) 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.

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). Basically, there are 2 methods to treat the sewage sludge which are aerobic process and anaerobic process then only it can be dispose. Before dispose to landfill site, 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 (Izrail S.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

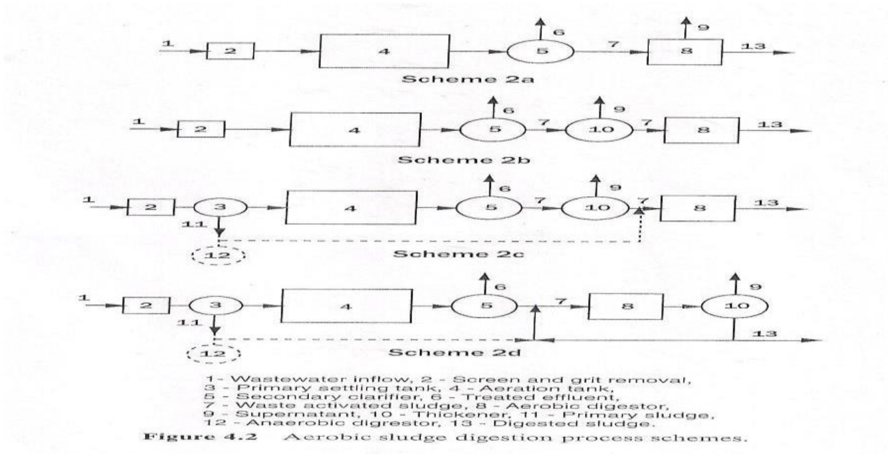

Figure 2-1: Aerobic Sludge Digestion Process Scheme Taken from (IzrailS.Turovskiy et al, 2006)

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,2007). 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 its 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, 2007). 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 and Kawase M, 1991). Theoretically, the reaction rate of thermophilic digestion is double than mesophilic rate. The operation temperature of thermophilic process is between 55^{0}C to 60^{0}C. 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 and ChungDWC, 1999; Maibaum C and 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

Anaerobic digestion involves bacterial fermentation of organic substances in the absence of free oxygen (Abbasi T et al., 2012a). The fermentation leads to the breakdown of complex biodegradable organics in a four step process (Khanal, 2008; Rosenzweig and Ragsdale, 2011) (Fig. 2-2). It is also referred as a three-phase process: hydrolytic phase (step 1), acid phase (steps 2 and 3), and methane phase (step 4). The steps are:

1.Decomposition of fats, cellulose, starch, proteins and other macromolecules into simpler,water soluble, monomers: amino acids, long-chain fatty acids, and sugars. This is brought about by exoenzymes (hydrolase) present in facultative and obligatory anaerobic bacteria.

2. Conversion of monomers during acidogenesis to form shorterchain (C1-C5) ‘volatile fatty acids’ (VFAs), principally lactic, propionic, butyric, and valeric acid.

3. Consumption of VFAs by homoacetogenic microorganisms to generate acetic acid, carbon dioxide, and hydrogen.

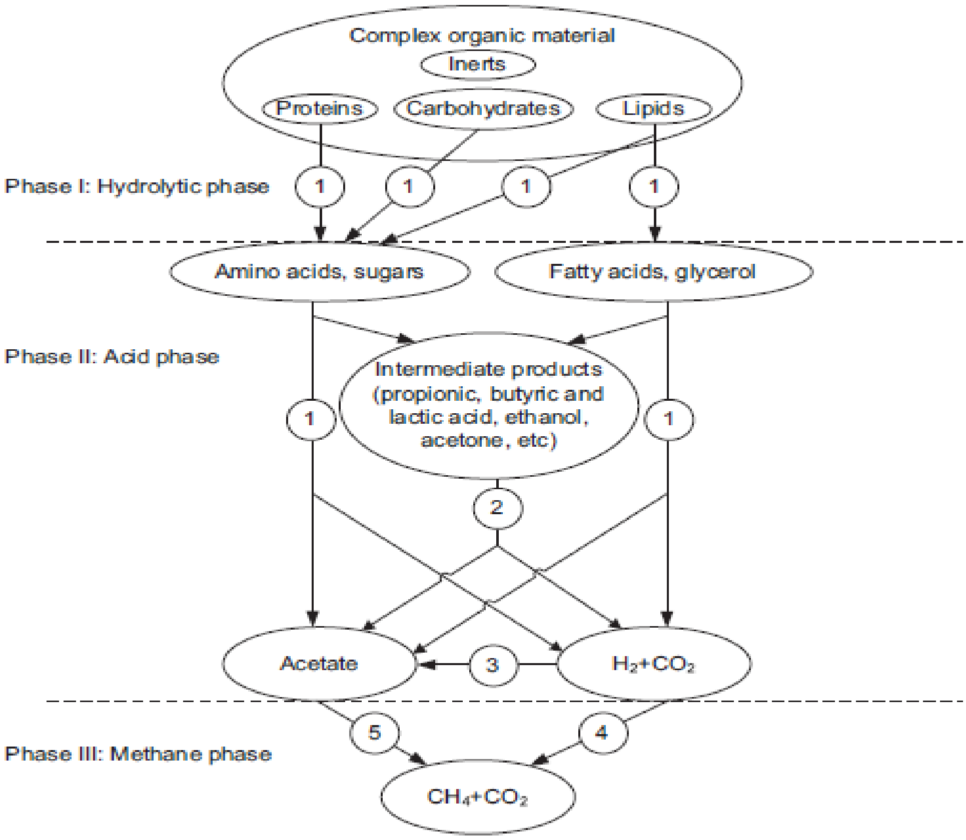

Figure 2-2: Steps associated with anaerobic digestion of organic materials

The bacteria involved are: (1) Hydrolytic and fermentative; (2) hydrogen producing acetogenic (3) hydrogen consuming acetogenic (4) carbon dioxide reducing and (5) aceticlastic methanogenic.

4. Methanogenesis: action of the strictly anaerobic methanogenic bacteria on the acetate, hydrogen, and some of the carbon dioxide to produce methane. Three biochemical pathways are used by methanogens to achieve this (Galagan et al., 2002);

a) acetotrophic pathway ($4CH_3COOH \rightarrow 4CO_2 + 4CH_4$);

b) hydrogenotrophic pathway ($CO2 + 4H_2 \rightarrow CH4 + 2H_2O$); and

c) methylotrophic pathway ($4CH_3OH + 6H_2 \rightarrow 3CH_4 + 2H_2O$).

Of these, the acetotrophic pathway is the primary one; hence theoretical yield calculations are often made using this pathway (Zhang et al., 2010). Methylated substrates other than methanol can also be converted. The gaseous products of step IV include 40-70% methane, CO2, and traces of other gases. This mixture is commonly referred as biogas (S.M. Tauseef et al.,2013)

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 Which Influence Anaerobic Digestion Of An Organic Substrate

Presence of adequate quantities of nitrogen, micronutrients, and water is essential if an organic substrate is to undergo anaerobic digestion and generate methane-rich biogas (Singh et al.,1999,Takashima et al.,2011). These are essentially the requirements of microorganisms especially methanogenic bacteria. Because these microorganisms are the ‘workers’ who take the fermentation along the desired route and at optimum pace, generating conditions which help these microorganisms ensures success of the process (Abbasi et al.,2012,Demirel B. and Scherer P.,2008). Some of the aspects which have to be kept in view for successful operation of an anaerobic digestion process for obtaining biogas are recounted below.

2.6.1 Dilution

Water should be added, if necessary, to the raw material to generate a slurry which is neither too thick nor too thin. If a material is diluted too much, the solid particles may settle down in the digester and may not get degraded properly. If the slurry is too thick, it may be difficult to stir and may impede the flow of gas to the upper part of the digester (Abbasi et al.,1992,Nipaney et al.,1992). Different systems can handle different levels of slurry density, generally in the range of 10–25% of solids (Abbasi et al.,2012).

2.6.2 pH Control

pH is an important factor for keeping functional anaerobic digestion. A typical pH is in the range of 6.5-7.6 (Parkin and Owen 1986). The accumulation of intermediate acids leads to pH drop during fermentation. In order to maintain stable operation, it is necessary to add bicarbonate or carbonate as an alkalinity buffer to neutralize volatile fatty acids and carbon dioxide (Parkin and
Owen 1986).

2.6.3 Temperature

The effects of temperature on anaerobic digestion are well recognized. Mesophilic (25-45^{0}C) and thermophilic (45-65^{0}C) anaerobic digestion are commonly applied in the field (O'Reilly et al. 2009). Most full-scale anaerobic digesters are operated at mesophilic temperature (Parkin and Owen 1986). Previous studies revealed several advantages of thermophilic digestion, including high organic removal rate, high degree of degradation and excellent solids stabilization (Buhr and Andrews 1977). Since wastewater and biosolids is discharged at relatively low temperature (e.g., 18 ^{0}C), recent research toward anaerobic treatment under psychrophilical condition becomes attractive. For instance, microbial communities involved in digestion are sensitive to temperature changes. However, researchers discovered that anaerobic digestion at low temperature showed reproducible microbial community structure and operational performance, suggesting that optimal cultivation of hydrogenotrophic methanogens is a effective way to improve process efficiency (O'Reilly et al. 2009). The rate of anaerobic degradation of organic substrates generally increases in the order of psychrophilic, mesophilic and thermophilic digestion. However, anaerobic digestion was traditionally operated in mesophilic range (25–45^{0}C) because of heat generation through methane combustion (Donoso-Bravo et al. 2009).

2.6.4 Retention Time

Most anaerobic systems are designed to retain the waste for a fixed number of days. Number of days the materials stays in the tank is called the Hydraulic Retention Time or HRT (Dennis A and Burke PE, 2001). The Hydraulic Retention Time is equal to the volume of the tank divided by the daily flow, HRT = Volume (V)/Flow (Q). In tropical countries like India, HRT varies from 30 to 50 days and is dependent on the weather conditions (Singh H and Maheshwari RC.,1995). HRT is important since it establishes the quantity of time available for bacterial growth and subsequent conversion of the organic material to gas. The HRT vary with the feedstocks, concentration of solids and temperature. Increase in temperature reduces the HRT of substrate into the digesters.

2.6.5 Light

Light does not kill methanogens but strongly inhibits methanation. Hence light should be blocked from entering the anaerobic digestion chamber.

2.7 Previous work on Anaerobic Treatment Methods

2.7.1 Fluidized bed reactor

Fluidize bed reactor can be used to carry out a variety of multiphase chemical reactions, and it exhibits several advantages that make it useful for treatment of high-strength wastewaters (NH Abdurahman et.al, 2012). Hickey and Switzenbaum (1988) reported on the development of the anaerobic expanded bed process, which was found to convert dilute organic wastes to methane at low temperatures and at high organic and hydraulic loading rates. Sen S and Demirer GN had done research on anaerobic treatment of real textile wastewater with a fluidized bed reactor. During the operation period, real cotton textile wastewater was fed to the anaerobic FBR. To achieve the maximum colour removal efficiency in the reactor, the effect of operational conditions was investigated. Based on the results obtained, it shows that anaerobic treatment for textile wastewater was possible as the amount of corresponding maximum COD, BOD, and colour removals were found to be around 82%, 94% and 59%, respectively. But, by increasing the external carbon source to be added into the real textile wastewater, the colour removal efficiency of the anaerobic FBR reactor will not increase. John S. Jeris reported that wastes containing from 5,000 to 54,000 mg/ℓ, were treated with 65 to 95 percent COD removal in 0.3 to 4.9 days hydraulic detention time. An energy comparison showed anaerobic treatment to produce a positive energy balance compared to an energy need for comparable activated sludge treatment. By using fluidized bed reactor, there are different COD removal efficiencies with every different types of waste. Based on POME waste water treatment, (Borja et al., 1995) reported that the COD removal efficiency is 78% to 94%. Hawkers et al., (1995) found that fluidized bed using granular activated carbon (GAC) gave about 60% COD removal. This shows that only suitable support material can be used using fluidized bed reactor to obtain high COD removal efficiency in the system.

2.7.2 Up-flow Anaerobic Sludge Blanket (UASB) Reactor

SE Nayono had been conducted on anaerobic treatment of waste water sugar cane recently by using Up-flow Anaerobic Sludge Blanket (UASB) reactor. The reactor was water jacketed and operated at constant temperature of 37^{o}C. Figure 2-3 shows the schematic diagram of UASB reactor.

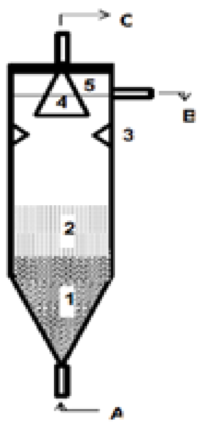

Figure 2-3: Typical cross section of a UASB reactor

On the 18th week of operation, the reactor experienced a failure at the thermostat due to twisting of warm jacket tube. This failure causes a temperature drop from 32^{o}C to about 24^{o}C. This effects the COD efficiency removal. The COD removal efficiency was also hindered when the temperature was suddenly dropped. It took 5 weeks to reach 80% of COD removal efficiency. This temperature decrease occurred when the operation of the reactor was considered as not yet stable after increment of its organic loading rate (COD removal efficiency has not yet reached 80 % and residual fatty acids concentration in the effluent were more than 10mM). The combination of both conditions caused the COD removal efficiency of the reactor dropped from 73 % to 59 % (SE Nayono, 2012).

Hampannavar and Shivayogimath conducted the experiment of anaerobic treatment on waste water of sugarcane industry, using UASB reactor. It is reported that the maximum COD removal efficiency of 89.4% was achieved. The COD rate linearly increases with the increase of OLR. The ratio of VFA to alkalinity is varied between 0.190.33 during the treatment. The methane content in the biogas was found to be between 73 and 82% at steady state conditions. This shows that anaerobic treatment is feasible in treating waste water of sugar industry.

Carol Connin (1996) had conduct a research on anaerobic treatment of brewery waste water using a UASB reactor seeded with activated sludge. Two UASB reactors were set up at the temperature range between 19^{0}C to 23^{0}C. The average sludge loading rate was different for both reactors since each was seeded with a different amount of sludge. Reactor B was seeded with 5.93 g VSS/l, while Reactor A was seeded with 1.98 g VSS/l, so that the sludge loading rate of Reactor A was about three times more than Reactor B. The methane composition content from both reactors increased as the HRT was reduced. Hickey et al., (1991) reported that brewery wastewater treated at an operating temperature of 19 – 23 ^{0}C inoculated with digested sewage sludge and activated sludge took 12 months to achieve the 90% of efficiency COD removal. The lower methanogenic activity of this sludge caused the methane biogas content on both reactors low (C Carol, 1996).

T.A. Elmitwalli, M. Shalabi, C. Wendland and R. Otterpohl have made a research on grey water treatment in UASB reactor at ambient temperature. The batchrecirculation experiments showed that a maximum total-COD removal of 79% can be obtained in grey-watertreatment in the UASB reactor. In the first phase, at the lowest temperature of 18^{0}C, the reactor has the lowest COD removal. For the second phase, the UASB reactor had the highest total-COD removal of41%, because the reactor was operated in the summer period at an average wastewatertemperature of 23^{0}C. When the HRT decreased to 8 hours at 20^{0}C at the third phase, the total COD removal decreased to 31%. Based on the result obtained, the removal of colloidal COD depended on the wastewater temperature, while the removal ofsuspended and dissolved COD depended on the wastewater temperature and the HRT of the UASB reactor.

The conventional UASB reactor concept showed severe limitations, mainly owing to problems related to mass transfer resistance and/or the existence of concentration gradients inside the systems. If the biogas production rate drops, e.g. for low-strength or cold wastewater, the degree of mixing must be raised hydraulically to ensure the required mass transfer (Van Lier et al, 2001).

2.7.3 Anaerobic Filtration

The anaerobic filter process was first developed by Coulter (1957) but was virtually forgotten until 1969 when Young and McCarty (1969) renewed interest by demonstrating the process's ability to treat a medium to high strength carbohydrate/protein wastewater (PY Chung, 1982).

PY Alice Chung (1982) conducted an experiment using anaerobic filtration. The anaerobic filtration was seeded by 30 gallons of sludge from apilot scale 50-gallon digester. During the entire experiment, the aerobic filter was effective in treating the oxygen demanding forms of nitrogen and sulphides produced during anaerobic fermentation. A total of 5971.9 gm of COD was removed, resulting in an apparent yield of 0.0019 gm VSS/gm COD removed. The values reported by Chain (1976) and Young and McCarty (1968) were 0.012 gm and 0.015 gm VSS/gm COD for fatty acid waste respectively (PYC Chung, 1982). The value in this experiment calculated is relatively low due to the sludge could only be partially drained. If the accumulation of the biological solids onto the plastic media were also measured, a higher yield would also be obtained. From this experiment, it concludes that the low production of biogas methane is due to two factors; low organic loading rates, and a few amounts of methane are loss through the effluent even though methane gas are considered as insoluble.

Anaerobic filters are capable of treating wastewaters to obtain good effluent quality with at least 70% of COD removal efficiency with methane gas composition of more than 50% (NH Abdurahman et al., 2012). But, clogging of anaerobic filter is a major disadvantage that always occur in the process (Bodkhe, 2008), (Jawed et al., 2000), (Parawira et al., 2006). Clogging usually occurs during the treatment process of POME (Borja et al., 1995b), and slaughterhouse wastewater. This is due to the high organic loading rate (OLR) which had higher suspended solid content compared to the lower one.

2.7.4 Anaerobic Contact Digester

All anaerobic digesters perform the same basic function. They hold manure in the absence of oxygen and maintain the proper conditions for methane forming microorganisms to grow. (WH Douglas, 2009). Anaerobic digesters are the aerobic equivalents of activated sludge process and are currently used for treating effluents from sugar processing, distilleries, citric acid and yeast production, industries producing canned vegetables, pectin, starch, meat products, etc. (NH Abdurahman et al., 2012).

Dennis A. Burke P.E (2001) conducted an experiment on dairy waste anaerobic treatment. Recent tests have established that screen and gravity separators can remove 75% to 80 % of the COD present in the waste stream. In one test the dairy parlor COD was reduced from 31,000 mg/l to 8,600 mg/l in the effluent from the gravity separator. In another the flush water influent to a separator system was 10,900mg/L while the effluent was 1,800 mg/L.

2.7.5 Membrane Separation Anaerobic (Mas) Treatment Process

This technology is still in a development stage. One of the studies for the treatment process by using membrane anaerobic processes is food industry (M Claudia et al., 2012).MF and UF systems can reduce suspended solids and microorganisms, whilst UF/RO combinations can also remove dissolved solids and provide a supply of process water and simultaneously reducing waste streams. UF systems can get more than 90% reduction in BOD and less than

5 mg.L-1 in residual solids and less than 50 mg.L-1 in grease and oil. NF systems are being used in a number of applications thank to the quick development in new membrane materials. In case of RO process, BOD removal rate of 90-99% is possible providing a low cost controlled source of bacteria-free water (M Claudia et al., 2012).Figure 2-4 shows schematically a typical hollow fiber module (Okokchina, 2010).

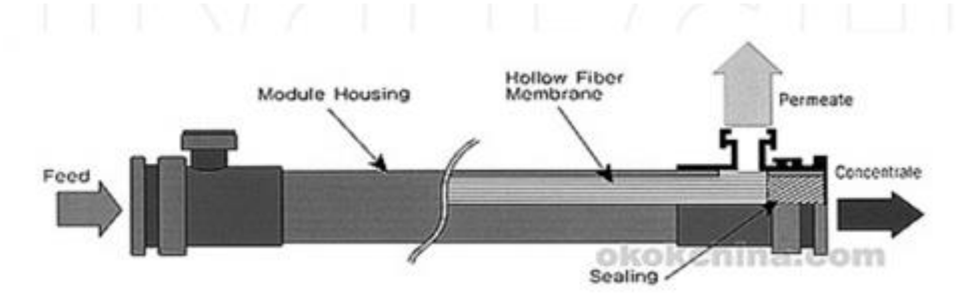

Figure 2-4: Scheme of the hollow fiber membrane module with crossflow. A large surface/volume ratio is expected for these modules.

Vourch et al., (2008) reported that membrane separation n process has special recognition in food wastewater treatment, applied to the end of conventional treatment systems. Membrane filtration acts as a separator of dissolved substances and fine particles from solutions.Membranefunctionedas semi-permeable and selective barriers that differentiate particles dependent upon molecular or physical size. Solutes smaller of solution than the membrane pore size have the ability to pass through the membrane as permeate flux while particles and molecules bigger than the membrane pore size are held.

2.7.6 Summary of Comparison on Reactors of Anaerobic Digestion

Based on Table 2-1, the comparisons on previously different methods of wastewater treatment has been classified into advantages and disadvantages scope (H.N Abdurahman and Z.Zafiqah, 2014).

Table 2-1 : Comparison based on reactors of Anaerobic Digestion

Type of Reactor	Advantages	Disadvantages
UASB	the granular sludge can be stored for many months without losing its activity (Lettinga et al., 1980 in Polprasert et al. 2001)	lower methanogenic activity, and problems related to mass transfer resistance and/or the existence of concentration gradients inside the systems
Anaerobic filter	Capable of treating wastewaters to obtain good effluent quality with at least 70% of COD removal efficiency with methane gas composition of more than 50% (NH Abdurahman et al., 2012)	Clogging usually occurs during the treatment process.
Membrane separation anaerobic treatment process	High COD removal in membrane anaerobic system (MAS)	Membrane fouling and low turbidity

2.8 Membrane Fouling

Membrane fouling is a process where a solute or particles stuck or deposit onto the membrane surface and affects the membrane performance. When membrane fouling occurs, severe flux declined will occur and the quality of water produced will be affected. Fouling is the most important issue affecting the development of membrane filtration-as it worsens membrane performance and shortens membrane life (Boerlage et al., 2004). There are two form of membrane fouling: the fouling layer that is readily removable from the membrane, it is often classified as polarization phenomena or reversible fouling and is removed by physical procedures. Internal fouling caused by adsorption of dissolved matter into the membrane pores and pore blocking is considered irreversible, which can be removed by chemical cleaning and other methods (Hughes & Field, 2006).

2.9 Cross-Ultrafiltration Membrane (CUF)

Ultrafiltration (UF) membrane techniques have attracted consider-able attention, due to their capacity to remove particulates by size exclusion, a process that usually produces a low-turbidity, pathogen-free from sewage sludge wastewater (B. Jilali et al., 2004). Ultrafiltration membrane has high permeability and porosity properties which is important for the membrane to easily filter the raw material feedstock. Nonetheless, membrane fouling implies a substantial loss of hydraulic permeability and requires frequent replacement of membrane modules, resulting in increased costs. Membrane fouling is a serious impediment to use in the low-pressure membrane systems as a substitute for conventional sewage sludge treatment process. Previous studies have shown that natural organic matter (NOM) is the main cause of membrane fouling (C. Margarida and R.J.Maria, 2010). Natural organic matter (NOM) is known to be detrimental to membrane filtration,due to adsorption on membrane surface, pore blocking and gel layer formation (Y.Gao *et al.*, 2012). NOM is mainly composed of hydrophobic and hydrophilic organic substances in raw wastewater .The mechanisms of membrane fouling involve a number of influencing factors, such as molecular weight distribution, Zeta potential and particles size. Additionally, the pH value of feed water has been found to affect organic matter characteristics, permeability and retention, demon- strating the fact that the membrane fouling is pH-sensitive (D.Nanda *et al*.,2010).

2.10 Methanogenic Activity Test

The analysis of the activity of individual trophic groups involved in the overall process of methanogenesis has focused on the determination of the activity of the acetotrophic methanogen population present in certain sludge. This focus on acetoclastic plays in methane production during anaerobic degradation (K Larisa, 2008). To date, no internationally accepted test protocols have been developed for the determination of the specific activity of individual trophic populations in anaerobic biomass (Colleran and Pender, 2002).

To determine the anaerobic biodegradability of organics in wastewater, Test methods developed have commonly been utilized to determine the specific activity. However, they have been modified to evaluate the specific activity of individual trophic groups and to determine the potential toxicity of organic/inorganic compounds related to the populations involved (Colleran and Pender, 2002).

2.10.1 Test medium and other conditions

i) **pH:** The pH of the environment is a key factor in the growth of organisms. Most bacteria cannot tolerate pH levels above 9.5 or below 4.0. Generally, the optimum pH for bacterial growth lies between 6.5 and 7.5. Therefore, during the experiment, it is important to always maintain the pH range of the sample.

ii) **Temperature:** Since anaerobic digesters typically operate under mesophilic or thermophilic conditions, there is a need to define the conditions of sludge handling, storage etc. prior to carrying out biodegradability, activity or toxicity tests. Thermophilic reactor sludge is particularly susceptible to exposure to low temperatures. If the sludge sample is stored at a low temperature, activity tests may present long lag phases in order to achieve a re-acclimatisation of the sludge population to the thermophilic test temperature (K Larisa, 2008).

2.10.2 Major mechanisms of methane formation

i) Acetic acid cleavage

$$CH_3COOH \rightarrow CH_4 + CO_2$$

ii) Carbon dioxide reduction

$$CO_2 + 8H \rightarrow CH_4 + 2H_2O$$

By comparing all the methods stated above, membrane anaerobic system will be used, by adding Ultrasonicated device. This is the new design proposed by (NH Abdurahman et al., 2012) in treating POME. Still, this method in a development stage and have many rooms that can be closed to be a successful method in avoiding membrane fouling. Therefore, this research will be conducted to improve the system in ultrasonic membrane anaerobic system (UMAS).

CHAPTER 3

MATERIALS AND METHODS

3.1 Raw Sewage Sludge

The sewage sludge waste water has been collected from anaerobic pond at Indah Water Konsortium Sdn. Bhd for about 100 Litres. The samples were collected from the pond before the effluents enters the treatment process. During collecting the samples, the temperature recorded is 36^{o}C. In order to remove the particles which are larger than 1.0-mm (mainly inert materials), the samples were filtered using sieve, and stored in a cold room at -4^{0}C prior to use. Samples analysed for chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), pH, and volatile suspended solids (VSS). The raw sewage sludge is stored inside the reactor, and then the sample will be left for 5 days for acclimation process to occur. After 5 days, the process will get started continuously for 5 hours period.

As soon as the reactor had been loaded with 50L of sewage sludge wastewater, the reactor was fully covered with aluminium foil to avoid sunlight from entering the reactor, with the hydraulic retention time (HRT) of 5 days, and organic loading rate (OLR) of 0.5 g COD/l.d. After 4 weeks of experiment, with approximately the same loading rate, steady-state removal efficiency was obtained. During the experiment, the pressure, pH, and temperature were kept constant with 1.5 bar, 7.0-7.6, and 32^{o}C respectively. Table 3-1 shows the parameters of the raw sewage sludge wastewater collected.

Table 3-1: The properties of the Raw Sewage Sludge

Parameter	**Concentration**
pH	7.23
COD	1040 mg/L
BOD	98.7 mg/L
TSS	98.6 mg/L
VSS	65.8 mg/L

3.2 Chemicals

The chemical used for this research is Sodium Hydroxide (NaOH). NaOH has been used to absorb CO_2 from the mixture of CO_2 and CH_4 after the methanogenic process.

3.3 Experimental Procedures

Raw sewage sludge will be treated by UMAS in a laboratory digester with an effective 100-litre volume. Figure 3.1 & 3.2 presents a schematic representation of the Ultrasonicated-Membrane Anaerobic System (UMAS) which consists of a cross flow ultra-filtration membrane (CUF) apparatus, a centrifugal pump, and an anaerobic reactor. 25 KHz multi frequency ultrasonic transducers (to create high mechanical energy around the membrane to suspends the particles) connected into the MAS system. The ultrasonic frequency is 25 KHz, with 6 units of permanent transducers and bonded to the two (2) sided of the tank chamber and connected to one (1) unit of 250 Watts 25 KHz Crest's Genesis Generator. The UF membrane module had a molecular weight cut-off (MWCO) of 200,000, a tube diameter of 1.25 cm and an average pore size of 0.1 µm. The length of each tube was 30 cm. The total effective area of the four membranes was 0.048 m^2. The maximum operating pressure on the membrane was 55 bars at 70 ºC, and the pH ranged from 2 to 12. The reactor was composed of a heavy duty reactor with an inner diameter of 25 cm and a total height of 250 cm. The operating pressure in this study was maintained between 2 and 4 bars by manipulating the gate valve at the retentate line after the CUF unit.

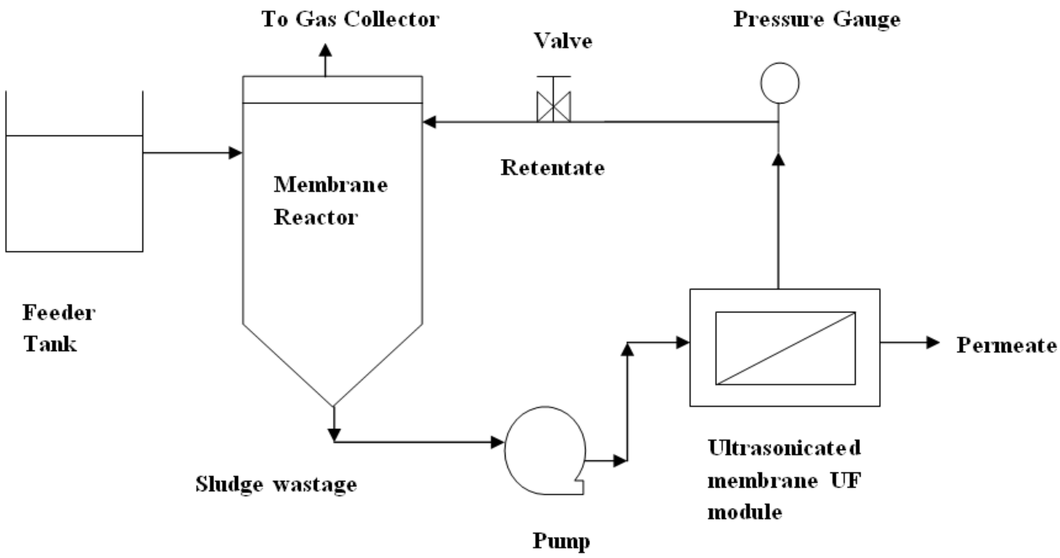

Figure 3-1: Experimental Set-up

Figure 3-2: Schematic for Ultrasonic Membrane Anaerobic System (UMAS)

3.4 Bioreactor Operation

The ultrasonicated membrane anaerobic system, UMAS Performance was evaluated with influent COD concentrations ranging from 1040 mg/L. In this study, the system was considered to have achieved steady state when the operating and control parameters were within ± 10% of the average value. A syringe connected to a tube was used to collect the biogas. The produced biogas contained only CO_2 and CH_4, so the addition of sodium hydroxide solution (NaOH) to absorb CO_2 effectively isolated methane gas (CH_4).

3.5 Feedstock

The raw sewage sludge is stored inside the reactor, and then the sample will be left for 5 days for acclimation process to occur. After 5 days, the process will get started continuously for 5 hours period.

3.6 Control Parameters

The controlled parameters in this experiment are pH, pressure and volume. The volume will be maintained for 50 L for every process that runs. After 5 hours, the amount of COD, BOD, TSS and VSS, are determined and recorded, which the measurements are analyzed from the reacted and permeate sample. The process was running for 10 times to compare the value of all the parameters stated.

3.7 Measurement of Chemical Oxygen Demand (COD)

2 mL of homegenized reacted and permeate samples are prepared for COD measurement and poured into COD Digestion Reagent Vial HR (High Range). Next, 2 mL of deionized water is poured into another vial for blank preparation. The COD Digestion Reactor is preheated to 150°C and the vials are placed in the reactor. The vials are heated for 2 hours and then cooled to room temperature . By using Spectrophotometer, HACH DR/2800, the blank and samples are placed into the adapter and the values of COD of the samples were determined and recorded.

3.8 Measurement of Biochemical Oxygen Demand (BOD)

Preparation of dilution water: 1mL each of phosphate buffer, magnesium sulfate, calcium chloride, ferric chloride solution are added into 1L volumetric flask. 1 L of distilled water is added. 10mL of wastewater sample is added into a beaker and dilution water is added up to 300mL into the same beaker. pH value of the solutions are adjusted to 6.5 to 7.5 by adding acid/alkali. Put all prepared samples and control in 300mL-incubation bottle each. Dissolved oxygen (DO) concentration for each sample are measured and recorded using Dissolved Oxygen Meter. All the bottles were put in BOD Incubator for five days. The temperature was setting at 20°C. Next, the final DO values are measured after five days. BOD_5 values are calculated according to the formula below;

$$BOD_5\text{, mg/L} = (D_1 - D_2) \times \text{Dilution factor}$$

$$\text{Dilution factor} = \text{Bottle volume (300mL)} / \text{Sample volume}$$

Where D_1= final DO reading after incubation

D_2= initial DO reading before incubation

3.9 Measurement Of Total Suspended Solids (TSS)

To measure TSS, the water sample is filtered through a pre-weighed filter. The residue retained on the filter is dried in an oven at 103 to 105° C until the weight of the filter no longer changes. The increase in weight of the filter represents the total suspended solids.

$$\text{mg TSS/L} = \frac{(A - B) \times 1000}{\text{Sample volume, mL}}$$

where;

A = weight of filter + dried residue, mg

B = weight of filter, mg

3.10 Measurement Of Volatile Suspended Solid (VSS)

The filter from TSS results were heated in a furnace at 500° C-550° C in about 20 minutes. Then the filter has been weighed to get the reading of volatile suspended solids.

$$\text{mg volatile solids/L} = \frac{(A-B) \times 1000}{\text{sample volume, mL}}$$

where:

A = weight of residue + dish before ignition, mg,

B = weight of residue + dish or filter after ignition, mg,

3.11 Removal Efficiency Calculation

Table 3-2 : Equations of Parameter Removal Efficiency

No.	Symbol	Unit	Description	Equation
1	% COD	%	Overall COD removal efficiency	$\frac{(COD_{in} - COD_{out})x100}{COD_{in}}$
2	% BOD	%	Overall BOD removal efficiency	$\frac{(BOD_{in} - BOD_{out})x100}{BOD_{in}}$
3	% VSS	%	Overall VSS removal efficiency	$\frac{(COD_{in} - COD_{out})x100}{COD_{in}}$
4	% TSS	%	Overall TSS removal efficiency	$\frac{(COD_{in} - COD_{out})x100}{COD_{in}}$
5	rCH_4	$I.CH_4/L$ day	Volumetric Methane production rate	$\frac{Q_{CH4}}{V_{an}}$

3.12 Methane Gas Measurement

3.12.1 J-Tube Syringe

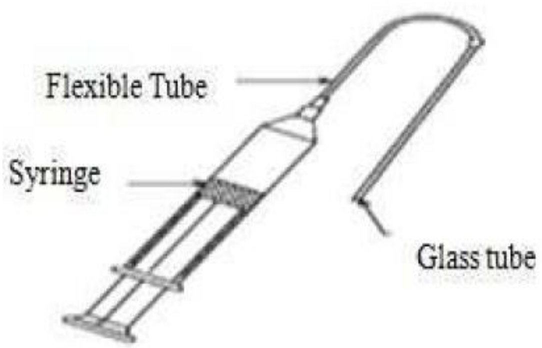

Figure 3-3 : J-Tube Syringe

The methane gas will be collected using J-tube syringe. A J-tube syringe is a piece of laboratory glassware used to insert or withdraw a volume of a gas from a closed system, or to measure the volume of gas evolved from a chemical reaction. Firstly, the NaOH will be filled inside of the J-tube syringe for half amount of volume. The tube will be inserted inside the reactor tank for about 30 minutes. Then, soak the tube inside distilled water for 5 minutes to achieve stability. Next, the gas will be collected by slowly pull and push the syringe for 10 minutes while suspending the bubbles. NaOH will absorb CO_2gas and methane gas will remain inside the glass tube. To calculate the percentage volume of methane gas, the following formula has been used :

$$\frac{Length\ L_2}{Length\ L_1} = \%\ CH_4$$

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 COD and BOD Removal Activity

The initial value of COD for the raw sewage sludge wastewater was 1040 mg/L. Figure 4-2 shows increasing COD removal efficiency of the permeate, after the anaerobic digestion process. COD removal efficiency of the permeate was approximately 25.87% for the first run of the UMAS reactor, which is after 5 days of acclimation process occurred. The COD percentage removal increased gradually to 39.62%, 52.50% and 70.58% on the 8th, 10th and 12th day of experiments respectively. On the 14th day onwards, the COD removal efficiency increased linearly from 77.98% and brought to the COD total removal rate of approximately 90% for both reacted and permeate samples, on the 28th day of experiment. This result was higher than the 85 % COD removal observed for POME treatment using anaerobic fluidised bed reactors (Idris, B.A. and A. Al-Mamun, 1998). According to Mahendran R *et al.*, (2014), when compared to the MAS treatment process of the wastewater (non-ultrasonicated), the removal efficiency for UMAS (ultrasonicated-system) is even 10 % greater compared to MAS, when he was conducting a study using sugarcane wastewater as substrate. At the same time, the BOD values of the wastewater, based on Table 4-3, was decreasing against HRTs. The BOD decreased significantly for both permeate and the reacted wastewater. The results showed that UMAS system, with the membrane filter was very effective for the removal of BOD from the wastewater. The reduction in BOD was 98.7 mg/L (raw water) to 4.1 mg/L (permeate) with a mean removal efficiency of 96%.

Similar results were reported, by H.N Abdurahman (2014), who assessed the reduction of BOD from sugarcane wastewater. This was largely a result of the washout phase of the reactor because the biomass concentration increased in the system (H.N. Abdurahman, 2012). Besides that, the significant reduction in BOD and COD indicates that reaction had occurred and leads to the reduction of soluble matters in the system. This is due to the activity of the bacteria, which uses up all the dissolved oxygen during the treatment process (H.N.Abdurahman, 2012).

Table 4-1: Experimental Data for Chemical Oxygen Demand (COD)

HRT (days)	REACTED (mg/L)	PERMEATE (mg/L)
5	921	771
8	810	628
10	644	494
12	491	306
14	349	229
16	295	162
19	187	149
24	168	136
26	149	130
28	142	92

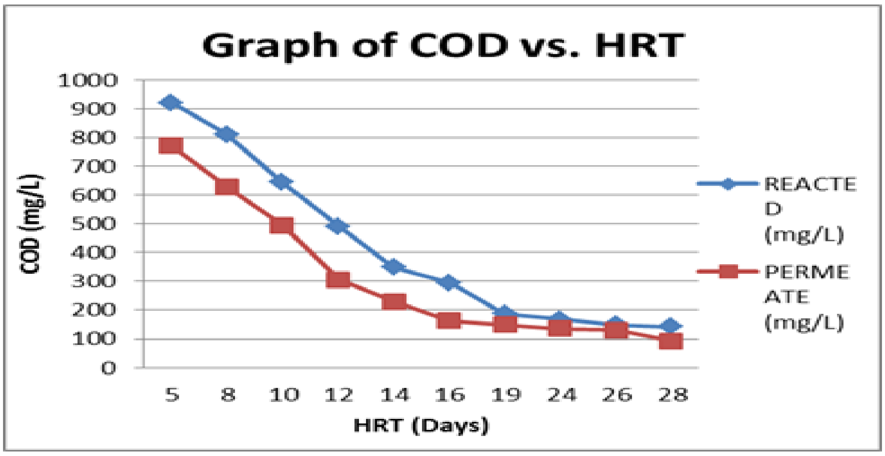

Figure 4-1: Graph of Chemical Oxygen Demand (COD) versus HRT

Table 4-2: Experimental Data for COD Removal Efficiency (%)

HRT (days)	REACTED (%)	PERMEATE (%)
5	11.44	25.87
8	22.12	39.62
10	38.08	52.50
12	52.79	70.58
14	66.44	77.98
16	71.63	84.42
19	82.02	85.67
24	83.85	86.92
26	85.67	87.50
28	86.35	91.15

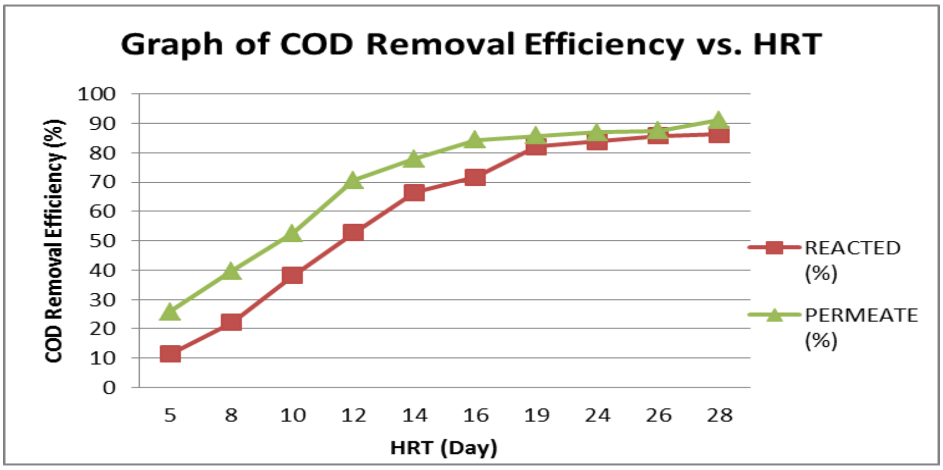

Figure 4-2: Graph of COD Removal Efficiency versus HRT

Table 4-3: Experimental Data of Biochemical Oxygen Demand (BOD)

HRT (days)	REACTED (mg/L)	PERMEATE (mg/L)
5	74.4	14.1
8	53.2	12.3
10	49.7	11.5
12	39.6	10.6
14	27.9	9.9
16	24.9	6.9
19	21.3	5.7
24	16.5	4.5
26	15.6	4.3
28	16.8	4.1

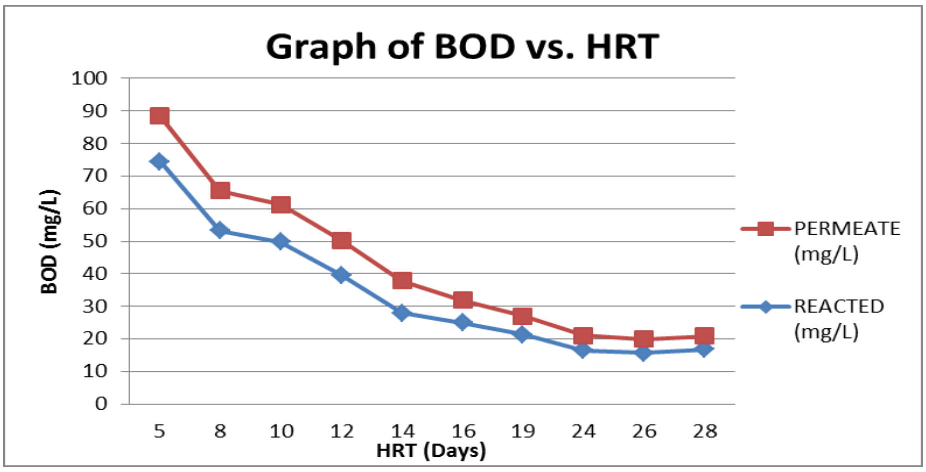

Figure 4-3: Graph of Biochemical Oxygen Demand (BOD) versus HRT

Table 4-4: Experimental Data for BOD Removal Efficiency (%)

HRT (days)	REACTED (%)	PERMEATE (%)
5	24.62	85.71
8	46.10	87.54
10	49.65	88.35
12	59.88	89.26
14	71.73	89.97
16	74.77	93.01
19	78.42	94.22
24	83.28	95.44
26	84.19	95.64
28	82.98	95.85

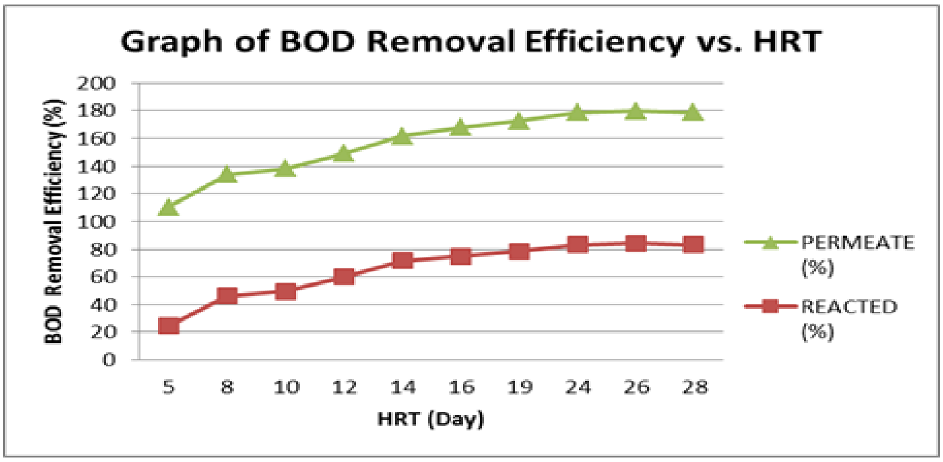

Figure 4-4: Graph of BOD Removal Efficiency versus HRT

4.2 TSS and VSS Removal Activity

Table 4-5 shows the value data of TSS while Figure 4-6 represents the removal efficiency of the wastewater, for both reacted and permeate samples of the sewage wastewater. Figure 4-8 illustrates the VSS removal efficiency by UMAS at various HRTs. The graphs indicate decreasing trends of TSS values, from 98.6 mg/L (raw sewage) to 35.5mg/L (reacted) and 6 mg/L (permeate). Basically the TSS and VSS efficiency's profile trends follow the trend obtained from COD and BOD removal (Mahendran R *et al.*,2014) shown previously in Figures 4-2 and 4-4, which correspond to a report stated by Basri et al (2010), and the study claimed high concentration of suspended solid is one of the factors that can lead to high removal rate of COD and BOD. Based on Figure 4-8, the VSS removal efficiency of permeate increased linearly starting from day 8th onwards, while for reacted samples, they show rapid increases. The reacted one had larger reductions in effluents for both TSS and VSS. As reported by (C.Carol, 1991), this happens due to the reacted is denser than permeate. The reacted TSS and VSS level at the beginning of the experiment is extremely high compared to permeate. This shows that the reacted one had experienced considerable sludge loss compared to permeate. Figure 4-6 and 4-8 show total removal efficiency of about 93% for both TSS and VSS parameters on the last 28th day of the experimental work. The removal rate is much higher when compared to a study conducted by Mahendran R *et al* (2014), which used MAS (non-ultrasonicated membrane anaerobic system) to treat sugarcane wastewater, with 79% removal efficiency (lower) .The study reported that clogging of inorganic particles on the membrane surface which inhibit smooth filtration process, will be the possible reason of the lower removal efficiency of the treatment. In another research done by Abdurahman *et al*. (2014), the TSS removal efficiency of POME substrate reached approximately 99% when the same UMAS system has been used for treatment, compared to MAS. Therefore, UMAS is much more considered as an ideal system to be used for various wastewater treatments.

Table 4-5: Experimental Data of Total Suspended Solids (TSS)

HRT (days)	REACTED (mg/L)	PERMEATE (mg/L)
5	93.7	52.8
8	89.1	51.7
10	87.9	49.2
12	85.2	43.9
14	81.6	43.6
16	79.3	43.5
19	76.6	40
24	54.1	26.9
26	42.9	14
28	35.5	6

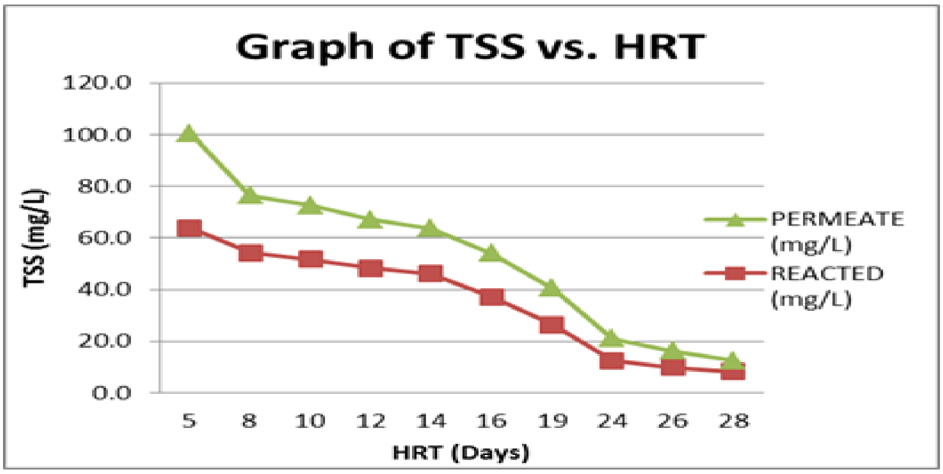

Figure 4-5 : Graph of Total Suspended Solid (TSS) versus HRT

Table 4-6: Experimental Data for TSS Removal Efficiency (%)

HRT (days)	REACTED (%)	PERMEATE (%)
5	4.97	46.45
8	9.63	47.57
10	10.85	50.10
12	13.59	55.48
14	17.24	55.78
16	19.57	55.88
19	22.31	59.43
24	45.13	72.72
26	56.49	85.80
28	64.00	93.91

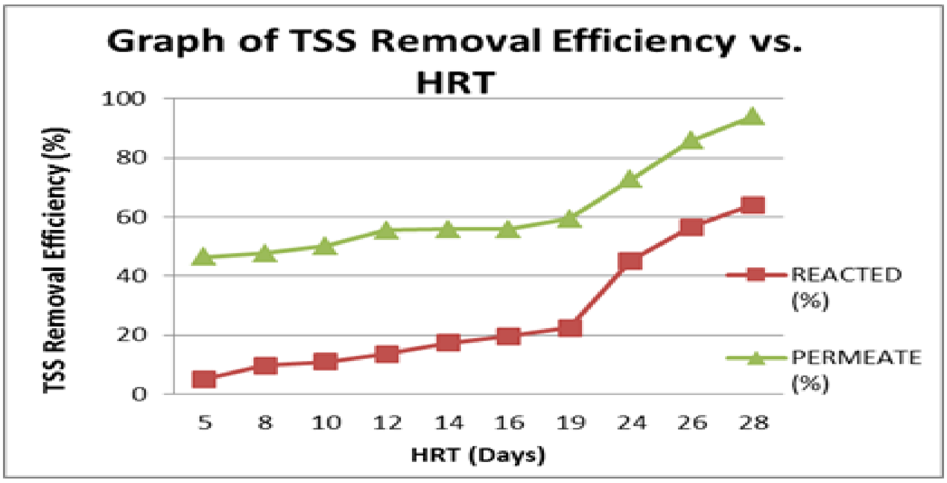

Figure 4-6: Graph of TSS Removal Effiecncy versus HRT

Table 4-7: Experimental Data of Votal Suspended Solids (VSS)

HRT (days)	REACTED (mg/L)	PERMEATE (mg/L)
5	63.9	36.5
8	54.3	22.0
10	51.6	20.9
12	48.3	18.7
14	46.1	17.5
16	37.2	16.9
19	26.4	14.2
24	12.5	8.6
26	9.8	6.4
28	8.3	4.2

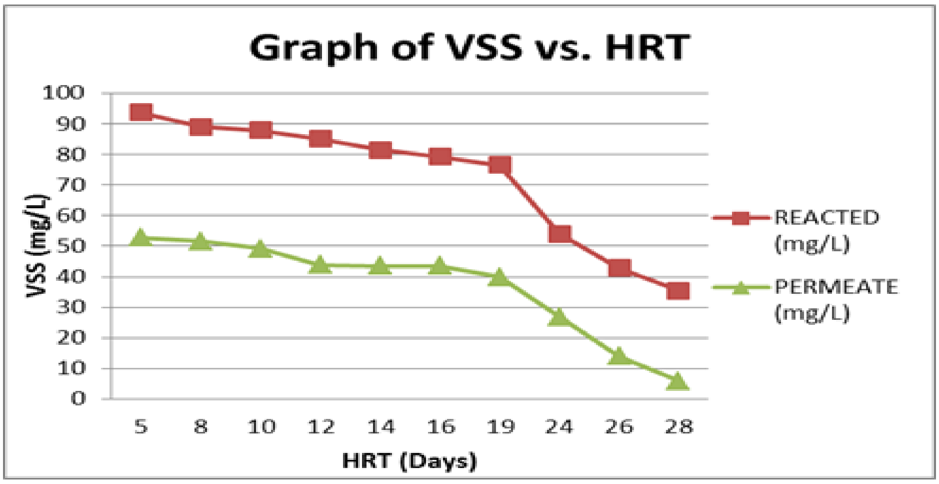

Figure 4-7: Graph of Volatile Suspended Solids (VSS) versus HRT

Table 4-8: Experimental Data for VSS Removal Efficiency (%)

HRT (days)	REACTED (%)	PERMEATE (%)
5	2.89	44.53
8	17.48	66.57
10	21.58	68.24
12	26.60	71.58
14	29.94	73.40
16	43.47	74.32
19	59.88	78.42
24	81.00	86.93
26	85.11	90.27
28	87.39	93.62

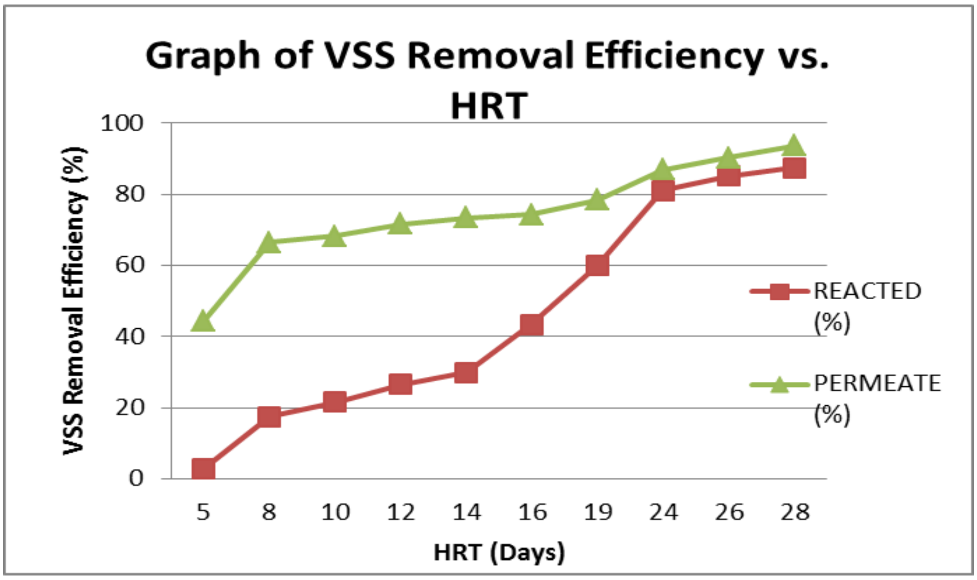

Figure 4-8: Graph of VSS Removal Efficiency versus HRT

4.3 Colour

The colour of the reacted and permeate samples are pictured and recorded for comparisons between before and after the experiment.

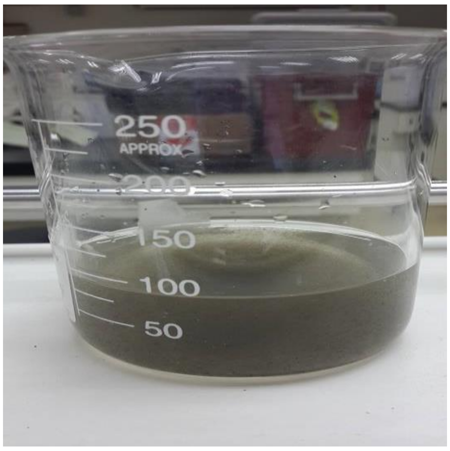

Figure 4-9: Colour of Raw Sewage Sludge Before Experiment

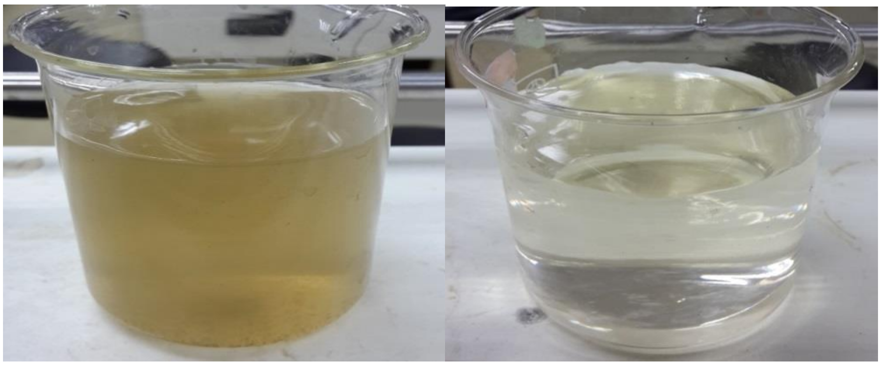

Figure 4-10: Reacted and Permeate for 1st Umas Experiment

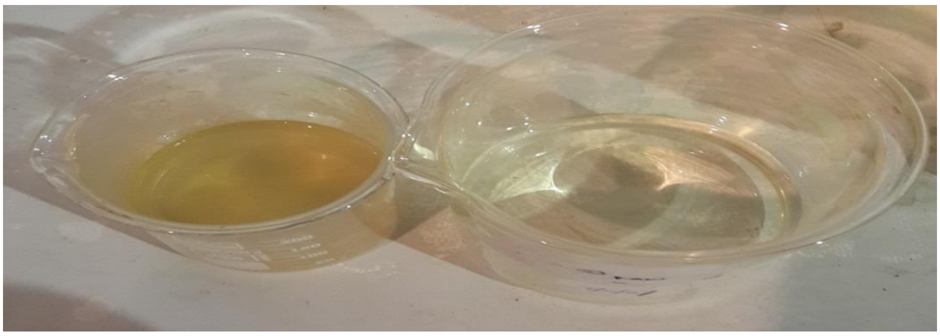

Figure 4-11: Reacted and Permeate for 2nd Umas Experiment

Figure 4-12: Reacted and Permeate for 3rd Umas Experiment

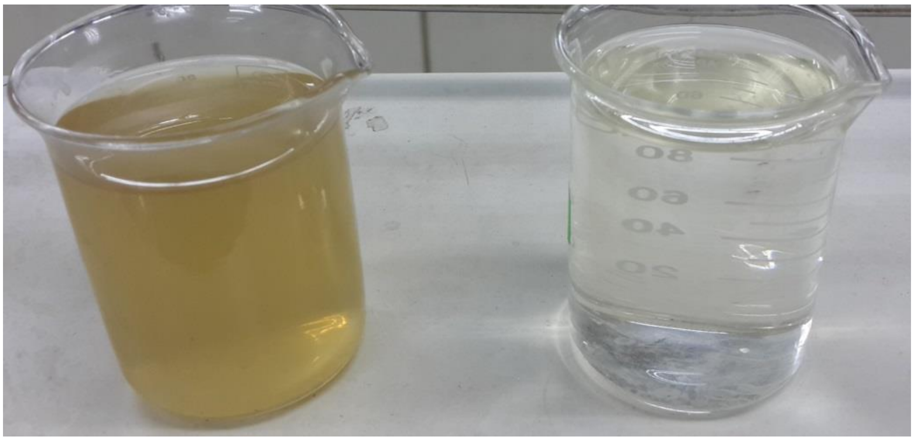

Figure 4-13: Reacted and Permeate for 4th Umas Experiment

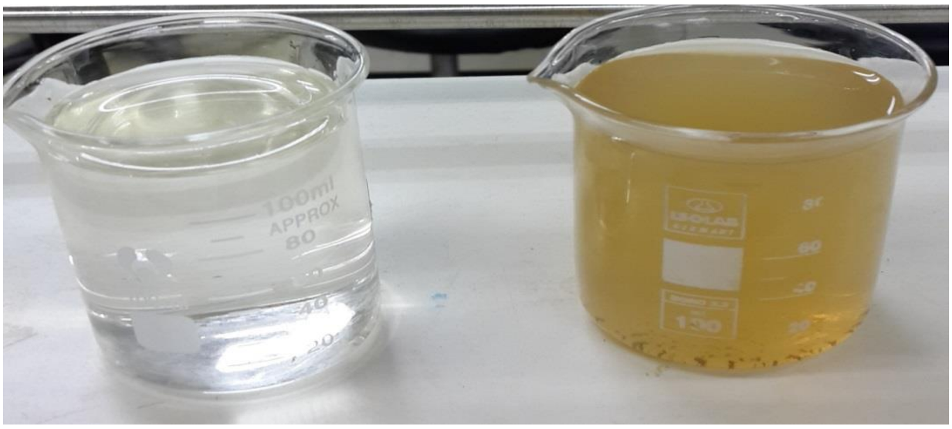

Figure 4-14: Reacted and Permeate for 5th Umas Experiment

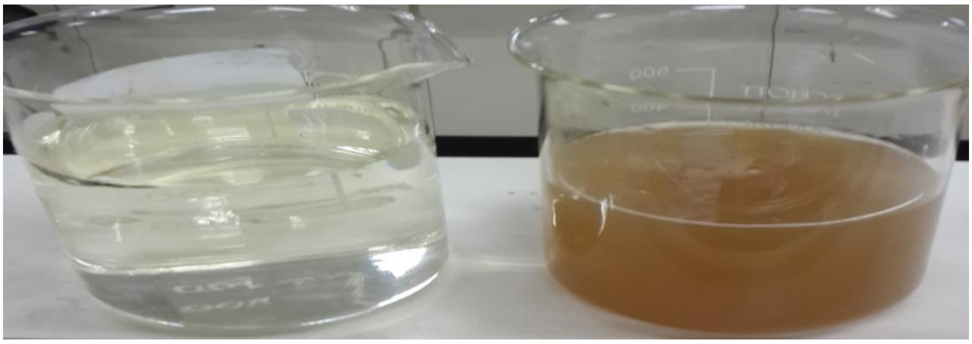

Figure 4-15: Reacted and Permeate for 6th Umas Experiment

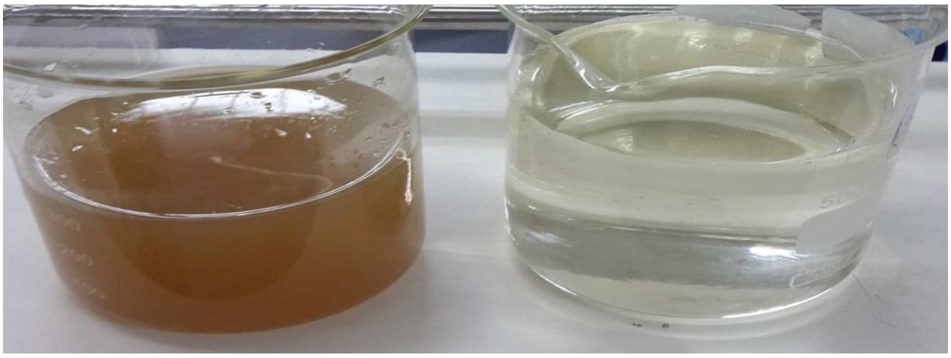

Figure 4-16: Reacted and Permeate for 7th Umas Experiment

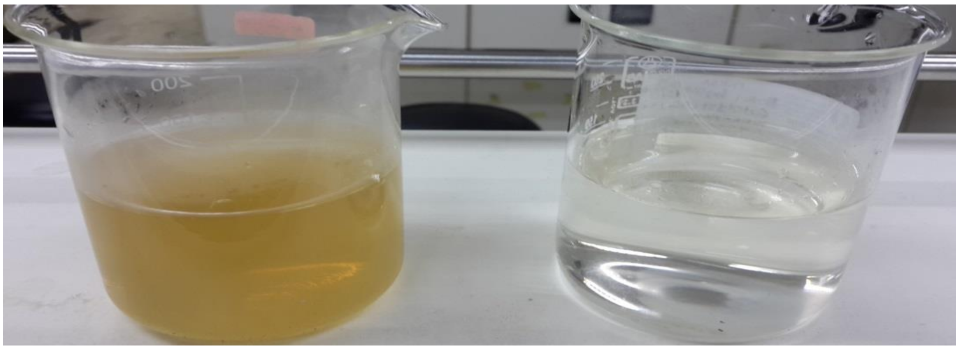

Figure 4-17: Reacted and Permeate for 8th Umas Experiment

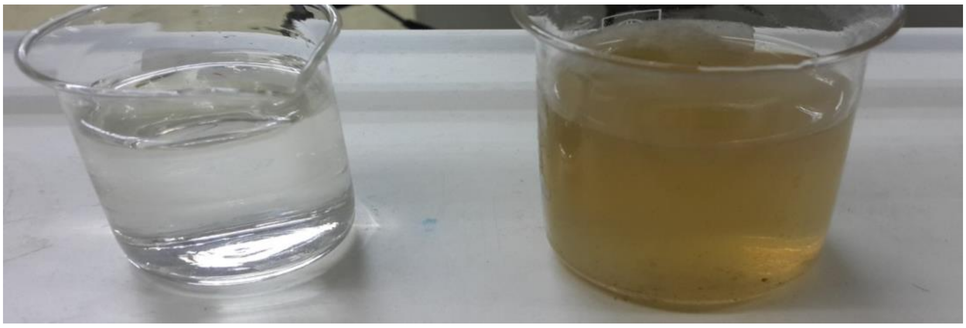

Figure 4-18: Reacted and Permeate for 9th Umas Experiment

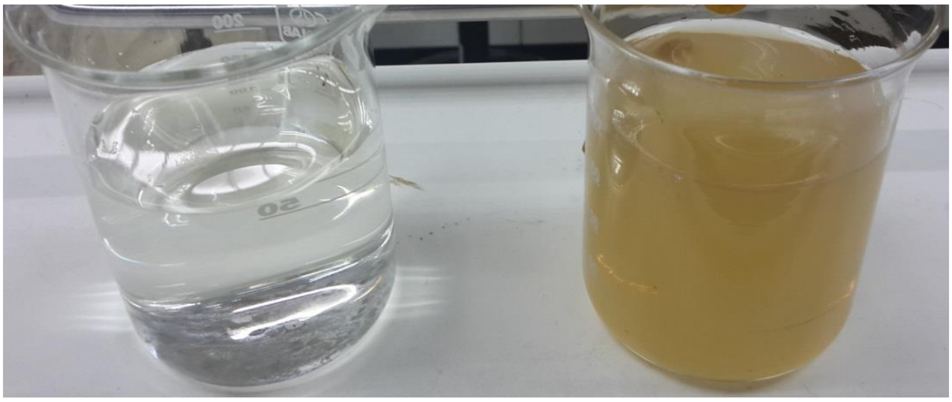

Figure 4-19: Reacted and Permeate for 10th Umas Experiment

4.4 Gas Methane Collection Data

The biogas composition is an important parameter to evaluate the system balance whereby it reveals the ratio between acid former and methanogens (N.H.Abdurahman and N.Nuri,2014). Based on the Table 4-9 and Figure 4-20 shown, the Methane (CH_4) gas composition recorded was about 96.5% on the day 14th of the experiment, after that the gas composition decreased to 90.2% on day 19th, and then declined to 84.5%, 82.9% and lastly became 79.3% on the 28th day of the experiment. The slight declining methane composition might be because of VFA accumulation, and this corresponds to a study which Gao et al., (2007) reported that volumetric biogas production began to decrease due to deterioration of COD removal efficiency, and these happened as well during the treatment of sewage sludge wastewater in UMAS reactor, where during this period the methane content of the biogas also decreased from 96.5% to 79.3%. The decline in methane gas content may also be attributed to the higher OLR, which favours the growth of acid forming bacteria over methanogenic bacteria. In this scenario, the higher rate of carbon dioxide; (CO2) formation reduces the methane content of the biogas (N. H. Abdurahman et al, 2012). Besides, the production of methane gas was low at the end of the experiment, this might due to the oxygen contamination during the manual recycle of permeate into the reactor that inhibit the methanogens growth (Basri et al., 2010). However, the collection is high compared to the experiment reported by (P.Y.C Alice, 1982) that treated low strength wastewater, only little amount of methane gas was collected during the experiment which is 6.5%, with the remainder is nitrogen gas. This happens due to the loss of methane gas during the collection period. The percentage of methane gas obtained from this experiment ranges from 79 to 96%, which is higher compared to the typical range, where the typical composition of methane is 55-75% (Karellas *et al*., 2010) while in another study, treatment processes that use conventional methods, CSTR and UASB reactors produced less which was about 60% Methane compostion (Sosnowski *et al.*,2003). However, in another case, the composition of the biogas produced from anaerobic membrane bioreactor; AnMBR appears to be: 70–90% methane (K.H. Choo and C.H. Lee, 1996).

Table 4-9 : Composition of Methane Gas (%)

HRT (days)	COMPOSITION OF CH4 (%)
14	96.5
19	90.2
24	84.5
26	82.9
28	79.3

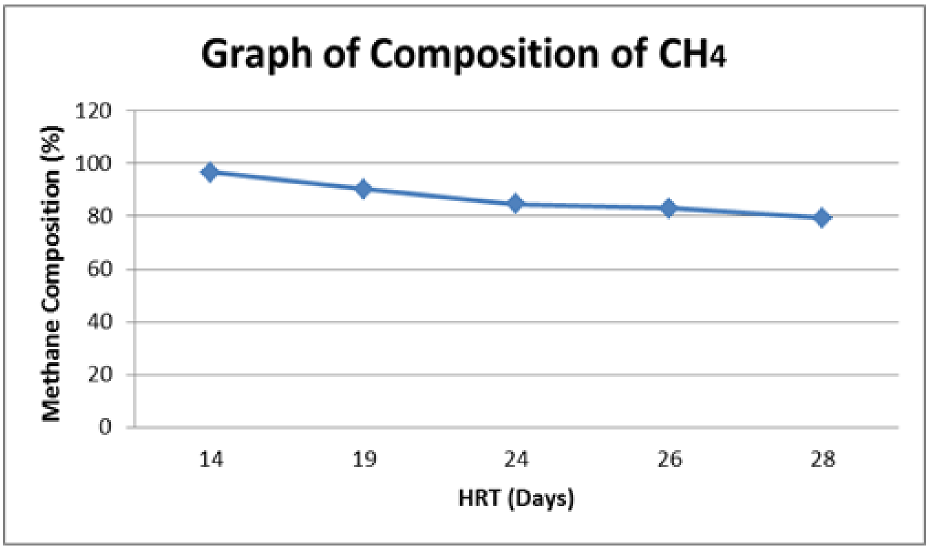

Figure 4-20 : Graph of Composition of Methane Gas (CH_4) versus Hydraulic Retention Time (HRT)

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

UMAS has reached 91% of COD removal efficiency, in a short period of time, and at the same time produced high composition of Methane gas, range from 79% to 96% which can be as a source of energy. It was found to be a successful and an effective system of wastewater treatment, as an alternative way which is cost-effective and UMAS reduced the retention time to 28 days, when compared to other conventional methods which normally takes about 60 days to complete. Other than that, the plant size can be reduced as well, for instance from 50x20 m area to 10x5 m, which is smaller compared to the area of larger ponds of other conventional methods. The system as well has overcome the problem of fouling membrane with ultrasonicated-device attached to the membrane. The overall substrate removal efficiency was very high; above 90%. The gas production, as well as the methane concentration in the gas was satisfactory and, therefore, could be considered (the produced methane gas) as an additional energy source.Thus, UMAS is found to be superior to the conventional processes due to low concentrations of VFA in the effluent, a high degree of sludge retention and stable reactor performance.

5.2 Recommendation

There are few problems spotted while running this experiment that can be overcome with few recommendations. It is crucial to control the pH before, during, and after acclimatization process. This is to ensure that methanogenic activity will be increase and reduce the fatty acids. The temperature plays an important role in this experiment (H.N.Abdurahman, 2014). As stated by (S.E Nayono, 2012), the combination of the decreasing in temperature inside the reactor and the formation of fatty acids will cause the COD removal efficiency to drop, and will affect the methane gas production inside the reactor. Thus, it is recommended to control the temperature of the reactor while running the experiment. It is also important to connect the ultrasonicated devices properly to the reactor to make sure that the membrane will work functionally.

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