SEWAGE SLUDGE TREATMENT BY MEMBRANE ANAEROBIC SYSTEM (MAS)

VISSALINY A/P SUBRAMANIAM

UNIVERSITI MALAYSIA PAHANG

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Signature :
Name of Supervisor : Mdm. Noor Ida Amalina Ahamad Nordin
Date : 29 April 2010

Signature :
Name of Co-Supervisor: Associate Professor Dr. Abdurahma Hamid Nour
Date : 29 April 2010

SEWAGE SLUDGE TREATMENT BY MEMBRANE ANEROBIC SYSTEM (MAS)

VISSALINY A/P SUBRAMANIAM

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

Faculty of Chemical & Natural Resources Engineering
University Malaysia Pahang

APRIL 2010

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 other degree.

Signature	:
Name	: Vissaliny A/P Subramaniam
Date	: 29 April 2010

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

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ABSTRACT

The application of Membrane Anaerobic System (MAS) process treating the raw sewage sludge and the overall MAS treatment efficiency were investigated. The MAS consists of a cross-flow Ultra-filtration membrane for solid-liquid separation with operational pressure of 1.5 to 2 bars. An enrichment mixed culture of methanogenic bacteria was developed and acclimatized in the digester for three days when the seed sludge is fed into the 30 L digester. The raw sewage sludge was collected from Indah Water Municipal Treatment Plant at Taman Seri Mahkota-Kuantan. The digester was mixed semi-continuously for 4 days at two different concentrations of samples. Two concentration ratios of 50% and 100% of the raw sewage were studied. Results showed throughout the study, the removal efficiency of COD was 88.27% to 94.56%. The Nitrate-N removal was 99.44% to 99.77%. While the removal efficiency of Ammonia-N found 31.69% to 44.44%. About 99.99% of turbidity removal was achieved while the total suspended solids removal found 98.72% to 100%. The methane production rate was between 0.234 L/g COD/d to 0.325 L/g COD/d. The membrane anaerobic system, MAS treatment efficiency was greatly affected by solid retention time, hydraulic retention time and organic loading rates. In this study, membrane fouling and polarization at the membrane surface played a significant role in the formation of the strongly attached cake layer limiting membrane permeability.

ABSTRAK

Aplikasi sistem anaerobik membran (MAS) dalam rawatan kumbahan mentah telah dikaji. Dalam kajian ini, MAS terdiri daripada membran penapisan ultra yang mempunyai tekanan sebanyak 1.5-2.0 bar. Campuran kultur bakteria yang diperkaya dengan bakteria metanogen telah dihasilkan dan ditinggalkan selama 3 hari dalam 30 L reaktor supaya bakteria yang telah dikultur dapat membiasakan diri dalam persekitaran reaktor yang baru. Sampel kumbahan mentah telah diperoleh daripada tapak perawatan kumbahan Indah Water yang berada di Taman Seri Mahkota, Kuantan. Reaktor rawatan telah dicampurkan secara semi-campuran selama 4 hari masa penahan hidraulik (HRT). Sampel kumbahan yang mempunyai dua jenis kepekatan yang berlainan telah dikaji, iaitu kepekatan sebanyak 50% dan 100%. Keputusan kajian menunjukkan bahawa, rawatan bagi kadar permintaan oksigen kimia (COD) telah dikurangkan daripada 88.27% kepada 94.56%. Kekurangan unsur Nitrat-N adalah daripada 99.44% kepada 99.77%. Manakala, kekurangan unsur Ammonia-N didapati daripada 31.69% kepada 44.44%. Sebanyak 99.99% daripada kekeruhan cecair dapat dikurangkan manakala keseluruhan tahanan pepejal (TSS) telah dikurangkan daripada 98.72% kepada 100%. Kadar penghasilan gas metana adalah diantara 0.234L/g COD/d dan 0.325L/g COD/d. Tahap kecekapan perawatan kumbahan dengan mengunakan sistem anaerobik membran dipengaruhi oleh masa penahanan pepejal (SRT), masa penahanan hidraulik dan kadar muatan organik. Dalam kajian ini, kerosakan membran dan pembibiran pada permukaan membran memainkan peranan penting dalam penghasilan lapisan kek yang tebal justeru mengurangkan keberkesanan lapisan resapan membran.

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LIST OF SYMBOLS/ABBREVIATION

3MAS	Membrane Anaerobic System
COD	Chemical Oxygen Demand (mg/L)
CH_4	Methane
HRT	Hydraulic Retention Time (day)
BOD	Biological Oxygen Demand
CO_2	Carbon Dioxide
H_2O	Water
$K_2Cr_2O_7$	Potassium Dichromate
μ_{max}	Maximum Growth Rate
RO	Reverse Osmosis
LR	Lower Range
HR	Higher Range
NaOH	Sodium Hydroxide
CUF	Crossflow Ultrafiltration
TSS	Total Suspended Solid (mg/L)
MWCO	Molecular Weight Cut-Off
PVC	Polyvinylchloride
MF	Microfiltration
cBOD	Carbonaceous Biological Oxygen Demand
CUMAR	Crossflow Ultrafiltrafiltration Membrane Anaerobic Reactor

CHAPTER 1

INTRODUCTION

1.1 Background of Research

Anaerobic digestion is a biological process that happens in environment. It occurs naturally in swamps, water-logged soils and paddy fields, deep bodies of water, estuaries and in the digestive systems of termites and large animals. It utilizes microorganisms to break down biodegradable organic materials with little or in the absence of oxygen. Almost any organic material can be processed with anaerobic digestion including waste papers, agriculture wastes, industrial effluents, leftover food, animal and human excreta. It is widely used for the treatment of wastewater sludge in many industries.

Due to the high organic fraction, anaerobic digestion is one of the fundamental processes in sewage sludge treatment for reducing and stabilizing the organic solids. There are more innovative waste treatment facilities attributed to improve anaerobic digestion technology. With the advancement of membrane technology, application of membrane filtration in the treatment of sewage sludge can contribute to developing an efficient sewage sludge treatment process that is capable of retaining biomass concentration within the reactor and producing high quality effluent. Membrane separation techniques have proven to be an effective method in separating biomass solids from digester. (Liew, *et al.,* 2005).

Sludge digestion occurs in anaerobic digesters. It produces conditions that encourage the natural breakdown of organic matter by bacteria in the absence of air.

Utilizing anaerobic digestion technologies can help to reduce the emission of greenhouse gasses in a number of key ways:

- Replacement of fossil fuels
- Reducing methane emission from landfills
- Displacing industrially-produced chemical fertilizers
- Reducing vehicle movements
- Reducing electrical grid transportation losses

Anaerobic digestion is a renewable energy source because the process produces biomethane which consist of methane (50%-80%), a powerful greenhouse gas helping replace fossil fuels. Methane is a gas that contains molecules of methane with one atom of carbon and four atoms of hydrogen (CH_4). It is the major component of the "natural" gas used in many homes for cooking and power generation. As methane is about twenty times more potent as carbon dioxide this has significant negative environmental effects. Besides, anaerobic digestion also releases carbon dioxide (20%-50%) and traces levels of other gases such as hydrogen, carbon monoxide, nitrogen, oxygen and hydrogen sulfide. The relative percentage of these gases depends on the feed material and management of the process.

Methane and power produced in anaerobic digestion facilities can be utilized to replace energy derived from fossil fuels, and hence reduce emissions of greenhouse gasses. Increasingly however, anaerobic digestion is seen not as a process for stabilizing sludge, but as an opportunity to recover the energy embedded in the substrate, traditionally in the form of methane. For instance it has been estimated that conventional anaerobic digestion of the UK's municipal solid waste could generate 1.4GW electricity or 1.9% of the nations demand (Abdurahman; 2000).

1.2 Problem Statement

In today's urbanized society, domestic sewage which consists of human and animal wastes, household wastes, small amounts of groundwater infiltration and small amounts of industrial wastes is discharged to streams, rivers, lakes and oceans. This can lead to severe water pollution when an overwhelming amount of waste accommodates in natural ecosystem. Hence it is very important to prevent the pollution of vital and limited resources of water by providing adequate treatment of liquid waste emanating from domestic sources.

The most significant components of sewage are usually suspended solids, biodegradable organics, and pathogens. Higher accumulations of these components can lead to high levels of organic pollution. Consequently, when the wastes are not destroyed as fast as they are produced, they make it unfavorable to humans and many other organisms. The anaerobic digestion of sewage sludge is considered as an excellent alternative to dumping, composting, incinerating of organic waste or to simple fermentation processes (Abdurahman, 2000).

The anaerobic process is time-tested does not require the purchase of special bacteria or nutrients. This is because the bacteria are anaerobic and they do not require oxygen like the organisms in an aerobic process. By using anaerobic digestion in the treatment of wastewater sludge, the overall cost of sewage treatment is reduced and it also furnishes a considerable power supply. Although many sludge stabilization methods exist, anaerobic digestion is unique for it has the ability to produce a net energy gain in the form of methane gas; it optimizes cost effectiveness and minimizes the amount of final sludge disposal, thus decreasing the hazards of wastewater and sewage treatment by-products. Thus for municipal wastewater treatment plants it is most cost effective and environmentally sound to use anaerobic digestion in the stabilization of sewage sludge. Besides, this process is helping clients to convert liabilities into assets and green energy; that is "From Waste to Energy".

1.3 Research Objectives

In the course of completing this research, there are few objectives to be fulfilled. Those are:

i. To evaluate the overall MAS treatment efficiency.

ii. To evaluate the influence of the hydraulic retention time and sewage concentration on turbidity, Chemical Oxygen Demand (COD), Ammonia-Nitrogen, Nitrate-Nitrogen, Total Suspended Solid (TSS) and methane yield.

1.4 Scope of Research

To accomplish the objectives of this research, the scope of this research focuses in:

- A 30 L digester is designed and used to treat sewage sludge which was taken from Indah Water Treatment Plant.
- Hollow fiber ultrafiltration membrane was used to increase the efficiency of the treatment with the following operational conditions:
    - The temperature of the process is in the mesophilic range, between 25°C-45°C.
    - The pressure to be used is 1.5-2.0 bars.
    - The pH of the reactor content is in the range of 6.5 to 7.5.
    - The laboratory digester is completely mixed semi-continuously.
- An enrichment mix culture of methanogenic bacteria was acclimatized in the digester after sample feeding.

- The next scope was to examine the influence of hydraulic retention time and different sewage concentration on turbidity, Chemical Oxygen Demand (COD), ammonia-nitrogen, nitrate-nitrogen and Total Suspended Solid (TSS).

- Finally this study measured methane gas production by using 20 L water displacement bottle and J-Tube technique.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Anaerobic fermentation is one of the oldest processes used in stabilization of solids and biosolids. It involves the decomposition of organic matter and inorganic matter such as ammonia and nitrate to digested particles in the absence of oxygen.

The major application of anaerobic digestion is applied in the stabilization of sewage sludge. Later on, it was successfully used for the treatment of industrial and domestic wastewaters. Mass reduction, methane production, and improved dewatering properties of the fermented sludge are important features of anaerobic digestion.

Anaerobic digestion consist of a series of microbiological processes that convert organic compounds to methane and carbon dioxide, and reduce volatile solids by 35 percent to 60 percent, depending on the operating conditions (U.S. EPA, 1992a; Gabriel, 2005). A net reduction in the quantity of solids and destruction of pathogenic organisms are also accomplished in the anaerobic digestion. Furthermore, anaerobic digestion of municipal sewage sludge can produce sufficient amount of digester gas to meet most of the energy needs for the plants.

2.2 Advantages and Disadvantages of Anaerobic Digestion

Anaerobic digestion offers several advantages and disadvantages over aerobic digestion and the methods of sludge stabilization, which include:

- The methane gas produced is a source of usable energy. In most cases the energy produced exceeds the energy required to maintain the temperature for sludge digestion. Excess methane can be used for heating building, running engines for aeration blowers, or generating electricity.

- Reduction in total sludge mass through the conversion of organic matter primarily to methane, carbon dioxide and water. Commonly, 30% to 65% of the raw sludge solids are destroyed. This can significantly reduce the cost of sludge disposal.

- The digested solids are generally free of objectionable odors.

- The digested biosolids contain nutrients such as nitrogen and phosphorus, and organic matter that can improve the fertility and texture of soils.

- A high rate of pathogen distribution can be achieved, especially with the thermophilic digestion process.

- There is a reduction of energy required for wastewater treatment.

- Anaerobic digestion is suitable for high-strength industrial wastes.

- There is preservation of the activity of anaerobic microorganisms, even if the digester has not been fed for long periods of time.

- Anaerobic systems can biodegrade xenobiotic compounds such as chlorinated aliphatic hydrocarbons (e.g., trichloroethylene, trihalomethanes) and recalcitrant natural compounds such as lignin (Gabriel, 2005).

Some disadvantages of anaerobic sludge digestion are:

- It is a slower process.
- The capital cost is high because it requires large closed digestion tanks fitted with systems for feeding, heating, and mixing the sludge.
- Large reactors are required to provide the hydraulic retention time in excess of 10days to stabilize the sludge effectively (Gabriel, 2005). This slow digestion process also limits the speed with which the system can adjust to changes in waste loads, temperature, and other environment conditions.
- Microorganisms involved in anaerobic digestion are sensitive to small changes in the environment. Therefore, the process is susceptible to upsets. Monitoring the performance, and close process control are required to prevent upsets.
- The process produces poor-quality sidestream. Supernatants often have a high oxygen demand and a high concentration of suspended solids, nitrogen, and phosphorus. These flows may require additional treatment before recycling to the influent flows in plants that are required to remove nitrogen and phosphorus from wastewater (Gabriel, 2005).

2.3 Chemical Oxygen Demand

Chemical oxygen demand (COD) is the amount of oxygen necessary to oxidize the organic carbon completely to CO_2, H_2O, and ammonia (Gabriel, 2005). Chemical oxygen demand is measured via oxidation with potassium dichromate ($K_2Cr_2O_7$) in the presence of sulfuric acid and silver and is expressed in mg/L. Thus, COD is a measure of the oxygen equivalent of the organic matter as well as microorganisms in the wastewater (Gabriel, 2005). If the COD value is much higher than the BOD value, the sample contains large amounts of organic compounds that are not easily biodegrade.

2.4 Factors Controlling Anaerobic Digestion

Anaerobic digestion is affected by temperature, pH, retention time, chemical composition of wastewater, competition of methanogens with sulfate-reducing bacteria, and the presence of toxicants.

2.4.1 Temperature

Methane production has been documented under a wide range of temperatures ranging between 0°C and 97°C. Although pcychrophilic methanogens have not been isolated, thermophilic strains operating at an optimum range of 50°C-75°C occur in hot springs. *Methanothermus fervidus* has been found in a hot spring in Iceland and grows at 63-97°C (Sahm, 1984).

In municipal wastewater treatment plants, anaerobic digestion is carried out in the mesophilic range at temperature from 25°C to up to 40°C, with an optimum at approximately 35°C. Thermophilic digestion operates at temperatures ranges of 50°C -65°C. It allows higher loading rates and is also conducive to greater destruction of pathogens. One drawback is its higher sensitivity to toxicants (Koster, 1988).

Because of their slower growth as compared to acidogenic bacteria, methanogens are very sensitive to small changes in temperature. As to utilization of volatile acids by methanogens, a decrease in temperature leads to a decrease of the maximum growth rate (μ_{max}), while the half saturation constant K_s increases (Gabriel, 2005). Thus, mesophilic digester must be designed to operate at temperature of 30°C -35°C for their optimal functioning.

2.4.2 Retention Time

The hydraulic retention time (HRT), which is depends on wastewater characteristics and environmental conditions, must be long enough to allow metabolism by anaerobic microorganisms in digesters. Digesters based on attached growth have a lower HRT (1-10 days) than those based on dispersed growth (10-60 days). The retention times of mesophilic and thermophilic digesters range between 25 and 35 days, but can be lower. Hydraulic retention time (HRT), which is the average time the liquid sludge is held in the digester. It can be defined operationally as follows: (Turovskiy and Mathai, 2006).

- HRT, in days, is equal to the volume of sludge in the digester (m^3) divided by the volume of digested sludge withdrawn daily (m^3/d).

2.4.3 pH

Most methanogens function optimally at a pH range of 6.8-7.5, but optimally at pH 7.0-7.2, and the process may fail if the pH is close to 6.0. Acidogenic bacteria produce organic acids that tend to lower the pH of the bioreactor. Under normal conditions, this pH reduction is buffered by bicarbonate produced by methanogens. Under adverse environmental conditions, the buffering capacity of the system can be upset, eventually stopping methane production. Acidity is inhibitory to methanogens than to acidogenic bacteria. An increase in volatile acids level thus serves as an early indicator of system upset. Monitoring the ratio of total volatile acids (as acetic acids) to alkalinity (as calcium carbonate) has been suggested to ensure that it remains below 0.1 (Sahm, 1984). One method for restoring the pH balance is to increase alkalinity by adding chemicals such as lime, anhydrous ammonia, sodium hydroxide, or sodium bicarbonate.

2.4.4 Toxicants

A wide range of toxicants are responsible for the occasional failure of anaerobic digester. Toxicity becomes less severe, however, once the anaerobic microorganisms become adapted to the toxic wastewater (Lettinga, 1995). Inhibition of methanogenesis is generally indicated by reduced methane production and increased concentration of volatile acids.

2.4.5 Chemical Composition of Wastewater

Methanogens can produce methane from carbohydrate, proteins and lipids, as well as from complex aromatic compounds (e.g. ferulic, vanillic, and syringic acids). However, a few compounds such as lignin and n-paraffin are hardly degraded by anaerobic microorganisms.

Wastewater must be nutritionally balances (nitrogens, phosphorus, sulfur, etc.) to maintain an adequate anaerobic digestion. Phosphorus limitation results in reversible decrease in methanogenic activity. The C:N:P ratio for anaerobic bacteria is 700:5:1 (Lettinga, 1995; Sahm, 1984). However, some investigators argue that the C/N ratio for optimal gas production should be 25-30: 1(Turovskiy and Mathai, 2006). Methanogens use ammonia and sulfide as nitrogen and sulfur sources, respectively. Although un-ionized sulfide is toxic to methanogens at levels exceeding 150-2mg/L, it is required by methanogens as a major source of sulfur (Speece *et al.*, 1983). Moreover, trace elements such as iron, cobalt, molybdenum, and nickel are also necessary. Nickel, at concentration as low as 10µM, significantly increases methane production in laboratory digesters (Turovskiy and Mathai, 2006). Nickel addition can increase the acetate utilization rate of methanogens from two to as high as 10g acetate g^{-1} VSS day^{-1} (Speece *et al*., 1983). Nickel enters in the composition of the co-factor F_{430}, which is involved in biogas production (Turovskiy and Mathai, 2006).

2.4.6 Suspended Solids

Solids suspended in wastewater consist of inorganic or organic particles or of immiscible liquids. Domestic wastewater usually contains large quantities of suspended solids that are mostly organic in nature. Suspended material is aesthetically displeasing and provides adsorption sites for chemicals and biological agents. Organic solids may be degraded biologically, resulting in objectionable by-products. Biologically active suspended solids may include disease-causing organisms such as toxin-producing strains of algae.

2.5 Process Microbiology

A group of microorganism species, especially bacteria and methanogens, are involved in the transformation of high-molecular-weight organic compounds to methane. Moreover, synergistic interactions between the various groups of microorganisms are implicated in anaerobic digestion of wastes. The overall reaction is shown in Eq. 2.1 (Gabriel, 2005).

$$\text{Organic matter} \longrightarrow CH_4 + CO_2 + H_2 + NH_3 + H_2S \qquad \text{Eq. 2.1}$$

Large numbers of strict and facultative anaerobic bacteria such as *Bacteroides, Bifidobacterium, Clostridium, Lactobacillus* and *Streptococcus* are implicated in the hydrolysis and fermentative of organic compounds (Gabriel, 2005). Four categories of microorganisms are involved in the transformation of complex materials into simple molecules such as methane and carbon dioxide. These microbial groups operate in a synergistic relationship (Barnes and Fitzgerald, 1987; Koster, 1988; Sahm, 1984; Gabriel, 2005) as shown in Figure 2.1.

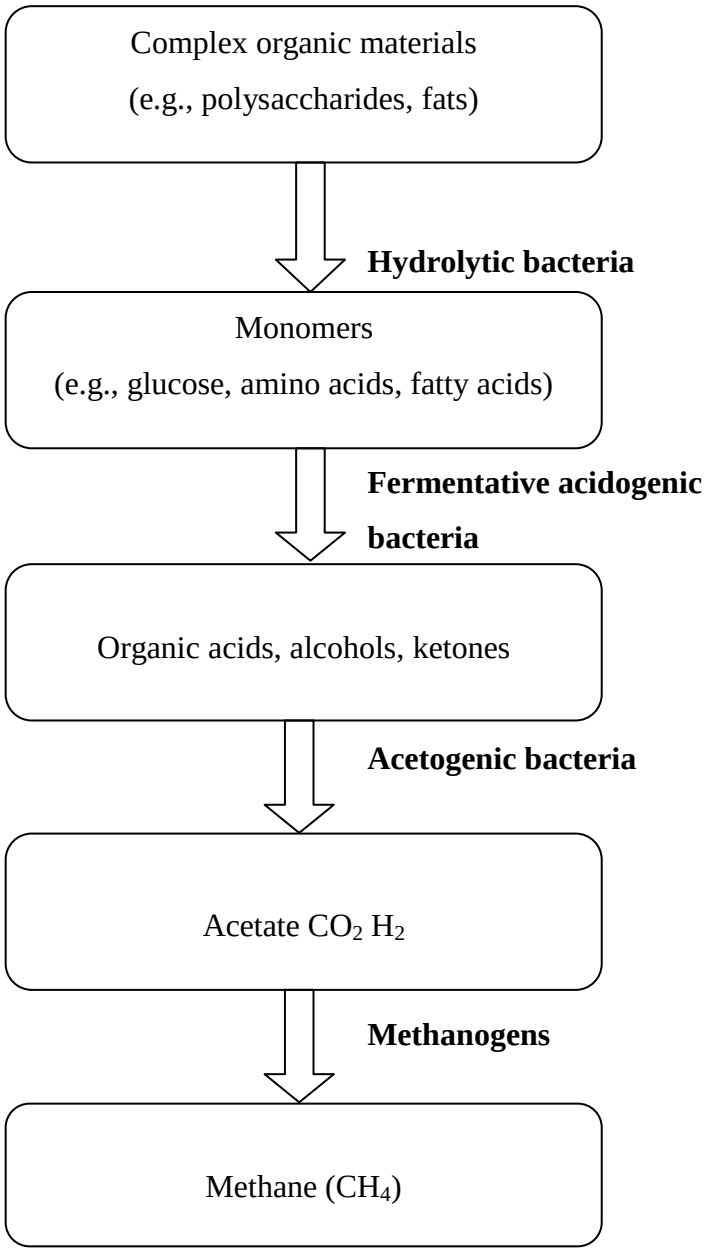

Figure 2.1: Metabolic bacterial groups involved in anaerobic digestion of wastes.

2.5.1 Hydrolytic Bacteria

Consortia of anaerobic bacteria break down complex organic molecules (e.g., proteins, cellulose, lignin, lipids) into soluble monomer molecules such as amino acids, glucose, fatty acids, and glycerol. The monomers are directly available to the next group of bacteria. Hydrolysis of complex molecules is catalyzed by

extracellular enzymes such as cellulases, protease, and lipases. However, the hydrolytic phase is relatively slow and can be limiting in anaerobic digestion of wastes such as raw cellulytic wastes that contain lignin (Speece, 1983; Gabriel, 2005). Hydrolysis is the rate limiting step in the acid-forming phase (Eastman and Ferguson, 1981; Turovskiy and Mathai, 2006).

2.5.2 Fermentative Acidogenic Bacteria

Acidogenic that is acid forming bacteria such as *Clostridium* converts sugars, amino acids, and fatty acids to organic acids (e.g., acetic, propionic, formic, lactic, butyric, or succininc acids), alcohols and ketones (e.g., ethanol, methanol, glycerol, and acetone), acetate, CO_2 and H_2. Acetate is the main product of carbohydrate fermentation. The products formed vary with the bacterial type as well as with culture conditions such as temperature, pH and redox potential. (Gabriel, 2005).

2.5.3 Acetogenic Bacteria

Acetogenic bacteria- acetate and hydrogen producing bacteria such as *Syntrobacter wolinii* and *Syntrophomonas wolfei* (Gabriel, 2005) converts fatty acids (e.g., propionic acid, butyric acid) and alcohols into acetate, hydrogen and carbon dioxide, which are used by the methanogens. This group requires low hydrogen tensions for fatty acid conversion, necessitating a close monitoring of hydrogen concentration. Under relatively high hydrogen partial pressure, acetate formation is reduced and the substrate is converted to propionic acid, butyric acod, and ethanol rather than methane. There is a symbiotic relationship between acetogenic bacteria and methanogens. Methanogens help to achieve the low hydrogen tension required by acetogenic bacteria. (Gabriel, 2005)

Ethanol, propionic acid and butyric acid are converted to acetic acid by acetogenic bacteria according to Eq. 2.2, Eq. 2.3, and Eq. 2.4: (Gabriel, 2005)

$$CH_3CH_2OH + H_2O \longrightarrow CH_3COOH + 2\ H_2 \qquad \text{Eq. 2.2}$$

ethanol — acetic acid

$$CH_3CH_2COOH + 2\ H_2O \longrightarrow CH_3COOH + CO_2 + 3\ H_2 \qquad \text{Eq. 2.3}$$

propionic acid — acetic acid

$$CH_3CH_2CH_2COOH + 2\ H_2O \longrightarrow 2\ CH_3COOH + 2\ H_2 \qquad \text{Eq. 2.4}$$

butyric acid — acetic acid

Acetogenic bacteria grow faster than methanogens.

2.5.4 Methanogens

A methanogen is a single celled microorganism that produces methane (CH_4) and carbon dioxide (CO_2), and it is a member of the Archaea. Archaea were once thought to be bacteria, and are unique because unlike most life on Earth that rely on oxygen and complex organic compounds for energy, Archaea rely on simple organic compounds (e.g., acetate) and hydrogen (H_2) for energy. Methanogens convert the volatile acids to methane and carbon dioxide under methanogenesis process. Methanogens do not use oxygen to breathe; in fact, oxygen inhibits the growth of methanogens.

Anaerobic digestion of organic matter in environment releases approximately 500 million tons of methane/year into the atmosphere, representing about 0.5 percent of the organic matter derived from photosynthesis (Sahm, 1984; Gabriel, 2005). The fastidious methanogens occur naturally in deep sediments or in the rumes of herbivores. Methanogenic microorganisms grows slowly in wastewater and their generation times range from 3 days at 35°C to as high as 50 days at 10°C.

2.6 Scales of Anaerobic Process

Anaerobic digestion can be carried out on a variety of scales: (Abdurahman, 2000)

- On-site using residues produced only on that farm or food-processing unit.
- As cooperative enterprise between several farmers.
- By developing centralized anaerobic digestion project supplied with feed stock from several sources including industrial sources.

There are two types of anaerobic process:

2.6.1 Mesophilic Digestion

A mesophile is an organism that grows best in moderate temperature, neither too hot nor too cold, typically between 15°C and 40°C (77°F and 104°F). The term is mainly applied to microorganisms. The habitats of these organisms include soil, the human body, animals, and etc. The optimal temperature of many pathogenic mesophiles is 37°C (98°F), the normal human body temperature. Mesophilic organisms have important uses in food preparation especially in cheese and yogurt making and in beer and wine making.

Organisms that prefer cold environments are termed psychrophilic, those preferring warmer temperatures are termed thermophilic and those thriving in extremely hot environments are hyperthermophilic.

2.6.2 Thermophilic Digestion

A thermophile is an organism a type of extremophile that thrives at relatively high temperatures, between 45°C and 80°C (113°F and 176°F). Many thermophiles are archaea. Thermophiles are found in various geothermally heated regions of the Earth such as hot springs like those in Yellowstone National and deep sea hydrothermal vents, as well as decaying plant matter such as peat bogs and compost.

Thermophiles are classified into obligate and facultative thermophiles: Obligate thermophiles (also called extreme thermophiles) require such high temperatures for growth, whereas facultative thermophiles (also called moderate thermophiles) can thrive at high temperatures but also at lower temperatures (below 50°C). Hyperthermophiles are particularly extreme thermophiles for which the optimal temperatures are above 80°C.

2.7 Comparison with Aerobic Digestion

Anaerobic biological treatment systems can offer a number of advantages over their aerobic counterparts. The operational costs associated with anaerobic systems are typically lower than with aerobic systems, and anaerobic systems also generate less waste sludge. In addition, the energy associated with the biogas produced during anaerobic biological treatment can potentially be recovered. However, to date, the use of conventional anaerobic biological systems for the treatment of dilute wastewaters has been relatively limited.

2.8 Application of Anaerobic Treatment

2.8.1 Anaerobic Treatment of Agricultural Wastes

In April 15, 2008, engineers at Washington University in St. Louis, using an impressive array of imaging and tracking technologies, have determined the importance of mixing in anaerobic digesters for bioenergy production and animal and farm waste treatment. As energy costs have continued to rise, there has been increased interest in anaerobic digestion of animal manures to generate energy. This interest has included the direct use of biogas on the farm, centralized digestion systems, co-digestion facilities, and digestion of manures as an energy source at ethanol plants.

2.8.2 Anaerobic Wastewater Treatment

Anaerobic wastewater treatment is the biological treatment of wastewater without the use of air or elemental oxygen. Many applications are directed towards the removal of organic pollution in wastewater, slurries and sludge. The organic pollutants are converted by anaerobic microorganisms to a gas containing methane and carbon dioxide, known as "biogas" as shown Figure 2.2

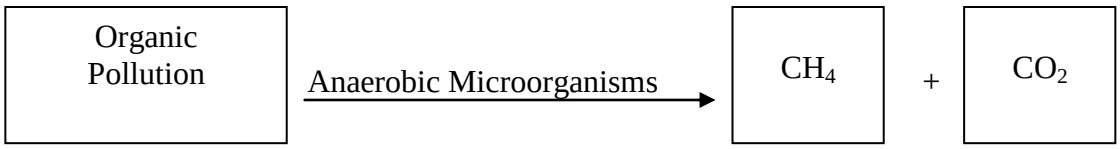

Figure 2.2.: Conversion of Organic Pollutants to Biogas by Anaerobic Microorganism

The COD in wastewater is highly converted to methane, which is a valuable fuel. Very little COD is converted to sludge. No major inputs are required to operate the system.

2.9 Methane Gas Usage

2.9.1 Fuel

Methane is important for electrical generation by burning it as a fuel in a gas turbine or steam boiler. Compared to other hydrocarbon fuels, burning methane produces less carbon dioxide for each unit of heat released. At about 891 kJ/mol, methane's heat of combustion is lower than any other hydrocarbon but the ratio of the heat of combustion (891 kJ/mol) to the molecular mass (16.0 g/mol) shows that methane, being the simplest hydrocarbon, produces more heat per mass unit (55.7 kJ/g) than other complex hydrocarbons. In many cities, methane is piped into homes for domestic heating and cooking purposes. In this context it is usually known as natural gas, and is considered to have an energy content of 39 mega joules per cubic meter, or 1,000 BTU per standard cubic foot.

Methane in the form of compressed natural gas is used as a vehicle fuel, and is claimed to be more environmentally friendly than other fossil fuels such as gasoline/petrol and diesel.

Research is being conducted by NASA on methane's potential as a rocket fuel. One advantage of methane is that it is abundant in many parts of the solar system and it could potentially be harvested in situ (i.e. on the surface of another solar-system body), providing fuel for a return journey.

Current methane engines in development produce a thrust of 7,500 pounds, which is far from the seven million pounds needed to launch the space shuttle.

Instead, such engines will most likely propel voyages from our moon or send robotic expeditions to other planets in the solar system.

Recently methane emitted from coal mines has been successfully converted to electricity.

2.9.2 Industrial uses

Methane is used in industrial chemical processes and transported as a refrigerated liquid (liquefied natural gas, or LNG). While leaks from a refrigerated liquid container are initially heavier than air due to the increased density of the cold gas, the gas at ambient temperature is lighter than air. Gas pipelines distribute large amounts of natural gas, of which methane is the principal component.

In the chemical industry, methane is the feedstock of choice for the production of hydrogen, methanol, acetic acid, and acetic anhydride. When used to produce any of these chemicals, methane is first converted to synthesis gas, a mixture of carbon monoxide and hydrogen, by steam reforming. In this process, methane and steam react on a nickel catalyst at high temperatures (700°C –1100 °C) as shown in Eq. 2.5.

$$CH_4 + H_2O \xrightarrow[700-1100^oC]{Ni} CO + 3H_2 \qquad \text{Eq. 2.5}$$

The ratio of carbon monoxide to hydrogen in synthesis gas can then be adjusted via the water gas shift reaction to the appropriate value for the intended purpose.

Less significant methane-derived chemicals include acetylene, prepared by passing methane through an electric arc, and the chloromethane (chloromethane, dichloromethane, chloroform, and carbon tetrachloride), and produced by reacting

methane with chlorine gas. However, the use of these chemicals is declining. Acetylene is replaced by less costly substitutes, and the use of chloromethane is diminishing due to health and environmental concerns.

2.10 Ultrafiltraion Membrane

Ultrafiltration (UF) is a low pressure membrane filtration in which hydrostatic pressure forces a liquid against a semipermeable membrane. Suspended solids and solutes of high molecular weight are retained due to its capacity to reduce formation of a concentration polarization layer, and consequently decreasing levels of fouling are pore clogging. Meanwhile water and low molecular weight solutes pass through the membrane.

2.11 Membrane Anaerobic System

Membrane Anaerobic System (MAS) is a combination of membrane separation technology with anaerobic treatment process. The limitations of standard filtration are overcome by operating Ultrafiltration in what can be called “Crossflow Configuration”.

Performance of Ultrafiltration depends upon the rate of solvent that passes through the membrane. The phenomenon of any accumulation of retained molecules or material at the surface is called as concentration polarization (Pradanos *et al*., 1995). This phenomenon can reduce the effective filtration rate. Concentration polarization occurs in a dynamic state but its effect is similar to the filter cake up at the separation surface in standard filtration.

2.12 Nutrient Agar

Nutrient Agar is a complex medium which contains Beef Extract (0.3%), Peptone (0.5%) and Agar (1.5%) in water. Beef extract is the commercially prepared dehydrated form of autolysed beef and is supplied in the form of a paste. Peptone is casein (milk protein) that has been digested with the enzyme pepsin. Peptone is dehydrated and supplied as a powder. Peptone and Beef Extract contain a mixture of amino acids and peptides. Beef Extract also contains water soluble digest products of all other macromolecules (nucleic acids, fats, polysaccharides) as well as vitamins and trace minerals. Although we know and can define Beef Extract in these terms, each batch can not be chemically defined. There are many media ingredients which are complex: yeast extract, tryptone, and others. The advantage of complex media is that they support the growth of a wide range of microbes.

Agar is purified from red algae in which it is an accessory polysaccharide (polygalacturonic acid) of their cell walls. Agar is added to microbiological media only as a solidification agent. Agar for most purposes has no nutrient value. Agar is an excellent solidification agent because it dissolves at near boiling but solidifies at 45^{o}C. Thus, molten agar can be prepared at 45^{o}C, mix cells with it, and then allow it to solidify thereby trapping living cells. Below 45^{o}C agar is a solid and remains so as the temperature is raised melting only when >95^{o}C is obtained.

CHAPTER 3

MATERIALS AND METHOD

3.1 METHODOLOGY

3.1.1 Introduction

To accomplish the objectives of the research, a 30 liter volume of laboratory scaled anaerobic reactor was used to treat sewage sludge which was taken from municipal treatment plant. This reactor was equipped with feeder, gas collector and sludge wastage which will be act as digested sludge collector. A schematic representation of the system is shown in Figure 3.1.

Firstly, the sewage sludge was screened through the strainer to remove coarse particles. Then initial analysis of pH, temperature, turbidity, Chemical Oxygen Demand (COD), Ammonia-N, Nitrate-N, and Total Suspended Solid (TSS) were done on the sludge. 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 fed into the 30 L digester.

The operating temperature for the anaerobic process was in the mesophilic range, between 25°C-45°C. The pressure was maintained at 1.5-2.0 bars by manipulating the ball valve at the retentate line after the hollow fiber ultrafiltration membrane. The pH of the reactor content was in the range of 6.5 to 7.5. The

laboratory digester will be mixed under semi-continuous flow. The digester was run for 4 days at two different concentrations.

After that, the biogas produced at the upstream of the digester was collected by using 20 L water displacement bottle. Next, the analysis of permeate and sludge waste at the bottom stream of the reactor were done on turbidity, COD, Ammonia-N, Nitrate-N and TSS. The total volume of methane gas evolved is measured. Finally, all the collected data were analyzed.

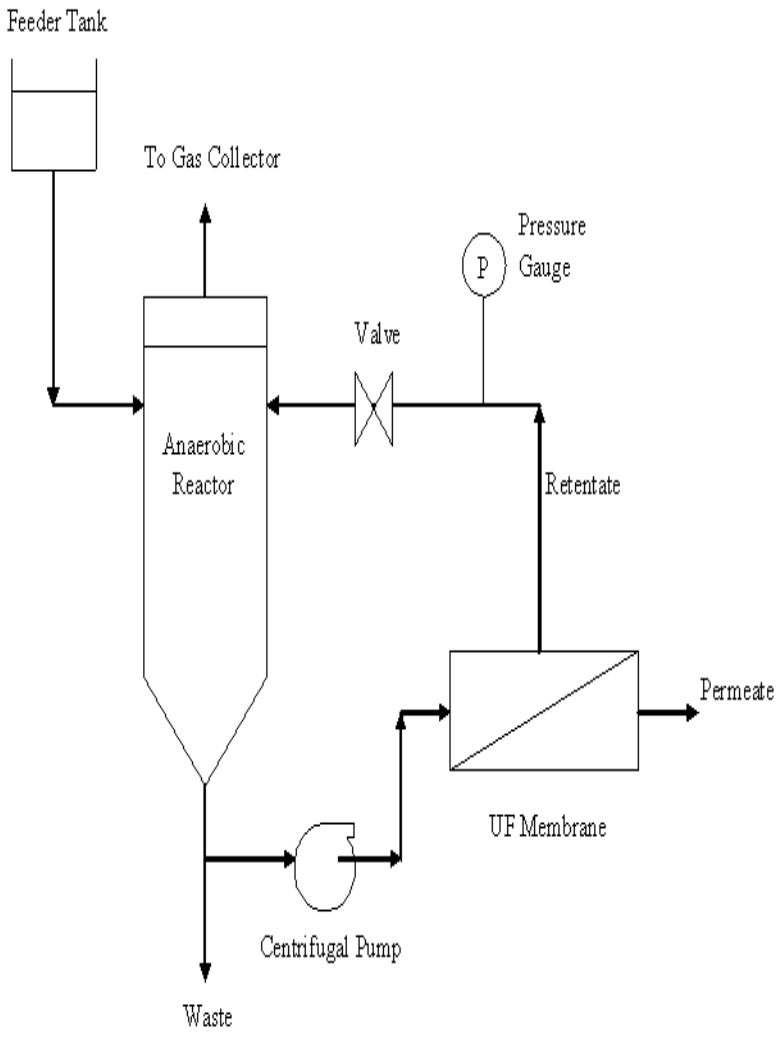

Figure 3.1.: Experimental Setup

3.2 Sampling of Sewage and Feed Preparation

In this study, the seed sludge was obtained from Indah Water sewage treatment plant in Taman Seri Mahkota, Kuantan. The cooperation from the Indah Water and the people in-charge, Mr. Zul lead to smooth sampling frequency and time. The sample was screened through strainer to remove coarse particles in order to avoid clogging in membrane and pump damage. Then, samples were freshly preserved at 4°C in the cooler. Figure 3.2 and Figure 3.3 showed the front view of Indah Water and the sampling point of raw sewage. While Figure 3.4 shows the sewage pond.

Figure 3.2: The front view of Indah Water Treatment Plant in Taman Seri Mahkota, Kuantan.

Figure 3.3: Sampling point of raw sewage.

Figure 3.4: Sewage pond.

The daily feed was poured into the feeding tank, and then the feed was follow by gravity into the reactor. The feeder tank is showed in Figure 3.5.

Figure 3.5: Feeder Tank

3.3 Screening

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

3.4 Characterization of Raw Sewage Sludge

The characteristic of the raw sewage, such as pH, turbidity, chemical oxygen demand (COD), Ammonia-N (NH_3-N) content, Nitrate-N (NO_3^--N) content, and total suspended solids (TSS) were determined according to the Standard Methods

for the Examination of Water and Wastewater and DR2400 Spectrophotometer Procedures Manual. About 80 L of raw of sewage sludge were collected freshly and determined in the laboratory at two different concentration ratios of 50% and 100% respectively. The initial characteristics of these two concentration ratios of raw sewage samples were illustrated in Appendix A.

3.5 Microbiological Cultures

Microbiological cultures utilize petri dishes that have a thin layer of universal agar based growth medium in them. Once the growth in the petri dish is inoculated with the desired bacteria medium (sewage sample which was diluted to 10^1), the agar plates were incubated in the incubator at 30°C for three days. After three days, the growth bacteria were suspended in universal liquid broth, a nutrient medium and were incubated again for another three days at 30°C and 100rpm in the shaker for uniform growth. The regeneration time, or the time required for a cell to mature and separate, may be as short as 20 minutes. The cultured plate and broth culture are shown in Figure 3.6.

Figure 3.6: Cultured Agar Plate with Bacterial Growth and Cultured Broth.

3.6 Membrane Cleaning

In the course of this study, there were two methods that the membranes were cleaned, I order to improve the permeate flux and permeate flowrate. The two methods which were followed in this study are:

- Mild brushing followed by flushing with water.
- Soaking the membrane into 0.1M NaOH solution for a day (24 hours) which is followed by vigorous brushing and flushing with water as shown in Figure 3.7.

In both methods, the membranes have been taken out from membrane housing.

Figure 3.7: Hollow Fiber Ultrafiltration membrane in NaOH solution

3.7 Cross flow Ultrafiltration Membrane (CUM) Unit

The CUF consists of four tubular Polysulphone membranes, which put inside steel membrane housing. The length of polysulphone is 30 cm and its

diameter was 1.25 cm. The total areas of the four membranes were 0.048 m^2 and the average pore size of 0.1µm. the molecular cut-off weight of 200 000.

The membrane can be operated at a maximum pressure of 55 bar at 70°C or at 70 bar at 20°C. The operating pressure in this study was maintained at 1.5-2.0bar, by manipulating the gate valve at the retentate line after the CUF unit. The CUF unit is shown if Figure 3.8.

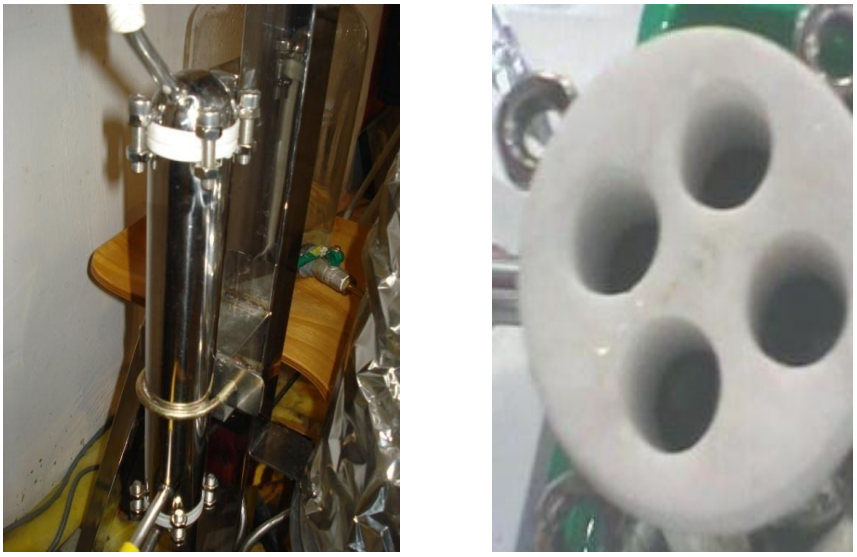

Figure 3.8: Crossflow Ultrafiltration (CUF) unit

3.8 Analytical Techniques

3.8.1 pH

The pH value of raw sludge, sample at 50% and 100% concentrations, reactor content and permeate was determined by using pH meter. The pH meter is shown in Figure 3.9.

Figure 3.9: pH Meter

3.8.2 Turbidity

The turbidity value of raw sludge, sample at 50% and 100% concentrations, reactor content and permeate was determined by using turbidity meter. Turbidity meter is shown in Figure 3.10.

Figure 3.10: Turbidity Meter

3.8.3 Chemical Oxygen Demand (COD) Measurement

The dichromate reflux method is preferred over procedures using other oxidants (e.g. potassium permanganate) because of its superior oxidizing ability,

applicability to a wide variety of samples and ease of manipulation. Oxidation of most organic compounds is 95%-100% of the theoretical value. In this procedure, the sample is heated at 150°C for two hours with a strong oxidizing agent, potassium dichromate which was in COD Digestion Reagent Vial HR. Oxidizable organic compounds react, reducing the dichromate ion ($Cr_2O_7^{2-}$) to green chromic ion (Cr^{3+}).

After two hour of heating, the vial is cooled to 120°C or less. Then, the COD content was measured by following the Colorimetric Determination Method 8000 with the aid of Spectrophotometer DR2400 HACH as shown in Figure 3.11.

Figure 3.11: Digital Reactor Block for COD Measurement

3.8.4 Total Suspended Solid (TSS) Analysis

A well-mixed measured sample of raw sludge, sample at 50% and 100% concentrations, reactor content and permeate were filtered through a weighed standard glass-fiber filter and the residue retained on the filter is dried to a constant weight at 103°C to 105°C. The increase in weight of the filter represents the total suspended solids. If the suspended material clogs the filter and prolongs filtration, it may be necessary to increase the diameter of the filter or decrease the sample volume. TSS apparatus is shown in Figure 3.12 as below.

Figure 3.12: TSS Apparatus

3.8.5 Ammonia-Nitrogen Measurement

In ammonia-nitrogen test, the procedures of Method 8155 were followed. Ammonia compounds in the sample combine with chlorine to form monochlorine. Monochlorine reacts with salicylate to form 5-aminosalicylate. The 5-aminosalicylate is oxidized in the presence of a sodium nitroprusside catalyst to form a blue-colored compound. The blue color is masked by the yellow color from the excess reagent present to give a final green-colored solution. Test results are measured by using Spectrophotometer DR2400 HACH at 655 nm.

3.8.6 Nitrate-Nitrogen Measurement

In nitrate-nitrogen test, the procedures of Method 8171 were followed. Cadmium metal reduces nitrates in the sample to nitrite. The nitrite ion reacts in an acidic medium with sulfanilic acid to form an intermediate diazonium salt. The salt couples with gentisic acid to form an amber colored solution. Test results are measured by using Spectrophotometer DR2400 HACH at 430 nm.

3.8.7 Methane Gas Measurement

The gas volume is measured daily by using a 20 litre displacement bottle as shown in Figure 3.13. The gas method used to perform this analysis was a J-tube gas analyzer as shown in Figure 3.14 (Abdurahman, 2000). The method assuming that the biogas produced composed only of two gases, CO_2 and CH_4. Then sodium hydroxide (NaOH) was added to the composition. Sodium hydroxide will absorb CO_2 and the remaining volume is CH_4.

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

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

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

Figure 3.13: 20 L Displacement Bottle

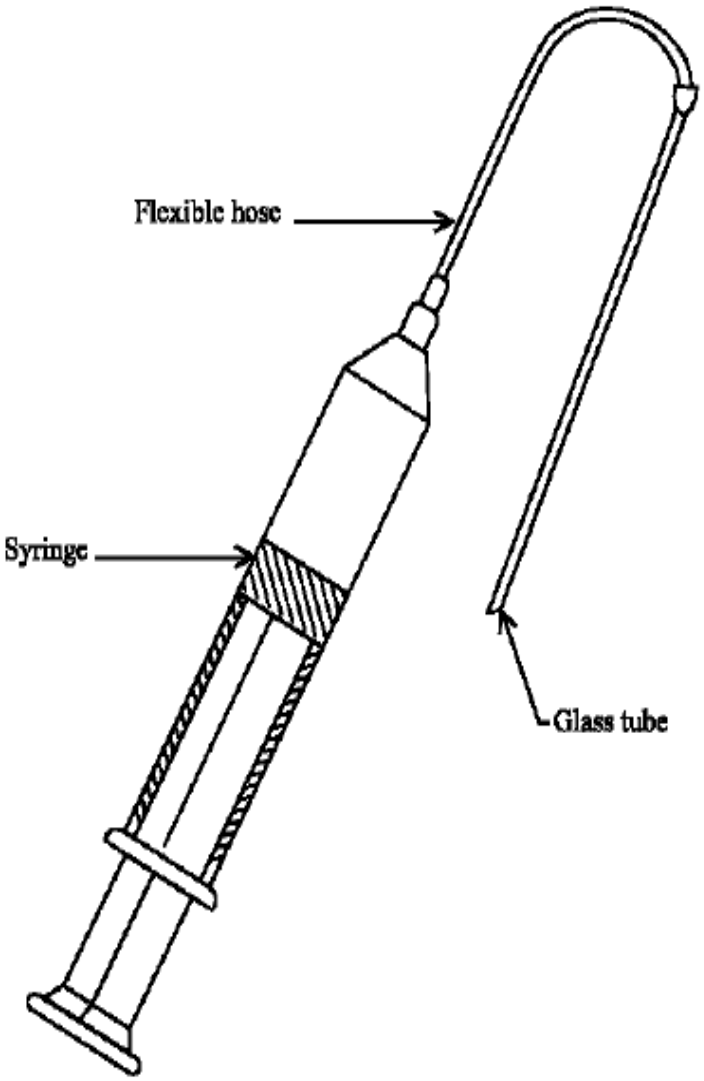

Figure 3.14: J-Tube Analyzer

3.9 Membrane Anaerobic System (MAS) Reactor Operation

In this study, the reactor pump was operated for a total of 8 hours per day. The initial sample test was done on the reactor content (influent) in order to measure the initial reading of pH, temperature, turbidity, COD, ammonia-nitrogen, nitrate-nitrogen and TSS. Some gas bubbles were found in the reactor on the first day. The parameters were measured daily for reactor content on every morning, reactor content after 8 hours and permeate (effluent). To maintain the level of the reactor

(30 liter), some of the treated sludge was recycled back to the reactor. The sample was acclimatized with bacteria for the first three days, and then it was run for four days for 50% and 100% concentration of sample respectively. The biogas produced was measured daily by using a 20 liter displacement bottle. Figure 3.15 shows the bubbles produced in 20 liter displacement bottle. While Figure 3.16 show the Anaerobic Reactor of Membrane Anaerobic System which equipped with feeder, feeder tank, 20 liter water displacement bottle and effluent collector. Then, Figure 3.17 show the CUF unit with pump and Membrane Anaerobic Unit.

Figure 3.15: Bubbles formed in 20 liter Displacement Bottle

Figure 3.16: Feeder, Feeder Tank, Anaerobic Reactor of Membrane of Membrane Anaerobic System, 20 liter Displacement Bottle, and Effluent Collector.

Note: The feeder tank is at the top of the reactor.

Figure 3.17: CUF Unit, Pump and Membrane Anaerobic Unit

CHAPTER 4

RESULT AND DISCUSSION

4.1 Result

The results obtained from experiment were tabulated and plotted in graphical form. The calculation of MAS reactor efficiency on Chemical Oxygen Demand (COD), Turbidity, Total Suspended Solids (TSS), Ammonia-Nitrogen, Nitrate-Nitrogen and methane yield data are shown in Appendix B.

4.1.1 Design of Experiments

The parameters such as pH, temperature, turbidity, Chemical Oxygen Demand (COD), Ammonia-Nitrogen, Nitrate-Nitrogen and Total Suspended Solids (TSS) were analyzed. Firstly, the initial value of each parameter was measured for reactor content. Then the reactor content was run through UF membrane for 8 hours. After 8 hours, the influent and effluent (permeate) were analyzed for each parameter. The experiment was done for 4 days of HRT on two different concentrations of raw sewages, 50% and 100% respectively. Figure 4.1 and Figure 4.2 show the pictures of raw sewage, influent, effluent and distilled water. Distilled water was used to compare the clarity of effluent obtained from both concentration ratios of raw sewage. The results obtained are tabulated in Table 4.1 and Table 4.2

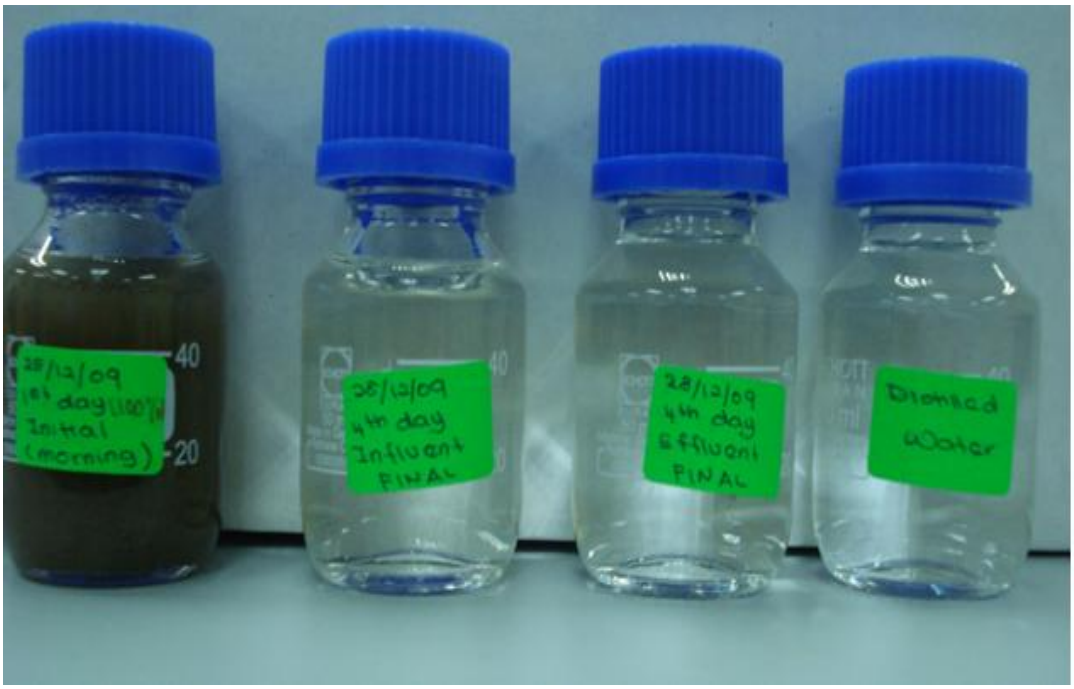

Figure 4.1: Raw sewage (50% concentration), influent, effluent, distilled water

Figure 4.2: Raw sewage (100% concentration), influent, effluent, distilled water

Table 4.1: Overall parameter changes for 50% concentration sample.

Parameters	**Initial**	**After Acclimatization**	**1st day**	**2nd day**	**3rd day**	**4th day**
Turbidity, (NTU)	2980.0	3960.0	1.1333	1.0733	0.9933	0.2933
COD (mg/L)	35700	33566.6667	2696.7	2156.7	2026.7	1936.7
Ammonia, (mg/L)	40.67	36.3333	24.667	20.0	18.0	15.0
Nitrate, (mg/L)	95.333	200.0	1.0	0.7333	0.6	0.5333
TSS (mg/L)	3900.0	7950.0	450.0	250.0	200.0	50.0
Methane Gas, (L/day)	0	0	0.163	0.691	0.761	0.730

Table 4.2: Overall parameter changes for 100% concentration sample.

Parameters	**Initial**	**After Acclimatization**	**1st day**	**2nd day**	**3rd day**	**4th day**
Turbidity, (NTU)	5970.0	6180.0	0.67	0.6167	0.3933	0.3767
COD, (mg/L)	54467	47900.0	22800	19840	9528	6388
Ammonia, (mg/L)	150.0	120.0	25.33	25.0	24.0	23.0
Nitrate, (mg/L)	186.7	143.3333	0.8	0.5667	0.475	0.4333
TSS (mg/L)	7650.0	15780.0	1250.0	50.0	0	0
Methane Gas, (L/day)	0	0	0.754	0.807	0.822	0.868

4.2 Discussion

4.2.1 pH

The effluent pH varies from 6.5 to 7.5 after 8 hours in 4 days for both 50% and 100% concentration ratios of raw sewage. In these range of pH values, the process of methanogenesis is more dominant than acidogenesis. This condition increases the activity of methanogenic bacteria in biodegradating organic materials and converts it to methane gas. Anaerobic processes are sensitive to pH and inhibitory substances. A pH value near neutral is preferred and below 6.8 the methanogenic activity is inhibited (Tchobanoglous *et al*., 2003). Higher level of pH might be toxic to the biomass-acidogenesis and methanogenesis. This would cause the low bioactivity and treatment efficiency.

4.2.2 Turbidity and Total Suspended Solid

The turbidity and TSS removal showed the same trends within the startup period. The turbidity was removed up to 99.99% while the removal efficiency of total suspended solid is found to be 98.72% to 100% by using ultrafiltration membrane. Because the activated sludge effluent from MAS is treated by filtration through a nominal 0.1µm membrane, very low concentration of effluent suspended solids and turbidity are produced with clearer permeate. MAS remove particulates from aqueous solutions using pressure-driven separation process and thus effectively separates solid-liquid phase from digester. Besides, the solids and particulate organic matters were hydrolyzed and fermented into soluble form as no significant increment of sludge volume was observed.

However, the turbidity and total suspended solid values after acclimatization period are higher than the initial reading which shows an increment from 3960.0 NTU to 7980.0 NTU and from 7950.0 mg/L to 15780.0 mg/L respectively. This is because, during acclimatization period, all the organic particles which have higher density than water are accumulated at the bottom of the digester and hence contributes to a large quantity of suspended solids. This causes the total concentration of suspended solid in the digester to increase and consequently produces higher turbidity value. Figure 4.3 and Figure 4.4 respectively show the efficiency of turbidity and total suspended solid removal.

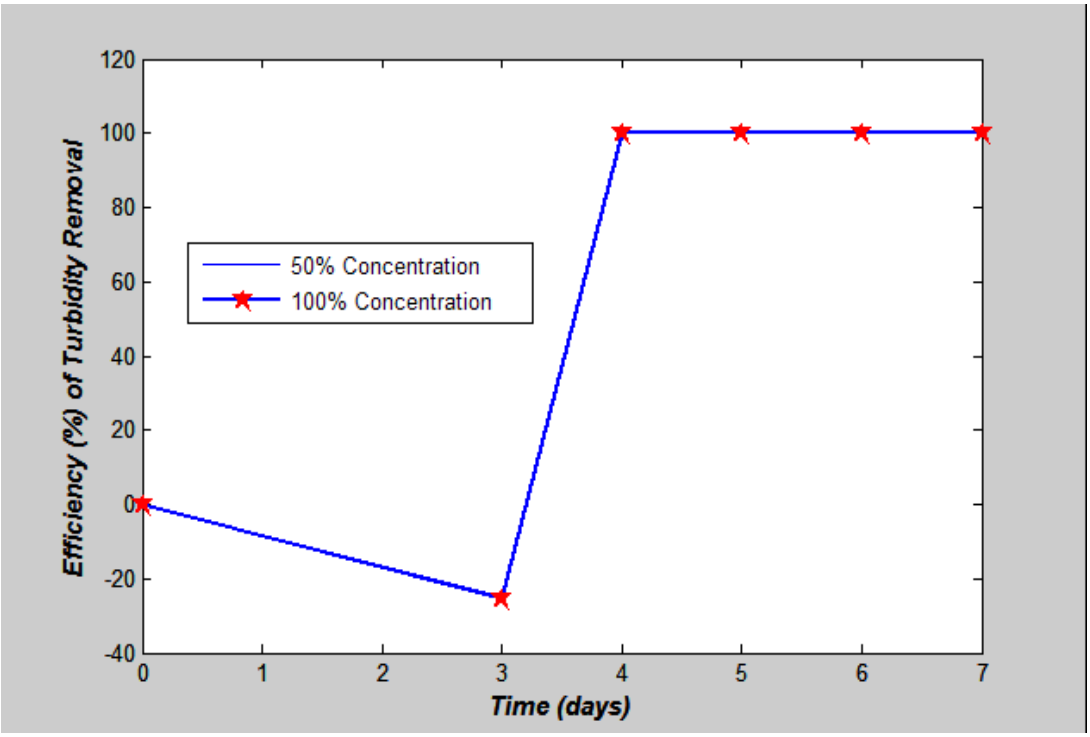

Figure 4.3: Efficiency (%) of turbidity removal with time (day).

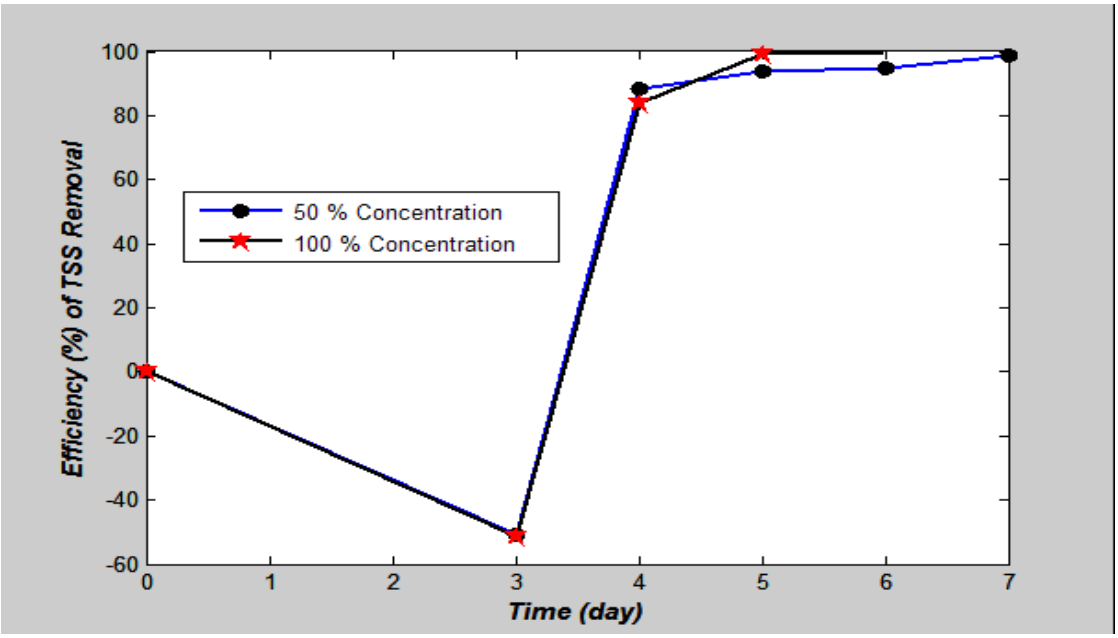

Figure 4.4: Efficiency (%) of total suspended solid removal with time (day).

4.2.3 Chemical Oxygen Demand (COD) Degradation

At the initial state, the COD of the raw sewage was found to be 35700 mg/L to 54466.7 mg/L. After acclimatization period, it was found to be 33566.67 mg/L to 47900.0 mg/L. During acclimatization period, methanogenic bacteria degrade sewage particulates in order to obtain energy for cellular activity and carbon for cellular synthesis-growth and reproduction. The cells' metabolic machinery "metabolizes" the elementary segments of organic material, and utilizes a certain amount of the food as carbon dioxide, water, and some low-molecular-weight organics. On the first day, the COD in permeate has been removed from 2696.7mg/L to 22800.0 mg/L which was 12.06% to 59.76% of the COD. This was somewhat low and can be attributed to the high content of suspended solids in the sewage sludge.

However, the COD removal efficiency was increased from 88.27% to 94.56% of the COD on the fourth day. High efficiency of COD has been achieved within a short

period of HRT by using ultrafiltration membrane because MAR system can retains biomass concentration within the reactor and can produce high quality effluent. Besides, higher temperature between 25°C-45°C and optimum pH of the reactor content which was in the range of 6.5 to 7.5 increases the activity of methanogenic bacteria in biodegradating organic materials and convert it to methane gas. At the same time, HRT period of the MAS had allowed for the decomposition of the suspended solids and subsequent conversion to methane and this observation was also reported by Yildiz et al. (2004). For more concentrated wastewater, the efficiency of COD degradation is less as it contains more organic matters where a higher HRT is needed to remove more COD. Longer HRT will provide longer contact between wastewater and the biomass and hence more organic matter will be converted to biogas. Figure 4.5 shows the efficiency of COD removal with time.

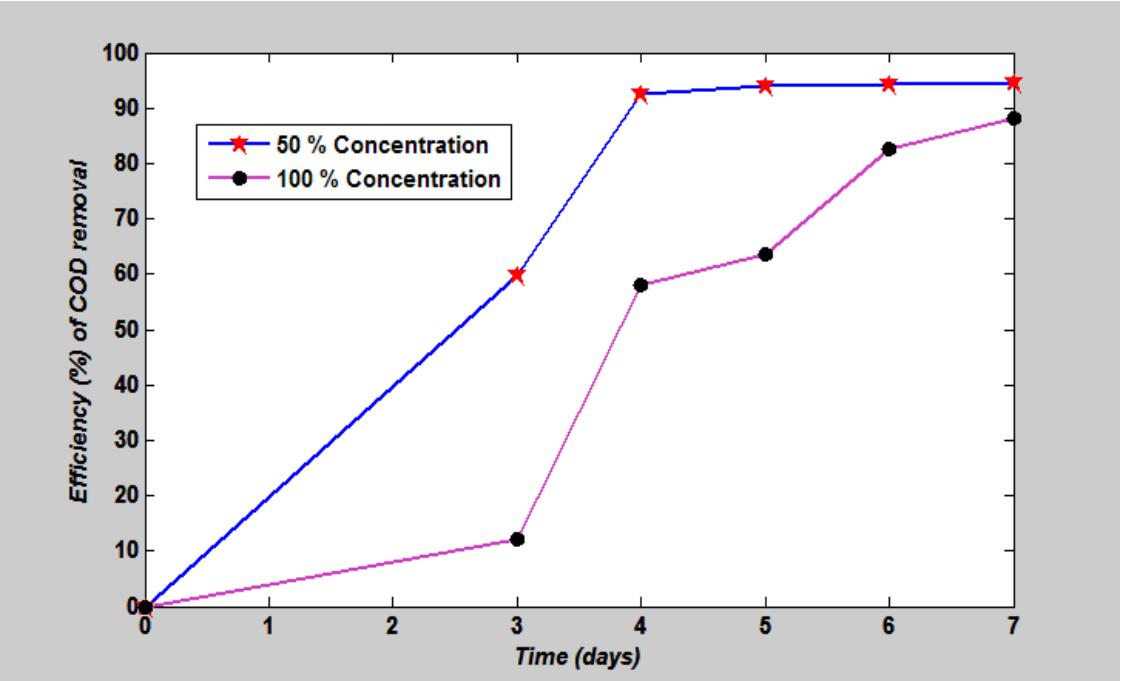

Figure 4.5: Efficiency (%) of COD removal with time (day).

4.2.4 Nitrification of Ammonia-N and Denitrification of Nitrate-N

Nitrification generally occurs when the time that the sludge stays in the system (called the mean cell residence time, or MCRT) is increased. A longer MCRT, therefore, allows an adequate population of nitrifying bacteria to be built up. In this research, the removal efficiency of Ammonia-N ranged from 31.69 % to 44.44 %. The efficiency was somewhat lower compared to Nitrate-N removal which was 99.44 % to 99.77 %. However, because the oxygen demand for complete nitrification is high, the efficiency of Ammonia-N removal found to be lower as the reaction took place in anaerobic condition. Moreover, optimum pH for the growth of nitrifying bacteria between 8 to 9, with pH levels below 7.5 causing a substantial reduction in nitrification activity. The overall nitrification can be expressed as shown as in Equation 4.1 (Michael, 2002):

$$2\,NH^{4+} + 3O_2 \longrightarrow 2NO^{2-} + 4H^{+} + 2H_2O \qquad \text{Eq. 4.1}$$

In instances when insufficient alkalinity exists, the pH in the system will drop, potentially inhibiting nitrification. Under favorable circumstances, nitrification is accomplished along with carbonaceous BOD removal.

While in the absence of adequate organic carbon or carbonaceous BOD (cBOD), biological denitrification can occur. In the denitrification process, nitrate is reduced to nitrogen gas. For reduction to occur the dissolved oxygen level must be at or near zero and a carbon supply must be available for bacteria. This process is favorable to anaerobic condition. Denitrifying bacteria degrade cBOD using nitrite ions and nitrate ions in the absence of free molecular oxygen. The bacteria degrade cBOD in order to obtain energy for cellular activity and carbon for cellular synthesis. The overall degradation of cBOD using nitrate ions can be expressed in two, simplistic biochemical reactions as shown in Equation 4.2 and Equation 4.3 (Michael, 2002):

$NO^{3-} + cBOD \longrightarrow NO^{2-} + CO_2 + H_2O$ Eq. 4.2

$NO^{2-} + cBOD \longrightarrow N_2 + CO_2 + H_2O$ Eq. 4.3

There are many factors that govern denitrification. To ensure acceptable activity of facultative anaerobe, the pH in the digester should be maintained at a pH value greater than 7.0. The optimal pH range for denitrification is 7.0-7.5. In this study, the pH was maintained at 6.5 to 7.5. Hence, this condition has increased the bacterial activity in degradation of nitrate. Besides, higher temperature also increases the rate of nitrate degradation by bacteria. Figure 4.6 and Figure 4.7 show the efficiency of Ammonia-N removal and Nitrate-N removal respectively.

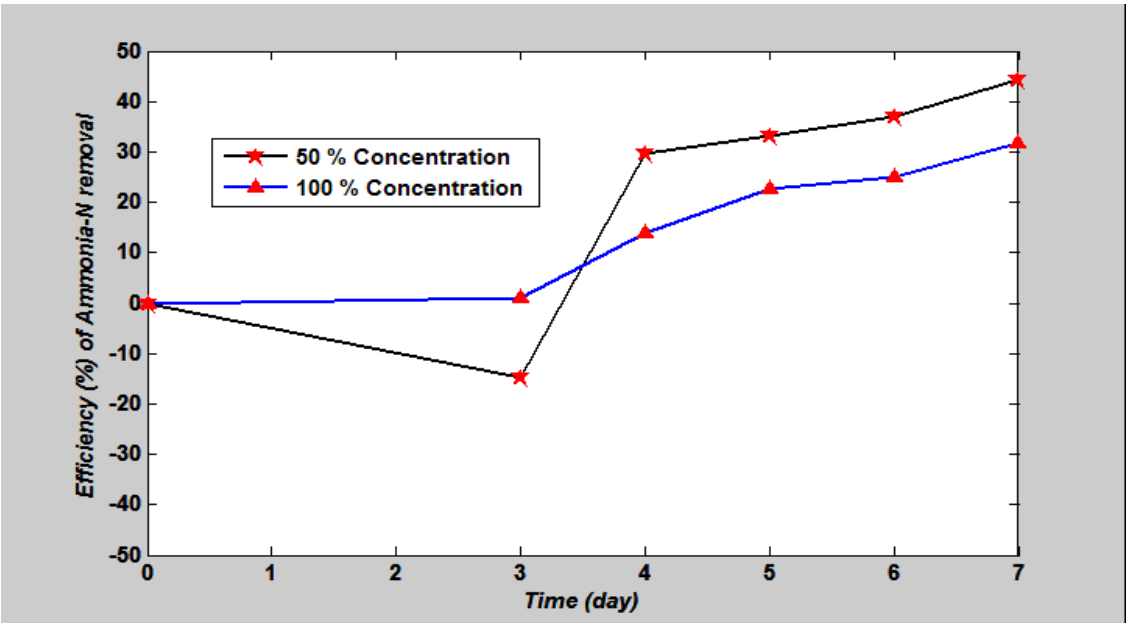

Figure 4.6: Efficiency (%) of Ammonia-N removal with time (day).

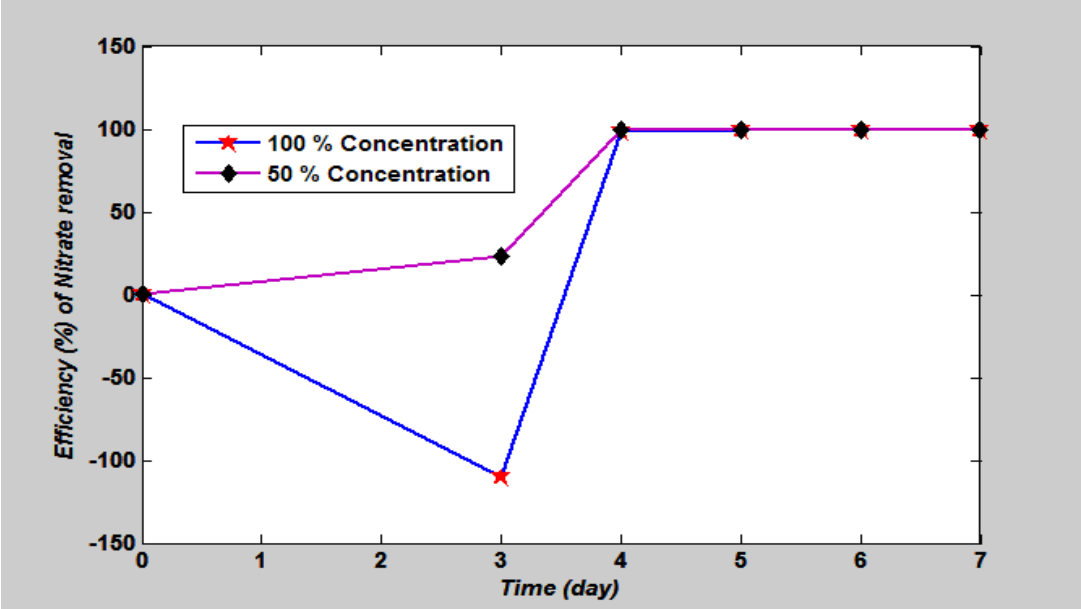

Figure 4.7: Efficiency (%) of Nitrate-N removal with time (day)

4.2.5 Methane Gas Production and Its Composition

The composition of the gas produced in the laboratory digester was determined by using a 20 L water displacement bottle. Methane gas composition was estimated using a J-tube analyzer (Abdurahman, 2000) as mentioned in Chapter 3. The constituents of gases determined in this analysis were methane gas and carbon dioxide. To verify the reliability of the experiment results obtained in this study, after 8 hours of run, the average daily methane production for the digester was determined from the measured volumes of gas produced and percentage of methane.

Many factors govern the performance of anaerobic digesters where adequate control is required to prevent reactor failure. The few major factors that greatly influence digester performances in sewage sludge treatment are pH, mixing, operating temperatures, nutrients for bacteria and organic loading rates into the digester. In this regards, the microbial community in anaerobic digester is sensitive to pH changes, in this study, the pH is maintained to the optimum (6.5-7.5) to avoid methanogens affect

which cause reduction of biogas production. The methanogenesis is strongly affected by pH. As such methanogenic activity will decrease when pH in the digester deviates from the optimum value. Mixing also provides good contact between microbes and substrates reduces resistance to mass transfer, minimizes build-up of inhibitory intermediates and stabilizes environmental conditions.

In this study, mechanical mixing and recirculation of biogas adopted to improve contact between active microbes and organic material. Results have shown that mixing improved the performance of anaerobic digester. Figure 4.8 shows the gas production rate and methane content of biogas produced by Membrane Anaerobic System (MAS). The biogas production of methane content registered a general incline with increasing HRT. However gas production will increase with HRT until a stage when metanogens can only convert acetic acid in diluted substrate to methane in a small amount as the sludge particulates amount decreasing. In this regards, the gas yields with increasing HRT. It increased from 0.234 L/g COD/d to 0.325 L/g COD/d. Thus, the production of biogas will increase when HRT increases. This is due to the longer time contact between substrate and activated sludge. The longer the time contact between substrate and activated sludge, the higher the degradation of biomass to biogas by methanogenic bacteria, and hence the higher the production of methane.

The operating temperature was 42°C and found that the substrate degradation rate and biogas production was higher than operating at 37°C. Higher temperature increases the rate of biological transformation and degradation of substrate as it take advantage of the fact that almost all microbial metabolism doubles in rate for each 10°C rise in temperature. The percentage of methane produced by membrane anaerobic system (MAS) is quite satisfactory considering that it comparable to the percentage of methane produced at mesophilic conditions, according to Borja & Banks (1993), of which Mahmoud. *et. al*., (2004) mentioned that thermophilic condition show better digestion at shorter HRT.

In order to produce higher methane composition and yield, the operation should be done at larger HRT than present hydraulic retention time that is equal to 4 days. The methane yield would be in the range of 0.585 L/g COD/d -0.813 L/g COD/d if the system was maintained until it reaches steady state (Abdurahman, H. N., 2000)

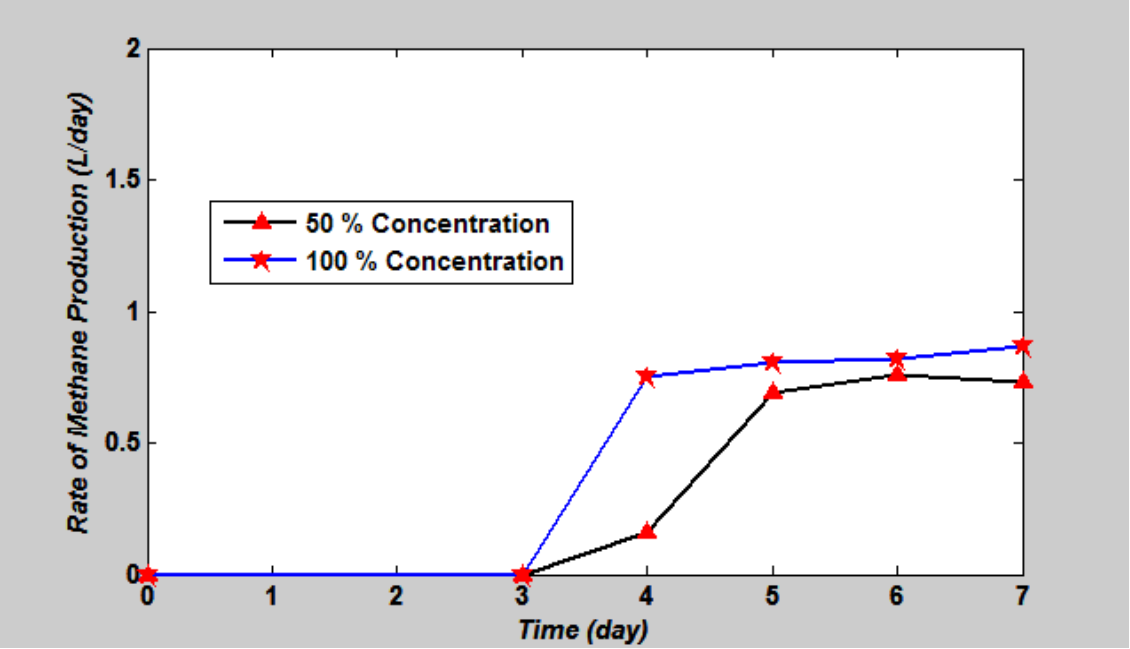

Figure 4.8: Rate of methane production (L/day) with time (day).

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the results of this study, it can be concluded that, the application of Membrane Anaerobic System (MAS) in the treatment of sewage sludge contributes to efficient sewage sludge treatment process as it is capable of retaining biomass concentration within the reactor and producing high quality of effluent. It effectively separates biomass solids from digester suspension.

About 99.99% of turbidity removal was achieved while the total suspended solids removal found 98.72% to 100%. Because the activated sludge effluent from MAS is treated by filtration through a nominal 0.1µm membrane, very low concentration of effluent suspended solids and turbidity are produced with clearer permeate. Besides, the solids and particulate organic matters were hydrolyzed and fermented into soluble form as no significant increment of sludge volume was observed.

Results showed throughout the study, the removal efficiency of COD was 88.27 % to 94.56 %. HRT period of MAS had allowed for the decomposition of suspended solid and subsequent conversion to methane. Higher temperature and optimum pH increases bacterial activity in biodegradation of organic materials.

The Nitrate-N removal was 99.44% to 99.77%. The efficiency is high as this process occurs rapidly under anaerobic condition. While, the removal efficiency of Ammonia-N found 31.69% to 44.44%. The efficiency is somewhat lower because oxygen demand for nitrification is high and since this research was conducted under anaerobic condition, the removal efficiency is lower. Besides, pH level between 6.5-7.5 doesn't allow the growth of bacteria and causing a substantial reduction in nitrification activity.

In this study, the gas produced from laboratory digester, is being analyzed for a gas composition. The total gas yield obtained was ranges from 0.234 L/g COD/d to 0.325 L/g COD/d. This is due to longer time contact between substrate and activated sludge because the longer the contact, the higher the degradation of organic particles to biogas by methanogenic bacteria. Besides, higher temperature also increases the rate of biotrasformation of substrate to methane gas.

The two methods of membrane cleaning (mild brushing, flush with water and soak in 0.5M NaOH for a day), are very important to increase the permeate flux, and flowrate. The membrane anaerobic system, MAS treatment efficiency was greatly affected by solid retention time, hydraulic retention time and organic loading rates. In this study, membrane fouling and polarization at the membrane surface played a significant role in the formation of the strongly attached cake layer limiting membrane permeability.

5.2 Recommendations

Based on the findings and concepts of waste treatment presented in his study, it should be possible to re-examinee, more productively, the environmental factors which influence the design and operation of anaerobic waste treatment systems. And the following observations are suggested as possible subjects for future work.

- Doing the experiment until it reaches steady state to estimate the exact HRT period.

- Fixing T-junction valve connected directly with NaOH solution, or fresh water for back flusshing purpose beside the pump.

- Using a variable speed pump, in order to clean the membrane automatically without taken membrane out from membrane housing.

- Using higher volume of raw sewage to produce more methane gas.

- Using methanogenic strain to culture bacteria so that more hydrolysis will occur at methanogenic condition.

- N-pump can be used for sludge pumping to avoid pump damage, and hence reducing the risk of clogging and maintain pumping efficiency, even under the worst of conditions.

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APPENDIX A

INITIAL SAMPLE RESULT

Table A.1: Fresh Sample Reading For 50% Concentration of Sample

Parameters	**Initial**
pH	6.882
Temperature, (°C)	27.4
Turbidity, (NTU)	5970.0
Chemical Oxygen Demand (COD), (mg/L)	54466.6667
Ammonia, (mg/L)	150.0
Nitrate, (mg/L)	186.6667
Total Suspended Solid, (mg/L)	7650.0

Table A.2: Fresh Sample Reading For 100% Concentration of Sample

Parameters	**Initial**
pH	6.605
Temperature, (°C)	29.6
Turbidity, (NTU)	2980.0
Chemical Oxygen Demand (COD), (mg/L)	35700.0
Ammonia, (mg/L)	40.67
Nitrate, (mg/L)	95.3333
Total Suspended Solid, (mg/L)	3900.0

APPENDIX B

RESULTS

Table B.1: Efficiency (%) of Turbidity Removal with Time (day)

Day	50% Concentration of Sample	100% Concentration of Sample
Initial	0.00	0.00
After Acclimatization	-24.75	-25.19
1	99.96	99.99
2	99.96	99.99
3	99.97	99.99
4	99.99	99.99

Table B.2: Efficiency (%) for Chemical Oxygen Demand Removal with Time (day)

Day	50% Concentration of Sample	100% Concentration of Sample
Initial	0.00	0.00
After Acclimatization	59.76	12.06
1	92.45	58.14
2	93.96	63.57
3	94.32	82.51
4	94.56	88.27

Table B.3: Efficiency (%) for Ammonia-N Removal with Time (day)

Day	50% Concentration of Sample	100% Concentration of Sample
Initial	0.00	0.00
After Acclimatization	-14.8	1.0
1	29.63	13.87
2	33.33	22.78
3	37.04	24.86
4	44.44	31.69

Table B.4: Efficiency (%) for Nitrate-N Removal with Time (day**)**

Day	50% Concentration of Sample	100% Concentration of Sample
Initial	0.00	0.00
After Acclimatization	-109.79	23.21
1	98.95	99.57
2	99.23	99.70
3	99.37	99.75
4	99.44	99.77

Table B.5: Efficiency (%) for Total Suspended Solid Removal with Time (day)

Day	50% Concentration of Sample	100% Concentration of Sample
Initial	0.00	0.00
After Acclimatization	-50.95	-51.52
1	88.46	83.66
2	93.59	99.35
3	94.87	100.00
4	98.72	100.00

Table B.6: Rate Methane Gas Production (L/day) with Time (day)

Day	50% Concentration of Sample (L/day)	100% Concentration of Sample (L/day)
Initial	0.000	0.000
After Acclimatization	0.000	0.000
1	0.631	0.754
2	0.691	0.807
3	0.761	0.822
4	0.730	0.868

APPENDIX C

PICTURES

The author is beside the membrane anaerobic system (MAS)
.

The crystal clear effluent that was collected.

Chemical Reagents used for Ammonia-Nitrogen Determination

Chemical Reagent used for Nitrate-Nitrogen Determination.

Sample was kept in tanks.

Sewage Treatment Plant of Indah Water in Taman Seri Mahkota, Kuantan.

With supervisor, Mdm. Noor Ida Amalina and team mates.