METHANE PRODUCTION FROM SEWAGE SLUDGE TREATMENT BY ULTRASONICATED MEMBRANE ANAEROBIC SYSTEM (UMAS)

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METHANE PRODUCTION FROM SEWAGE SLUDGE TREATMENT BY ULTRASONICATED MEMBRANE ANAEROBIC SYSTEM (UMAS)

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Thesis submitted in fulfilment of the requirements
for the award of the degree of
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SUPERVISOR'S DECLARATION

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DEDICATION

To my parents;

Beloved husband;

Brothers and sisters

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First and for most, I want to give all the praise and glory to my Almighty God. I am greatly grateful for all the difficulties and testing he put upon me for my own sake in the future.

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ABSTRACT

Sewage Sludge wastewater causes serious environmental pollution due to its high chemical oxygen demand (COD) and biological oxygen demand (BOD). Traditional methods of treating sewage sludge wastewater are disadvantages from both economic and environmental perspectives. In this study, the potentials of Ultrasonicated Membrane Anaerobic System (UMAS) in treating wastewater as an alternative and cost effective method was investigated. Waste sludge samples used in the study were collected from sewage treatment plant of INDAH WATER in Kuantan, Malaysia. The temperature during collection of the raw sewage sludge was 32 ^{o}C. The wastewater was stored in a cold room at 4 ^{o}C prior to use The study began with some characterization studies to provide understanding of fundamental issues such as conventional separation, ultrasonic and membrane separation. The aim was to obtain optimum operation conditions, maximum methane production as well as overall performance of UMAS in treating sewage sludge, upon which further development on wastewater processes could be developed. Four steady states were attained as a part of this study that considered concentration ranges from 6500 to 2.300 mg/l for mixed liquor suspended solid (MLSS). UMAS was used to treat the sewage sludge at organic loading rates ranging from 0.06 to 0.12 kg COD /M_3/day, and throughout the experiment, the removal efficiency of COD was from 79% to 93% and the methane gas percentage was between 93 and 85. The ammonia and nitrogen removal efficiency were 56 - 77 and 56 - 72 percentage respectively. The reactor pH is slightly changing during the experimental period with values around 6.8, 7.1, 7.2 and 7.00 in steady state 1, 2, 3 and 4, respectively. The slight changes in the alkalinity levels of pH indicate process stability. The gas volume was measured daily using a 20-litre displacement bottle. Biogas from sewage digester usually contain 55% to 65% of methane, 35% to 45% of carbon dioxide and < 1% nitrogen. Besides the main components, biogases also contain hydrogen sulphide and other sulphide compound, siloxanes, aromatic and halogenated compounds. The results obtained in this study have exposed the capability of ultrasonic assisted membrane anaerobic system (UMAS) in treating wastewater. Thus, using UMAS for the treatment is a challenging and interesting area; in this research work it is limited to study the steady states operation to provide continuous addition of feed solution (Raw sewage sludge) by gravity flow from feeder tank, which is on top of the reactor. In future, this study could be improved using specific type of ultrasonic against specific type of membrane anaerobic to increase the production methane, thus the performance of full process of UMAS will be increased and can produce more methane as well as it will reduce the time and cost. Further works are nevertheless required to provide deeper understanding of the mechanisms involved to facilitate the development of an optimum system applicable to the industry.

ABSTRAK

Air buangan Enapcemar Kumbahan menyebabkan pencemaran alam sekitar yang serius kerana keperluan oksigen kimia (COD) dan keperluan oksigen biologinya (BOD) yang tinggi. Kaedah tradisional merawat air buangan enapcemar kumbahan mendatangkan keburukan dari sudut ekonomi dan persekitaran. Dalam kajian ini, potensi Sistem Anaerobik Membran Berultrasonik (UMAS) dalam merawat air buangan sebagai suatu alternatif dan kaedah yang menjimatkan telah dikaji. Contoh-contoh enapcemar buangan yang digunakan dalam kajian ini diambil dari loji rawatan kumbahan INDAH WATER di Kuantan, Malaysia. Suhu semasa pengambilan enapcemar kumbahan mentah ialah 32 ^{o}C. Air buangan tersebut telah disimpan dalam bilik sejuk di bawah suhu 4 ^{o}C sebelum digunakan. Penyelidikan dimulakan dengan kajian pencirian untuk memberi pemahaman mengenai isu asas seperti pemisahan konvensional, ultrasonik dan pemisahan membran. Tujuannya adalah untuk mendapatkan syarat-syarat operasi yang optimum, penghasilan metana yang maksimum serta pencapaian keseluruhan UMAS dalam merawat enapcemar kumbahan di mana pembangunan lanjut ke atas proses-proses air buangan boleh dijalankan. Empat keadaan mantap telah diperolehi sebagai sebahagian daripada kajian ini yang mengambilkira julat kepekatan 6500 hingga 2.300 mg /l untuk pepejal campuran likuor terampai (MLSS). UMAS telah digunakan untuk merawat enapcemar kumbahan pada kadar muatan organik meliputi dari 0.06 hingga 0.12 kg COD/M_3/hari dalam seluruh eksperimen dengan kecekapan penyingkiran COD adalah dari 79% hingga 93% dan peratusan gas metana adalah antara 93 dan 85. Kecekapan penyingkiran nitrogen dan ammonia, masing-masing ialah 56 - 77 dan 56 - 72 peratus. Kadar pH reaktor sedikit berubah semasa tempoh eksperimen dengan nilai sekitar 6.8, 7.1, 7.2 dan 7.00, masing-masing dalam keadaan mantap 1, 2, 3 dan 4. Tahap-tahap kealkalian pH yang sedikit berubah menunjukkan kestabilan proses. Jumlah gas telah disukat setiap hari menggunakan botol sesaran berkapasiti 20 liter. Biogas dari penghadam kumbahan biasanya mengandungi 55% hingga 65% metana, 35% hingga 45% karbon dioksida dan < 1% nitrogen. Selain komponen utama, biogas juga mengandungi hidrogen sulfida dan sebatian sulfida lain, siloxanes, sebatian aromatik dan menghalogenkan. Keputusan yang diperolehi dari kajian ini mendedahkan keupayaan sistem anaerob membrane ultrasonik (UMAS) dalam merawat air buangan. Oleh sebab itu, penggunaan UMAS untuk rawatan ialah suatu bidang yang menarik dan mencabar; dalam kerja penyelidikan ini, ia dihadkan untuk mengkaji operasi dalam keadaan stabil bagi menyediakan tambahan penyelesaian suapan yang berterusan (Enapcemar kumbahan mentah) melalui aliran graviti dari tangki suapan yang terletak di atas reaktor. Pada masa akan datang, kajian ini boleh diperbaik menggunakan jenis ultrasonik tertentu terhadap membran anaerob tertentu untuk meningkatkan penghasilan metana supaya prestasi proses penuh UMAS akan ditingkatkan dan boleh menghasilkan lebih banyak metana serta mengurangkan masa dan kos. Walaubagaimanapun, kajian lanjut diperlukan bagi memberi pemahaman mendalam berkenaan mekanisme-mekanisme yang terlibat untuk memudahkan pembangunan satu sistem yang optimum kepada industri.

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LIST OF ABBREVIATIONS

AD	Anaerobic digestion/Digester
BLR	Biological loading rate
BOD	Biochemical oxygen demand
C: N:P	Carbon to Nitrogen to Phosphor ratio
CH_4	Methane
CO_2	Carbon dioxide
COD	Chemical oxygen demand (mg/L)
CSTR	Continuously stirred tank reactor
CUF	Cross flow ultra-filtration membrane
d	Day
EC	European community
g	Gram
GHG	Greenhouse gas
hr	Hour
HRT	Hydraulic retention time (day)
L	litre
m	Meter
m^3	Cubic meter (gas volumes assume 0°C and 1.101 bar
MAS	Membrane anaerobic system
MLSS	Mixed liquid suspended solid (mg/L)
MLVSS	Mixed liquid volatile suspended solid (mg/L)
MSW	Municipal solid waste

MWCO	Molecular weight cut-off
OLR	Organic loading rate (kg/m^3/d)
SRT	Solids retention time (day)
SS	Steady state
T	Time (d)
TS	Total solids
TSS	Total suspended solid (mg/L)
UASB	Up flow anaerobic sludge blanket
UMAS	Ultrasonicated membrane anaerobic system
VS	Volatile solids
VSS	Volatile suspended Solids (mg/l)
WAS	Waste activated sludge
y	year

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Sewage sludge is an important source of inland water pollution when it is released into local rivers or lakes without treatment. Sewage Sludge has negative effect to the environment; it contains organic wastes, sewages and fertilizers contain nutrients such as nitrates, sulphates and phosphates (Halim, 1988). Its chemical oxygen demand (COD) and biochemical oxygen demand (BOD) are high. The effluent is non-toxic because no chemicals are added during the sample extraction process (Singh et al., 1999). Most commonly, sewage sludge treatment use anaerobic digestion for the primary treatment.

Over the last century, anaerobic digestion (AD) has emerged as a reliable treatment solution for the stabilization and disintegration of sludge. The process was initially used for the treatment of domestic wastewater and sewage sludge in the municipal treatment plants. But over the past 20 years, the true potential of anaerobic digestion has been explored and major advances in reactor design, configuration and operation and in our understanding of the nature of the microbial biochemistry; physiology and ecology have been reported (Craik et al., 1995). The growing interest of the researchers in this process is a testimony to the viability and applicability of the process .High ultrasonicated membrane anaerobic system treatment (UMAS) would reduce treatment costs by increasing the digestion rate and eliminating the need for cooling facilities prior to biological treatment (Chiemchaisri et al., 1995).

The feed system was designed to provide continuous addition of feed solution (Raw sewage sludge) by gravity flow, from feeder tank which is on top of the reactor. The laboratory digester is completely mixed-semi continuous followed steady state operation, so that the experimental results could be used to investigate the performance of ultrasonicated membrane anaerobic system (UMAS) under steady state conditions .And the volume of biogas produced is measured by using a 20 litres water displacement bottle.

1.2 RESEARCH BACKGROUND

Anaerobic digestion is biological process that occurs in environment. It occurs naturally in swamp, water -logged soil and paddy fields, deep bodies of water, and the digestive systems of terminates and large animal. It utilizes microorganisms to break down biodegradable organic material 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 (Residua, 2003).

Anaerobic digestion is a renewable energy source because the process produces bio methane which consists of methane (50 - 80%). Methane is a gas that contains molecules of methane with one atom of carbon and four atom of hydrogen (CH_4). It is the major component of the "natural" gas used in many home for cooking 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 sulphide. (Noor et al., 2010).

The relative percentage of these gases depends on the feed material and management of the process. Anaerobic digestion is one of the fundamental processes in sewage sludge treatment for reducing and stabilizing the organic solids due to its high organic fraction. 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 solid from digester (Noor et al., 2010).

Anaerobic digesters produce 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: such as

Replacement of fossil fuels, reducing methane emission from landfills, displacing industrially-produced chemical fertilizers, reducing vehicle movements and reducing electrical grid transportation losses. 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 (Horan and Nigel, 2009). The major contaminants found in wastewater are biodegradable organic compounds, volatile organic compounds, recalcitrant xeno biotic, toxic metal, suspended solid, nutrients (nitrogen and phosphorus), microbial pathogens and parasites as displayed in Figure 1.1.

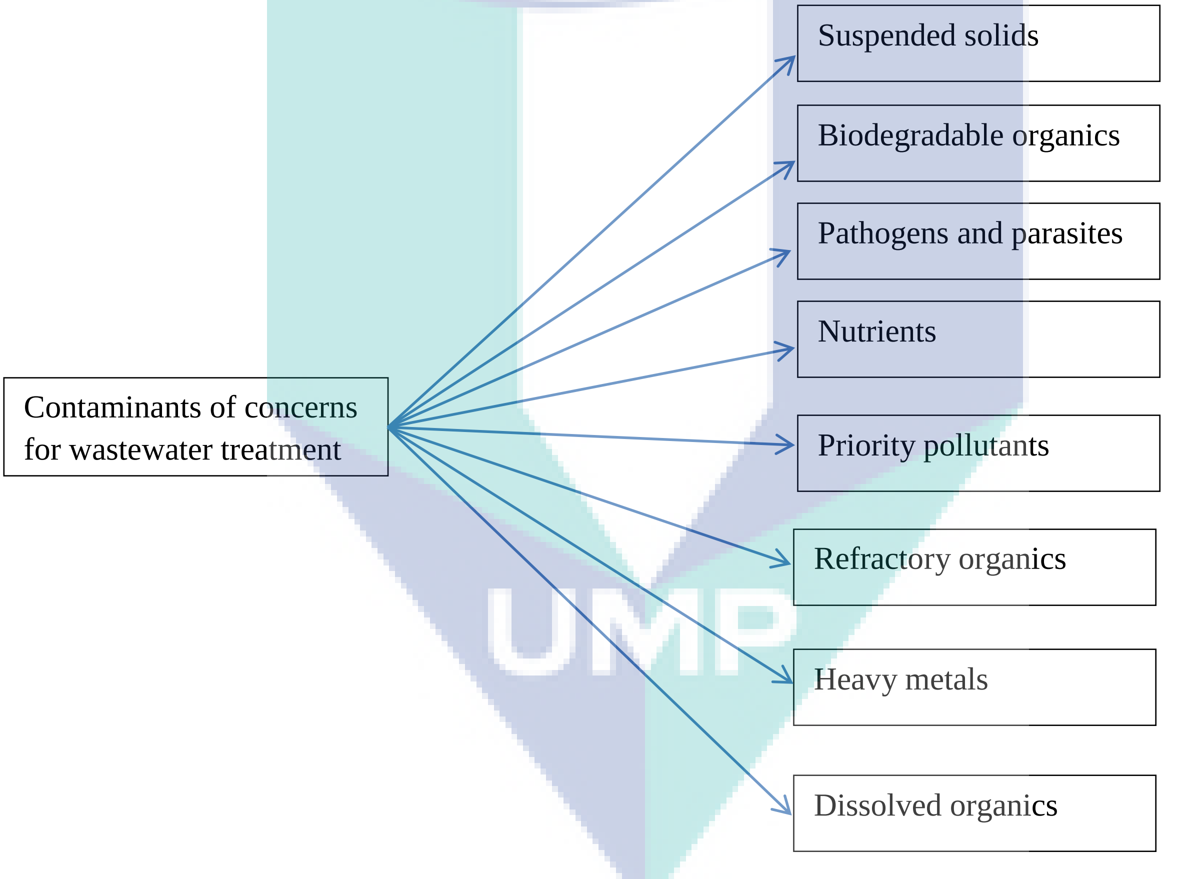

Figure 1.1: Major contaminants in waste water

Source: Gabriel and Bitton (2005).

Domestic wastewater is a combination of human and animal excreta (feces and urine) and grey water resulting from washing, bathing and cooking. People excrete 100 - 500 g wet weight of feces and between 1 and 1.3 litres of urine per capita per day. Each person contributes 15 - 20 g BOD_5/day (Feachem et al., 1987; Gabril and Braune, 2005 and Sterritt and Lester, 1988). Other characteristic of human feces and urine were displayed in Table 1.1. Whereas, the chemical characteristics of untreated wastewater are displayed in Table 1.2

Table 1.1: Composition of human feces and urine

Component	**Feces**	**Urine**
Quantity (wet) per person per day	100-400g	1.0-1.31kg
Quantity (dry solids) per person per day	30-60g	50-70g
Moisture content	70-85%	93-96%
Approximate composition (percent dry weight) organic matter	88-97	65-85
Nitrogen(N)%	5.0-7.0	15-19
phosphorus(as P_2O_5)%	3.0-5.4	2.5-5.0
Potassium(as K_2O)%	1.0-2.5	3.0-4.5
Carbon (C)%	44-55	11-17
Calcium (as CaO)%	4.5	4.5-6.0
C/N ratio	6-10	1
BDO_5 content per person per day	15-20	10g

Source: Polprasert (1989)

Table 1.2: Typical characteristic of domestic waste water

Parameter	**Concentration**		
	Strong (mg/L)	Medium (mg/L)	Weak (mg/L)
BDO_5 mg/L	400	220	110
COD mg/L	1000	500	250
Organic N mg/L	35	15	8
NH3-N mg/L	50	25	12
Total N mg/L	85	40	20
Total P mg/L	15	8	4
Total solids mg/L	1200	720	350
Suspended solids mg/L	350	220	100

Source: Gabril and Braune (2005); Metcalf and Eddy (1991)

1.3 PROBLEM STATEMENT

Environmental pollution became one of the tedious problem facing today's world and it continuously increasing with every passing year and causing grave and irreparable damage to the earth. Water pollution is one of the main reasons that lead to pollution of the environment (Natural Resources Management and Environment Department, 2009).Water pollution happens when toxic substances enter water bodies such as lakes, rivers, oceans and so on, getting dissolved in them, lying suspended in the water or depositing on the bed. This degrades the quality of water. Not only does this spell disaster for aquatic ecosystems, the pollutants also seep through and reach the groundwater, which might end up in our households as contaminated water we use in our daily activities, including drinking.

Water pollution can be caused in a number of ways, one of the most polluting being city sewage and industrial waste discharge. Indirect sources of water pollution include contaminants that enter the water supply from soils or groundwater systems and from the atmosphere via rain. In Malaysia rivers play a major role for communities especially in fisheries and as a source of water for people residing within the vicinity. Water quality is of utmost importance and it covers a wide range of approaches and conflicts. The continues increase in socio-economic activities in this area has been accompanied by an even faster growth in pollution stress on river quality.

One of the challenges in evaluating and improving water quality are the many different factors affecting water quality. Water quality is affected by air quality, pesticides and toxics (Cunningham et al., 2007). In today's urbanized society, as an example many commercial and industries releasing organic wastes, sewages and fertilizers contain nutrients such as nitrates, sulphates and phosphates to stream, rivers lakes and oceans. This can lead to severe water pollution when an overwhelming amount of waste accumulates in natural ecosystem. Consequently, when the wastes are not destroyed as fast as produce they make it unfavourable to humans and many other organisms. Sewage sludge produced in large quantities in Poland; about 359, 819 tons of dry matters in 2000, from those almost 156, 128 tons of dry matter was land filled is considered to be another example. Thus a twofold increase of sewage sludge mass in 2014 relation to 2000 is expected (Sonsnowskia and Klepacz, 2007) .Sewage sludge is one of the factors that contribute to the issue if discharge into environmental without pre-treatment. Besides the dramatic increases in sewage sludge production, the increases cost of land and public awareness of environmental and health issues encourage sewage sludge treatment. The treated sewage sludge is less contaminated with trace elements which include heavy metals and organic compound.

Sewage sludge contains pathogenic bacteria, viruses and protozoa along with the other parasitic helminthes which can give rise to potential hazards to the health of humans, animals and plants. 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 and industrial sources. The numbers of pathogenic and parasite organisms in sewage sludge can be significantly reduced by anaerobic digestion. According to WHO Report (1981) on the risk to health of microbes in sewage sludge applied to land identified salmonellae and Taenia as giving rise to greatest concern (Natural Resources Management and Environment Department, 2009). Sewage sludge is renamed compost due to its toxic nature of sewage sludge. Federal Clean Water Act (CWA) classifies sewage sludge as hazardous pollutant (Abby, 2002). The facilities to treat and dispose the sewage sludge are limited. However, the producing of sewage sludge is increasing in every year due to the population is increasing. The sewage sludge treatment is complicated, taking longer time and occupied big area of land. Sewage sludge is hazard to environmental and public health if the excess sewage sludge is untreated due to limited treatment plant. Therefore, alternative sewage sludge treatment is needed to manage the large capacity of sewage sludge production.

The anaerobic digestion of sewage sludge can be considered as an excellent alternative to dumping, composting, and incinerating of organic waste or to simple fermentation processes (Sosonwskia and klepacz, 2008) .Anaerobic sewage treatment is one of the major waste treatment processes in use today. It is not a new technology and indeed it is the innovative approach used by water companies to stabilize sludge as the first stage in the process of generating bio solid intended for recycling to agricultural land. More recently there has been considerable interest in applying this process to the treatment of strong and medium strength industrial wastes (Noor et al., 2008). The anaerobic process is time tested and does not require the purchase of special bacteria or nutrients because the bacteria are anaerobic 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 the 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 form "Form Waste to Energy".

In recent years, there has been an increasing interest worldwide in the production of alternative energy from the waste. To circumvent the problem, UMAS is used to treat the sewage sludge before discharge to the earth. Sewage sludge treatment ensures the hygienic safety and sensory acceptability of the sludge. It is also a contribution to save the environment by reducing the waste in the world. The more sewage sludge is used as fuel in generating renewable energy, the more reduction in greenhouse gas emissions. By this way, sewage sludge can be utilized as a valuable resource rather than to be considered merely as a waste to be got rid of. Thus using the UMAS to treat the waste and produce methane gas which is benefit to human by producing the methane gas. The methane gas produced at the end of the experiment is used to heat the digester and, in some cases, also to fuel gas engines to generate electricity. The sludge resulting from anaerobic digestion is much less offensive in order than the untreated raw sludge and is generally suitable for use in agriculture in liquid or solid form (Noor et al., 2010).

1.4 OBJECTIVES OF THE RESEARCH

There are four objectives of this research, which are:

1. To examine experimentally the treatability of sewage sludge by controlling operation process parameters in UMAS.
2. To investigate the performance of ultrasonic membrane anaerobic system (UMAS) under steady state conditions.
3. To determine the chemical oxygen demand (COD) removal efficiencies and biogas production
4. To evaluate the formation of methane gas production from sewage sludge by ultrasonic membrane anaerobic system (UMAS).

1.5 SCOPES OF RESEARCH

- Firstly, this research uses 50 litres volume of laboratory scaled ultrasonicated membrane anaerobic system (UMAS) combining ultra-filtration (UF) membrane and centrifugal pump with anaerobic reactor was designed and used to treat raw sewage sludge which was taken from sewage treatment plant.
- Secondly, enrichment cultures of methanogenic bacteria were developed in the digester which is semi-continuously mixed under steady state operation.

- Thirdly, the process comprises only three general degradation phases: hydrolysis, acidogenesis, and methanogenesis.
- Fourthly, study the parameters that affect the performance of UMAS such as pH, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and Total Suspended Solid (TSS). However this study is focused to determine the result of COD.
- Finally, measure the percentage of methane gas production by using J-Tube gas Analyzer.

1.6 LAYOUT OF THE THESIS

This thesis has been prepared to give details about the facts, calculations, parameters and procedures in order to meet its objectives. Chapter 1, generally describes the brief background of anaerobic digestion, methane production, and major contaminant in wastewater, the problem statement, objectives, and scope of the research. Chapter 2, reviews the anaerobic process wastewater treatment, application of anaerobic digestion , types of anaerobic process, scale of anaerobic process, reasons of anaerobic process, benefit of anaerobic digestion, comparison with aerobic digestion, chemical oxygen demand, VFAs, factors controlling anaerobic digestion, mechanism of biological, types of reactors used in anaerobic process, microbiology of anaerobic process, methane gas usage, membrane separation technology, ultrafiltration membrane, ultrasound and ultrasonic machining. Chapter 3, presents the treatment of sewage sludge by using ultrasonicated membrane anaerobic system, Materials, Methods, bioreactor operation, membrane cleaning, experimental procedures, analytical techniques and gas measurement. Chapter 4, elaborates the data and experimental results and analysis for the steady states, semi-continuous ultrasonic membrane anaerobic system (UMAS) performance, effect of organic loading rate and solid retention time and gas production and composition. The conclusions of the present research are summarized and presented in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Anaerobic fermentation is one of the oldest processes used in stabilization of solids and bio-solids. 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 (Metcalf and Eddy, 2004). Furthermore, anaerobic digestion of municipal sewage sludge can produce sufficient amount of digester gas to meet most of the energy needs for the plants. Anaerobic conversion of organic materials and pollutants is an established technology for environmental protection through the treatment of wastes and wastewater. The end product is biogas a mixture of methane and carbon dioxide, which is a useful, renewable energy source (Fruteau-de-Laclos et al., 1997).

Anaerobic digestion is a technologically simple process, with a low energy requirement, used to convert organic material from a wide range of wastewater types, solid wastes and biomass into methane. A much wider application of the technology is desirable in the current endeavours towards sustainable development and renewable energy production. In the 1980's several projects were initiated in the Netherlands to produce biogas from wastes. Many projects were terminated due to insufficient economic viability. Currently, the production of methane from wastes is receiving renewed attention as it can potentially reduce CO_2 emissions via the production of renewable energy and limit the emission of the greenhouse gas methane from especially animal manure. This trend is supported by the growing market demand for 'green' energy and by the substantial optimization of anaerobic digestion technologies in the past decades, especially the development of modern ‘high rate’ and co-digestion systems. (Ad-nett, 1997).

Biogas or landfill gas is primarily composed of methane (55 - 75 vol%), and carbon dioxide (25 - 45 vol%) with smaller amounts of H_2S (0 - 1.5 vol%) and NH_3 (0 - 0.05 vol%). The gas mixture is saturated with water vapour and may contain dust particles and trace amounts of H_2, N_2, CO and halogenated compounds depending on the feed-stock and process conditions (Wellinger and Lindberg, 1999). The fuel value of biogas containing 55 - 75 vol % methane ranges between 22 - 30 J/Nm (Higher Heating Value) and 19 - 26 MJ/Nm_3 (Lower Heating Value), respectively. Biogas can be utilised for the production of heat, co-generation of electricity and heat (CHP) or for upgrading to natural gas or fuel gas quality. A part of the biogas energy is utilised on site to provide for the internal energy requirement of the plant (digester heating, pumps, mixers etc.). Membrane processes cover a group of separation processes in which the characteristics of a membrane (porosity, selectivity, electric charge) are used to separate the components of a solution or a suspension. In these processes the feed stream is separated into two: the fraction that permeates through the membrane, called the permeate, and the fraction containing the components that have not been transported through the membrane, usually called the retentate The size of the components to be separated and the nature and magnitude of the driving force provide criteria for a classification of the membrane separation processes.

Membrane processes do not require heating, which makes the process suitable for the treatment of thermolabile products. In addition the relatively low capital and operating costs involved make membrane processes an appealing alternative to more conventional separation processes, particularly when dealing with dilute solutions, (Bowen, 1991). According to Biwater UK (2002) Microfiltration, 7,500m^3/day (2 MGD) the Biwater is supplied and installed the microfiltration water treatment plant near Lydden, Kent, after carrying out the complete Mechanical, Electrical and Civil design for the plant. The plant is a cryptosporidia barrier for raw water sources from three boreholes. The work was carried out for Folk stone and Dover Water Services Limited and was undertaken on a site that is environmentally sensitive as it is classified as an area of outstanding natural beauty, surrounded by areas of ancient woodland with an adjacent site of special scientific interest (SSSI).

2.2 ANAEROBIC WASTE WATER TREATMENT

Anaerobic treatment is a process in which microorganisms convert organic matter into biogas in the absence of oxygen. Anaerobic treatment is an energy-efficient process that is typically utilized to treat high-strength industrial wastewaters that are warm and contain high concentrations of biodegradable organic matter (measured as BOD, COD and/or TSS), (Lettinga and Antonie, 1987). An anaerobic system can be used for pre-treatment prior to discharging to a municipal wastewater treatment plant or before polishing in an aerobic process. Anaerobic processes offer substantially lower energy use, lower chemical usage, and reduced sludge handling costs compared to aerobic treatment options. In addition, the biogas produced in the anaerobic process is a form of renewable energy that can be used to displace fossil fuels such as oil or natural gas, or to generate electricity. Anaerobic digestion is the most common (mesophilic) treatment of domestic sewage in septic tanks, which normally retain the sewage from one day to two days, reducing the biochemical oxygen demand (BOD_5) by about 35 to 40 percent. This reduction can be increased with a combination of anaerobic and aerobic treatment by installing Aerobic Treatment Units (ATUs) in the septic tank.

According to Biomass using anaerobic digestion, the mesophilic anaerobic digestion (MAD) is also a common method for treating sludge produced at sewage treatment plants. The sludge is fed into large tanks and held for a minimum of 12 days to allow the digestion process to perform the four stages necessary to digest the sludge. These are hydrolysis, acidogenesis, acetogenesis and methanogenesis. In this process the complex proteins and sugars are broken down to form more simple compounds such as water, carbon dioxide and methane. One major feature of anaerobic digestion is the production of biogas (with the most useful component being methane), which can be used in generators for electricity production and/or in boilers for heating purposes. Many larger sites utilize the biogas for combined heat and power, using the cooling water from the generators to maintain the temperature of the digestion plant at the required 35 ± 3 °C.

Anaerobic treatment systems such as the conventional activated sludge (CAS) process are widely adopted for treating low strength wastewater (< 1000 mg COD/L) like municipal wastewater. CAS process is energy intensive due to the high aeration requirement and it also produces large quantity of sludge (about 0.4 g dry weight/g COD removed) that has to be treated and disposed off. As a result, the operation and maintenance cost of a CAS system is considerably high. Anaerobic process for domestic wastewater treatment is an alternative that is potentially more cost-effective, particularly in the subtropical and tropical regions where the climate is warm consistently throughout the year. Anaerobic wastewater purification processes have been increasingly used in the last few decades. These processes are important because they have positive effects: removal of higher organic loading, low sludge production and high pathogen removal, methane gas production and low energy consumption (Nykova et al., 2002).

Anaerobic digestion consists of several interdependent, complex sequential and parallel biological reactions, during which the products from one group of microorganisms serve as the substrates for the next, resulting in transformation of organic matter mainly into a mixture of methane and carbon dioxide. Anaerobic digestion takes place in four phases: hydrolysis/liquefaction, acidogenesis, acetogenesis and methanogenesis. To ensure a balanced digestion process it is important that the various biological conversion processes remain sufficiently coupled during the process so as to avoid the accumulation of any intermediates in the system. Microorganisms from two biological kingdoms, the bacteria and the archaea, carry out the biochemical process under strict anaerobic conditions (Parawira, 2004). Anaerobic reactors have been used mainly for industrial wastewater treatment. Researchers have shown than anaerobic systems such as the Up flow Anaerobic Sludge Blanket (UASB), the Anaerobic Sequencing Batch Reactor (ANSBR) and the anaerobic filter (AN) can successfully treat high-strength industrial wastewater as well as low-strength synthetic wastewater.

The predominant reason given for is, that municipal sewage are to weak (to low BOD or COD) to maintain high biomass (in the form of granules-suspended solids or fixed film) content in reactor. There are however, some successful examples in pilot and full scale (Orozo, 1997) investigated a full scale anaerobic baffled reactor (ANBR) to treat municipal sewage of an average BOD of 314 mgO_{2}/L for a hydraulic retention time of 10.3 hours, (organic loading rate 0.85 kg/m3·d) and achieved a 70% removal efficiency. It has to be stressed that the process was run at very low temperature between 13 and 15 ^{o}C. Treatment of domestic wastewater in a UASB and two anaerobic hybrid (ANH) reactors was conducted by Elmitwalli et al. (1999) at a temperature of 13 ^{o}C. For pre-settled wastewater treatment, the ANH reactors removed 64% of total COD, which was higher than the removal in the UASB reactors. The main objective is to decrease the cost of sewage treatment and minimize the amount of excess sludge produced. There is however, another important aspect, which can make application of anaerobic treatment as the first step of municipal or industrial treatment attractive. It was many times proven that many refractory difficult biodegradable organic compounds can be decomposed (at least to simpler substances) under anaerobic conditions.

2.3 APPLICATION OF ANAEROBIC PROCESS

2.3 .1 Sewage Sludge Treatment

The effects of pre-treatment of secondary sludge by microwave irradiation on anaerobic digestion investigated by Park et al. (2004), shows the microwave pre-treated sludge contained higher concentration of soluble chemical oxygen demand (COD). Anaerobic digestion of the pre-treated sludge achieved higher volatile solid (VS) reduction, biogas production and COD removal rate than that of untreated sludge. High-powered ultrasound was applied to waste activated sludge (WAS) to rupture the cellular material and reduce the particle size (Hogan et al., 2004). Increased biogas production from sonicated WAS and better solids reduction was achieved in anaerobic digestion. The digested sludge also had improved dewatering characteristics. The ultrasound treatment of primary and secondary sludge's, it was indicated that secondary sludge had a more remarkable improvement after sonication than the primary sludge (Mao et al., 2004). Optimal solids concentration range for optimum sonication was proposed to investigate the influence of pressure pulses produced by an ultrasonic homogenizer on the disintegration of the sludge. It was found that the degree of disintegration, as indicated by COD and protein release, increased significantly when the energy intensity applied with the ultrasonic homogenizer was increased (Rai et al., 2004).

MBR-US system which is developed by incorporating an ultrasonic cell disintegration process to a conventional membrane bioreactor. The results showed that sludge production was completely prevented using the hybrid system. However, the effluent quality of MBR-US slightly deteriorated due to the return of disintegrated sludge (Yoon et al., 1923). Sewage sludge homogenization into anaerobic digestion. More energy generation and sludge reduction was achieved during the following anaerobic digestion process (Onyeche, 2004). The study investigated the ozonation of industrial and sewage sludge. Sludge liquefying by release of 110 and 160 mg COD/g total suspended solid (TSS) had been reached at specific ozone consumption of 0.03 and 0.06 kg O_3/kg TSS (Sievers et al., 2004). The subsequent biological treatment reached a mass reduction of 19% for the anaerobic stabilization. The treatment of a mixture of primary and secondary municipal sewage sludge with an anaerobic digester coupled with ozonation process (Goel et al., 2004). Due to sludge ozonation and long solids residence time (SRT), high VSS degradation efficiency of approximately 80% was achieved at a reactor solid concentration of 6.5%. The high inorganic content in the digested sludge resulted in better sludge dewater ability. laboratory and pilot tests conducted to investigate the use of ionizing radiation in the sludge treatment where the radiation caused permanent effects in measured sludge parameters including solids content, COD, ammonia-nitrogen, specific surface area, resistance to filtration, pH, organic acid production, and digester gas evolution (Merroff et al., 2004).

Thermal-alkaline solubilisation of WAS as a pre-treatment stage for anaerobic digestion. At pH 11 and a temperature of 90 °C the concentration of the volatile suspended solid (VSS) was 6.82%, the VSS reduction reached 45% within ten hours. The total efficiency for methane production was 0.28 l CH_4/g of VSS loading (Vlyssides and Karlis, 2004). Two sludge pre-treatment techniques: ultrasonication and alkaline treatment. Both treatments released a marked amount of insoluble organic matter in soluble form. Alkaline treatment was proved to be more efficient than the ultrasonication (Chu and Lee, 2004). The influence of different pre-treatments on anaerobic digestion of WAS. Results showed that thermo-chemical pre-treatments were the most efficient on COD solubilisation. Pre-treatment of WAS under optimal conditions (170 °C and pH 10) led to 71% COD degradation, 59% total solids (TS) degradation and 54% increase in biogas production in the following anaerobic digestion (Valo et al., 2004)

The effect of sludge pre-treatment on anaerobic digestion. The disintegration techniques used included a stirred ball mill, an ultrasound disintegrator, a lysate centrifuge and ozone treatment. An enhancement of the degree of degradation of 7.4-20% was observed compared to a reference system without pre-treatment (Muller et al., 2004). The effect of sludge pre-treatment with pulsed electric fields on the anaerobic digestion. Pre-treatment increased the sludge disintegration by 20% and the degradation rate of organic matter increased about 9%) (Kopplow et al., 2004). The effect of sludge processing on the anaerobic digestion of WAS. The results suggested that sludge processing for phosphorus recovery (heat treatment followed by calcium phosphate precipitation) could improve digestive efficiency and methane productivity at both mesophilic and thermophilic temperatures (Takigudhi et al., 2004).

Improvement of anaerobic digestion of sludge. The Implementation of thermophilic anaerobic digestion (55 °C) and excess sludge disintegration by means of lysate-thickening centrifuge can improve the raw sludge biodegradation and biogas production to an extent that the wastewater treatment plant can be energetically self-sufficient (Dohanyos et al., 2004). Anaerobic digestion of sewage sludge by mesophilic and thermophilic temperature co-phase anaerobic digester, single-stage mesophilic digester, and single-stage thermophilic digester. The temperature co-phased reactor achieved higher VS reduction and process stability than the single-stage reactors. The better performance was attributed to the well-functioned thermophilic digester and selection of high substrate affinity anaerobic microorganisms in the co-phase system (Song et al., 2004).

The effect of solids retention time (SRT) and process temperature on the hydrolysis, acidification and methanogenesis of primary sludge. Hydrolysis was found to be the rate limiting-step of the overall digestion process, for the reactors operated at 35 °C and 25 °C, except for the reactor operated at 10 days and 25 °C. At the latter conditions, methanogenesis was the rate-limiting step of the overall digestion process (Mahmoud et al., 2004). Comparison of the liquid state bioconversion of sewage sludge in fermenter and in shake flask. The results revealed that the overall performance of fermenter was higher than the shake flask in terms of bio solids accumulation and biodegradation (Alam and Fakhrul Razi, 2004). Mineralization of long chain fatty acids (LCFA) associated with anaerobic sludge. It was concluded that LCFA did not exert a bactericidal or permanent toxic effect toward the anaerobic consortia (Pereira et al., 2004).

Solubilisation of sewage sludge by alternating aerobic and anaerobic operations. Nitrogenous compounds among intracellular matters released by the lysis were completely removed biologically under an optimal condition due to appropriate reaction balance among hydrolysis, nitrification and denitrification rates (Jung et al., 2004). The side-by-side evaluations of alternative sludge digestion systems. The VS reduction in laboratory thermophilic-mesophilic-phased digestion systems at total retention times of 10 and 12.5 days were found to be higher than in single-stage mesophilic digestion at 20 days, single stage thermophilic digestion at 15 days, or acid/methane-phased digestion system at 20 days (Reusser and Zelinka, 2004). Two-stage thermophilic anaerobic-aerobic digestion of WAS. The process showed a VSS removal of 61.8% and COD removal of 57.4% in 15 days hydraulic retention time (HRT). Comparison of the processes with recently published research indicated that this process was better than most published two-stage processes (Ros and Zupancic, 2004). Anaerobic sludge digestion in mesophilic anaerobic digestion elutriated phased treatment system (M-ADEPT) and thermophilic anaerobic digestion elutriated phased treatment system (T-ADEPT). Both M-ADEPT and T-ADEPT showed better effluent quality, reduced reactor volume requirements, and more stable methanogenesis than complete stirred tank reactors (CSTR), (kit et al , 2004).

2.3.2 Municipal Waste Water Treatment

Since 1983, Canadian municipalities have continued to upgrade their level of wastewater treatment. The percentage of Canadians on municipal sewers with secondary treatment or better has improved from 40% in 1983 to 69% in 2009, leaving approximately 18% with primary treatment or less and another 13% of Canadians using household septic systems to treat their sewage. Every day, millions of cubic meters of sanitary sewage are flushed from homes, businesses, institutions and industries through sink drains and toilets into city sewer systems. Municipal wastewater contains sanitary sewage and is sometimes combined with storm water from rain or melting snow draining off rooftops, lawns, parking lots and roads. The sewer system either takes the wastewater to a municipal wastewater treatment plant or releases it directly into a lake, river or ocean. Municipal wastewater is one of the largest sources of pollution, by volume, to surface water in Canada (European Environment Agency, 2001). Municipal wastewater normally receives treatment before being released into the environment. The higher the level of treatment provided by a wastewater treatment plant, the cleaner the effluent and the smaller the impact on the environment. Despite treatment, pollutants remain in treated wastewater discharged into surface waters. Treated wastewater may contain grit, debris, biological wastes, disease-causing bacteria, nutrients, and hundreds of chemicals such as those in drugs and in personal care products like shampoo and cosmetics.

2.3.3 Municipal Solid Waste Treatment

The effect of thermal wet oxidation on the anaerobic biodegradability and methane yields from different bio wastes. Measured methane yields for raw yard waste, wet oxidized yard waste, raw food waste, and wet oxidized food waste were 345, 685, 536, and 571 mL CH_4/g VSS, respectively. The increase of the specific methane yield for the full-scale biogas plant by applying thermal wet oxidation was 35 - 40% (Lissens et al., 2004). The influence of bovine rumen fluid inoculums tested during anaerobic treatment of the organic fraction of

MSW. The data obtained affirmed that the inoculums used substantially improved the performance of the process. Bio stabilization time was decreased from 459 to 234 days and biogas methane content was increased from 3.6% to 42.6% when inoculums/MSW ratio was increased from 0 to 1/9 (Lopes et al., 2004). Optimized reactor start-up protocol based on the dry anaerobic digestion of organic fraction of MSW and other organic compounds (garden waste, rice hulls, animal waste and sludge). A system operating the optimized protocol showed a rapid start-up. The gas production was 6.5 l/d (Forster et al., 2004). Barnes and Keller investigated the possibility of degrading cellulosic organic materials in MSW using rumen-based microbial inoculums and anaerobic sequencing batch reactor (ASBR). The rumen ASBR system was found to achieve high acid production rate, 210-230 mg COD/ l•h at a cellulose loading rate of 10 g/l•d, which was comparable to previously described rumen simulation systems (Barnes and Keller, 2004). Kim and others studied the co-digestion of sewage sludge and food waste using a temperature-phased anaerobic sequencing batch reactor (TPASBR). The TPASBR showed higher VS reduction, methane yield, and methane production rate than those of the mesophilic sequencing batch reactor (SBR). The enhanced performance of TPASBR was attributed to longer SRT, fast hydrolysis, higher methane conversion rate, and balanced nutrient condition of co-substrate, (Kim et al., 2004).

The batch digestion of organic fraction of MSW. The net bio energy yield from MSW and corresponding bioprocess conversion efficiency over the length of the digestion time were observed to be 12528 kJ/kg VS and 84.51%, respectively. The feasibility of nearly complete conversion of lignocellulosic waste (70% food crops, 20% faecal matter and 10% green algae) into biogas was investigated (Lissens et al., 2004). The treatment system included a mesophilic CSTR, an up flow bio film reactor, a fiber liquefaction reactor employing the rumen bacterium Fibro bactersuccinogenes and a hydrothermolysis system in near-Critical water. The total process yielded biogas corresponding with conversions up to 90% of the original organic matter (Roa and Singh, 2004). Anaerobic digestion of pineapple peel waste that was rich in cellulose, hemicellulose and other carbohydrates. Ensilaging of pineapple peel resulted in the conversion of 55% carbohydrates into VFAs. Biogas digester fed with ensilaged pineapple peel resulted in the biogas yield of 0.67 m3/kg VS added with methane content of 65%, (Rani and Nand, 2004).

Lee and others investigated the in vitro stimulation of rumen microbial fermentation of cellulose by a rumen anaerobic fungal culture (AFC). The addition of AFC, filtered AFC, and autoclaved AFC caused a marked increase in gas production of 50, 29, and 32% after 24 hrs, respectively. It was suggested that the positive responses be caused by the high fibro lytic enzyme addition from the fungal cultures and increased microbial population despite of the antagonistic relationship of fiber break down by rumen fungi to rumen bacteria and unknown inhibitor factors in the rumen fluids (Lee et al., 2004). The anaerobic digestion of cellulose using a carbon felt fixed-bed reactor. In the batch operation, the VS reduction and cumulative methane production during mesophilic and thermophilic digestion were 52.2% and 15.9%, 96.7 and 49.2 mL/g TS fed, respectively. In the semi-continuous mesophilic digestion, cellulose degradation reached its highest level of 67.6% at HRT of 9 days (Yang et al., 2004). Anaerobic degradation of cellulose by rumen microorganisms at various pH values. The degradation efficiency increased with pH and the highest value of about 78% was achieved at pH 6.8 and 7.3 (Hu et al., 2004).

Biochemical methane potential of fruits and vegetable solid wastes. The ultimate methane yields of fruit wastes and vegetable wastes ranged from 0.18 to 0.73 l/g VS and 0.19-0.4 l/g VS. These results provided a database on extent and rates of conversion of fruits and vegetable solid wastes that significantly contribute to organic fraction of MSW (Isidori et al., 2004). Anaerobic batch co-digestion of sisal pulp and fish wastes. While the highest methane yields from sisal pulp and fish waste alone were 0.32 and 0.39 m3 CH4/kg VS, respectively, co-digestion with 33% of fish waste and 67% of sisal pulp gave a methane yield of 0.62 m3 CH4/kg VS, (Mshandete et al., 2004). Two-stage process (BIOCELL) converting food waste to hydrogen and methane. The BIOCELL process demonstrated that, at the high VS loading rate of 11. 9 kg/m^3•day, it could remove 72.5% of VS and convert VS removed to H_2 (28.2%) and CH4 (69.9%) on a COD basis in 8 days, Han and Shin, (2004). The VFA production from solid pineapple waste. It was found that acid production was enhanced when the digester was operated at neutral pH (Babel et al., 2004).

Two coupled ASBR operated at mesophilic temperature to digest fruit and vegetable wastes. Phase separation with conventional ASBR reactors resulted in high process stability, significant biogas productivity and better effluent quality. The overall COD removal in the treatment system was 96%. Bacterial 16S rDNA showed at least 7 different major species with a very prominent one corresponding to a Mega sphaeraelsdenii in acidogenic reactor whereas bacterial 16S rDNA of a methanization bioreactor showed 10 different major species (Bouallagui et al., 2004). The effect of temperature on the performance of an anaerobic tubular reactor treating fruit and vegetable waste. Biogas production from thermophilic digester was 144% and 41% higher than from psychrophilic and mesophilic digesters, respectively. VFAs could be obtained at 50 g/kg waste within 14 days when operating at pH 6.5-7.5 (Bouallagui et al., 2004).Demir tested the effect of leachate recirculation on the methane generation rates in landfill site. Due to the appropriate conditions such as moisture content, solid waste decomposition rate in test cell with leachate recirculation was enhanced at a rate of 79% relative to that of test cell without leachate recirculation (Demir et al., 2004)

Co-disposal of solid waste with three types of sludge's, including primary settling sludge, secondary settling sludge and a mixture of primary sludge and WAS. The stabilization of solid waste in the reactor receiving the mixture of primary settling sludge and was faster, as indicated by the total gas production and COD removal data (Cinar et al., 2004). Anaerobic co-digestion of urban organic waste with sludge. Higher biogas yield was found during co-digestion than should be expected from digestion of the two materials separately (D'Annibale et al., 2004). The effects of mixture ratio and HRT on single-stage anaerobic co-digestion of food waste and WAS. The optimum operating conditions of the single-stage anaerobic digester were found to be an HRT of 13 days and a mixture of 50:50. The VS removal efficiency and biogas production rate in this condition were 56.8% and 1.24 m3/m3•d, respectively with an organic loading rate (OLR) of 2.43 kg VS/ m3•d, (Heo et al., 2004).

2.3.4 Industrial Waste Treatment

The different types of contamination of wastewater require a variety of strategies to remove the contamination 1 - 2. Most solids can be removed using simple sedimentation techniques with the solids recovered as slurry or sludge. Very fine solids and solids with densities close to the density of water pose special problems. In such case filtration or ultrafiltration may be required. Although, flocculation may be used, using alum salts or the addition of polyelectrolyte. Many oils can be recovered from open water surfaces by skimming devices. Considered a dependable and cheap way to remove oil, grease and other hydrocarbons from water, oil skimmers can sometimes achieve the desired level of water purity. At other times, skimming is also a cost-efficient method to remove most of the oil before using membrane filters and chemical processes. Skimmers will prevent filters from blinding prematurely and keep chemical costs down because there is less oil to process. Because grease skimming involves higher viscosity hydrocarbons, skimmers must be equipped with heaters powerful enough to keep grease fluid for discharge. If floating grease forms into solid clumps or mats, a spray bar, aerator or mechanical apparatus can be used to facilitate removal (Water and Wastewater News, 2004). However, hydraulic oils and the majority of oils that have degraded to any extent will also have a soluble or emulsified component that will require further treatment to eliminate. Dissolving or emulsifying oil using surfactants or solvents usually exacerbates the problem rather than solving it, producing wastewater that is more difficult to treat.

The wastewaters from large-scale industries such as oil refineries, petrochemical plants, chemical plants, and natural gas processing plants commonly contain gross amounts of oil and suspended solids. Those industries use a device known as an API oil-water separator which is designed to separate the oil and suspended solids from their wastewater effluents. The name is derived from the fact that such separators are designed according to standards published by the American Petroleum Institute (API) (Beychok and Milton R, 1967); (API, 1990). The API separator is a gravity separation device designed by using Stokes Law to define the rise velocity of oil droplets based on their density and size. The design is based on the specific gravity difference between the oil and the wastewater because that difference is much smaller than the specific gravity difference between the suspended solids and water. The suspended solids settles to the bottom of the separator as a sediment layer, the oil rises to top of the separator and the cleansed wastewater is the middle layer between the oil layer and the solids (Beychok and Milton R, 1967).

Typically, the oil layer is skimmed off and subsequently re-processed or disposed of, and the bottom sediment layer is removed by a chain and flight scraper (or similar device) and a sludge pump. The water layer is sent to further treatment consisting usually of an electro flotation module for additional removal of any residual oil and then to some type of biological treatment unit for removal of undesirable dissolved chemical compounds.

2.3.5 Agricultural Waste Treatment

Agricultural wastewater treatment relates to the treatment of wastewaters produced in the course of agricultural activities. Agriculture is a highly intensified industry in many parts of the world, producing a range of wastewaters requiring a variety of treatment technologies and management practices. Non-point source pollution from farms is caused by surface runoff from fields during rain storms. Agricultural runoff is a major source of pollution, in some cases the only source, in many watersheds (EPA, 2005). Soil washed off fields is the largest source of agricultural pollution in the United States. Excess sediment causes high levels of turbidity in water bodies, which can inhibit growth of aquatic plants, clog fish gills and smother animal larvae (EPA, 2005). Farmers may use Integrated Pest Management (IPM) techniques (which can include biological pest control) to maintain control over pests, reduce reliance on chemical pesticides, and protect water quality (EPA, 2008). There are few safe ways of disposing of pesticide surpluses other than through containment in well managed landfills or by incineration. In some parts of the world, spraying on land is a permitted method of disposal. Piggery waste is comparable to other animal wastes and is processed as for general animal waste, except that many piggery wastes contain elevated levels of copper that can be toxic in the natural environment. The liquid fraction of the waste is frequently separated off and re-used in the piggery to avoid the prohibitively expensive costs of disposing of copper-rich liquid. Ascarid worms and their eggs are also common in piggery waste and can infect humans if wastewater treatment is ineffective.

Fresh or wilted grass or other green crops can be made into a semi-fermented product called silage which can be stored and used as winter forage for cattle and sheep. The production of silage often involves the use of an acid conditioner such as sulphuric acid or formic acid. The process of silage making frequently produces a yellow-brown strongly smelling liquid which is very rich in simple sugars, alcohol, short-chain organic acids and silage conditioner. This liquor is one of the most polluting organic substances known. The volume of silage liquor produced is generally in proportion to the moisture content of the ensiled material. Silage liquor is best treated through prevention by wilting crops well before silage making. Any silage liquor that is produced can be used as part of the food for pigs. The most effective treatment is by containment in a slurry lagoon and by subsequent spreading on land following substantial dilution with slurry. Containment of silage liquor on its own can cause structural problems in concrete pits because of the acidic nature of silage liquor (EPA, 2008).

2.4 TYPES OF ANAEROBIC PROCESS

2.4.1 Mesophilic Digestion

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 hyper thermophilic.

2.4.2 Thermophilic Digestion

Thermophile is an organism 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. 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). Hyper thermophiles are particularly extreme thermopiles for which the optimal temperatures are above 80 °C.

2.5 SCALE OF ANAEROBIC PROCESS

Anaerobic digestion can be carried out on a variety of scales (Kusch, 2007; Noor, 2010)

- On-site using residues produced only on 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.

2.6 REASONS OF ANAEROBIC PEOCESS

Anaerobic digestion is the only system for dealing with organic waste which is sustainable, recovers the maximum energy, is a completely closed system with no emissions to air or land, which retains the fertilizer and water content, and facilitates the recovery of heavy metals. Anaerobic digestion may be initiated from several perspectives:

- Commercial interests such as electricity companies, fertilizer and compost manufactures.

- Residue (waste) producers (farmers, land owners and food processers).
- Local community initiatives such as partnerships between local authorities and farmers had. Some mechanical knowledge and ability and had access to technical support. Increased the profitability of biogas systems through the utilization and sale of manure by products. (www.ad-nett.org)

2.7 BENEFITS OF ANAEROBIC TREATMENT

2.7.1 Environmental Benefits

Anaerobic digestion (AD) collects methane and provides a source of renewable energy that is carbon neutral i.e. provides energy that increases in atmospheric CO_2. Moreover AD can lower the odour from farm slurries by up to 80% and also compared to undigested slurry, the nitrogen in digestate is more readily available as a plant nutrient, since it kills many weed seeds and hence there is less need for herbicides can lower the biological oxygen demand, (BOD - a measure of the polluting strength of a material) in the feedstock to less than 40% of that in the digestate. However, BOD of digestate is still extremely high relative to the discharge standards for wastewaters and pathogens in the feedstock, such as salmonella, are lowered by AD (Rutledge, 2005)

2.7.2 Economical Benefits

Biogas gives direct financial returns when used to generate electricity. Including the value for renewable obligation certificates (ROCs) further increases these returns. Use of a combined heat and power (CHP) unit to produce electricity and hot water is of further benefit, provided the heat produced can be utilized fully to heat the digester and for export. Biogas can also be used in modified gas boilers to produce hot water for use on site, or for export. In addition, biogas can be scrubbed of impurities and fed into a natural gas grid, or used as a fuel for cars, buses and trains (US EPA, 2011).

2.8 COMPARISON BETWEEN ANAEROBIC AND AEROBIC DIGESTION

Anaerobic biological treatment systems can offer a number of advantages and disadvantages over aerobic digestion and the other methods of sludge stabilization. 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 (Ros and Zupancic ,2004)

2.9 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 and Braune, 2005). Chemical oxygen demand is measured via oxidation with potassium dichromate ($K_2Cr_2O_7$) in the presence of sulphuric 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 and Braune, 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.

2.10 VFAs

Low-molecular mass carboxylic acids, (C2-C7mono-carboxylic aliphatic acids) are important intermediates and metabolites in biological processes. These carboxylic acids are known as volatile fatty acids (VFAs) or short-chain fatty acids (SCFAs). The presence of VFAs in a sample matrix is often indicative of bacterial activity .VFA analysis is significant in studies of health and disease in the intestinal tract (Tangerman and Nagengast, 1996)]. Volatile fatty acids originate from anaerobic biodegradation of organic matter. Therefore, they are widely present in activated sludge (Lie and Welander,1997), waste and landfill leachates (Manni and Caron,1995), and wastewater. Recently, the determination of VFAs has become of increasing interest since it has been found that they are involved in different processes, for example in biological removal of phosphorus from water (Randalla et al.,1997) or nitrification- denitrification in activated sludge (Eilersen et al.,1995).

Carboxylic acids may also affect the storage stability of waste incineration residues by reducing Ph value and increasing the mobility of heavy metals and radionuclides. In addition, VFAs constitute one of the chemical classes responsible for unpleasant odour generated in wastewater, together with amines and sulfur compounds. Additionally, large quantities of potassium and sodium salts of VFAs are used as airplane, runway and apron deicers. After being used, these compounds can contribute to the increase of chemical oxygen demand, (COD) thus decreasing overall water quality. In winter, the biodegradation of used deicing solutions can be limited by microbial inhibition due to low temperatures. In these seasons, VFAs are usually accumulated in various environmental compartments and their concentrations increase in waters (Siedlecka and Downar, 2004).Volatile fatty acids exist in environmental matrices in different concentrations.

2.11 FACTORS CONTROLLING ANAEROBIC DIGESTION

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

2.11.1 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. Methan other musfervidus has been found in a hot spring in Iceland and grows at 63 - 97 °C (Sha et al., 2011**).**

2.11.2 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 (Turorskiy and Mathai, 2006). HRT, in days, is equal to the volume of sludge in the digester (m3) divided by the volume of digested sludge withdrawn daily (m3/d).

$$HRT = {}^{V}\!/_{Q} \tag{2.1}$$

Where V = Digester Volume and Q = Volume wasted each day.

The HRT is closely related to the OLR and substrate concentration, thus a good balance has to be achieving for good digester operation (N.H Abdurahman, 2010). Solids Retention Time (SRT) is the average time the activated-sludge solids are in the system. The SRT is an important design and operating parameter for the activated-sludge process and is usually expressed in days (Lenntech, 2010). Although the calculation of the solids retention time is often improperly stated, it is the quantity of solids maintained in the digester divided by the quantity of solids wasted each day as shown in equation below:

$$SRT = V\,(Cd)Qw\,(Cw) \qquad (2.2)$$

Where V = Digester Volume, Cd = Solid Concentration in the digester, Cw = Solid concentration in the waste and Qw = sludge volume wasted each day.

In a conventional completely mixed, or plug flow digester, the HRT equals the SRT. However, in a variety of retained biomass reactors the SRT exceeds the HRT. (D.A Burke, 2001) As a result, the retained biomass digesters can be much smaller while achieving the same solids conversion to gas. At a low SRT sufficient time is not available for the bacteria to grow and replace the bacteria lost in the effluent. If the rate of bacterial loss exceeds the rate of bacteria growth, "wash-out" occurs. The SRT at which “wash-out” begins to occur is the "critical SRT" (M.Clara et al., 2004).

2.11.3 pH

pH is one of the important factor that can affect the performance of the anaerobic process since methane bacteria is sensitive to pH. The acidogenesis organism is less sensitive and can live in wide range of pH between 4.0 and 8.5 (Hwang et al., 2004**)**. At low pH the main product are acetic and butyric acid while at pH of 8.0, acetic and propionic acid are 15. Produced (Boe, 2006). The volatile fatty acid produce during the process tend to reduce pH of the system.

2.11.4 Total Suspended Solids (TSS)

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 (Howard, 1985). 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.

2.12 MECHANISM OF BIOLOGICAL

It has been established that three physiological groups of bacteria are involved in the anaerobic conversion of organic materials to methane during these phases. In the first phase of anaerobic digestion hydrolysis. The first group of bacteria hydrolytic bacteria converts the complex organics such as carbohydrates, lipids and proteins to their soluble forms and hydrolysed further to simple monomers. In the second phase, acid genesis, the second group of acid-forming bacteria convert the products formed in the first phased to short-chain organic acid; primarily acetic ,propionic, lactic acid, hydrogen and carbon dioxide. In the third phase, methanogenesis, the third group consists of methane forming bacteria; convert the volatile acids to methane and carbon dioxide. The anaerobic digester is semi-continuously mixed under steady state operation. The experiment results are used to evaluate the developed steady state kinetic models. The overall reaction is shown in Equation 2.3 (Gabriel and Braune, 2005).

$$\text{Organic matter} \rightarrow CH_4 + CO_2 + H_2 + NH_3 + H_2S \quad (2.3)$$

These microbial groups operate in a synergistic relationship, as shown in Figure 2.1.

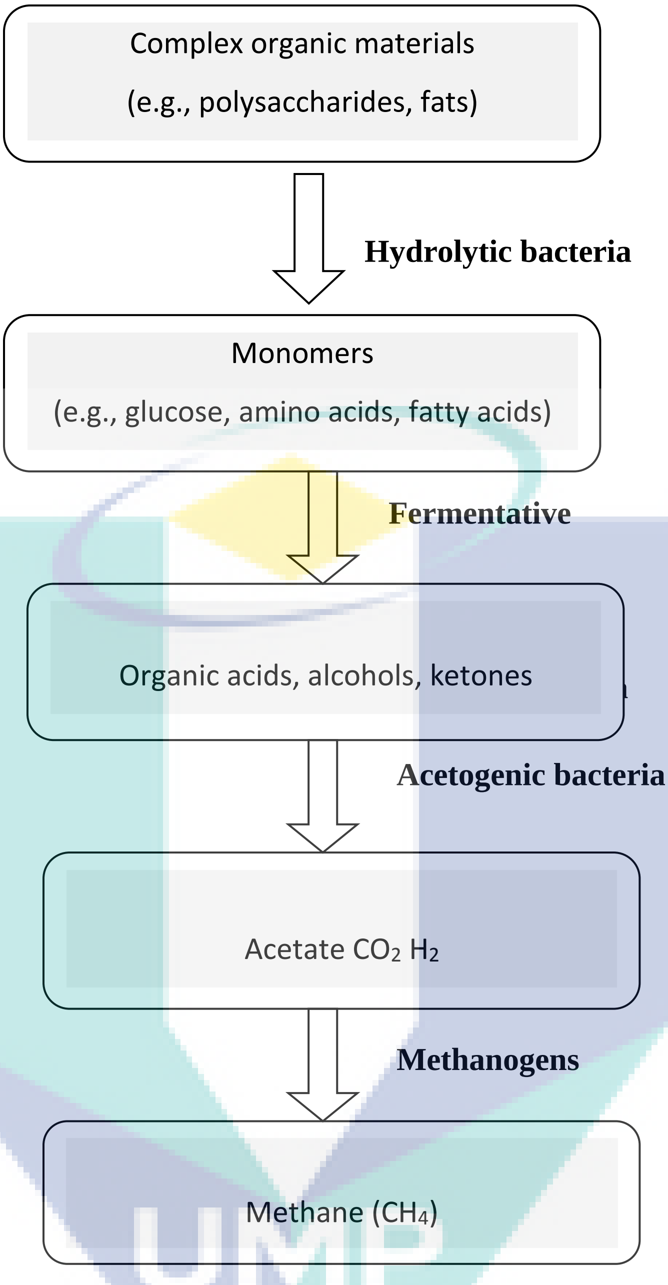

Figure 2.1: Metabolic bacterial groups involved in anaerobic digestion of wastes.

Source: Gabriel and Braune (2005)

2.12.1 Hydrolytic Bacteria

Consortia of anaerobic bacteria break down complex organic molecules (proteins, cellulose, lignin and lipids) into soluble monomer molecules such as amino acids, glucose, fatty acids, and glycerol.

2.12.2 Fermentative Acidogenic Bacteria

Acidogenic that is acid forming bacteria such as Clostridium converts sugars, amino acids and fatty acids to organic acids (acetic, propionic, formic, lactic, butyric or succininc acids), alcohols and ketones (ethanol, methanol, glycerol, and acetone), acetate, CO_2 and H_2.

2.12.3 Acetogenic Bacteria

Ethanol, propionic acid and butyric acid are converted to acetic acid by acetogenic bacteria according to equation. 2.4, equation.2.5, and equation. 2.6 (Gabriel and Braune, 2005)

$$CH_3CH_2OH + H_2O \rightarrow CH_3COOH + 2\,H_2 \quad (2.4)$$

ethanol + water → acetic acid + Hydrogen

$$CH_3CH_2COOH + 2\,H_2O \rightarrow CH_3COOH + CO_2 + 3\,H_2 \quad (2.5)$$

propionic acid + water → acetic acid+ carbon dioxide

$$CH_3CH_2CH_2COOH + 2\,H_2O \rightarrow 2\,CH_3COOH + 2\,H_2 \quad (2.6)$$

putyric acid + water → acetic acid+ hydrogen

2.12.4 Methanogens

A methanogen is a single cell 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. Methanogens have slow –growth rates and also they very sensitive to pH changes .Inhibition of methanogens will occur if the pH falls out of the range of the 6.5 - 7.8 (six and sahm, 1987) certain methanogen are also capable of converting other substrate to methane.

2.13 TYPE OF REACTORS USED IN ANAEROBIC PROCESS

2.13.1 Analytical Contact Process

The anaerobic contact process is a type of anaerobic digester. Here a set of reactors are created in series, often with recycling. This recycled material is pumped up into the bottom of the first reactor, an up flow reactor. The up flow anaerobic process is a large reactor which allows the waste to flow up from the bottom and separates the waste into three zones. At the very top is the biogas zone where the gas is collected. Bacteria digest waste in the lowest portion of the up flow reactor; the bioreactor zone. In between these two stages is the clarifier zone where which exports the stabilized waste (Owen and William, 1982). Anaerobic filters are widely used as secondary treatment step in household grey water or black water

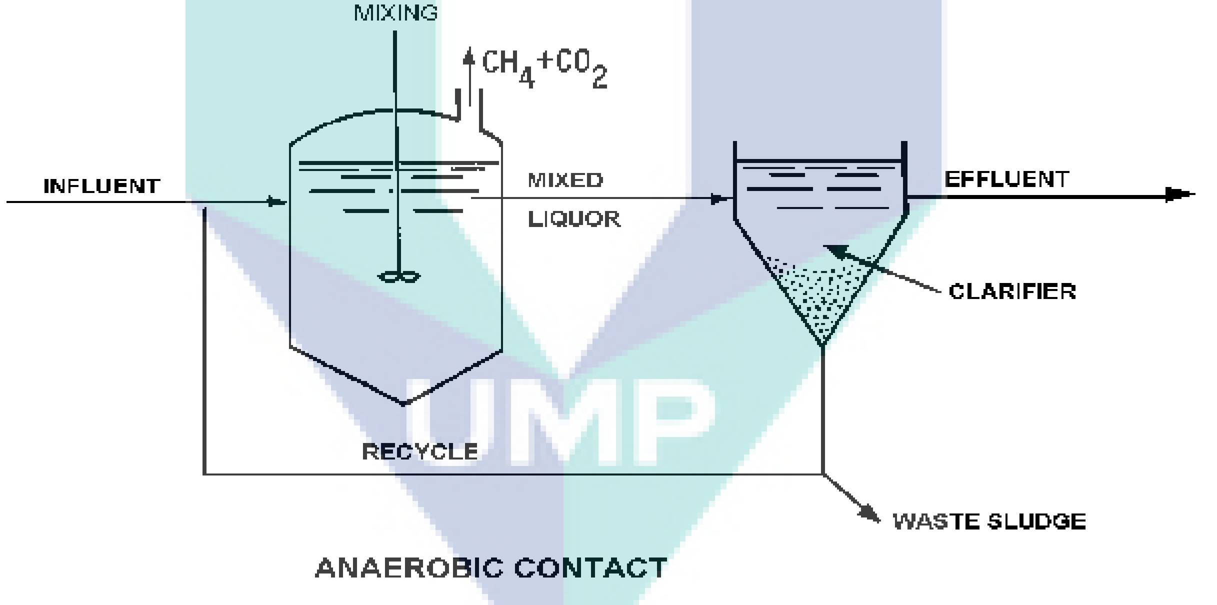

Figure 2.2: Anaerobic contact process

2.13.2 Anaerobic Filter Process

An anaerobic filter is an attached bio film system (fixed bed or fixed film reactor treatment systems. Or, together with other treatment units in a so-called decentralized wastewater treatment system (DEWATS) (e.g. for biodegradable industrial wastewater.) that aims at removing non-settleable and dissolved solids (Morel and Diener, 2006). As septic tanks or anaerobic baffled reactors, anaerobic filters are based on the combination of a physical treatment (settling) and a biological treatment (anaerobic digestion, see also anaerobic digestion general factsheet). It comprises a watertight tank containing several layers of submerged media, which provide surface area for bacteria to settle. As the wastewater flows through the filter usually from bottom to top (up-flow), it comes into contact with the biomass on the filter and is subjected to anaerobic degradation (Morel and Diener, 2006). Anaerobic filters are used for wastewater with a low percentage of suspended solids and narrow COD/BOD ratio (Chemical Oxygen Demand/Biological Oxygen Demand). It is suitable for domestic wastewaters and all industrial wastewater, which has a lower content of suspended solids. Pre-treatment in settlers or septic tanks may be necessary to eliminate solids of larger size before they are allowed to enter the filter (Sasse, 1998). Recovering biogas may be considered in case of a BOD concentration >1,000 mg/L (Sasse, 1998).

2.13.3 Expanded Granular Sludge Bed Digestion

An expanded granular sludge bed (EGSB) reactor is a variant of the up flow anaerobic sludge blanket digestion (UASB) concept for anaerobic wastewater treatment (Morel and Diener, 2006). The distinguishing feature is that a faster rate of upward-flow velocity is designed for the wastewater passing through the sludge bed. The increased flux permits partial expansion (fluidization) of the granular sludge bed, improving wastewater-sludge contact as well as enhancing segregation of small inactive suspended particle from the sludge bed. The increased flow velocity is either accomplished by utilizing tall reactors, or by incorporating an effluent recycle (or both). A scheme depicting the EGSB design concept is shown in this EGSB diagram. The EGSB design is appropriate for low strength soluble wastewaters (less than 1 to 2 g soluble COD/l) or for wastewaters that contain inert or poorly biodegradable suspended particles which should not be allowed to accumulate in the sludge bed.

2.14 MICROBIOLOGY OF ANAEROBIC PROCESS

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 2.3. 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.

Figure 2.3: Conversion of organic pollutants to biogas by anaerobic microorganism

2.15 METHANE GAS USAGE

2.15.1 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 (Demirbas, 2006). Research has 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 (Demirbas, 2002). Recently methane emitted from coal mines has been successfully converted to electricity.

2.15.2 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 (EIA, 2009). 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 Equation 2.7.

$$CH_4 + H_2O \xrightarrow[700-1100^oC]{Ni} CO + 3H_2 \tag{2.7}$$

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. (Demirbas, 2002).

2.16 MEMBRANE SEPARATION TECHNOLOGY

The term "membrane technology" is used to collectively represent the separation processes by employing specific semi-permeable membrane filters to concentrate or fractionate a liquid into two liquids of different compositions by selectively allowing some compounds to pass while encumbering the others. The liquid that is able to pass the membrane is known as "permeates" and the retained liquid is known as "retentate" or "concentrate". The efficiency of membranes is largely governed by the hydrostatic pressure gradients (also known as "transmembrane pressure") across the membrane and concentration gradient of the liquids. In few a cases, electric potential has important role (Winston and Sirkar, 1992). Membrane Separation technology is always employed in waste treatment as it's able to produce consistent and good water quality after treatment plants as well as it's able to disinfect the related water. There have been inspiring performances by using membrane separation technology. For instances, (Ahmad et al., 2003) have shown that the combination of UF & RO is able to achieve COD removal of 98.8%,BOD removal of 99.4%, Turbidity of 100% and pH 7 as a result. Another group of researcher have incorporated Hollow fiber membrane in their three phase decanter system to give 89.9% COD removal, 99.4% of TSS elimination, 97.9% Turbidity reduction and 92.9% for color removal (Raja et al., 2005).However, short membrane life, membrane fouling and expensive cost are major constraint of this technique. In order to prolong the membrane life span and produce crystal clear effluent as well as methane as the end product, the integration of anaerobic system and membrane separation technology in abio reactor is investigated by some researchers.

The utilization of membranes in dairy industry has been greatly enhanced with the introduction of novel base materials viz. cellulose acetate, polyamides, polysulphons accompanied by newer technological processes such as reverse osmosis, diafiltration (DF) and nanofiltration (NF). In the present scenario, different types of membrane separation technologies such as micro-filtration, ultra-filtration (Balannec et al., 2005), nano-filtration (Vourch et al., 2005) and reverse osmosis (RO) are being made available for use in the dairy industry.

2.17 ULTRAFILTRATION MEMBRANE

Ultra filtration (UF) is a low pressure membrane filtration in which hydrostatic pressure forces a liquid against a semi permeable 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. (Balannec et al., 2005). Membrane Anaerobic System (MAS) is a combination of membrane separation technology with anaerobic treatment process. The limitations of standard filtration are overcome by operating Ultra filtration in what can be called "Cross flow Configuration". The idea of integration of the anaerobic digestion system and membrane separation technology is to enable the biomass to be retained in the reactor which improves methane gas emission as well as producing constant high quality effluent. According to (Zhang et al in 2007) , the(EGSB)) with UF & RO was being incorporating Expanded Granulated Sludge Blanket (EGSB). As a result, COD Removal of 93%, biogas conversion rate of 43% is achieved. As we compared the result to the previous table, the biogas generation appears to improve drastically. In the later years**,** Abdulrahmen have shown another more inspiring result by his Membrane Anaerobic System which a design of anaerobic bioreactor equipped with UF module membrane where COD Removal efficiency 96.6% -98 .4% and biogas conversion rate up to 73% as a final result. (Abdurahman et al., 2011). Performance of Ultra filtration 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 .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.

2.18 ULTRASOUND

Is a cyclic sound pressure wave with a frequency greater than the upper limit of human hearing. Ultrasound is thus not separated from "normal" (audible) sound based on differences in physical properties, only the fact that humans cannot hear it. Although this limit varies from person to person, it is approximately 20 kilohertz (20,000 hertz) in healthy, young adults. The production of ultrasound is used in many different fields, typically to penetrate a medium and measure the reflection signature or supply focused energy. The reflection signature can reveal details about the inner structure of the medium, a property also used by animals such as bats for hunting. The most well-known application of ultrasound is its use in sonography to produce pictures of fetuses in the human womb (Novelline, 1997).

2.18.1 Uses of Ultrasound

- Ultrasound is used in sonography- looking at human babies in the mother's womb. Ultrasound can be used to work out how old the baby is, determine its location, find the location of the placenta, and determine the sex of the baby (male or female), check for heartbeat, check for normal fetal growth and check for any abnormalities (Novelline, 1997).
- In industry, ultrasound is used to determine how thick objects such as metals and plastic are.
- Ultrasound has been shown to work with antibiotics in killing bacterial cells (Neis et al., 2000)

- Bacteria, particularly those in sewage, can be disintegrated (killed) by using ultrasonic waves. (Wang et. al., 2005)
- Ultrasound can be used to clean teeth. Dental hygienists use ultrasound.
- Focused pulses of ultrasound can break up kidney stones and gallstones into little fragments that can be passed from the body with less difficulty.
- Recently, studies have shown that ultrasound can stimulate the growth of bones.
- Ultrasound is used in elastography. This allows doctors to work out which tissues in the body are healthy and which are unhealthy.
- Ultrasonic waves can be used to weld plastic together. The waves make heat energy between the objects that are joined (Kumar et al., 2008).
- Ultrasonic cleaners are used by jewellers and doctors to clean things like watches, jewellery, lenses and surgical instruments. (Hans, 2006).

2.19 ULTRASONIC MACHINING

Ultrasonic shave been used in several ways for machining metals. Lathe tools may benefit from deliberately-induced vibrations to prevent "chatter" which compromises the surface finish of the finished component. Ultrasonic drills, used on very hard ceramics, work by grinding or eroding material away - a liquid slurry around the drill bit contains loose hard particles which are smashed into the surface by the vibrations, eroding material away and creating more loose hard particles incorporating ultrasound to anaerobic membrane bioreactor is expected to make good control for membrane fouling. Ultrasound is cyclic sound pressure (compression and expansion) with a frequency greater than 20 KHz. It has three ranges: power ultrasound (20- 100 KHz), High frequency ultrasound (100 KHz-1MHz) and Diagnostic ultrasound (1-500MHz). Cavitations is the process by which micro bubbles form, grow and collapse violently producing very high temperature and pressure (5000 °C, 500 atm) respectively cavitations phenomena is responsible for sludge disintegration during anaerobic stabilization of sonicated activated sludge (Tiehm et al.,2001). We use ultrasound for these reasons:-

- The application of low frequency ultrasound has proven to be environmentally friendly, time saving and economically viable.
- It enhances the reduction of the sludge volume, increases in biogas production, floc size reduction and cell lyses, (E.AI.Dein.Muhammed, 2009).

- Ultrasound application enables the filtration system to operate more efficiently for a much longer period without maintenance, (Manson, 2007).

CHAPTER 3

MATERIALS AND METHODS

3.1 INTRODUCTION

This chapter gives the information on the materials and methods used in this thesis.

3.2 MATERIALS

3.2.1 Sludge

Waste sludge samples used in the study were collected from sewage treatment plant, INDAH WATER in Kuantan, Malaysia. The temperature during collection of the raw sewage sludge was 32 ^{o}C. The wastewater was stored in a cold room at 4 ^{o}C prior to use. Maximum storage period of sludge was one week to minimize microbial degradation. Samples analysed for chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), pH, volatile suspended solids (VSS), volatile fatty acid, and nitrogen contents. The characteristics of the raw sewage are presented in Table 3.1.

3.2.2 Ultrasonicated-Membrane Anaerobic System (UMAS):

The ultrasonicated-membrane anaerobic system (UMAS), consists of a cross flow ultra-filtration membrane (CUF) apparatus, a centrifugal pump, and an anaerobic reactor. The membrane was attached with ultrasonic.

3.2.2.1 Reactor

The reactor was composed of a heavy duty reactor. The reactor is made up from clear PVC with an inner of 15 cm and a total height of 100 cm. The volume of the reactor is 200liter, and connected with centrifugal pump.

3.2.2.2 Pump

A one phase 0.63 kW, 4.6 Amps, 220/250 voltage pump model no. 5130 one R Motor type 353 was used to pump the digester content into cross flow ultrafiltration (CUF) and recycle the retentate back into the reactor.

3.2.2.3 Ultrasonic

The 25 KHz multi frequency ultrasonic transducers 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.

3.2.2.4 Cross Flow Ultrafiltration Membrane (CFUM) Unit

The (FCUM) consists of two tubular PCI model FP200 Polyulphone 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 two membranes were 0.024 m^2 and the average pore size of 0.1 µm. The molecular cut-off weight of 200000. The membrane can be operated at a maximum pressure of 55 bars at 70 ^oC or at 70 bars at 20 ^oC. The operating pressure in this study was maintained at 1.5 - 2 bars, by manipulating the gate valve at the retentate line after the CFUM unit.

3.3 METHODS

To accomplish objectives of the research, a laboratory digester of ultrasonicated membrane anaerobic system (UMAS) with an effective 200-litres volume used to treat raw sewage sludge. In order to avoid the clogging and pump damage, First the sewage sludge was screened through strainer, before being added to the digester. After that seed sludge was poured in to a 200 litres of ultrasonicated membrane anaerobic system (UMAS). The reactor was covered with an aluminium foil, which prevent the reactor from any direct of sun light. Enrichment cultures of methanogenic bacteria were developed in digester for four days. In day five we on the system. Operating pressure was maintained at 1.5 - 2 bars, Temperature was in the range between 25 - 45 ^{o}C.

pH of the sludge in the reactor content was maintained the range of 6.8 - 7.5,The digester was completely mixed-semi continuously under different steady state operations. The system was operated every day five hours .after five hours Samples from reactor and permeate analysed for chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), pH, volatile suspended solids (VSS), volatile fatty acid, and nitrogen contents, so that the experimental results could be used to investigate the performance of ultrasonicated membrane anaerobic system (UMAS) under steady state conditions. The volume of biogas produced is measured by using a 20 litres water displacement bottle. A schematic representation of laboratory of ultrasonicated membrane anaerobic system (UMAS) which consists of cross flow ultrafiltration membrane (CUF) apparatus, a centrifugal pump, and an anaerobic reactor is shown in Figure. 3.1. The feed system was designed to provide continuous addition of feed solution (Raw sewage sludge) by gravity flow, from feeder tank which is on top of the reactor.

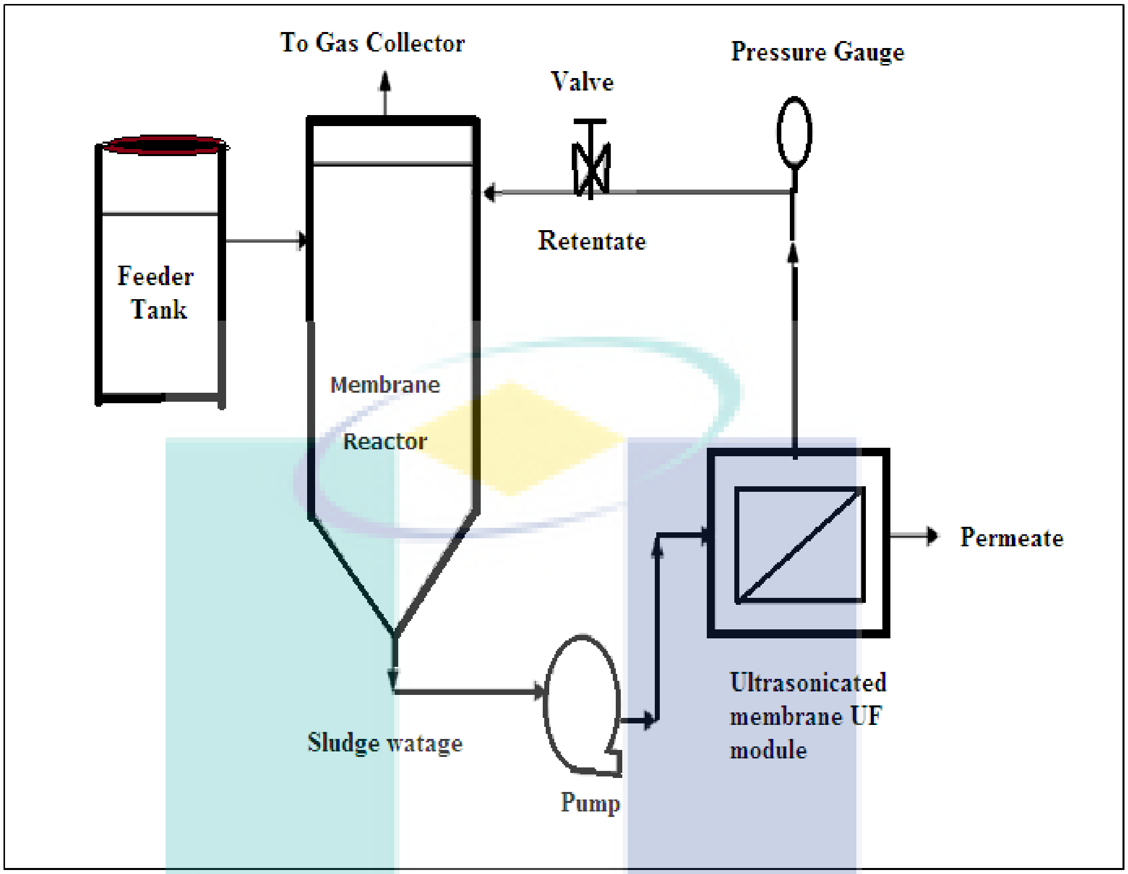

Figure 3.1: Experimental set-up

3.4 BIOREACTOR OPERATION

The ultrasonic membrane anaerobic system, UMAS Performance was evaluated under four steady-states with influent COD concentrations ranging from (675 to 1088.3 mg/l) and organic loading rates (OLR) between (0.12 and 0.06 kg COD/m^3/d). 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 20-litre water displacement bottle was used to measure the daily gas volume. The method assumes that 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 MEMBRANE CLEANING

In the course of this study, there were two ways that the membranes were cleaned, in order to improve the permeate flux and permeate flow rate. The two methods, which were followed in this study, the first method is mild brushing, flush with water, 20-30 minutes. The second method is soak the membrane in 0.1M NaOH for a day, (24 hours) rigorous brushing, with water. In both methods, the membranes have been taken out from membrane housing. The summary of all procedures was illustrated in Figure 3.2.

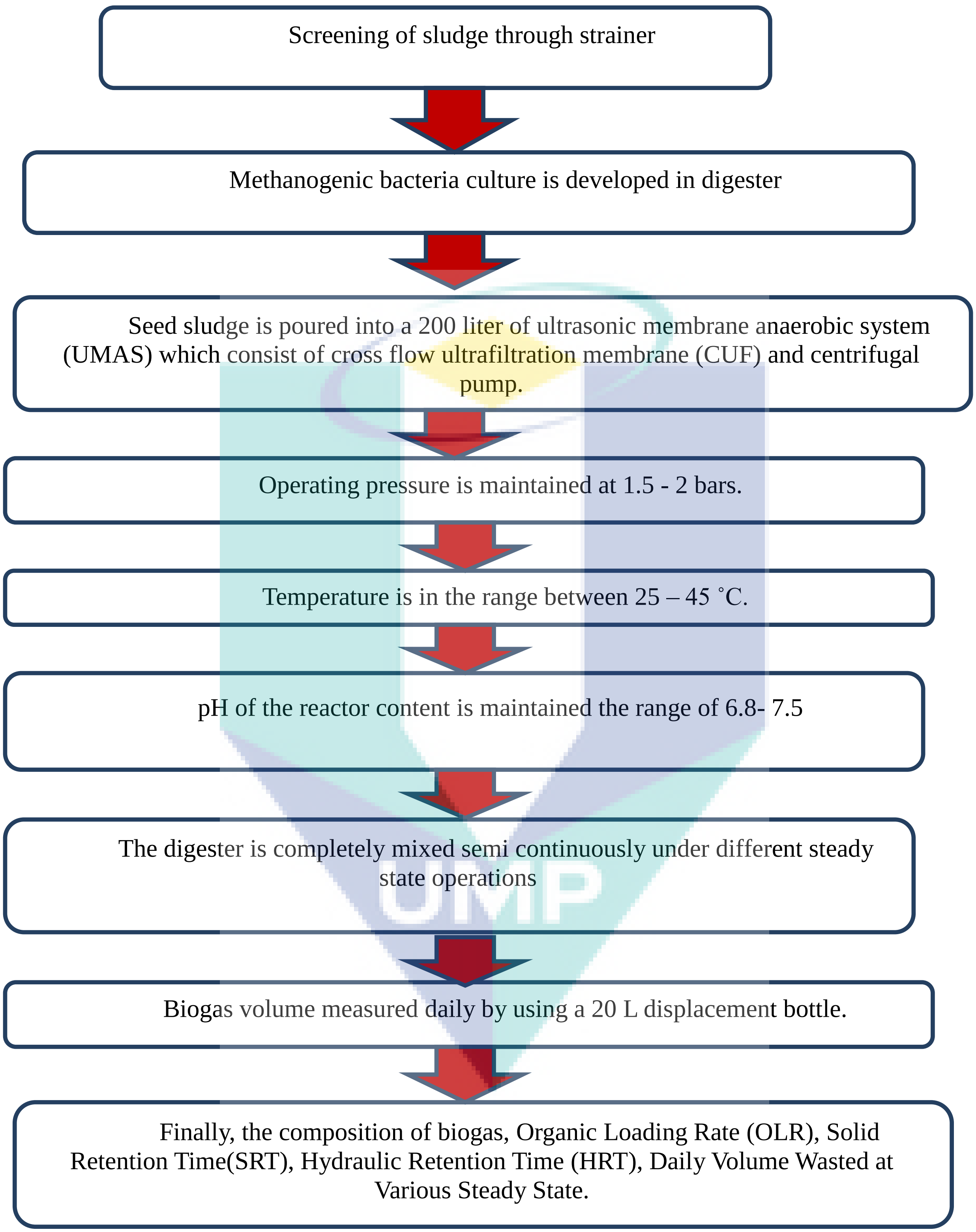

Figure 3.2: Experimental procedures of UMAS

3.6 ANALYTICAL TECHNIQUES

Laboratory test was conducted to observe waste water quality parameters, and classify the wastewater conditions. Samples from raw sewage sludge ,permeate and reactor were analysed for chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), pH, volatile suspended solids (VSS), volatile fatty acid, and nitrogen contents.

3.6.1 pH

pH was determined by the both of pH meter and litmus paper. For raw sludge, reactor contents, and permeates.

3.6.2 COD

The chemical oxygen demand (COD) of feed solution, effluent sample, and mixed liquor suspended solids (reactor content) were determined by the dichromate reflux (HACH Water Analysis Method).

3.6.3 Suspended Solids

Digester mixed liquor suspended solids was determined by filtration through a glass fiber filter method. The analytical procedure employed was essentially the same as that described for the determination of suspended solids in sewage and activated sludge.

3.6.4 Nitrogen

Ammonia nitrogen and nitrate nitrogen was determined by using spectrophotometric

3.6.5 VFA

Volatile fatty acid was determined by a combination of the potentiometric titration methods for acidity and alkalinity.

3.7 GAS MEASURMENT

The gas volume was measured daily, using a 20-litre displacement bottle. The gas method used to perform this analysis was a J-tube gas analyser (Yau, 1983) which was shown in Fig 3.3. The method assuming that the biogas produced composed only of two gases CO_2 and CH_4. Then sodium hydroxide solution (NaOH) was added to the composition. Sodium hydroxide was absorbing the CO_2. The remaining volume is methane gas CH_4. The same method was used by (Jawed and Tare (1996)) they used potassium hydroxide (KOH) to determine CH_4 composition.

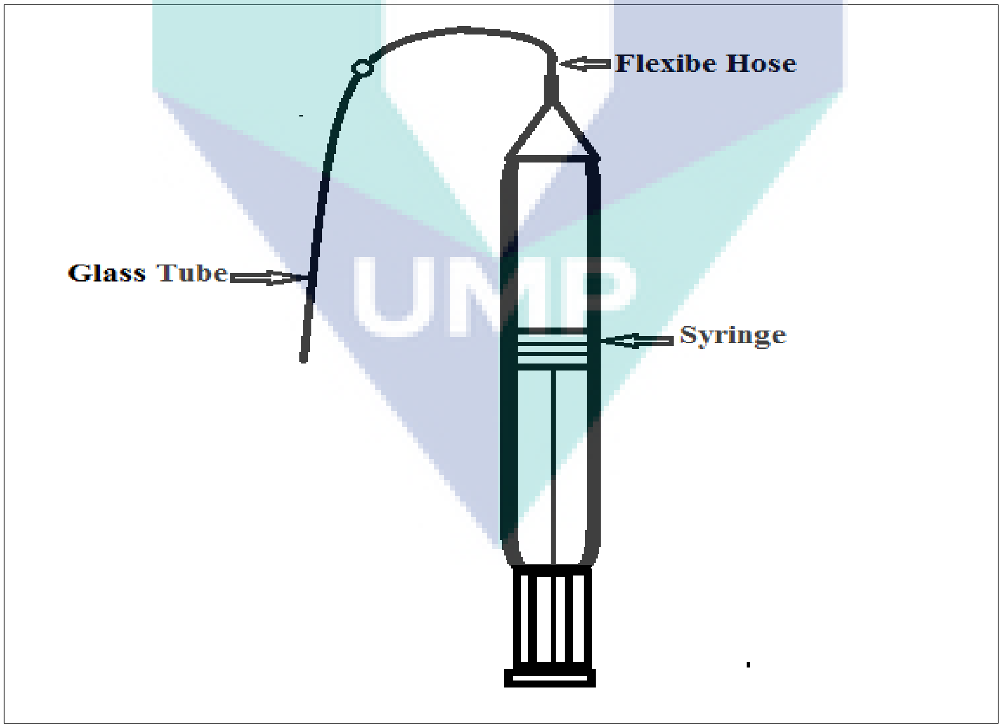

Figure 3.3: J-tube gas analyzer

Source: Yau, (1983)

The device was consists of a glass-tube connected by a flexible hose to a syringe. Initially the device was filled with 0.5 M NaOH solution, 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 then immersed in water. By manipulating the syringe, many times, the NaOH solution was absorb the carbon dioxide CO_2, as evidenced from reduction in the length of the biogas column, and then measured the biogas column again. Final length of gas column represents the final length of the gas column and Initial length of gas columns represents the Initial length of the gas column

The percentage of methane in the biogas = $\frac{\mathrm{Finallengthofgascolumn}}{\mathrm{Initiallengthofgascolumn}} \mathrm{x}10$ (3.1)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The mechanism of anaerobic transformation of sewage sludge of methane in ultrasonic membrane anaerobic system (UMAS) was reviewed and discussed in chapter 1 and chapter 2. This chapter will discuss all results using the methods described in chapter 3. In achieving the objective of this study, a laboratory digester of ultrasonic membrane anaerobic system (UMAS) with an effective 200-litre volume used to treat raw sewage sludge. The laboratory digester is completely mixed-semi continuous followed steady state operation. Lastly the results used to investigate the performance of ultrasonic membrane anaerobic system (UMAS) under steady state conditions .And the volume of biogas produced is measured by using a 20 liter water displacement bottle.

4.2 EXPERIMENTAL RESULTS AND ANALYSIS FOR THE FIRST RUN

The description of the experimental result starts with the characteristics of the raw sewage as shown in table 4.1 which consist various parameters such as pH, BOD_5, COD, TSS, VSS, Nitrogen content in Ammonia and Nitrate form and Volatile fatty acid.

Table 4.1: Characteristics of the raw sewage

Parameter	Concentration			
	Feed(SS1)	Feed(SS2)	Feed(SS3)	Feed(SS4)
pH	6.4	6.8	7.5	7.1
BOD5, mg/L	395.1	155.8	96.3	75
COD ,mg/L	1088.3	796	804	675
TSS, mg/L	1.44	2.4	1.96	2.35
VSS, mg/L	0.87	5.04	0.63	0.371
N-Ammonia, mg/L	9.3	15.3	4.00	6.99
Volatile fatty acid, mg/L	309.7	107.3	187	200

Moreover the data provided in Table 4.2 summarizes the results of values for pH, BOD_5, COD, TSS,VSS, Nitrogen content in Ammonia and Nitrate form and Volatile fatty acid. This table summarizes UMAS performance of the first inflow rate (at first steady-state), which were established at HRTs (9 d) and with influent COD concentrations of 1088.3 mg\l, the pH was around 6.4, for this feed, because methanogenesis is also strongly affected by pH, methanogenic activity and biogas Decreased when the pH in the digester deviates from the optimum value. For this reason sodium hydroxide was added to the digester for restoring the pH balance (6.8-7.5) and to increase alkalinity. At this study, the MLSS concentration was about 2.84 mg/l whereas, the MLVSSconcentrations was 2.43 mg/l, equivalent 41% of the MLSS. The BOD_5 results showed that the value was decreased from 395.1 mg/l for the feed to 163.4 mgl - 199mg/l for permeate and reactor, respectively after 5 days incubation. This indicates that the oxygen which present in the sewage was rapidly consumed by anaerobic bacteria and the sample is rich with bacteria, because BOD_5 serves as a food source for microbes.

The high influent COD was recorded at first steady-state (1088.3 mg/l) and corresponded to an OLR of 0.12 kg COD/m^3/d. At this OLR the, UMAS achieved 50% COD removal and an effluent COD of 538.4 mg/l. The ammonia content in the feed and permeate was 3.87 mg/l and 5.18 mg/l while the nitrate content was 9.3 mg/l and 12.16 mg/l respectively. This is good indicator because the process requires and consumes oxygen. And this contributes to the BOD or biochemical oxygen demand of the sewage. The process is mediated by the bacteria Nitrosomonas and Nitrobacteria which require an aerobic (presence of oxygen) environment for growth and metabolism methanogens use ammonia and nitrate as nitrogen sources.

Table 4.2: Summary of Result of First run

Steady State 1	Feed	Permeate	Reactor
pH	6.4	6.9	6.8
BOD_5, mg/L	395.1	163.4	199
COD ,mg/L	1088.3	538.4	1248.2
TSS, mg/L	1.44	0.46	2.84
VSS, mg/L	0.82	0.48	2.43
N-Ammonia, mg/L	3.87	5.18	5.68
N-Nitrate, mg/L	9.3	12.16	14.46
Volatile fatty acid, mg/L	309.7	101.2	202.1

The percentage volume of methane in biogas is = 93.65%

4.3 EXPERIMENTAL RESULTS AND ANALYSIS FOR THE SECOND RUN

The data provided in Table 4.3 summarizes the results of values for pH, BOD_5, COD, TSS, VSS, Nitrogen content in Ammonia and Nitrate form and Volatile fatty acid. The table summarizes UMAS performance of the second inflow rate (at second steady-state), which were established at HRTs (10 d) and with influent COD concentrations of 796 mg/l, UMAS performed well and the pH in the reactor remained within the optimal working range for anaerobic digesters (6.8-7.5). At this steady-state, the MLSS concentration was about 2.29 mg/l whereas the MLVSS concentration was 0.5 mg/l, equivalent 65% of the MLss. The BOD_5 results shows that the value was decrease from 155.8 mg/l for the influent to 109.1 mg/l - 135.3 mg/l for the effluent and reactor respectively after 5 days incubation at 20 ^{o}C. This indicates that the oxygen which present in the sewage sludge was rapidly consumed by anaerobic bacteria because BOD serves as a food source for microbes. The influent COD at second steady-state (796 mg/l) and corresponded to an OLR of 0.062 kg COD/m^3/d. At this OLR the, UMAS achieved 61.7% COD removal and an effluent COD of 304.5 mg/l.

The ammonia content in the feed and permeate was 4.06mg\l and 7.07mg\l while the nitrate content was 15.3mg\l and 13.31mg\l respectively. This is good indicator because the process requires and consumes oxygen. And this contributes to the BOD or biochemical oxygen demand of the sewage. The process is mediated by the bacteria *Nitrosomonas* and *Nitrobacteria* which require an aerobic (presence of oxygen) environment for growth and metabolism Methanogens use ammonia and nitrate as nitrogen sources.

Table 4.3: Summary of sesult of Second run

Steady State 1	**Feed**	**Permeate**	**Reactor**
pH	6.8	7.2	7.1
BOD_5, mg/L	155.8	109.1	135.3
COD ,mg/L	**804**	304.5	745
TSS, mg/L	2.4	0.48	2.29
VSS, mg/L	5.04	3.76	1.91
N-Ammonia, mg/L	4.06	7.07	7.01
N-Nitrate, mg/L	15.3	13.31	16
Volatile fatty acid, mg/L	107.3	46	77.8

The percentage volume of methane in biogas is= 91.4%

4.4 EXPERIMENTAL RESULTS AND ANALYSIS FOR THE THIRD RUN

The data provided in Table 4.4 summarizes the results of values for pH, BOD_5, COD, TSS, VSS, Nitrogen content in Ammonia and Nitrate form and Volatile fatty acid. This table summarizes UMAS performance of the third inflow rate (at third steady-state), which were established at HRTs (10 d) and with influent COD concentrations of 804 mg\l. UMAS performed well and the pH in the reactor remained within the optimal working range for anaerobic digesters (6.8-7.5). At this steady-state, the MLSS concentration was about 0.73 mg/l whereas the MLVSS concentration was0.77 mg/l, equivalent 73% of the MLSS. The BOD_5 results showed that the value was decrease from 96.3mg/l for the feed to 44mg/l - 70.9 mg/l for permeate and reactor respectively after 5 days incubation. This result indicates that the oxygen which present in the sewage was rapidly consumed by anaerobic bacteria because BOD serves as a food source for microbes. The influent COD at third steady-state (804mg/l) and corresponded to an OLR of 0.08 kg COD/m^3/d. At this OLR the, UMAS achieved 79% COD removal and an effluent COD of 161.6 mg/L. The ammonia content in the feed and permeate was 6.31 mg\l and 3.77 mg/l while the nitrate content was 4mg\l and 1.11 mg/l respectively. This is good indicator because the process requires and consumes oxygen. And this contributes to the BOD or biochemical oxygen demand of the sewage. The process is mediated by the bacteria Nitrosomonas and Nitrobacteria which require an aerobic (presence of oxygen) environment for growth and metabolism Methanogens use ammonia and nitrate as nitrogen sources.

Table 4.4: Summary of result of third run

Steady State 1	**Feed**	**Permeate**	**Reactor**
pH	7.5	7.2	7.2
BOD_5, mg/L	96.3	44	70.9
COD ,mg/L	**796**	161.5	660.3
TSS, mg/L	1.96	0.53	0.73
VSS, mg/L	0.63	0.91	0.72
N-Ammonia, mg/L	6.31	3.77	7.01
N-Nitrate, mg/L	15.3	13.31	16
Volatile fatty acid, mg/L	187	291.77	221.83

The percentage volume of methane in biogas is = 88.79%

4.5 EXPERIMENTAL RESULTS AND ANALYSIS FOR THE FOURTH RUN

The data provided in Table 4.5 summarizes the results of values for pH, BOD_5, COD, TSS, VSS Nitrogen content in Ammonia and Nitrate form and Volatile fatty acid. This table summarizes UMAS performance of the four inflow rate (at fourth steady-state), which were established at HRTs (10 d) and with influent COD concentrations of 675 mg/l. UMAS performed well and the pH in the reactor remained within the optimal working range for anaerobic digesters (6.8-7.5). At this steady-state, the MLSS concentration was about 1.033 mg/l whereas the MLVSS concentration was 0.993 mg/l, equivalent 83.2% of the MLSS. The BOD_5 results showed that the value was decrease from 75 mg/l for the feed to 35.7 mg/l - 51.3mg/l for permeate and reactor respectively after 5 days incubation. This result indicates that the oxygen which present in the sewage was rapidly consumed by anaerobic bacteria because BOD serves as a food source for microbes. The influent COD at third steady-state (675 mg/l) and corresponded to an OLR of 0.067 kg COD/m^3/d. At this OLR the, UMAS achieved 85% COD removal and an effluent COD of 99.3 mg/L. The ammonia content in the feed and permeate was 10.8mg\l and 7.73 mg/l while the nitrate content was 6.99 mg/l and 3.15/l respectively. This is good indicator because the process requires and consumes oxygen. And this contributes to the BOD or biochemical oxygen demand of the sewage. The process is mediated by the bacteria

Nitrosomonas and Nitrobacteria which require an aerobic (presence of oxygen) environment for growth and metabolism Methanogens use ammonia and nitrate as nitrogen sources.

Table 4.5: Summary of result of fourth run

Steady State 1	Feed	Permeate	Reactor
pH	7.1	6.9	7.00
BOD_5, mg/L	75	35.7	51.3
COD ,mg/L	675	99.3	243.1
TSS, mg/L	2.351	0.793	1.033
VSS, mg/L	0.371	1.02	0.993
N-Ammonia, mg/L	10.8	7.73	9.33
N-Nitrate, mg/L	6.99	3.15	5.71
Volatile fatty acid, mg/L	200	379.2	334.63

The percentage volume of methane in biogas is = 85.75%

4.6 SEMI CONTINUOS ULTRASONIC MEMBRANE ANAEROBIC SYSTEM (UMAS) PERFORMANCE

Table 4.6 summarizes UMAS performance of four inflow rates all (at four steady-states), which were established at different HRTs and influent COD concentrations. At steady-state conditions with influent COD concentrations of 675-1088.3 mg/l, UMAS performed well and the pH in the reactor remained within the optimal working range for anaerobic digesters (6.7-7.8) because methanogenesis is strongly affected by pH, methanogenic activity and biogas production will effect when the pH in the digester deviates from the optimum value also biogas production effect by the time it decreased by increasing of HRT as shown in Figure 4.1.

The first steady-state, the MLSS concentration was about 2.84 mg/l whereas the MLVSS concentration was 2.43 mg/l, equivalent to 41% of the MLSS. This low result can be attributed to the high suspended solids contents in the sample .At the four steady-states conditions, however, the volatile suspended solids (VSS) fraction in the reactor increased to 83.2 % of the MLSS. This indicates that the long SRT of UMAS facilitated the decomposition of the suspended solids and their subsequent conversion to methane (CH4) this conclusion is supported by (Nagano et al., 1992). Figure 4.2 shows the relationship between the SRT and the methane content.

Table 4.6: Summary of result of (4-S: Steady state)

Steady State (SS)	**1**	**2**	**3**	**4**
COD feed, mg/L	1088.3	804	796	675
COD permeate, mg/L	538.4	304.5	161.6	99.3
COD reactor, mg/L	1248.2	745	660.3	243.1
Gas production (L/d)	933.6	925.7	909.6	897
Total gas yield, L/g COD/d	1.16	0.77	0.6	0.21
% Methane by volume	93.65%	91.4	88.79	85.75
Ch4 yield, L/g COD/d	0.99	0.75	0.51	0.16
MLSS, mg/L	2.84	2.29	0.731	1.033
MLVSS, mg/L	2.43	0.51	0.72	0.993
%VSS	41	75	73	83.2
HRT, d	9	10	10	11
SRT, d	6.47	8.38	25.47	26.868
OLR, kg COD/m3/d	0.12	.06	0.08	0.07
Percent COD removal (UMAS	50.5	61.7	79.9	85.28

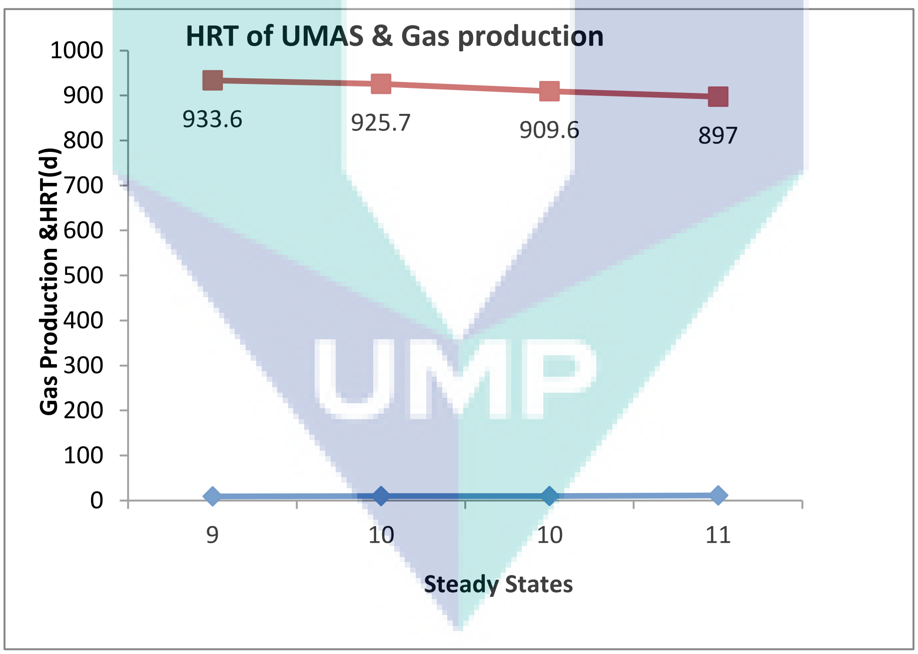

Figure 4.1: Effect of HRT on the biogas production

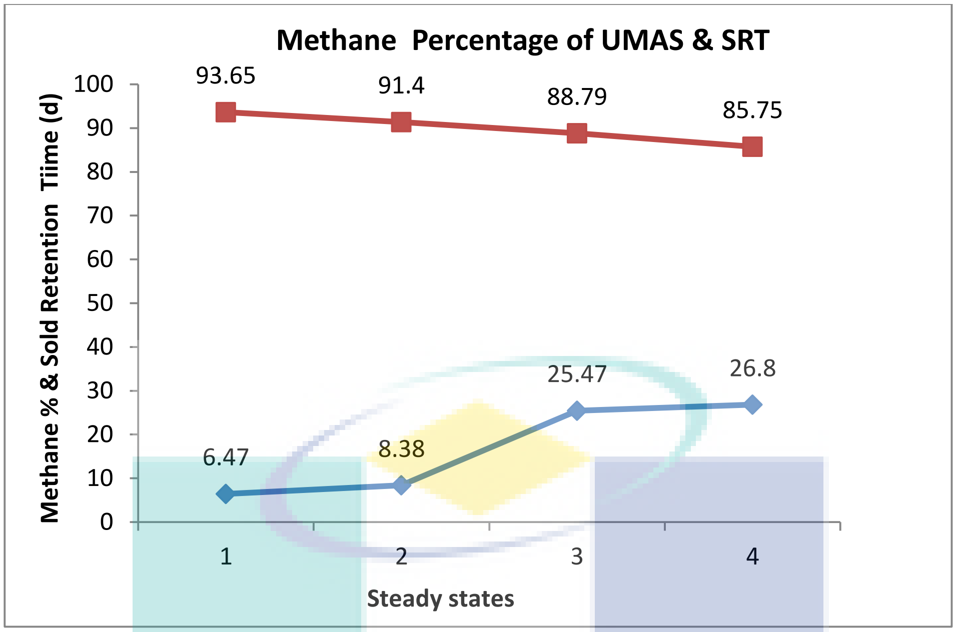

Figure 4.2: Relationship between SRT and methane percentage

The highest influent COD was recorded at the first steady-state (1088.3 mg/l) and corresponded to an OLR of 0.12 kg COD/m^3/d. At this OLR the, UMAS achieved 50.5% COD removal and an effluent COD of 538.4 mg/l, while the highest COD removal 85.28% was achieved at the fourth steady state with an influent COD 675 which corresponded to an OLR of 0.07 kg COD/m^3/d and an effluent COD 99.3 kg COD/m^3/d Fig 4.3 .. The removal of COD is reflected in the rise in biomass concentration, as the dissolved organics were converted into new cells. COD removal efficiency increased as HRT increased from 9 to 11 days and was in the range of 50.5% - 85.28%. This result was higher than the 85 % COD removal observed for POME treatment using anaerobic fluidized bed reactors (Idris and Al-Mamun, 1998) Figure 4.4 shows the percentages of COD removed by UMAS at various HRTs.

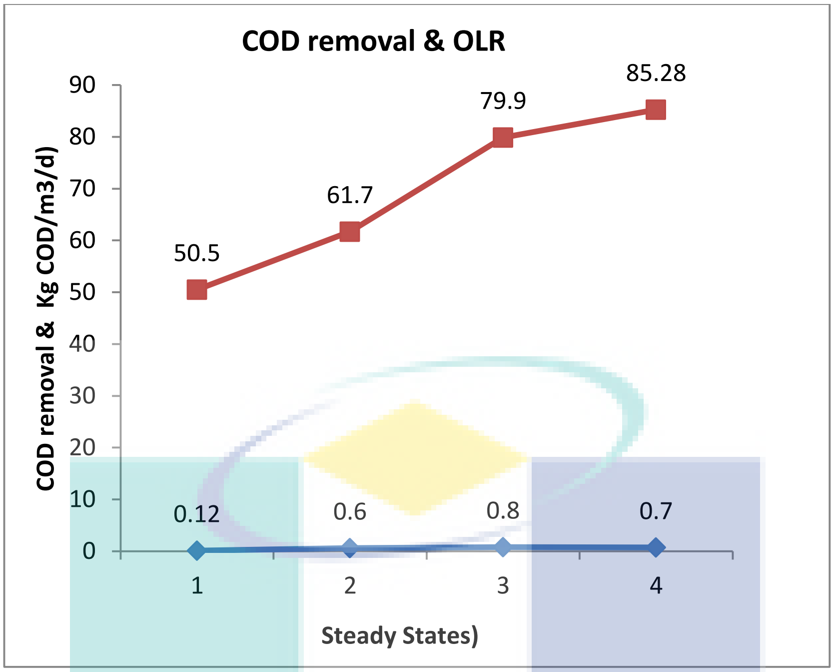

Figure 4.3: Organic loading rate and COD removal percentage

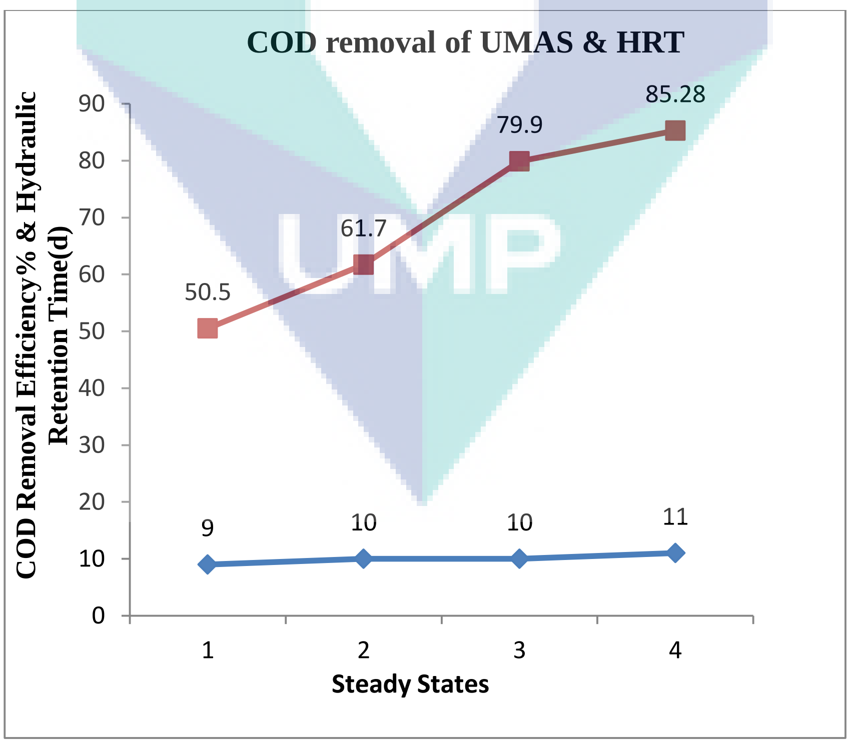

Figure 4.4: the percentages of COD removed by UMAS at various HRTs

Volatile fatty acids (VFA) in the influent and effluent were also measured throughout the study. The level of VFA was varied during the four steady state. At the first and second steady state the VFA level decrease and the measurement VFA indicated that some of the influent COD could be attributed to the VFA in the effluent which occurred at the reduction in the concentration by 67.32% and 57.12% at the two stages. AT the third and fourth steady state the VFA level increase and the measurement VFA indicated that the influent COD could not be attributed to the VFA in the effluent. Figure 4.5 shows the relationship between VFA reduction and the percentage of methane.

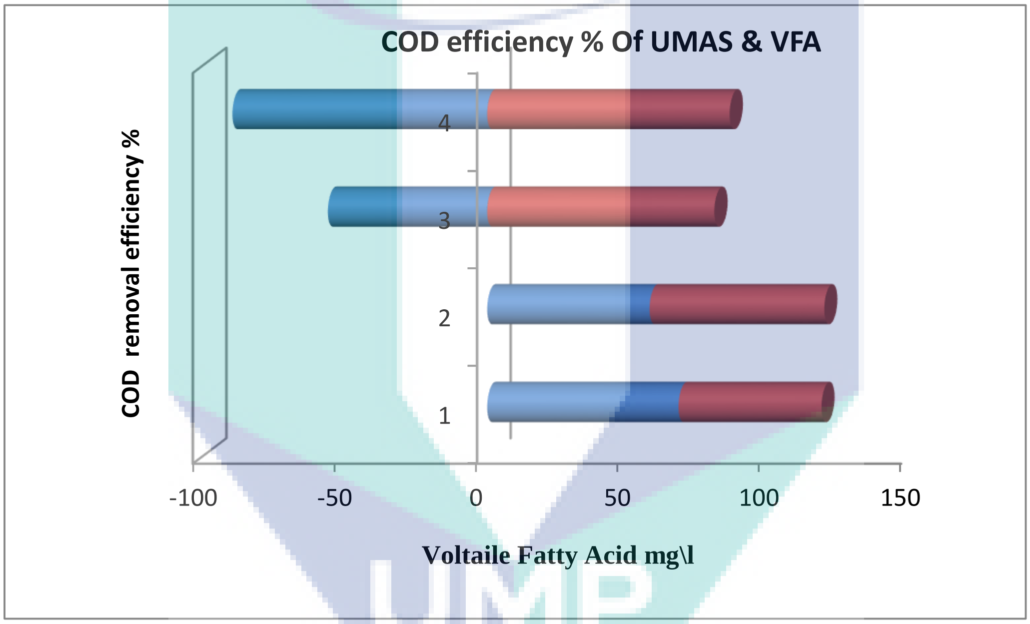

Figure 4.5: The relationship between VFA reduction and the percentage of COD removal

4.7 EFFECT OF ORGANIC LOADING RATE AND SOLID RETENTION TIME

Table 4.7 summarize the organic loading rates (OLR), solid retention times (SRT), hydraulic retention times (HRT), and daily Volume Wasted at Various Steady States. The organic loading rate is the maximal amount of organic dry matter in the reactor volume per day which can be delivered without overfeeding bacteria and leading to process inhibition. The loading rate is obviously critical process parameters in anaerobic treatment .This result study adopted the mechanical mixing and biogas recirculation.

Table 4.7: Organic loading rates (OLR), solid retention times (SRT), hydraulic retention times (HRT), and daily volume wasted at various steady states

Steady State (SS)	OLR (kg/m3/d)	SRT	HRT (Day)	Volume Wasted (L/d)
1	0.12	6.5	9	4.4
2	0.06	8.4	10	4
3	0.08	25.5	10	3.5
4	0.07	26.9	11	3.2

At the four steady state the OLRs start to decrease with increasing the solid retention time and hydraulic retention time. The UMAS reactor took 9 days to reach to 50. % COD removal in the first steady state ,while the same reactor took 11 days to reach 85.28% COD removal. The shorter retention time achieved low removal and visa verse. This indicated that the long retention attributed to rapid the degradation process of anaerobic digestion Fig. 4.6 shows the gas production rate and the methane content of the biogas. The methane content generally declined with increasing OLRs. Methane gas contents ranged from 85.75 % to 93.65% and the methane yield ranged from 0.16 to 0.99 CH_4/g COD/d. Biogas production increased with increasing OLRs. The decline in methane gas content may be attributed to the higher VFA, which favours the growth of acid forming bacteria over methanogenic bacteria. In this scenario, the higher rate of carbon dioxide; (CO_2) formation reduces the methane content of the biogas.

A study of the effect of organic loading rate on the performance of anaerobic digestion of sewage sludge in UMAS was carried out in a laboratory- digester with an effective 200-litre volume under four steady-states with influent COD concentrations ranging from (675 to 1088.3 mg/l) and organic loading rates (OLR) between (0.12 and 0.06 kg COD/m^3/d). In this study COD removal efficiency decreased from 85.28% to 50.5% when the OLR increased from 0.6 to 0.12 kg COD/m^3/d. It was found that when the OLRs is higher favoured process failure, decreasing pH, COD removal efficiency and methane production rates.

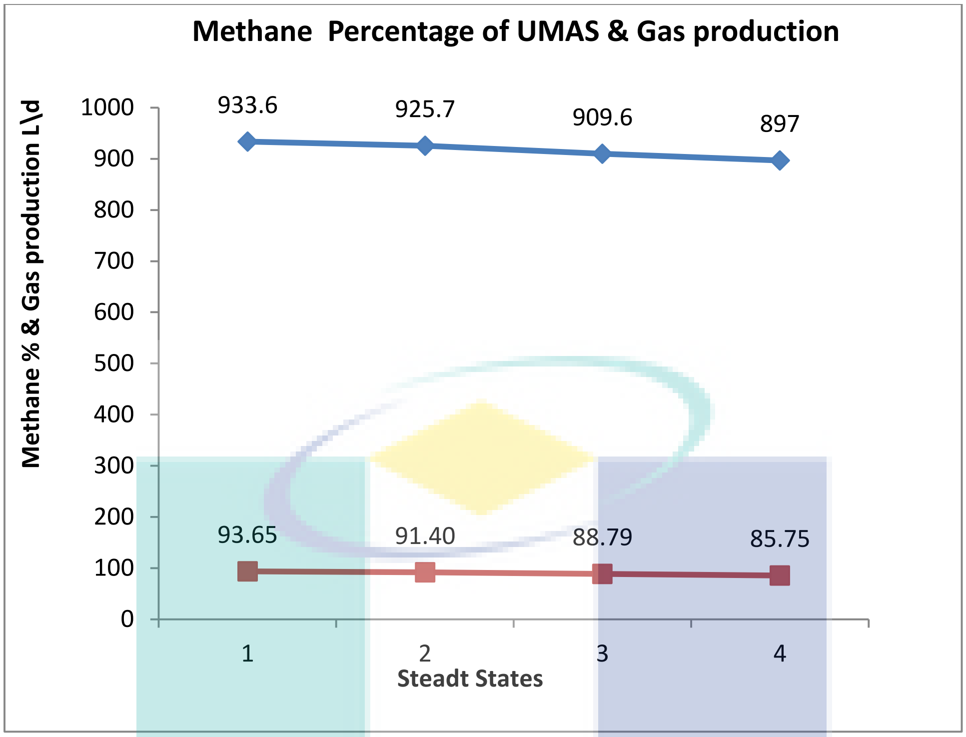

Figure 4.6: Gas production and methane content

4.7.1 Organic Loading Rate and COD Removal Percentage

It is very important in the study of this research to determine the performance of anaerobic digestion process when operated at different loading rates. For this reason, it was highly important to evaluate process performance in term of COD reduction, biogas composition and production to various loading rates. The reduction of COD concentration in anaerobic process at different organic loading rates are shown in Fig 4.7. COD degradation value of 85.28 % was achieved while operating loading rate 0.07 kg COD/ (m^3.d). This COD reduction is higher compared with the result of 77.1% reported by (Castillo, 2006). By increasing the loading rate in steady state 1,2and 3, COD removals were decreased to 50.5 %, 61.7 % and 79.9% respectively as illustrated in Fig4.7. The COD degradation was decreased while organic loadings were increased.

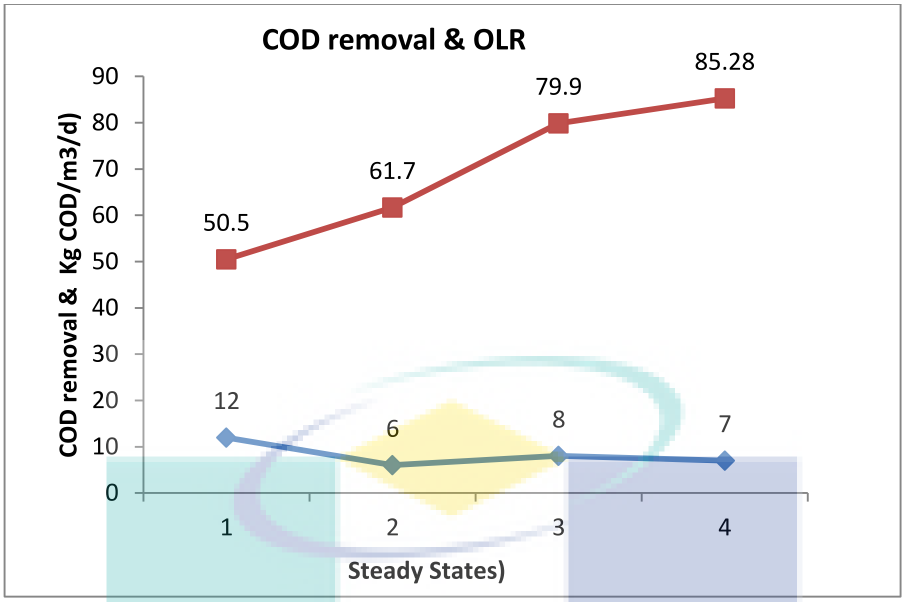

Figure 4.7: Organic loading rate and COD removal percentage

4.7.2 Organic Loading Rate and Gas Production

For the purpose of evaluating the effect of loading rate on the process efficiency, COD reduction and biogas yield were both taken into account as the indicators to assess the reactor performance and efficiency of each loading rate. Production of biogas during anaerobic process at different organic loading rates is shown in Fig. 4.8. The daily biogas production obtained during four steady state were approximately 933.6 l/d, 925.7l\d, 909.6l\d and 897 l/d respectively .The daily biogas production in run 1 was found approximately 933.6 l/d. Further increase of the organic loading rate as 0.12kgCOD/ (m^3.d) results in increased biogas production rates. Generally we found that the gas production was decreased by decreasing of OLRs.

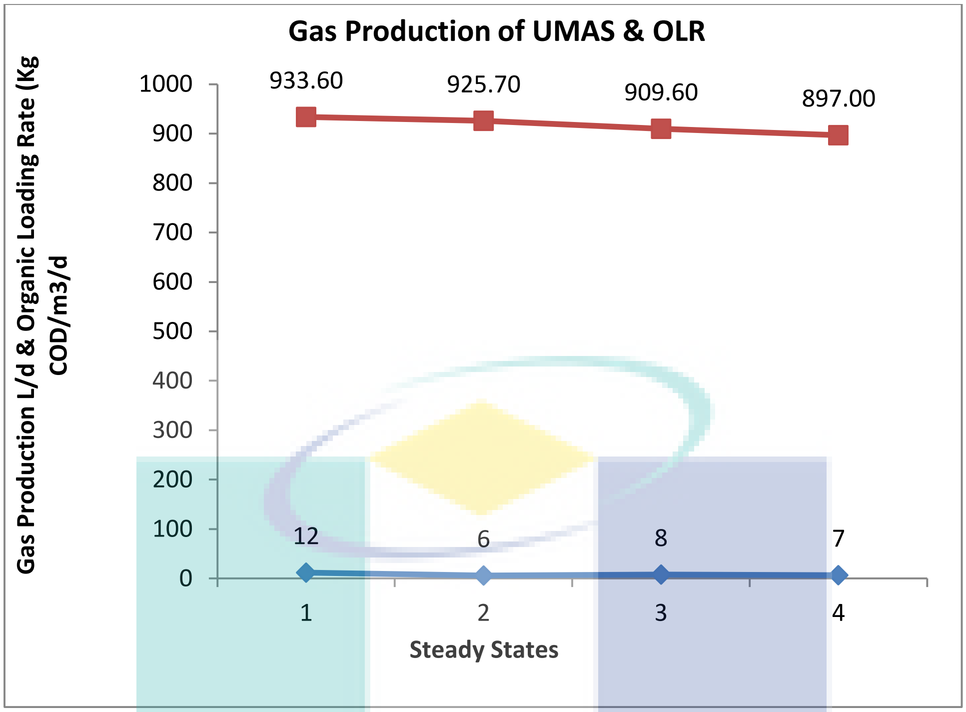

Figure 4.8: Organic loading rate and gas production

4.7.3 Organic Loading Rate and Methane Content

The loading rate is obviously critical process parameters in anaerobic treatment. The influence of organic loading on the methane yield have been shown in Figure 4.10. These findings are in agreement with the results of (Alvarez et al., 2008). They reported that there was a linear relationship between methane yield and loading rate at lower loading rates. The maximum methane yield was observed, 0.99 L/g COD/d when the OLR was 0.12 kg COD/m3/d because of the suitable type and composition of substrate, microbial composition and temperature. The methane yield was starting to decrease with OLR decreasing; the first steady state is the breakpoint indicates the beginning of biological stress and beyond this point, the methane production rate decreased. The methane yield during the steady state was 0.99, 0.75, 0.51 and 0.16 L/g COD/d for loads of 0.12, 0.06, 0.08 and 0.07 kg COD/m3/d, respectively, this result was higher than the yields at 35°C. (Callaghan et al., 2002) have reported the methane yield of 0.23 kg VS\m3\d and 50% VS reduction by using a co-digestion system of fruit and vegetable waste (FVW) and Chicken manure with HRT of 21 days at 35°C. According to(

Salminen et al., 2002),the potential methane yield of solid poultry slaughterhouse waste and HRT of 50–100 days at 31°C is high, from 0.52 to 0.55 m3/kg VS. The treatment of wastewaters containing high levels of TS or indigestion components, such as slaughterhouse wastewater or straw, will require a longer reaction period for complete degradation of particles, especially at lower temperatures. Sewage sludge wastewater containing low levels of TS or indigestion components this is the most important reason of high methane yield in this case study compared with the others' results. Design parameters and related data are presented in Table 4.5.

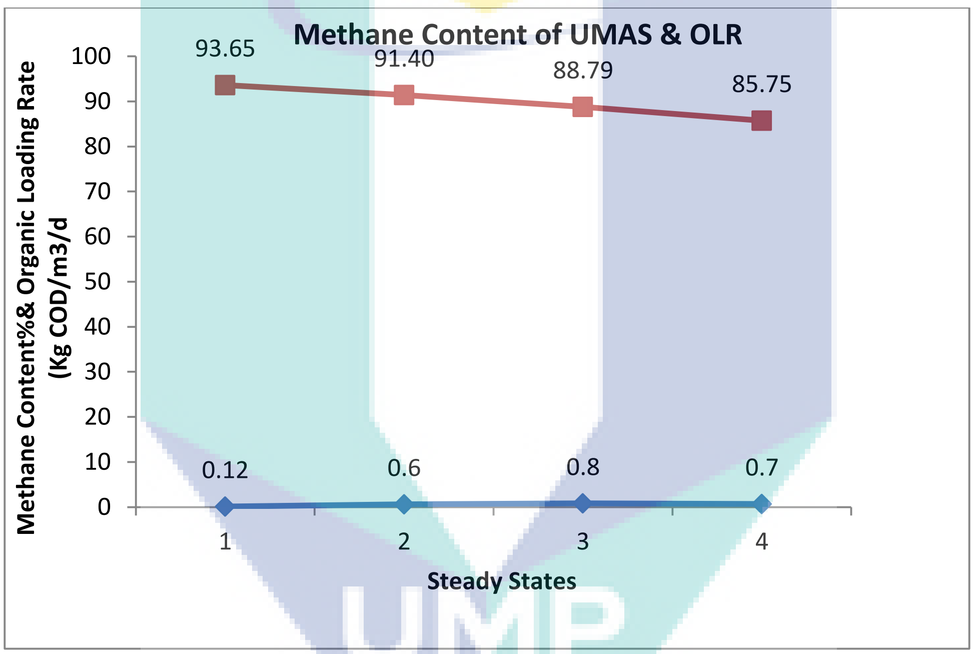

Figure 4.9: Organic loading rate and methane content

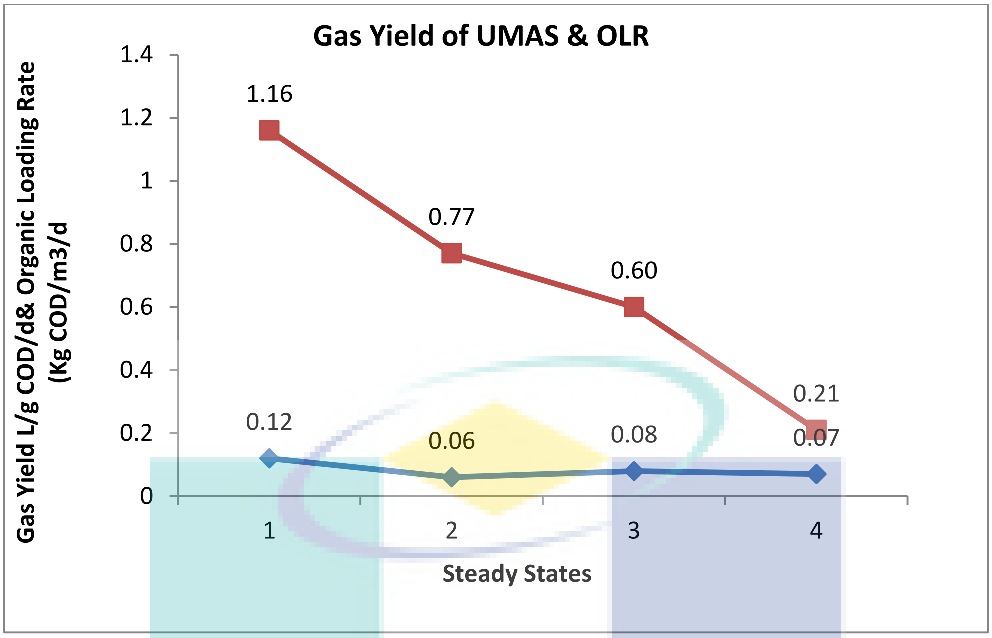

Figure 4.10: Organic loading rate and gas yield

4.7.4 Solid Retention Time and COD Removal

AT the first steady state the reactor was fed with sewage sludge wastewater with a COD concentration of 1088.3mg\l. The reactor was operated in semi- continues UMAS till reaching 50.5 % of COD removal. While the reactor was reached in the last steady state with COD concentration of 675mg\l till 85.28% of COD removal. The average retention time for achieving the treatment efficiency during these stages varied. The UMAS reactor took 9 days to reach to 50% COD removal in the first steady state, while the same reactor took 11 days to reach 85.28% COD removal. The shorter retention time achieved low removal and visa verse. This indicated that the long retention attributed to rapid the degradation process of aerobic digestion .The SRT of UMAS for the four steady state is ranged between 6.5d -26.9d. Fig 4.11 showed the relation between the SRT and the COD removal. These results suggest that UMAS significantly facilitated substrate degradation rate and COD removal efficiency this result supported by (Abdurahman et al, 2010).

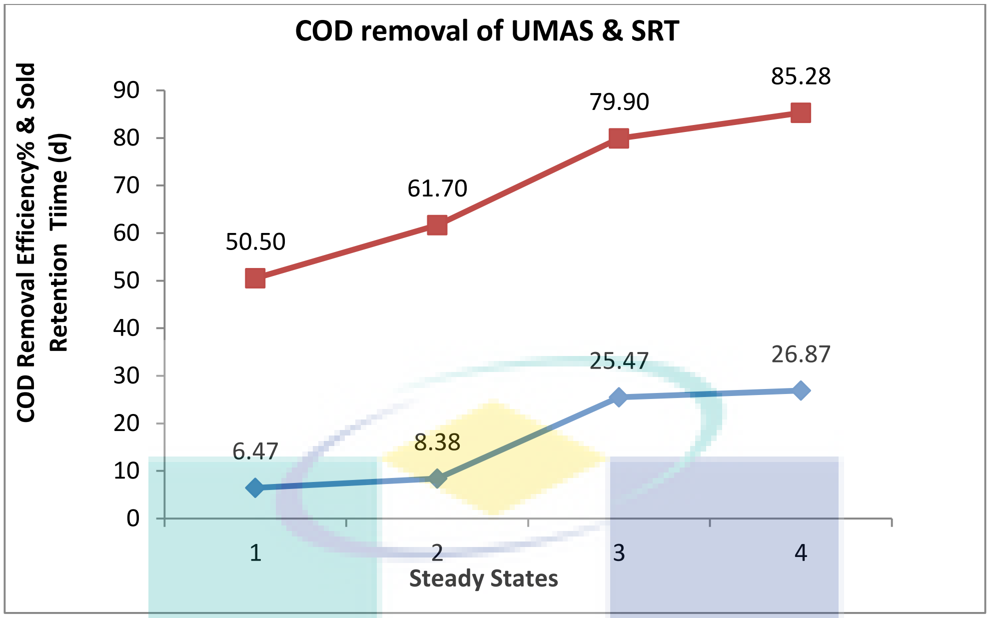

Figure 4.11: Solid retention time and COD removal

4.7.5 Solid Retention Time and Gas Production

Such variations can also be presented by COD removal rates. As shown in table 4.5, the COD removal rates for the four steady state in UMAS systems varied significantly and changed depending on the COD concentrations. At the four steady state, the gas production and the gas yield increases with increasing SRT .Fig 4.12and 4.13 showed the effect of SRT to the gas production and HRT to gas yield. During the initial stage of operation, when the COD concentration was high, COD removal rate for the reactor averaged around 50.5 mg/L, which was lower than that of the last stage however, COD concentration was low, COD removal rate averaged 85.28% .This low result may be resulted because of the high suspended content in the initial feed comparing with that in the last stage.

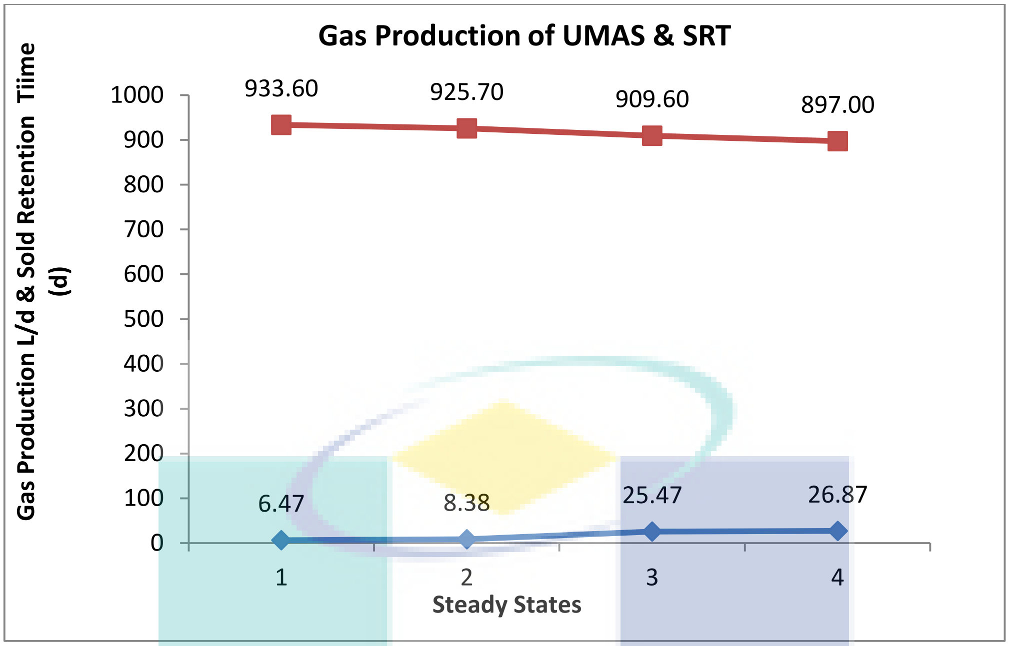

Figure 4.12: Solid retention time and gas production

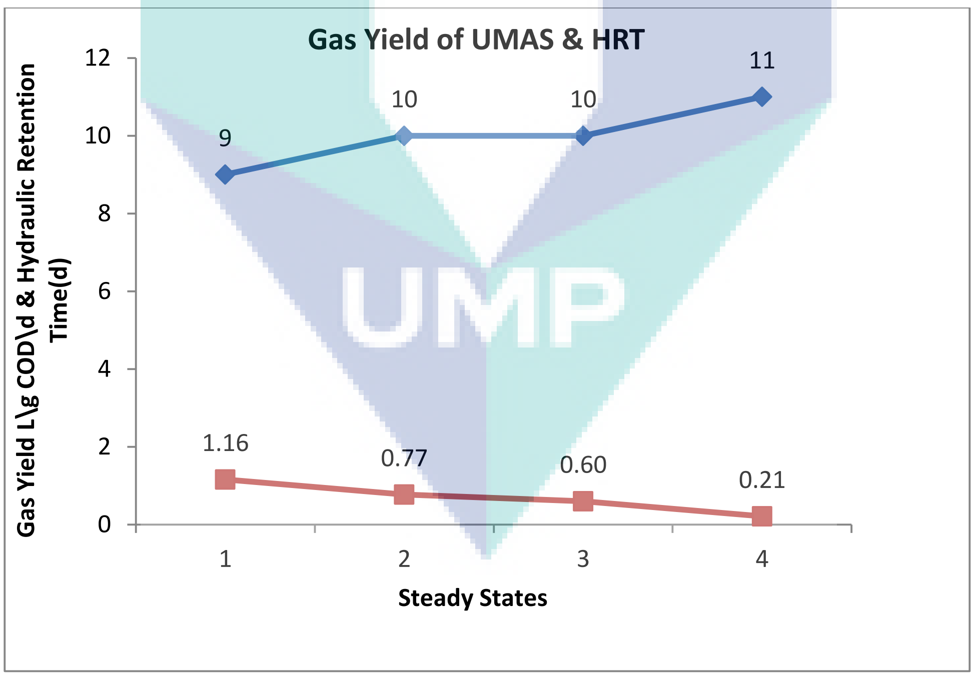

Figure 4.13: Hydraulic retention time and gas yield

However, when the COD concentration decreased to around 796 mg/L or less, the removal rate for the anaerobic reactor was about 61.77 mg/L. This rate was similar to that of the initial stage, but significantly less than that of the last stage. This observation may be interpreted using the different degradation natures and the process affected by many factor controlled the UMAS performance. This study showed that was able to treat concentrated organics more efficiently, but the effluent COD was highly depending on the solid retention time (McCarty and Rittmann, 2001).

4.7.6 Effect of Nutrients in Biogas Production

The presence of ions in the feed is a critical parameter since it affects the granulation process and stability of reactors like UMAS. The bacteria in the anaerobic digestion process requires micronutrients and trace elements such as nitrogen, phosphorous, sulphur, potassium, calcium, magnesium, iron, nickel, cobalt, zinc, manganese and copper for optimum growth. Although these elements are needed in extremely low concentrations, the lack of these nutrients has an adverse effect upon the microbial growth and performance. Methane forming bacteria have relatively high internal concentrations of iron, nickel and cobalt. These elements may not be present in sufficient concentrations in wastewater streams from the processing of one single agro-industrial product like corn or potatoes or the wastewater derived from condensates. In such cases, the wastewater has to be supplemented with the trace elements prior to treatment (Hulshoff, 1995). The required optimum C: N: P ratio for enhanced yield of methane has been reported to be 100:2.5:0.5 (Somayaji, 1992). The minimum concentration of macro and micronutrients can be calculated based on the biodegradable COD concentration of the wastewater, cell yield and nutrient concentration in bacterial cells (Hulshoff, 1995). Ammonia is formed in the anaerobic digestion process as a reduction product of the microbial mediated biochemical breakdown of proteins or non-protein nitrogenous compounds (Hobson and Wheatley, 1993).

4.7.7 Effect of Time in Biogas Production

Cacho, (2005) investigated optimization of solids destruction in anaerobic digestion of excess municipal sludge and found that a key factor in anaerobic digestion of wastewater solids is the solids retention time (SRT). Cacho's studies were conducted using selected SRTs (5, 10, 20 and 40 days). Twelve bench scale reactors were used in the experiment. The reactor was divided into the four different SRTs and it was operated under mesophilic conditions. Digester effluent ammonia,, COD (chemical oxygen demand), pH, and VFA (Volatile Fatty Acids) were analysed and evaluated in response to SRT variation.

Ammonia and nitrate concentrations were analysed and were found to correlate directly to HRT and SRT and to solids destruction. Ammonia concentration and organic nitrogen concentration decreased as the SRT increased anaerobic reactor. At a HRT of 9 days the reactor start with ammonia-N and nitrate N concentration were in the range of 3.87-9.3 mg\l respectively and increased in the permeate to 5.18-12.16 mg\l respectively, this indicated that the UMAS facilitated the conversion, composting, and incinerating of organic waste or to simple fermentation processes. At HRT of 11 days the reactor start with ammonia-N and nitrate N concentration in the range of 10.8 -6.99 mg\l and decreased in the permeate to7.73 - 3.15 mg\l respectively. This is good indicator because the process requires and consumes oxygen. And this contributes to the BOD or biochemical oxygen demand of the sewage. The process is mediated by the bacteria Nitrosomonas and Nitrobacteria which require an aerobic (presence of oxygen) environment for growth and metabolism Methanogens use ammonia and nitrate as nitrogen sources. Analyses of supernatant samples from the anaerobic digesters showed that the concentration of ammonia and nitrate N increased as the SRT increased. This result supported by (Kiyohara et al. 2000). They reported that there The concentration of ammonia-N in the mesophilic process increased from 553 mg/L to 1,340 mg/L as the SRT increased from 2.5 to 40 days .

4.7.8 Effect of VFA

At the first and second steady states the volatile fatty acid (VFA) was decrease, this indicate that the reduction in volatile fatty acid facilitated the decomposition or the conversion of the suspended solids and their subsequent to methane (CH4), As shown in many studies, the conversion rates of VFAs to methane vary in the order of acetic acid (HAc) > ethanol (HEt) > butyric acid (HBu) > propionic acid (HPa) (Ren et al, 2003). UMAS performance at first and second steady states condition result in high methane gas content about 93.65% and 91.4 respectively. A possible reason for these findings is that when VFA concentration decreased there was no significant inhibition of the methanogenic bacteria concentration and their activity would not effected these advanced bacteria growth, and consequently accelerated the conversion from VFAs to HAc and the total methane gas consequently became high. These findings are consistent with the results of a previous study by (Ren et al, 2003).

At the third and fourth steady-states, however, the level of volatile fatty acids (VFAs) in the influent and in reactor increased, the percentage of methane was high about 88.79% and85.75% respectively. This result adverted to the fact because in normal condition when the VFA increased in the system, inhibition of methanogens will occur and the production of methane will reduce while the amount of carbon dioxide will increase. Fig 4.14 showed the effect of VFA reduction and the percentage of methane. As shown in many studies, the conversion rates of VFAs to methane vary in the order of HAc > ethanol (HEt) > butyric acid (HBu) > propionic acid (HPa) (Ren et al, 2003). , because propionic acid is the main inhibitor to the activity of methanogenic bacteria may be if the concentration of it is very low comparing with the concentration of the (acetic acid, butyric acid and ethanol) in VFAs, For this reason did not affect the production of methane .A possible reason for these findings is that increases in the HAc and HBu concentrations advanced AB growth, and consequently accelerated the conversion from VFAs to HAc. Decrease in the HPa concentration advanced the growth of AB, and increase the degradation of VFAs, followed by increase in the activity of MB. These findings are consistent with the results of a previous study by Ren et al., 2003. Also the other explanations of these finding may refer to this studied substrate concentrations examined, MB growth rate had a significant negative correlation with the original HPa concentration ($P < 0.01$), and a positive correlation with the original HBu concentration (0.01 < P <0.05), but had no correlations with the original Het and HAc concentrations (P > 0.05) . A partial correlation analysis showed that an excessive original HPa concentration would seriously limit the growth of MB and reduce the methane yield, while increase in the original HEt ,HAc and HBu concentrations would enhance the methane yield (Ren et al, 2003).

Another possible reason may refer to (certain methanogens also capable to converting other substrate to methane such as converting (hydrogen , acetate ,formate ,methanol ,trimethylamine,dimethalamine and monomethylamine) to methane. (B.K Ahring et al, 1995) Several studies shown that high concentration of VFA have no effect on the biogas process.

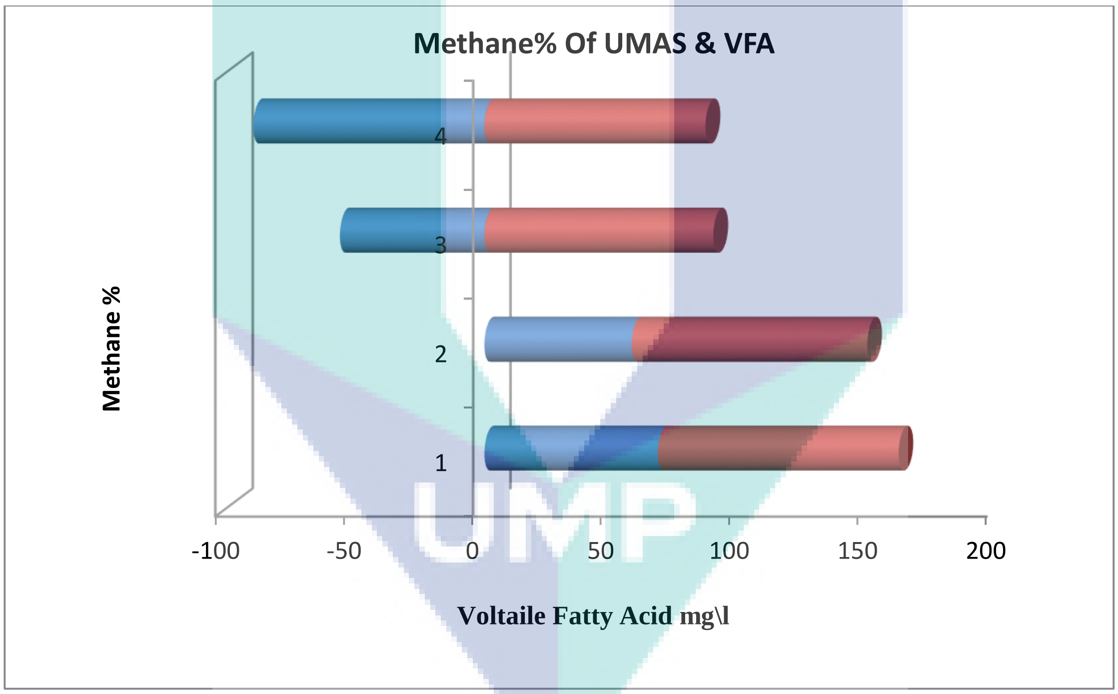

Figure 4.14: The relationship between VFA reduction and the percentage of methane.

4.7.9 Effect of TSS on Cumulative Biogas Yield

Total suspended solid in waste water measurement usually abbreviated in TSS. Total suspended solids (TSS) are solids (i.e., sediment, decaying plant and animal material, industrial waste, sewage) that can be filtered out. High TSS can increase surface water temperature and decrease water clarity. Surface water temperature increases because the suspended particles absorb heat from sunlight. Because warmer waters hold less dissolved oxygen, dissolved oxygen levels tend to fall even further.

4.7.10 Effect of pH on Cumulative Biogas Yield

pH is the crucial factor that determine whether the Membrane anaerobic system is working. The microbial community in anaerobic digester is sensitive to pH change. The pH affects the process in 2 ways that are affecting the enzymatic activity by changing their protein structure which may occur drastically as a result of changes in the pH and affecting the toxicity of a number of compounds indirectly eg sulphide toxicity. The optimum pH for methane producing microorganism to achieve optimum growth range between 6.6 and 7.4 (V.S Marcos et al, 2005). Methane producing bacteria require a neutral to slightly alkaline environment (pH 6.8 to 7.5) in order to produce methane (D.A Burke et al, 2001). Acid forming bacteria grow much faster than methane forming bacteria. If acid-producing bacteria grow too fast, they may produce more acid than the methane forming bacteria can consume. Excess acid builds up in the system. The pH drops, and the system may become unbalanced, inhibiting the activity of methane forming bacteria. Methane production may stop entirely.

Besides, the methanogenesis is strongly affected by pH and will be inhibited by the acid condition. The optimum pH for the methanogenesis stage is pH between 7.2- 8.2 .If the pH fall below the pH of 6, anaerobic degradation rate will decrease and the lipids are not degraded (Ling,L.Y., 2007).The Acetic and butyric acids are favourable substrate for methanogens which form under neutral and acidic condition. In addition, sudden pH change (pH shock) can adversely affect the process, and recover depend on series of factors, related to the type of damage caused to the microorganism (either permanent or temporary). The buffer capacity used must be understood to avoid changes in pH (V.S Marcos et al, 2005).

The activity of anaerobic reactions are highly pH dependent. The optimal pH range for methane producing bacteria is 6.8±7.2 while for acid-forming bacteria, a more acid pH is desirable (Mudrak and, Kunst ,1986). The pH of an anaerobic system is typically maintained between methanogenic limits to prevent the predominance of the acid-forming bacteria, which may cause VFA accumulation. It is essential that the reactor contents provide enough buffer capacity to neutralize any eventual VFA accumulation, and thus prevent build-up of localized acid zones in the digester. In general, sodium bicarbonate is used for supplementing the alkalinity since it is the only chemical, which gently shifts the equilibrium to the desired value without disturbing the physical and chemical balance of the fragile microbial population (Hulshoff, 1995). Throughout the study period, PH in the reactor varied from (6.8 -7.2) .Fig 4.15 showed the effect of pH. It may be illustrated that pH is slightly changing along the treatment process indicating the alkalinity raised with time, however the days between 3 And 8 Lowest PH levels was shown, but then it increased with time. The pH range was found within the prescribed permissible limit for wastewater (6.8-7.5) .The study was observed that there was no significant change in pH value during the interior operation period. The reactor pH is slightly changing during the experimental period with values around 6.8, 7.1, 7.2 and 7.00 in steady state 1, 2,3 and 4, respectively. As shown in Fig 4.15, the slightly changing in the alkalinity levels of PH indicating process stability.

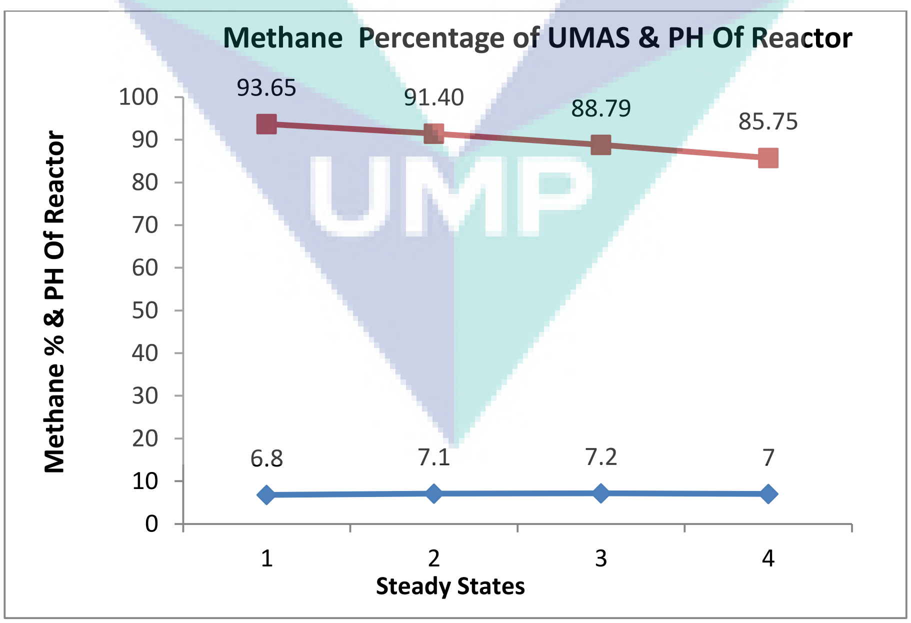

Figure 4.15: The relationship between pH reactor and the percentage of methane.

4.8 GAS PRODUCTION AND COMPOSITION

Many factors must be adequately controlled to ensure the performance of ultrasonic membrane anaerobic digesters and prevent failure. For sewage sludge treatment, these factors include pH, operating temperature, Suspended Solids, Chemical Composition of Wastewater, Toxicants, Retention Time , nutrient availability and organic loading rates into the digester. In this study, the microbial community in the anaerobic digester was sensitive to pH changes. Therefore, the pH was maintained in an optimum range (6.8-7.5) (by addition of NaOH) to minimize the effects on methanogens that might biogas production. Because methanogenesis is also strongly affected by pH, methanogenic activity will decrease when the pH in the digester deviates from the optimum value. Mixing provides good contact between microbes and substrates, reduces the resistance to mass transfer, minimizes the build-up of inhibitory intermediates and stabilizes environmental conditions.

This study adopted the mechanical mixing and biogas recirculation. Fig. 4.16 shows the gas production rate and the methane content of the biogas. The methane content generally declined with increasing OLRs. Methane gas contents ranged from 85.75 % to 93.65% and the methane yield ranged from 0.16 to 0.99 CH_4/g COD/d. Biogas production increased with increasing OLR. The decline in methane gas content may be attributed to the higher VFA, which favours the growth of acid forming bacteria over methanogenic bacteria. In this scenario, the higher rate of carbon dioxide; (CO_2) formation reduces the methane content of the biogas.

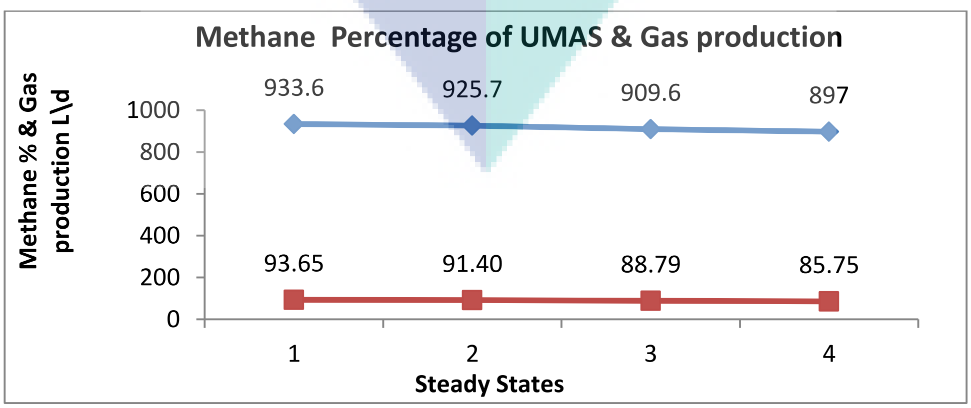

Fig 4.16: Gas production and methane content

CHAPTER 5

CONCLUSIONS AND RECOMMANDATIONS

5.1 INTRODUCTION

This chapter has been designed into two main stages, which is covering the overall conclusion that can be made from the findings obtained during the work followed by recommendation of ideas for further work in order to gain better results.

5.2 CONCLUSIONS

As a new approach ultrasonic treatment effects on anaerobic digestion of waste sludge were examined in this study. Experimental results showed that using an ultrasonic homogenizer as a disintegration method improved processing of the sludge's. Experimental studies showed that the treatability and the degradation of sludge increased significantly with increasing SRT and HRT. The ultrasonic membrane anaerobic system, UMAS seemed to be adequate for the biological treatment of sewage sludge wastewater, since reactor volumes are needed which are considerably smaller than the volumes required by the conventional digester. UMAS were found to be an improvement and a successful biological treatment system that achieved high COD removal efficiency in a short period of time (no membrane fouling by introduction of ultrasonic). Higher reductions in COD were obtained in ultrasonic membrane anaerobic system .The overall substrate removal efficiency was about 85.28%. Nitrogen concentration in sludge was increased with increasing time.

Maximum methane production was achieved .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 for the use in the sewage sludge wastewater. Preliminary data on anaerobic digestion at 30 ^{o}C in UMAS showed that the proposed technology has good potential to substantially reduce the pollution load of sewage sludge wastewater. UMAS was efficient in retaining the biomass. The UMAS process will recover a significant quantity of energy (methane 93.65%) that could be used to heat or produce hot water at the sewage sludge.

5.3 Future work and Recommendations

The growing interest of the researchers in the process of UMAS is a testimony to the viability and applicability of the process .High ultrasonicated membrane anaerobic system treatment (UMAS) would reduce treatment costs by increasing the digestion rate and eliminating the need for cooling facilities prior to biological treatment (Chiemchaisri et al., 1995). Thus using UMAS for the treatment is a challenging and interesting area, in this research work it is limited to study the steady state operation to provide continuous addition of feed solution (Raw sewage sludge) by gravity flow, from feeder tank which is on top of the reactor. In future this study could improve using specific type of ultasonic against specific type of membrane anaerobic to increase the production methane, thus the performance of full process of UMAS will be increased and can produce more methane as well as it will reduce the time and cost.

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Appendix

Publication

Altoum, E.H. and Nour A.H. 2013. Performance of ultrasonicated membrane anaerobic (UMAS) under steady state conditions. *International Journal of Biotechnology and Allied Fields*. **1**(4): 243-249.