STUDY THE EFFECT OF ULTRASONIC MEMBRANE ANAEROBIC SYSTEM (UMAS) IN TREATING LANDFILL LEACHATE AND METHANE GAS PRODUCTION

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Thesis submitted on partial fulfillment of the requirements

for the award of the degree of

Bachelor of Chemical Engineering (Pure)

Faculty of Chemical and Natural Resources Engineering

UNIVERSITI MALAYSIA PAHANG

JULY 2014

ABSTRACT

Direct discharge of landfill leachate leads to severe environmental pollution due to its high chemical oxygen demand (COD), biological oxygen demand (BOD), Total Suspended Solid (TSS) and Volatile Suspended Solid (VSS). Therefore, leachate needs proper treatment before discharging it into the river in order to reduce environmental pollution. This paper presents the study to evaluate efficiency of ultrasonic membrane anaerobic system (UMAS) in treating landfill leachate. This study is also an attempt to apply waste to energy concept by capturing methane gas from biodegradation of landfill leachate. Landfill leachate was treated using membrane anaerobic system (MAS) for seven days and UMAS for another seven days to compare the effect of membrane treatment and ultrasound added membrane treatment in treating landfill leachate and generating methane gas. The performances of both systems were analyzed based on COD, BOD, TSS and VSS removal efficiency as well as methane production. Throughout the experiment, COD removal was 92.6% for UMAS while 82% in MAS. BOD removal efficiency was higher in UMAS which was 83.2% compared to MAS which is only 71.5%. UMAS achieved TSS removal of 95.6% which is higher than MAS which only able to remove 80% of TSS. VSS removal in UMAS was 95% while MAS only achieved 74% of VSS removal efficiency. Methane gas production was 80.7% in UMAS and 71.3% in MAS. UMAS has also reduced membrane fouling and recovered permeate volume. The results obtained clearly show that UMAS is an effective system in treating landfill leachate and producing methane gas by reducing membrane fouling. Thus, this study will be useful in providing an effective way to treat leachate as well as affording an alternative renewable energy source in order to reduce the dependency on fossil fuels.

Keywords: Landfill leachate, Methane, Anaerobic digestion, membrane anaerobic treatment, ultrasound

ABSTRAK

Pelepasan terus larut leachate tapak pelupusan akan membawa kepada pencemaran alam sekitar yang teruk disebabkan oleh Permintaan Oksigen Kimia (COD), Permintaan Oksigen Biologi (BOD), Jumlah Pepejal Terampai (TSS) dan Jumlah Pepejal Terampai yang Meruap (VSS) yang tinggi. Oleh itu, leachate perlu dirawat sebelum dilepaskan ke dalam sungai untuk mengurangkan pencemaran alam sekitar. Kertas kerja ini membentangkan kajian untuk menilai kecekapan ultrasonik sistem anaerobik membran (UMAS) dalam merawat leachate tapak pelupusan. Kajian ini juga adalah satu cubaan untuk memerangkap gas metana daripada biodegradasi leachate. Leachate telah dirawat menggunakan sistem anaerobik membran (MAS) selama tujuh hari dan UMAS selama tujuh hari lagi untuk membandingkan kesan rawatan membran dan rawatan membrane ditambah ultrasound untuk merawat leachate dan menjana gas metana. Prestasi kedua-dua sistem telah dianalisis berdasarkan kecekapan penyingkiran COD, BOD, TSS dan VSS serta penjanaan gas metana. Sepanjang eksperimen, penyingkiran COD adalah 92.6 % bagi UMAS manakala 82% untuk MAS. Kecekapan penyingkiran BOD adalah lebih tinggi dalam UMAS iaitu 83.2% berbanding MAS yang hanya mampu memyingkirkan 71.5% daripada BOD keseluruhan. UMAS telah mencapai penyingkiran TSS sebanyak 95.6% iaitu lebih tinggi berbanding dengan MAS yang hanya dapat mengeluarkan 80% daripada TSS. Penyingkiran VSS menggunakan UMAS adalah 95% manakala MAS hanya mencapai 74% daripada VSS keseluruhan. Pengeluaran gas metana adalah 80.7% dalam UMAS dan 71.3% dalam MAS. UMAS juga telah mengurangkan kejadian membran tersumbat dan pulih jumlah meresap. Hasil eksperimen jelas menunjukkan bahawa UMAS adalah sistem yang berkesan dalam merawat tapak pelupusan sampah leachate dan menghasilkan gas metana dengan mengurangkan penyumabatan membran. Oleh itu, kajian ini akan berguna dalam menyediakan satu cara yang berkesan untuk merawat leachate dan juga memberi ruang sumber tenaga boleh diperbaharui alternatif bagi mengurangkan pergantungan kepada bahan api fosil.

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LIST OF ABBREVIATIONS

ABBREVIATION	MEANING
kg	Kilogram
MAS	Membrane Anaerobic System
UMAS	Ultrasonic Membrane Anaerobic System
HRT	Hydraulic Retention Time
BOD	Biological Oxygen Demand
DO	Dissolved Oxygen
COD	Chemical Oxygen Demand
TSS	Total Suspended Solid
VSS	Volatile Suspended Solid
GHG	Green House Gas
TS	Total Solid
NTU	Nephelometric Turbidity Unit
UF	Ultrafiltration
MF	Microfiltration
MBBR	Moving Bed Biofilm Reactor
UASB	Upflow Anaerobic Sludge Blanket
CH_4	Methane
CO_2	Carbon Dioxide
H_2	Hydrogen
MBR	Membrane bioreactor

AnMBR	Anaerobic Membrane Biorector
OLR	Organic Loading Rate
kHz	kilohertz
VFA	Volatile Fatty Acids
L	Liters
CUF	Cross Flow Ultrafiltration
PVC	Polyvinyl Chloride
cm	Centimeter
NAOH	Sodium Hydroxide
mL	Milliliters
mg/l	Milligram/litre
CSTR	Completely Stirred Tank Reactor
POME	Palm Oil Mill Effluent
m^2	Metre square
$L/m^2.h$	Litre per metre square per hour
MLSS	Mixed Liquor suspended solid

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Solid waste is all type of discarded solid substances such as garbage, refuse, trash that exist due to human activities. Wastes are produced mainly from human activities especially from residential, restaurants as well as institutions such as hospitals and schools. Amount of solid wastes generated in Malaysia increasing proportionally to the increasing growth rate of inhabitants. Malaysia has generated 7.34 million tones of solid waste whereby each person generates 1 kg of solid waste per day (Idrus *et al*., 2008). Land filling gets more attention as the best way to eliminate these wastes. This is because land filling is the cheapest way to dispose wastes. Other than its economic advantage, land filling minimizes environmental pollution by allowing controlled decomposition to transform organic materials into relatively inert and stabilized material. However, land filling has its problem of producing effluent liquid known as leachate. Leachate is produced when some of the rainwater percolates through landfill and mixes with the waste.

The main problem caused by leachate is that it contains harmful inorganic, organic and toxic chemicals which can violate the environment (Wong and Malvinic, 1982; Baterman *et al*., 2004). Leachate also can contaminate the waters by mixing with the streams or rivers. The contaminated streams and rivers will then enter and pollute the sea waters. Furthermore, it is also capable to pollute the groundwater aquifiers

(Pfeffer, 1992). The leachate will mix with the groundwater if it reaches the water table. Consequently, this occurrence will affect or pollute nearby drinking water source. Channeling the polluted groundwater to the soil will affect its fertility due to increase in soil acidity.

Therefore, leachate is needed to be treated in order to reduce the mentioned risks. There are many methods available to treat the landfill leachate. Treatment available will be leachate transfer (Lema *et al*., 1988) which comprise of combined digestion with domestic sewage, recycling, lagooning with recycling, biological method (Di Laconi *et al*., 2006) which includes aerobic as well as anaerobic treatment last but not least physical or chemical treatments (Meunier *et al*., 2006) which are chemical oxidation, adsorption, chemical precipitation, coagulation/ flocculation, sedimentation/flotation and air stripping.

At the same time, Malaysian government is urged to look for alternative energy due to depleting fossil fuels as well as the rise in oil price. As an appropriate step, Malaysian government has launched The Green Technology Financing Scheme (GTFS) on 26th Jan 2010 to motivate the effect of finding alternative energy. Methane is one of the widely available renewable energy sources. Methane is commonly produced by biogasification of coal (Volkwein *et al*., 1994) as well as hydrogenation of carbon dioxide (Wang *et al*., 2011). These production methods are considered harmful to the environment as the processes will emit greenhouse gases (Jessop *et al*., 1995). Thus, generating methane by anaerobic digestion of renewable biomass such as organic wastes is considered environmental friendly (Chynoweth *et al*., 2001). Therefore, production of methane from landfill leachate is a good way to reduce the risk caused by leachate by turning it into a valuable product such as methane.

Anaerobic digestion is the decomposition of complex organic matters under a condition without oxygen. In this process, the complex matters in the leachate are degraded into biogas which includes methane and carbon dioxide. This decomposition process comprises a sequence of reactions which are hydrolysis, acidogenesis, acetogenesis and methanogenesis (Chandra *et al*., 2012). Methane is generated as the final product of anaerobic digestion. Accordingly, objective of this research which is to produce energy from waste can be achieved.

However, there are huge amount of biomass and harmful organic matters that cannot be removed from leachate by anaerobic digestion. Membrane Anaerobic System (MAS) whereby membrane separation system added to the anaerobic system is able to solve this problem. Membrane system will produce high quality effluent without any biomass or harmful organic matters (Vishvanathan *et al*., 2012; Renou *et al*., 2007 and Lema *et al*., 1988). This is because membrane system able to filter and retain the biomass concentration within the reactor. This will produce a clear effluent without any solid particles contained in it.

Nonetheless, the membrane anaerobic system (MAS) possesses major drawback which is fouling and degradation issue (Huang *et al*., 2011). MAS treating landfill leachate has high tendency to cause membrane fouling as it is concentrated with suspended solids. The suspended solid and bulky organic particles tend to clog the membrane causing the membrane to be inefficient for clean filtration process. This is called membrane fouling. Degradation refers to damage of membrane which is caused by the bacterial growth on the membrane surface. However, it is proposed that the membrane fouling and degradation problem can be solved by passing ultrasonic waves to the membrane (Wen *et al*., 2008). Ultrasonic device attached to membrane anaerobic system will be able to increase the efficiency of anaerobic process as well as produce high quality effluent.

Hence, this study is an attempt to evaluate the performance of Ultrasonic Membrane Anaerobic System (UMAS) to treat landfill leachate by refucing membrane fouling. This study is also an attempt to apply waste to energy concept by producing methane gas from biodegradation of landfill leachate.

1.2 Motivation

Our environment is facing water pollution problem due to direct discharge of untreated landfill leachate into rivers. The strongly polluted leachate is very much acidic and will affect the groundwater if leachate is mixed with groundwater without proper treatment. At the same time, surging oil price have encouraged people to search for alternative energy source such as methane. Therefore, anaerobic digestion of leachate will be able to treat the leachate and at the same time produce methane gas. However, there are huge amount of biomass and harmful organic matters that cannot be removed from leachate by anaerobic digestion. Membrane attached to anaerobic system able to filter and retain the biomass concentration which will produce a clear effluent without any biomass or harmful organic matters. Nonetheless, membrane anaerobic system (MAS) treating landfill leachate has high tendency towards membrane fouling as it is concentrated with suspended solids. Membrane fouling can be solved by passing ultrasonic waves to the membrane. Therefore, ultrasonic membrane anaerobic system (UMAS) is very much feasible as it is able to increase the efficiency of biomethanation as well as produce high quality effluent by reducing membrane fouling.

1.3 Problem Statement

Leachate is a dense wastewater with harmful organic and inorganic substances as well as suspended particles. Direct discharge of untreated leachate to rivers will affect the groundwater if river water containing leachate is mixed with groundwater which will consequently pollute the drinking water source. Concurrently, the increasing oil price urges to find an alternative resource for energy which is methane. Therefore, transforming leachate to valuable product such as methane is a good alternative as it can reduce the risk that caused by the wastewater as well as produce an alternative energy source. Thus, anaerobic degradation of organic waste to energy which is considered more appealing and cost effective makes people grow their interest on wastewater treatment. Membrane anaerobic system (MAS) has been widely used in wastewater treatment in order to produce high quality effluent. However, Ultrasonic Membrane

Anaerobic System (UMAS) is introduced to control fouling in MAS as well as improvise the effluent quality and methane generation.

1.4 Objective of Study

The goal of this research is to overcome the problem statements by achieving the following objectives:

1. To make an overall comparison between Membrane Anaerobic System (MAS) and Ultrasonic Membrane Anaerobic System (UMAS) in treating landfill leachate.

2. To compare the quantity of methane gas generated from the process of using Membrane Anaerobic System (MAS) and Ultrasonic Membrane Anaerobic System (UMAS).

1.5 Scope of Research

This research will be conducted using landfill leachate collected from Jabor landfill, Pahang. In order to achieve the objectives, a 50 L bioreactor is used. The experiment is first carried out using Membrane Anaerobic System (MAS) for HRT of 7 days. Temperature and pH are maintained at optimum condition. The membrane system in the bioreactor is then fit with an ultrasonic device to improvise the MAS to Ultrasonic Membrane Anaerobic System (UMAS). The wastewater is also treated in UMAS for another 7 days in order to compare the efficiency of MAS and UMAS to treat the wastewater and produce methane gas. The performance of the system is analyzed using parameters such as Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Suspended Solid (TSS) as well as Volatile Suspended Solid (VSS) for untreated wastewater and the treated permeate.

1.6 Rationale and Significant of Study.

This study can benefit people by affording an alternate renewable energy that is applicable in industry in order to overcome the dependency on fossil fuel which requires high implementation cost. Furthermore, this system provides an effective way to manage leachate rather than directly discharging it into rivers. This system can be practiced widely by Malaysian municipal authorities to control and reduce the pollution issues related to landfill leachate.

CHAPTER 2

LITERATURE REVIEW

2.1 Landfill Leachate

Leachate is known as aqueous effluent produced as a result of rainwater percolation via wastes, biochemical processes in waste's cells and the inherent water content of wastes themselves (Renou *et al*., 2008; Pokhrel and Viraraghavan, 2004). Leachate will carry along organic, inorganic, heavy matter, colloids and pathogens when it percolates through the wastes (Tatsi and Zoubolis, 2002). Therefore, leachate possesses polluting properties as it is rich in soluble organic and inorganic compounds as well as toxic chemical (Wong and Malvinic, 1982; Baterman *et al*., 2004). Leachate appears in black, yellow or orange colour cloudy liquid with strong odour. Leachate has pungent smell as it contains hydrogen, nitrogen and sulphur rich organic species like mercaptans. It is considered very acidic due to the presence of the components mentioned above. **Figure 2.1** shows the stages of decomposition for domestic landfills in order to form the leachate.

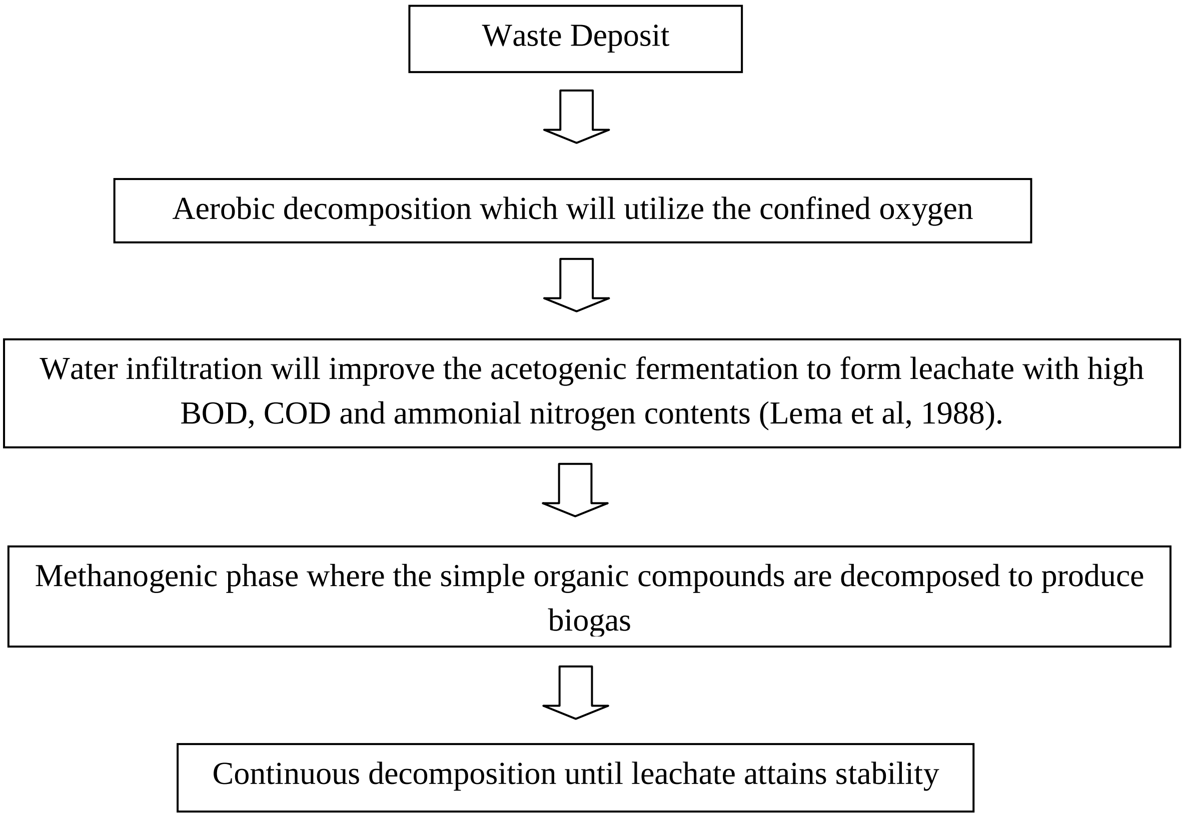

Figure 2.1: Stages of decomposition for domestic landfills in order to form the leachate (Renou *et al*., 2008).

Figure 2.2 shows the landfill leachate generation process. When the landfill waste started to decompose, it will produce liquid. When rainwater passes through these wastes, it will wash out the liquid produced during waste decomposition. The rainwater combined with the waste liquid is called leachate.

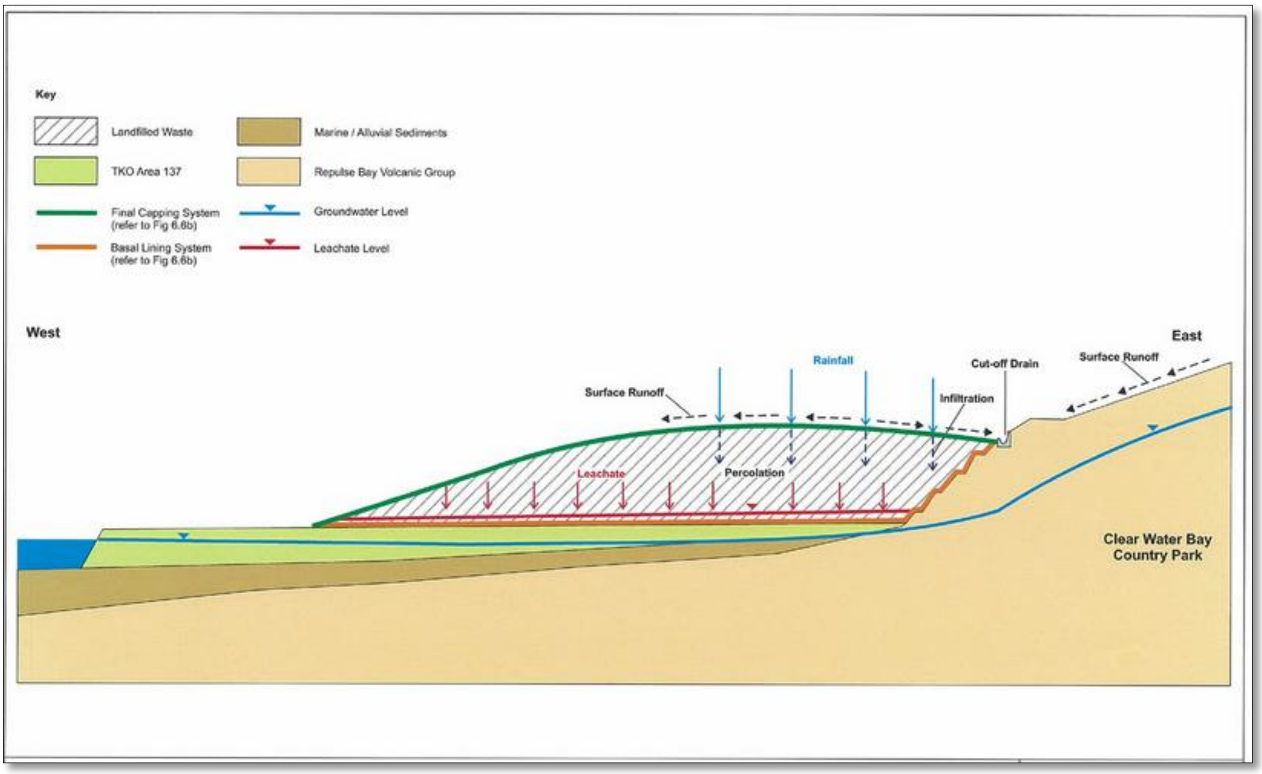

Figure 2.2: Generation process of Landfill Leachate

(Source: Water Quality Assessment at South East New Territories)

Leachate is classified into three types which are young, intermediate and old according to the age of the landfill as shown in **Table 2.1**. The leachate will decompose all the while it is in the landfill. Therefore, the longer the period of leachate in the landfill, the more it will decompose to form a stable leachate with low toxic and undesirable material content. In short, the old leachate is considered to be stable.

Table 2.1: Leachate classification (Baig *et al*., 1940)

Leachate Type	Young	Intermediate	Stabilised
Landfill age (year)	<5	5-10	>10
pH	<6.5	7	>7.5
COD (mg/l)	>10,000	4,000-10,000	< 4,000
BOD/COD	>0.3	0.1-0.3	<0.1
TOC/COD	0.3	-	0.4
Organic Matter	80% VFA	5-30% VFA + HMW	HMW
Nitrogen	100-2000 mg/l TKN		
Biodegradability	High	Medium	Low
Metals (g/l)	2	<2	<2

Basically the leachate is noted as strongly polluted wastewater as it contains harmful inorganic, organic and toxic chemicals (Chian *et al*., 1976). Components of leachate cause adverse effect to the environment and livestock. It is very much acidic and will affect the groundwater if leachate is mixed with groundwater without any proper treatment (Pfeffer, 1992). Hence, the soil will lose its fertility if the groundwater containing leachate is channeled towards the soil.

Table 2.2 shows the comparison of characteristics of the untreated leachate and Malaysian discharge standard of the leachate. Therefore, it is really important to treat the leachate with high COD, BOD, TSS and VSS values compared to Malaysian discharge standard before it can be discharged.

Table 2.2: Characteristics of untreated leachate and the discharge standard in Malaysia (Kashani *et al*., 2012)

Characteristics	**Untreated Leachate**	**Malaysian Discharge Standard**
Total Solid (TS) (mg/l)	6800	4000
Total Suspended Solid (TSS) (mg/L)	1450	300
Volatile Suspended Solid (VSS) (mg/L)	850	Not Available
Biological Oxygen Demand (BOD) (mg/L)	240	250
Chemical Oxygen Demand (COD) (mg/L)	30000	100
Dissolved Oxygen (DO) (mg/L)	2.3	Not Available
Turbidity (NTU)	54.3	Not Available
pH	9	5.5-9

2.2 Methane

Methane is one of the most abundant green house gases in the atmosphere. It is a natural gas and it is used as an energy source to heat houses and commercial buildings as well as to produce electric power. Methane is produced by biogasification of coal (Volkwein *et al*, 1994) as well as hydrogenation of carbon dioxide (Wang *et al*., 2011). However, production of methane gas through these methods will give rise to the environmental problems such as global warming and greenhouse gas (GHG) emission (Jessop *et al*., 1995). Thus, an alternative way is producing methane gas from biomass. Hence, this process uses renewable biomass sources such as organic wastes which are environmental friendly as they could mitigate the carbon dioxide emission by replacing fossil fuels (Chynoweth *et al*., 2001).

Lately, there are many research conducted to generate energy in the form of methane gas using waste products from different industrial waste such as palm oil mill effluent (POME), sewage sludge, animal manure and landfill wastes through anaerobic digestion (Di Palma *et al*., 2002). Anaerobic digestion of organic matter can produce methane gas efficiently; about 75-80% of methane gas can be produced by decomposing organic matter (Lema *et al*., 1988). The process of converting organic matter into methane gas is known as methanogenesis.

2.3 Ultrasound

Ultrasound is a cyclic sound pressure frequency greater than the limit of human hearing range and usually the device can operate at frequencies more than 5 kHz (Chai *et al*., 1998). Ultrasonification is the application of ultrasound and it is being done by inducing cavitation and acoustic steaming by ultrasonic waves. The vibrations caused by those waves able to prevent precipitation and cake formation on the membrane surface thus enhancing the membrane filtration rate. Mikko *et al*. (2004) reported that the presence of ultrasound can enhance membrane permeability and mitigate membrane fouling effectively during wastewater treatment.

2.4 Membrane

Membrane is a selective barrier that able to separate one component from mixture of liquids or gases. The specialty of membrane is that it able to trap suspended particles contained in a fluid. As for this reason, membranes act as viable means for waste water treatment. Ultrafiltration membrane or microfiltration membrane are the common membranes used in waste water treatment plant (Ki *et al*., 2006). The membrane is used in waste water treatment plant to trap the organic and inorganic particles, microorganisms as well as toxic compounds contained in the waste water (Vishvanathan *et al*., 2012). Waste water treatment using membrane technology able to produce clean effluent without any organic or toxic particles (Lin *et al*., 2013). **Table 2.3** shows the filtration process with their properties and application.