ULTRASONICATED MEMBRANE ANAEROBIC SYSTEM (UMAS) FOR SEWAGE SLUDGE TREATMENT

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ABSTRACT

Sewage sludge wastewater causes serious environmental pollution due to its high concentration in term of pollutants. Traditional methods of treating sewage sludge wastewater are disadvantages from both economic and environmental perspectives. In this study, the potentials of Ultrasonic Assisted Membrane Anaerobic System (UMAS) in treating sewage sludge was investigated. The study began with some characterization studies to provide understanding of fundamental issues such as conventional separation, ultrasonic and membrane separations. The aim was to obtain optimum operating conditions, maximum methane production as well as performance of UMAS in treating sewage sludge, upon which further developments on wastewater processes could be developed. A pilot plant scale of UMAS has been used to treat sewage sludge. Different organic loading Rates have been fed to the system, which operated semi continuously at mesophilic temperature and pressure ranges of 1.5 – 2 bar. Seven steady states were attained as a part of a kinetic study that considered concentration ranges of 2670.90 mg/L to 7549.75 mg/L for Mixed Liquor Suspended Solids (MLSS). Kinetic equations from Monod, Contois and Chen and Hashimoto were employed to describe the kinetics of sewage treatment at organic loading rates ranging from 0.904 to 0.952 kg COD/m^3/day, throughout the experiment, the removal efficiency of COD was from 90.6 % to 92.78 %. The growth yield coefficient, Y, was found to be 0.391 g VSS/g COD, the specific microorganism decay rate was 0.012 day^{-1} and the methane gas percentage was between 74 % and 89.64 %. The ammonia and nitrogen removal efficiency were 56-81 % and 56-78 % respectively. The K values were in the range of 0.294 to 0.312 g COD/g VSS/day and μ_{max} values were between 0.287 and 0.312 day^{-1}. The highest color and turbidity removal efficiency were 92.1 % and 96.59 % respectively. The optimum conditions obtained were pH of 6.76 and organic loading rate of 0.90 kg/m^3/d, giving a maximum methane production of 87.3 % while the predicted maximum methane percentage was 88 %. The results obtained in this study have exposed the capability of ultrasonic assisted membrane an aerobic system (UMAS) in treating wastewater. 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 sisa pepejal kumbahan telah menyebabkan pencemaran alam sekitar yang serius kerana tingginya bahan cemar. Kaedah biasa yang digunakan untuk merawat air sisa kumbahan didapati memberi kesan tidak baik kepada ekonomi dan alam sekitar. Dalam kajian ini potensi sistem anaerobik membran dengan bantuan ultrasonik telah dikenal pasti untuk merawat sisa pepejal kumbahan. Kajian ini bermula dengan pengelasan untuk memberi kefahaman terhadap isu-isu asas seperti pemisahan biasa, ultrasonik dan pemisahan menggunakan membran. Objektif kajian ini adalah untuk mengetahui keadaan proses optimum, penghasilan metana yang maksimum dan prestasi UMAS dalam merawat air sisa pepejal yang mana kemajuan dapat dihasilkan dalam proses-proses air sisa. UMAS dengan skala pilot telah digunakan untuk merawat sisa pepejal. Kadar beban organik yang berbeza telah disalurkan kepada sistem berkeadaan separa berterusan pada suhu mesofilik dan lingkungan tekanan antara 1.5 hingga 2 bar. Tujuh keadaan tetap telah dikenal pasti melalui kajian kinetik yang mengambil kira julat kepekatan daripada 2670.90 mg/L kepada 7549.75 mg/L untuk campuran likat pepejal terampai (MLSS). Persamaan kinetik daripada Monod, Contois dan Chen, dan Hashimoto telah digunakan untuk menentukan kinetik rawatan kumbahan pada kadar beban organik dalam julat antara 0.904 hingga 0.952 kg COD/m^3/hari. Melalui eksperimen, kecekapan penyisihan kadar keperluan oksigen kimia (COD) adalah antara 90.6 % dan 92.78 %. Koeffisien penghasilan tumbesaran, Y, yang didapati adalah 0.391 g VSS/g COD, kadar spesifik pereputan mikroorganisma adalah 0.012 hari^{-1} dan peratusan gas metana adalah antara 74 % and 89.64 %. Kecekapan penyisihan ammonia dan nitrogen masing-masing adalah 56-81 % and 56-78 %. Nilai K adalah dalam julat 0.294 to 0.312 g COD/g VSS/hari dan nilai μ_{max} adalah antara 0.287 dan 0.312 hari^{-1}. Warna tertinggi dan kecekapan penyisihan kekeruhan pula masing-masing adalah sebanyak 92.1 % and 96.59 %. Keadaan optimum yang didapati adalah dengan pH 6.76 dan kadar beban organik sebanyak 0.90 kg/m^3/d yang menghasilkan maksimum metana pada 87.3 % manakala maksimum peratusan penghasilan metana yang diramalkan adalah 88 %. Keputusan yang diperolehi dalam kajian ini menunjukkan bahawa sistem membran anaerobik dengan bantuan ultrasonik berupaya merawat air sisa. Oleh itu, kajian pada masa hadapan adalah sangat diperlukan untuk memahami mekanisma yang terlibat secara lebih mendalam bagi membantu membangunkan sistem rawatan yang lebih optimum agar dapat diaplikasikan dalam industri.

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LIST OF SYMBOLS

μ	Maximum Specific Growth Rate (T^{-1})
μ_{max}	Maximum Growth Rate (d^{-1})
b	Specific Microorganism Decay Rate (d^{-1})
B	Specific Methane Production (m3 CH_4/kgVS)
B_o	Ultimate Methane Yield (m^3CH_4/kgLVS)
E_s	Specific Energy (kJ/kgTS)
f	Resonant Frequency KHz
ɣ	Ratio of the Resonant Bubble Radius
K	Chen and Hashimoto Kinetic Constant
K_c	Contois Saturation Constant
K_s	Half Velocity Coefficient (mg COD/L)
P	Applied Power (W)
P_o	Pressure Exerted on the Liquid (bar)
R_r	Resonant Bubble Radius (mm)
r_s	Substrate Utilization Rate (gCOD/m^3.h)
S	Effluent Substrate Concentration (mg/L)
S_o	Influent Substrate Concentration (mg/L)
T	Time
U	Specific Substrate Utilization Rate (SSUR) (gCOD/gVSS/d)
V	Treated Volume (m^3)
X	Micro Organism Concentration (mg/L)
Y	Growth Yield Coefficient (gVSS)/gCOD)

θ	Hydraulic Retention Time (d)
θ_c	Solids Retention Time (mean cell residence time (d)
ρ_w	Density of Water
ω_r	Resonant Angular Frequency

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CCD	Central Composite Design
COD	Chemical Oxygen Demand (mg/L)
CUF	Cross Flow Ultra-filtration Membrane
EDC	Endocrine Disruptor Chemical
PE	Population Equivalent
HRT	Hydraulic Retention Time (d)
MAS	Membrane Anaerobic System
MBR	Membrane Bioreactor
MLSS	Mixed Liquid Suspended Solid (mg/L)
MLVSS	Mixed/liquid Volatile Suspended Solid (mg/L)
MWCO	Molecular Weight Cut- Off
OLR	Organic Loading Rate ($kg/m^3/d$)
pH	Potential Hydrogen
R	Correlation Coefficient
R^2	Coefficients of Multiple Determinations
RSM	Response Surface Methodology
SRT	Solid Retention Time (d)
SS	Steady State
SSUR	Specific Substrate Utilization Rate (kg COD/kgVSS/d)
SUR	Substrate Utilization Rate ($kg/m^3/d$)
TOC	Total Organic Carbon

TSS	Total Suspended Solid (mg/L)
UASB	Upflow Anaerobic Sludge Blanket
UMAS	Ultrasonicated Membrane Anaerobic System
VFA	Volatile Fatty Acids (mg/L)
VSS	Volatile Suspended Solids (mg/L)
WAS	Waste Activated Sludge
VS	Volatile Solid (mg/L)

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Recently there has been rising concern in the global environmental problems, particularly in the global warming issues. This has led to intense research and development of a large diversity of energy saving technologies. Since fossil fuel is the main source of carbon dioxide which emits causing the global warming, it can be replaced with biogas from digesting sludge. One way of using wastewater treatment for global warming counteraction is subrogating fossil fuel with energy from biogas produced from wastewater treatment and also this can share in reducing energy consumption.

The sewage sludge treatment has a substantial purpose to recycle resources without providing harmful substance to humans or environment. Also, to avoid the deposit sludge on landfill since the degradation of its organic constituents on landfill produces carbon dioxide and methane which recirculates carbon back to the atmosphere and causes global warming (Wang et al., 2010). Sewage sludge is produced during wastewater treatment in large amounts. It produced as the single largest residual product of the sewage treatment process. This amount is growing hugely with the increase of wastewater treatment. The sludge is disposed of by throwing on land after incineration or dropping on oceans. But since it is in increasing and have dangerous effects on the environment including humans, animals, plants, soils, ground water and air, there are strict legislations related to that. So it must be a proper treatment of the sludge (Arthurson, 2008).

Biological processes like aerobic and anaerobic digestion are most used for sludge degradation, which not only minimize the disposed sludge volume, but also produces valuable methane gas (during anaerobic digestion) and high quality bio-solids for soil application. Aerobic digestion is economically non viable to treat big quantities of sludge, due to the large capacity aerator which consumes high energy resulting in very expensive process (Oh, 2006). Therefore anaerobic process is the most implemented in medium and massive wastewater treatment plant. Anaerobic disintegration of organic matter particles and macromolecules undergo to series of four steps which are namely hydrolysis, acidogenesis, acetogenesis, and methanogenesis. In the sewage disintegration condition, the hydrolysis has been identified as the rate limit step. So, the pretreatment of sewage sludge using chemical, mechanical, or thermal disintegration could ameliorate the following anaerobic degradation. The sludge retention time in the anaerobic digestion reactor can be reduced from the standard of 15-30 days, if sludge disintegration is utilized and the hydrolysis reaction is accelerated. Consequently, more investment and operating costs can be saved due to the reduced reactor volume, which allows more compact plants (Drinan, 2001).

Waste water bio-solids are mainly composed of highly putrescible volatiles compared to forest and agricultural bio-solids. It is very important to treat the raw sewage sludge biologically assuring an ensuing environmentally safe utilization and disposal. The standard stabilization process for waste water solids is the anaerobic fermentation. In this process a net reduction of the bio-solids mass and volume is realized (Arthurson, 2008). Anaerobic disintegration takes place as a series involve molder of biodegradable matter by microorganisms in deprivation of oxygen. It is utilized for domestic or industrial aims of dumb management and/or energy production. Anaerobic disintegration is the solitary in the renewable energy methods that is quite thoughtful, totally scalable, and produces an energy production that can be saved directly. Anaerobic disintegration is most applied as a renewable energy provenance due to the release of the methane and carbon dioxide fully loaded biogas during the process which is proper stock for energy generation and fossil fuels replacement. The nutrient-rich output digestate can be utilized as fertilizer (Nickel, 2002). It is highly potential that anaerobic digestion will be carried out growingly at minimal levels if the technology is moreover integrated as a consort to different scalable renewable choices like wind and photovoltaic solar cells. But due to the shortages of the anaerobic the membrane separation process has been introduced to overcome the anaerobic limitations.

The separation by means of membrane includes molecules transportation across a film. This is usually a solid and can also be a liquid. The membrane can be a homogeneous material or a composite material with a very thin active layer supported by a stronger but more porous material. Membrane processes have received considerable interest during recent years, and many new research programs have begun during the last 10 to 20 years. This growth in interest in membranes has resulted largely from improvements in membrane technology. Interest in membrane technologies seemed to jump significantly with the discovery (or development) of effective reverse osmosis membranes in the 1960s for desalination (Blackman, 2001). The technology of membrane bioreactor (MBR) has great chance in several varieties of applications which involve municipal and industrial wastewater treatment, groundwater and drinking water regression, solid dumb management, and odor control. The feasibility of this technique has been proved via numerous studies in pilot and bench scale. Wide world full scale processes are operational and substantial growth in the number and volume is in prospect for the near future (Cicek, 2003). Membrane bioreactor systems have stood out as an efficient solution to transforming change wastewater into high quality discharge appropriate to be disposed into the environment and furthermore into a reusable product. The membrane have disadvantage of fouling which is a major problem since cost high expenditure and waste a lot of time for cleaning. Incorporating ultrasound to anaerobic membrane bioreactor is expected to make good control for membrane fouling.

The primary effect of ultrasound on a liquid (or sludge) is the formation of cavitation bubbles. The effects are either used as the destructive powers of the imploding bubbles or the degassing effect of bubbles rising to the surface audible range. A wave propagates in a liquid through alternating cycles of compression (high pressure) and rarefaction Ultrasound has a frequency of 20 kH_z and above. Above certain intensity the attractive forces of the liquid can be overcome during rarefaction and a small bubble is formed; a phenomenon called cavitation. Dissolved gas and other impurities in a liquid can act as nuclei for cavitation bubbles (Dewil et al., 2007). Instead they grow and fill with more dissolved gas from the surrounding liquid and eventually rise to the surface, finally giving rise to a degassing. Traditionally ultrasound has been used to degas a variety of water-based liquids and metal smelt (Anders, 2005). Anaerobic digestion of wastewater treatment sludge is slow and incomplete as a conclusion for the rate-limiting step (sludge hydrolysis), because of the presence of extracellular biopolymers and the weak biodegradability of the cell walls. Procedures to improve the biogas production should maximize the substrate constituent's availability to the microorganisms. Different pre-treatments have been investigated such as chemical, thermal and mechanical (Dewil et al., 2007; Müller et al. 1998 and Climent et al., 2007). All pretreatments lead to some degrees of disintegration of sludge cells. Low-frequency ultrasound treatment is found to be as a convenient technology (Appels et al., 2008).

1.2 PROBLEM STATEMENT

Sewage sludge disposal is an arising environmental problem. The conventional disposal is a major source of pollution and need very large land area. The conventional methods of sludge stabilization like composting, burring or incineration are not adequate for eliminating the negative effects of the sewage sludge. The proper treatment of sewage sludge is very important not only for humans, but for animals, plants, air and soil as well. Since the accumulation of the organic materials without degradation will interrupt the integrated system of natural life. Sludge stabilization is a prevalent acting with anaerobic disintegration as predominant operation due to organic matter is conversion to biogas, thus the final amount of sludge to be disposed is reduced, which is odour free and rich nutrients to use as fertilizer. Also possible hazards can be limited when the micro-organisms present in the sludge are considerably destroyed. Different methods for pre-treatment have been investigated involve mechanical, thermal, chemical and biological interferences (Dewil et al., 2007; Neyens and Baeyens, 2003 and Climent et al., 2007). All of the methods concluded with a certain degree of lysis or degradation of sludge cells, thus putting out and solubilizing intracellular matter into the water and switching refractory organic components into biodegradable substance. The anaerobic digestion technology has become very important since it is a renewable energy source which can be used instead of the other polluting and limited energy sources. The anaerobic digestion is time consuming, large reactor volumes are needed and has low efficiency in case of low concentration wastewater in cold climates. So, the membrane system introduced to overcome the anaerobic reactor limitations. However membrane fouling is an obstacle since it needs additional cost and time for cleaning and replacement.

Obviously there is gap in the methods and technologies using for sewage sludge treatment. So, by this research we are trying to fill this gap using Ultrasonicated Membrane Anaerobic System (UMAS) technology. In which the membrane was attached with ultrasound in order to prevent the membrane foaling. By this way there is a more feasible, helpful and environmentally friendly method.

1.3 OBJECTIVES

The main objectives of the current work are:

1. To experimentally assess the effect of organic loading rates and retention time on methane production.

2. To assess the performance of UMAS in the treatment of sewage sludge and production of methane.

3. To evaluate the application of three known kinetic models (Monod, Contois and Chen and Hashimoto).

4. To determine the optimum conditions of methane gas CH_4 production by the UMAS, using response surface methodology (RSM).

1.4 SCOPES OF STUDY

The scopes that have been identified to accomplish the above objectives are:

- To design a 50 L digester (Reactor) for sewage sludge treatment.
- To evaluate the overall microbial kinetics.
- To determine the deferent coefficients of the three mentioned kinetic models.
- To monitor parameters such as BOD, COD, TSS, VSS, VFA, pH.
- To determin the optimum conditions for maximum methane gas production via sewage sludge treatment using UMAS by applying factorial design of Response Surface Methodology Using Design-Expert software.

1.5 OVERVIEW OF THE THESIS

This thesis consists of five chapters: Chapter one states the back ground of the research, problem statements, objectives of the research, scopes of the study as well as overview for the thesis. Chapter two is presenting different concepts and literature review about ultrasonicated membrane anaerobic reactor for sewage sludge treatment. Chapter three presents the materials and chemicals used and the details of the methods and procedures of the experiments run to achieve the aims of this study. Chapter four contains the results of the experiments and the discussions of these results. In chapter five the thesis has been concluded and summarized outcomes of this research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Sewage sludge is an inevitable side product of wastewater treatment. Raw sludge in addition to organic carbon and microorganisms are loaded with heavy metals and different environmental pollutants. Therefore, this sludge should be settled so that it can be safely disposed or utilized. The cost to treat sewage sludge is very high and longer time is needed for the treatment.

Rapid urbanization, a consequence of economic development and increased population has led to production of huge quantities of sewage sludge in Malaysia and has serious environmental problems for their disposal. In Malaysia, sewage sludge mainly produced from domestic and light industrial areas. In 2007, the yearly feed-rate of domestic wastewater entering wastewater treatment plants throughout the country was estimated at 4.9 million cubic meters. In 2011, the sludge production capacity of Malaysian domestic wastewater treatment plants is estimated at approximately million cubic meters per year and resulted in an annual disposal cost of US$ 0.3 billion (Abbas et al 2011). Based on the perspective on sludge production factor (SPF), about 5.3 million m^3 per year of sewage sludge was handled by a national sewage company, Indah Water Konsortium (Salmiati et al 2012). The amount of sludge produced and treatment options in Malaysia are shown in Table 2.1. In Malaysia, there are numerous environmental and health risk related issues associated with the disposal of domestic sewage sludge in which if not mitigated, will cause serious problems to the country. Sewage sludge enters into soils due to illegal damping, disposal in landfill, septic tanks, leaking sewer lines and land application. Sewage sludge contains heavy metals, which affects soil quality and human health and high concentrations of heavy metal are harmful to plants, animals and humans (Majid et al 2012).

Table 2.1: Amounts of sludge produced and treatment options in Malaysia.

Sludge	Generation rate (million m^3)	Treatment options (million m^3)	
		Centerlized facilities*	Non-centerlized facilities
Sewage sludge	7.40	5.30	2.10
Industerial sludge	9.90	6.40	3.50

*Bio-Soil (BS), Bio-Filter (BF), Rotating Biological Filter (RBC), Sewage Aeration Treatment System (SATS), Hi-Kleen (HK), Fine Bubble Activated Sludge (FBAS).

Source: Salmiati et al., (2012)

2.2 SEWAGE SLUDGE

Sewage sludge can be defined as the solids discarded during wastewater treatment. It contains settleable solids such as (depending on its origin) fecal material, fibres, alluvium, food dumps, biological flocs, organic and inorganic chemical components. Sludge can be assorted to primary sludge, secondary sludge and chemical sludge.

2.2.1 Primary Sludge

Primary sludge is produced from the isolation of precipitate solids of the raw wastewater through the treatment operation of the primary sedimentation. The concentration of the overall solids in raw primary sludge varies between 5% and 9%. Primary sludge solids generation may range normally from 0.1 kg/m^3 to 0.2 kg/m^3 out of wastewater treated. Generally, one-third of the influent wastewater biochemical oxygen demand (BOD) is combined with the primary sludge of which the main portions

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CHAPTER 3

MATERIALS AND METHODS

3.1 INTRODUCTION

In this chapter, specific focus will be given on describing the experimental design, the operational methods used and the procedures of different experiments, which needed to be done for this research. It is also together with sample collection and preservation, the analytical methods and calculations for the sewage sludge samples.

3.2 SAMPLE COLLECTION AND MONITORING

Sewage sludge samples were gathered from the anaerobic tank in the wastewater treatment plant, which belongs to Indah Water Consortium Kuantan in the state of Pahang, Malaysia, with 1500 PE capacity. Samples were kept in PVC vessels at a temperature of around 4°C, but higher than freezing point, for the reason of controlling the sludge from subjecting to biodegradation due to microbial reaction. The conservation of samples and the experimental work was implemented in the Environment Laboratory, Faculty of Chemical and Natural Resources Engineering, UMP, Malaysia.

3.3 EXPERIMENT PILOT SCALE

The Ultrasonicated membrane Anaerobic System (UMAS) consisted of a cross flow ultra-filtration membrane (CUF) with a number of four membranes, a centrifugal pump, an anaerobic digester of effective volume of 50 L and 6 ultrasonic transducers that were fasten to the membrane unit holder and linked to one unit of 250 watts 25 KHz Crest's Genesis Generator as shown in Figure 3.1 and Figure 3.2. The UF have 2000 Daltons of molecular weight cut-off (MWCO), a mean pore size of 0.1 µm with each tube was 30 cm at length and a diameter of 1.25 cm. The overall area of the membrane was 0.048 m^2. The ultimate operating pressure on the membrane was 55 bar at 70°C, and it works at all pH ranges. The reactor was consisting of a heavy duty reactor with 15 cm inner diameter and 100 cm length. The operating pressure in this research was preserved in the range of 1.5 bar and 2 bar by tampering on the gate valve at the retentate line after the CUF unit.

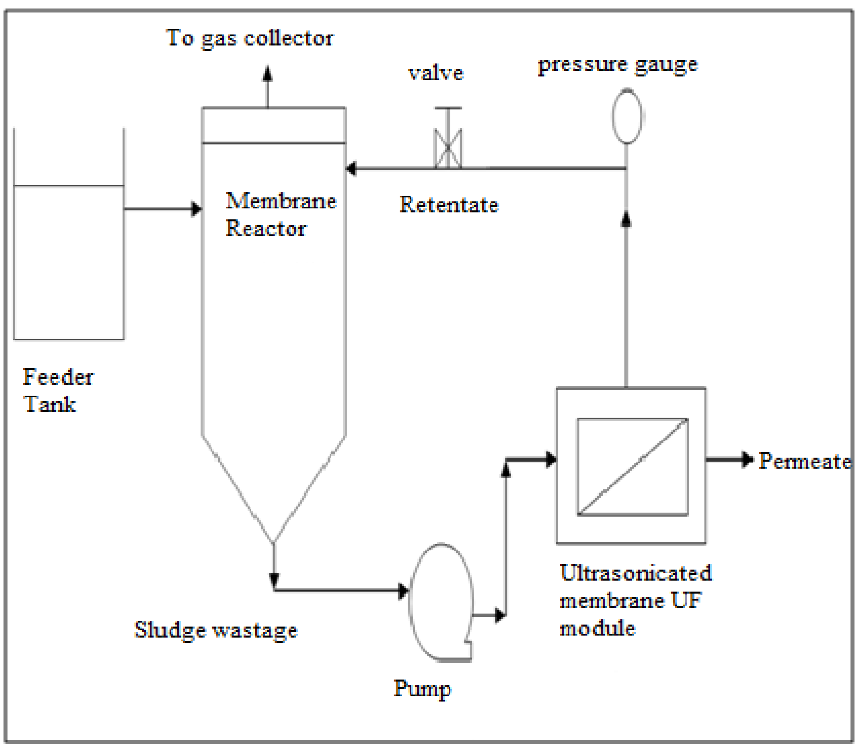

Figure 3.1: A schematic diagram for the ultrasonicated membrane anaerobic system.

Figure 3.2: Ultrasonicated membrane anaerobic system.

3.3.1 The Anaerobic Reactor Set up

The reactor which was made of PVC, was covered with aluminium foil to prevent the direct light. The reactor volume was 50 L with inner of 15 cm and it was a 100 cm of total height.