ULTRASONIC ASSISTED MEMBRANE ANAEROBIC SYSTEM (UMAS)

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STUDENT'S DECLARATION

I declare that this project report entitled *"Ultrasonic Assisted Membrane Anaerobic System (UMAS)"* is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : NURULASMA BINTI ZAINUDIN

Date : .....

To my beloved father, mother, father in law, mother in law, my husband, my daugthers and all of my family members

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ABSTRACT

The direct discharge of Palm oil mill effluent (POME) wastewater causes serious environmental pollution due to its high chemical oxygen demand (COD), Total suspended solids (TSS) and biochemical oxygen demand (BOD). Traditional ways for POME treatment have both economical and environmental disadvantages. In this study, ultrasonic assisted-membrane anaerobic system (UMAS) was designed used as an alternative, cost effective method for treating Palm oil mill effluent (POME) wastewater. This system has a value proposition and advantage in market segmentation. Through the market strategies and financial analysis, the future market of the system can be easily to penetrate. Six steady states were attained as a part of a kinetic study that considered concentration ranges of 12,960 to 25,600 mg/l for mixed liquor suspended solids (MLSS) and 10,091 to 22,528 mg/l for mixed liquor volatile suspended solids (MLVSS). Kinetic equations from Monod, Contois and Chen & Hashimoto were employed to describe the kinetics of POME treatment at organic loading rates ranging from 0.5 to 9.5 kg COD/m^3/d. Throughout the experiment, the removal efficiency of COD was from 96.6 to 98.5% with hydraulic retention time, HRT from 480.3 to 5.4 days. The growth yield coefficient, Y was found to be 0.58gVSS/g COD the specific microorganism decay rate was 0.21 d^{-1} and the methane gas yield production rate was between 0.27 l/g COD/d and 0.59 l/g COD/d. Steady state influent COD concentrations increased from 67,000 mg/l in the first steady state to 91,400 mg/l in the sixth steady state. The minimum solids retention time, θ_c^{min} which was obtained from the three kinetic models ranged from 6 to 15.6 days. The k values were in the range of $0.36-0.525$ g COD / g VSS. d and μ_{max} values were between 0.28 and 0.377 d^{-1}. The solids retention time (SRT) decreased from 860 days to 10.6 days. The complete treatment reduced the COD content to 3000 mg/l equivalent to a reduction of 98.6% reduction from the original.

ABSTRAK

Pelepasan sisa air kilang kelapa sawit (POME) secara langsung menyebabkan pencemaran alam sekitar yang serius berikutan keperluan oksigen kimia (COD), jumlah pepejal terampai (TSS) dan keperluan oksigen biokimia (BOD) yang tinggi. Cara tradisional untuk merawat POME mempunyai kelemahan ekonomi dan alam sekitar. Dalam kajian ini, sistem ultrasonik dibantu membran anaerobik (UMAS) telah direka dan digunakan sebagai alternatif, kos efektif untuk merawat sisa air kilang kelapa sawit (POME). Sistem ini mempunyai nilai dan kelebihan dalam segmen pasaran. Melalui strategi pemasaran dan analisis kewangan, pasaran masa hadapan sistem ini akan mudah untuk ditembusi. Enam aras stabil telah dicapai sebagai sebahagian daripada kajian kinetik dan dianggarkan kepekatan adalah diantara 12,960 kepada 25,600 mg/l untuk likur campuran pepejal terampai (MLSS) dan 10,091 kepada 22,528 mg/l untuk likur campuran keras pepejal terampai meruap (MLVSS). Persamaan kinetik dari Monod, Contois dan Chen & Hashimoto telah digunakan untuk menerangkan kinetik untuk merawat POME pada kadar beban organik antara 0.5-9.5 kg COD/m^3/d. Sepanjang eksperimen, kecekapan penyingkiran COD adalah daripada 96.6-98.5% dengan tahanan masa hidraulik, HRT daripada 480.3 hingga 54 hari. Pekali hasil pertumbuhan, Y telah didapati menjadi 0.58gVSS / g COD, kadar spesifik pereputan mikroorganisma adalah 0.21 d^{-1} dan kadar hasil pengeluaran gas metana adalah antara 0.27 l/g COD/d dan 0,59 l/ g COD/d. Aras stabil yang mempengaruhi kepekatan COD telah meningkat daripada 67,000 mg/l dalam aras stabil pertama hingga 91,400 mg/l aras stabil keenam. Masa tahanan minimum pepejal θ_c^{min} yang telah diperolehi daripada tiga model kinetik antara 6 hingga 15.6 hari. Nilai K adalah dalam julat $0.36 - 0.525$ g COD / g VSS. d dan nilai-nilai μ_{max} adalah antara 0.28 dan 0.377 d^{-1}. Tahanan masa pepejal (SRT) telah menurun dari 860 hari kepada 10.6 hari. Rawatan lengkap telah mengurangkan kandungan COD hingga 3000 mg/l bersamaan dengan 98.6% pengurangan daripada yang asal.

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LIST OF ABBREVIATIONS

COD	-	Chemical Oxygen Demand (mg/l)
OLR	-	Organic Loading Rate (kg/m^3/d)
CUF	-	Cross flow Ultra-Filtration membrane
SS	-	Steady State
SUR	-	Substrate Utilization Rate (kg/m^3/d)
TSS	-	Total Suspended Solid (mg/l)
MLSS	-	Mixed Liquid Suspended Solid (mg/l)
HRT	-	Hydraulic Retention Time (day)
SRT	-	Solids Retention Time (day)
SSUR	-	Specific Substrate Utilization Rate (kg COD/kg VSS/d)
MAS	-	Membrane Anaerobic System
UMAS	-	Ultrasonicated Membrane Anaerobic System
MLVSS	-	Mixed Liquid Volatile Suspended Solid (mg/l)
VSS	-	Volatile Suspended Solids (mg/l)
MWCO	-	Molecular Weight Cut-Off
BLR	-	Biological Loading Rate
CAGR	-	Compound Annual Growth Rate
GNI	-	Gross National Income
EPP	-	Entry Point Project
NKEA	-	National Key Economic Areas
CDM	-	Clean Development Mechanism
SWOT	-	Strength, Weaknessess, Opportunities, Threats

LIST OF SYMBOLS

X	Microorganism concentration (mg/I)
t	Time (day)
b	Specific microorganism decay rate (day^{-1})
Y	Growth yield coefficient (gVSS/gCOD
U	Specific substrate utilization rate (kgCOD/kgVSS/d)
A	Maximum specific growth rate (T^{-1})
S_0	Influent substrate concentration (mg/l)
S	Effluent substrate concentration (mg/l)
K_s	Half velocity coefficient
θ	Hydraulic retention time (day)
θ_c	Solids retention time (mean cell residence time (day)
y	The displacement at any time (t)
ω	The angular frequency
f	The frequencies of the wave
u_o	Particle velocity amplitude
p_o	Pressure amplitude
Z_a	Acoustic impedance
R_a	Electrical resistance
P	Density of medium
c	Velocity of sound
δ	Logarithmic decrement
A_0	The initial amplitude
A_n	The amplitude after n complete cycle
y	Displacement at certain position (x) at time
C	Certain velocity
λ	Wavelength
ρ_m	The density of the mixture calculated from the mixing rule
C	Compressibility of the mixture calculated from the mixing rule
D	The wavelength
I	The intensity of the wave after it has traveled the distance
x	Through the medium

I_0	The intensity at x = 0
α	The absorption coefficient.
A_{sw}	The sums of the amplitude of the individual waves
P_{sw}	The sums of the amplitude of the individual waves
β_w	Compressibility of the medium
β_c	Compressibility of the particles
P_c	Density of the medium
ρ_w	Density of the particles
V_c	Volume of the particle
E_{ac}	Energy density of the acoustic wave
Z	Distance from the pressure node
R	Radius of the droplet Wave number
k	Acoustic contrast factor
V_1	The volumes of the two interacting droplets
V_2	The volumes of the two interacting droplets
d	The separating distance between them
F_d	The hydrodynamic drag force
μ	The viscosity of the fluid
$\hat{\mu}$	The ratio of the viscosities of the drop to the continuous phase
V°	The speed of the drop
$\zeta 1$	Amplitude of the wave travelling in the position x direction
$\zeta 2$	Amplitude of the wave travelling in the position opposite direction
ϕ	Phase angle between the two waves
E_{ac}	Energy density of acoustic field
Z	Distance from the pressure node
R	Radius of the drop
K	Wave number in the hosting fluid

LIST OF APPENDICES

CHAPTER 1

PROJECT INTRODUCTION

1.1 Project background

Palm oil mill effluent (POME) is an important source of inland water pollution when released into local rivers or lakes without treatment. The production of palm oil, however, results in the generation of large quantities of polluted wastewater commonly referred as palm oil mill effluent (POME). In the process of palm oil milling, POME is generated through sterilization of fresh oil palm fruit bunches, clarification of palm oil and effluent from hydro-cyclone operations (Borja et al., 1996a).

Figure 1.1: A palm oil mill effluent pond in West Kalimantan, Borneo.

POME is a viscous brown liquid with fine suspended solids at pH ranging between 4 and 5 (Najafpour et al., 2006). Figure 1.1 is shown a palm oil mill effluent pond in West Kalimantan, Borneo.

In general appearance, palm oil mill effluent (POME) is a yellowish acidic wastewater with fairly high polluting properties, with average of 25,000 mg/l biochemical oxygen demand (BOD), 55,250 mg/l chemical oxygen demand (COD) and 19,610 mg/l suspended solid (SS). This highly polluting wastewater can cause several pollution problems. Therefore, direct discharge of POME into the environment is not encouraged due to the high values of COD, BOD and SS. Over the past 20 years, the technique available for the treatment of POME in Malaysia has been basically biological treatment, consisting of anaerobic, facultative and aerobic pond systems (Chooi, 1984; Ma, 1999). Anaerobic digestion has been employed by most palm oil mills as their primary treatment of POME (Tay, 1991). More than 85% of palm oil mills producers in Malaysia have adopted the ponding system for POME treatment (Ma et al., 1993) due to its low capital and operating costs, while the rest opted for open digesting tank (Yacop et al., 2005). These methods are regarded as conventional POME treatment method whereby long retention times and large treatment areas are required.

High-rate anaerobic bioreactors have also been applied in laboratory-scaled POME treatment such as up-flow anaerobic sludge blanket (UASB) reactor (Borja et al., 1994a); up-flow anaerobic filtration (Borja et al., 1994b); fluidized bed reactor (Borja et al., 1995a; 1995b) and up-flow anaerobic sludge fixed-film (UASFF) reactor (Najafpour et al., 2006). Anaerobic contact digester (Ibrahim et al., 1984) and continuous stirred tank reactor (CSTR) have also been studied for PMOE treatment (Chin, 1981). Other than anaerobic digestion, POME has also been treated using membrane technology (Ahmad et al., 2006; 2007), (Fakhru'l-Razi, 1994) and (Abdurahman et al., 2011). (POME's) chemical oxygen demand (COD) and biochemical oxygen demand (BOD) are very high; COD values greater than 80,000 mg/l and; acidic pH values between (3.8 and 4.5) are frequently reported and the incomplete extraction of palm oil from the palm nut can increase COD values substantially. The effluent is non-toxic because no chemicals are added during the oil extraction process (Ma et al., 1988; Polprasert,

1989; Singh et al., 1999). (POME) is a brownish colloidal suspension, characterized by high organic content, and high temperature (70-80 ^{o}C) (Anon, 1995). Most commonly, palm oil mills use anaerobic digestion for the primary treatment (Tay, 1991; Idris et al., 1998). The three widely used kinetic models considered in this study are shown in Table 1.This paper aims to introduce a new technique of ultrasonic assisted membrane anaerobic system (UMAS) in treating POME and producing methane and to determine the kinetic parameters of the process, based on three known models; (Monod, 1949), Contois (1959) and Chen and Hashimoto (Chen et al., 1980).

1.2 Objectives

In carry out of this project, the objectives are as follows in order to fulfill the requirement of Ultrasonic Assisted Membrane Anaerobic System (UMAS) for palm oil mill effluent (POME):

i. To evaluate the application of three known kinetics models, (Monod, Contois and Chen and Hashimoto).
ii. To experimentally assess the influence of organics loading rates, temperature and retention times on the kinetics models.
iii. To evaluate the overall performance of ultrasonic assisted membrane anaerobic system (UMAS) in treating POME.

1.3 Project Scopes

This project is intends to concentrate on the scopes as follows:

i. Scale the ultrasonic assisted membrane anaerobic system (UMAS) with an affective 200 liter volume was designed and used to treat raw palm oil mill effluent.

ii. Examine the importance of kinetics parameter as a measurement to study the performance of the ultrasonic assisted membrane anaerobic systems (UMAS) during the sonication process.

iii. Developing a steady state kinetics model.

1.4 Project report overview

This document is arranged as follows:

i- Chapter one gives an introduction and general overview of the study. It focuses on the research problem and motivation for the study.

ii- Chapter two provides a brief outline on Anaerobic Digestion system, Anaerobic Treatment, Kinetics and Modeling, Digestion Operations, Membrane Separations, Acoustic Theory, transducer, Characteristics of Sound Waves and Wave Motion.

iii- Chapter three highlights the economy analysis which consist of Demand of Wastewater Treatment System for POME, Demand of Biogas (Methane) from POME, Market Opportunity, Marketing Strategy, and Financial Analysis.

iv- Chapter four discusses about the methodology of Ultrasonic Assisted Membrane Anaerobic System (UMAS).

v- Chapter five is discusses about the result and performance of Ultrasonic Assisted Membrane Anaerobic System (UMAS), which is consist of Semi-continuous ultrasonic-membrane anaerobic system (UMAS) performance, Determination of bio-kinetic coefficients and Gas production and composition and the result of financial.

vi- Chapter Six concludes the findings of the study.

CHAPTER 2

LITERATURE REVIEWS

2.1 Anaerobic Processes in Waste Treatment

Anaerobic digestion is a biochemical conversion technology that can substantially destroy complex organic matter in wastes. When used in a fully engineered system, anaerobic digestion not only provides pollution prevention, but also allows for sustainable energy and nutrient recovery. As the technology continues to mature, anaerobic digestion is becoming a key method for both waste reduction and recovery of a renewable fuel and other valuable co-products. The main objective of this article is to provide an overview of the recent research on the anaerobic digestion of agricultural, industrial and municipal wastes. Information of the recent development in anaerobic microbiology and mathematical modeling is also covered in the article.

Celis-Garcia evaluated the granular sludge and biofilm for their susceptibility to sulfide and dissolved oxygen. It was found that both sulfate reduction and methanogenesis in attached biomass exhibited a better tolerance to high concentrations of total sulfide and dissolved oxygen than those in granular sludge. The better performance if biofilm was attributed to the selective attachment of biomass(Celis-Garcia et al., 2004). Rulkens summarized the existing sludge treatment processes with a focus on the valuable use of organic carbon compounds treatment processes with a forcus on the valuable use of organic carbon compounds as an energy source(Rulkens and Biens, 2004). Lahav reviewed the titration measurement of volatile fatty acids (VFA) and carbonate alkalinity concentrations for monitoring of anaerobic digestion processes(Lahav et al., 2002). Jordao

summarized the cost-effective solutions, particularly chemical enhanced primary treatment and upflow anaerobic sludge bed (UASB) processes, for sewage treatment in Brazil(Jordao and Volschan, 2004). Angenent reviewed the biological processing strategies that can produce bioenergy or biochemicals, (Angenent et al., 2005) while treating industrial and agricultural wastewater, Yin reviewed the different techniques that could be used to enhance the gas production rate from solid substrates (Yin at al., 2004). Rulkens presented a survey of the sludge treatment options that can eliminate the risk for environment and recover tha valuable compounds in the sludge. Brief assessment was also given of the specific future technological development (Rulkens, 2004).

2.2 Application of Anaerobic Digestion

The application of anaerobic digestion is very wide. It was used in many treatment system such as for sewage sludge, municipal solid waste, municipal wastewater, industrial waste and agricultural waste.

2.2.1 Sewage Sludge Treatment

The effects of pretreatment of secondary sludge by microwave irradiaton on anaerobic digestion was investigated. The microwave pretreated sludge contained higher concentration of soluble chemical oxygen demand (COD). Anaerobic digestion of the pretreated sludge achieved higher volatile solid (VS) reduction, biogas production and COD removal rate than that of untreated sludge (Hong et al., 2006). 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 solid reduction was achieved in anaerobic digestion. The digested sludge also had improved dewatering characteristics. Mao studied the ultrasound treatment of primary and secondary sludges. It was indicated that secondary sludge had a more remarkable improvement after sonication than the primary sludge. Optimal solids concentration range for optimum sonication was proposed (Mao et al., 2004). Rai investigated 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). Yoon developed an MBR-US system by incorporating an ultrasonic cell disintegration process to a conventional membrane bioreactor. The results showed that the 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., 2004).

The integrated sewage sludge homogenization into anaerobic digestion was studied. More energy generation and sludge reduction was achieved during the following anaerobic digestion process(Onyeche, 2004). The ozonation of industrial and sewage sludge was investigatedSludge 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 O3/kg TSS. The subsequent biological treatment reached a mass reduction of 19% for the anaerobic stabilization(Sievers et al., 2007). Goel investigated the treatment of a mixture of primary and secondary municipal sewage sludge with an anaerobic digester coupled with ozonation process. 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 dewaterability(Goel et al., 2003).

Meeroff conducted laboratory and pilot tests to investigate the use of ionizing radiation in the sludge treatment. Radiation caused permanent effects in measured sludge parameters including solids content, COD, ammonia-nitrigen, specific surface area, resistance to filtration, pH, organic acid production and digester gas evalution(Meeroff et al., 2004).Vlyssides investigated the thermal-alkaline solubilization of WAS as a pretreatment stage for anaerobic digestion. At pH 11 and a temperature of 90^{o}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). Chu studied two sludge pretreatment techniques of ultrasonication and alkaline treatment.both treatment 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, 2001).Valo investigated the influence of different pretreatments on anaerobic digestion of WAS. Reslts showed that thermo-chemical pretereatment were the most efficient on COD solubilization. Pretreatment of WAS under optimal conditions (170 ^{o}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 disintegration techniques used included a stirred ball mill, an ultrasound disintegrator, a lysate centrifuge an ozone treatment. An enhancement of the degree of degradation of 7.4-20% was observed compared to a reference system without pretreatment with pulsed electric fields on the anaerobic digestion. Pretreatment increased the sludge disintegration by 20% and the degradation rate of organic matter increased about 9%. The effect of sludge processing on the anaerobic digestion of WAS was investigated. The results suggested that sludge processing for phosphorus recovery (heat treatment followed by calcium phosphate precipitation) could im[rove digestive efficiency and methane productivity at both mesophilic and thermophilic temperatures(Takiguchi et al., 2004).

The two-stage thermophilic anaerobic-aerobic digestion of WAS was studied. 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 two-stages processes(Ros and Zupancic, 2002). Kim studied the anaerobic sludge digestion in mesophilic and thermophilic anaerobic digestion elutriated phased treatment system (M-ADEPT and T-ADEPT). Both M-ADEPT and T-ADEPT showed better effluent quality, reduced reactor volume requirements, and more stable mathanogenesis than complete stirred tank reactors(CSTR) (Kim et al., 2004).

2.2.2 Municipal Solid Waste (MSW) Treatment

The effect of thermal wet oxidation on the anaerobic biodegradability and methane yields from different biowastes was investigated. 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). Lopes tested the influence of bovine rumen fluid inoculums during anaerobic treatment of the organic fraction of MSW. The data obtained affirmed that the inoculums used substantially improved the performance of the process. Biostabilization time was decreased from 459 to 234 days and biogas methane content was increased from 3.6% to 42.6% when inoculums/MSW ration was increased from 0 to 1/9 (Lopes et al., 2004). Forster-Carneiro developed an 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-Carneiro et al., 2004).

Barnes 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 studied the co-digestion of sewage sludge and food waste using the temperatured-based anaerobic sequencing batch reactor (TPASBR). The TPASBR showed higher VS reduction, methane yield, and ethane production rate than those of the mesophilic sequencing batch reactor (SBR) (Kim et al., 2004).

The enhanced performance of TPASBR was attributed to longer SRT, fast hydrolysis, higher methane conversion rate, and balanced nutrient condition of co-substrate. Rao studied the batch digestion of organic fraction of MSW. The net bioenergy 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 (Rao and Singh, 2000). 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 upflow biofilm reactor, a fiber liquefaction reactor employing in the rumen bacterium Fibrobacter succinogenes and a hydrothermolysis system in near-critical water. The process yielded biogas corresponding with conversions up to 90% of the original organic matter.

2.2.3 Municipal Wastewater Treatment

Alvarez studied the anaerobic digestion of raw domestic wastewater by a novel technology consisting of a UASB reactor and a completely mixed digester. The steady state efficiency of the UASB system was 79% TSS removal, 52% Total COD removal and 60% BOD5 removal at 6-8 h HRT, 15-16 ^{o}C and 330-360 mg/L of influent Total COD (Alvarez et al., 2004) . Kunte developed a two stage anaerobic digestion process, consisting of separate acidogenic and methanogenic digesters to treat human night soil. The process achieved complete inactivation of enteric pathogens while maintained efficient biogas generation.

Thickening the primary sludge and increasing the VS loading rate were used to optimize the operation of the digestion system. It was also found that Chen-Hashimoto model and first-order model could be used to predict the volumetric methane production rate and efficiency of VS reduction, respectively (Kunte et al., 2004). Singh studied the treatment of municipal wastewater by a UASB process. Changes in temperature and HRT impacted the reactor performance. Overall reactor performance (70-90% COD removal) was found to be stable up to an HRT of hour and temperature of 11 ^{o}C. This study demonstrated that UASB could be applied successfully with some minor adjustment for the treatment of municipal wastewater in temperature and cold regions (Singh and Viraraghavan, 2004).

2.2.4 Industrial waste Treatment

Ortega-Clemente investigated the biological treatment of recalcitrant effluent (weak black liquor) from pulp mills by an integrated system consisting of a methanogenic fluidized bed reactor and an aerobic up flow reactor. Overall, the two-stage treatment achieved approximately 78% removal of the original organic matter and 75% removal of color and ligninoid contents (Ortega-Clemente et al., 2004). Yu tested the biodegradability of thermomechanical pulping wastewater. A biochemical methane potential test showed approximately 13$\pm$ 1% of the COD was anaerobically biodegradable. Addition of glucose enhanced the fragmentation of lignocellulosics by more than six times(Yu et al.,2003). Oz studied than anaerobic digestion of a chemical synthesis-based pharmaceutical wastewater. The CSTR can treat

wastewater consisting 100% pre-aerated wastewater. However, total failure of anaerobic reactor was observed at 60% wt/v raw wastewater fed (Oz et al.,2004). Fountoulakis investigated the toxic effect of six chemicals present in pharmaceuticals on anaerobic biomass. Acetolastic methanogens were found to be the most sensitive group of microorganisms (Fountoulakis et al., 2004).

Pharmaceuticals tested caused a mild inhibition to the methanogens, related directly to the tendency of the compounds to adsorb on the anaerobic biomass. Duran studied the anaerobic digestion of an industrial waste with 84% TS and 57% VS. it was concluded that the co-digestion of this industrial waste with the WAS was beneficial from the digestion kinetics point of view since the maximum specific substrate utilization rate increased approximately 20% from 0.138 to 0.165 g COD/g VSS·d (Duran and Tepe, 2004).Wang studied the effect of di-n-butyl phthalate (DBP) on activated sludge. Although DBP showed inhibitory effect on activated sludge and unacclimated activated sludge could not degrade DBP, the acclimated activated could degrade up to 100 mg/l DBP completely (Wang, 2004).

2.2.5 Agricultural Waste Treatment

The effect of organic volumetric loading rate on the performance of a down-flow anaerobic fixed bed reactor treating settled piggery waste was studied. The reactor achieved good removal efficiencies and stability at OLR between 1.1-6.8 g COD/l·d (Sanchez et al., 1994). Ahn developed a novel high-rate anaerobic digestion alutriated phased treatment (ADEPT) process for treating a slurry-type piggery waste. The ADEPT process contained an acid elutriation reactor for hydrolysis and acidification, followed by a UASB reactor for methanification. Methane production and content in the system were 0.3 l CH_4/g VS fed and 80% of COD removal and methane-rich biogas production that was used to generate electrical and thermal energy. The electricity could supply 50% of the energy required to further reduce ammonia and residual COD by an electro-chemical treatment (Ahn et al., 2004).

Zhang developed a bench scale integrated swine wastewater treatment system consisted of one ASBR, one or two aerobic SBR, one sludge settling tang, one sand

filter and one reverse osmosis unit. The COD and solids in the wastewater were reduced by 89% and 97% after treatment with ASBR and SBRs(Zhang et al., 1997) .

2.3 Anaerobic Treatment

The anaerobic treatment has provided a solution to the treatment of high strength wastes for many years, mostly for animal wastes (Iza et al., 1991). During the past decade much research work has been done by a diverse group of scientists, including engineers, microbiologist, chemist and mathematicians. Recently, the developments of different reactors that separate hydraulic retention time (HRT) and solid retention time (SRT) has created a new era for the process. These reactors with smaller HRT and very high SRT can achieve good treatment efficiencies treating large volumes of wastewater's in small reactor volumes.

Anaerobic contact reactors, anaerobic filters (AF), up flow anaerobic sludge blanket reactors (UASB) and fluidized bed reactors (FB) are such reactors an allow slowly growing micro-organisms to remain within the reactor independent of the wastewater flow. Thos achieved in the following ways in the above reactors. The slowly growing microorganisms are allowed to grow on inert media either fixed (AF) or in suspension (FB), and on granulated settling sludge in suspension (UASB). In the case of contract reactors the mechanism is similar to the activated sludge process. These systems have reactor hydraulic retention time of 10 to 15 days as compared with 30 to 60 days in conventional anaerobic digesters (Metcalf and Eddy, 1991).

Detailed knowledge of microbiology is not necessary in order to run anaerobic digester. However, general knowledge of the microbiology of digestion is important. It is necessary to find out which part of the interdependent complex processes are limiting and therefore require control and improvement in operation or digester design. Therefore, the following sections hope to bring forth that useful and vital background knowledge needed in this study.

2.3.1 Important of Anaerobic Digestion

Anaerobic projects may be initiated from several perspectives:

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

ii) Residue producers (farmers, land owners and food processor).

iii) Local community initiatives such as partnerships between local authorities and farmers.

2.3.2 Scales of Anaerobic Operations

Anaerobic Digestion can be carried out on variety of scales:

i) On-site using residues produced only on that farm or food processing unit.

ii) As cooperative enterprise between several farmers.

iii) By developing centralized AD project supplied with feed stock from several sources including industrial sources.

2.4 Types of Anaerobic Process

There are two types of anaerobic process which is mesophilic and thermophilic digestion.

2.4.1 Mesophilic Digestion

The digester is heated to 30 ℃ -35 ℃ and the feed stock remains in the digester typically for 15-30 days, mesophilic digestion tends to be more robust and tolerant than the thermophilic process, but gas production is less, larger digestion tanks are required separate process stage.

2.4.2 Thermophilic Digestion

The digestion is heated to 55 ℃ and the residence time is typically 12-14 days. Thermophilic digestion system offer higher methane production, faster throughput, better pathogen and virus 'kill' but require more expensive technology, greater energy input and higher degree of operation and monitoring. During the process 30-60% of the digestible solids are converted into biogas. This gas must be burned and can be use to generate heat or electricity of both. It can be burned in a conventional gas boiler and used to power associated machinery or vehicles. Alternatively, it can be burned in a gas engine to generate electricity, if generating electricity it is usual to use a more efficient combined heat and power (CHP) system, where heat can be removed in the first instance to maintain the digester temperature and any surplus energy can be used for other purpose. A later scale CHP plant can supply larger housing or industrial developments, or supply electricity to the grid (Singh et al., 2009).

A fresh feedstock is added to the system umpped from the digester to a storage tank, biogas continues to be produced in the storage tank, collection and combustion may be an economic and safety requirement. The residual digestive can be stored then applied to the land at an appropriate time without further treatment, or it can be separated to produce fiber and liquor. The fiber can be use as a soil conditioner or composed prior to use scale. The liquor contains a range of nutrients and can be used as a liquid fertilizer which can be sold or used on-site as part of a crop nutrient management plan (Singh et al., 2009).

Anaerobic digestion products can help farmers reduce their requirement for non renewable form of energy such as fossil fuels and the digestate, if correctly used can reduce demand for synthetic fertilizers and other soil conditioners which may manufactured using less sustainable methods.

2.5 Benefit of Anaerobic Digestion

There are a lots of benefits by using of anaerobic digestion such as environmental, economy and practical benefits.

2.5.1 Environmental Benefits

i) Energy balance

ii) Reducting green house gasses

iii) Displacing use of finite fossil fuels

iv) Recycling nutrients

v) Reducing demand for peat

vi) Reducing odour

vii) Supporting organic farming

2.5.2 Economic and practical benefits

Many of the environmental benefits outlines above will translate into economic benefits and vice versa. Anaerobic digestion will have further economic and practical benefits as outlined below:

i. Improving farm waste management.
ii. Reducing spread of weeds and disease.
iii. Contribution to nutrient regimes.
iv. Financial incentives.
v. Biogas and energy.
vi. Local economic development.

2.6 Microbiology of Anaerobic Digestion

Anaerobic bacteria convert organic matter to methane and carbon dioxide in the absence of oxygen. This occurs naturally in many environments, which include intestinal tracts and sediments. In biotechnology, the degradation of organic wastes by anaerobic bacteria is term anaerobic digestion and this process may be used to treat domestic, agricultural and industrial wastes in order to produce methane or use as a fuel to avoid pollution.

The major degradative steps in methanogenesis from wastes are irrespective to either the waste composition or the type of digester (e.g high rate reactor, animal slurry digester or landfill). Because there are a number of steps involved in anaerobic digestion, there are necessarily a number of different bacterial species involved.

The microbiology of the anaerobic digestion process is consequently very complicated and yet the prime requirement of the process is that it be reliable. Control of industrial processes which utilize pure species need not to be simple, and yet in anaerobic digestion the problems are exacerbated by the number of bacterial species, variations in composition and amount of waste, and so on. The need for reliability is paramount and yet the need for other desirable features of anaerobic digesters should not be underestimated. For example, in the treatment of dilute soluble wastes start up times should be minimized and treatment rates should high. There is a need for rationally an improved understanding of the bacteria involved and of the interactions (Gareth, 2001).

The reaction thought to have occurring in three steps:

i. Enzyme mediated hydrolysis.
ii. Conversion of the end products from the first step into lower molecular weight intermediate compounds called acidogenesis.
iii. Conversion of the intermediate compound into simple and products called methanogenesis which are acidogenesis (acid formers) bacteria and methanogenesis (methane formers).

Ideal environmental conditions for the effective anaerobic degradiation:

i. Void of DO.
ii. Free from inhibitory concentrations of metals and sulfides.
iii. pH between 6.6 to .6
iv. Sufficient alkalinity in order to make sure that pH does not drop below 6.2.
v. Alkalinity: 1000 -1500mg/l.
vi. Volatile fatty acids < 2500mg/l
vii. Sufficient amount of nitrogen and phosphorous and growth factors.
viii. Optimum range of temperature 30°C - 38°C mesophilic 49°C - 57°C thermophilic.

2.7 Comparison with Aerobic Process

There are a few comparison between anaerobic and aerobic digestion which is consist of advantages and disadvantages.

2.7.1 Disadvantages

The rate of degradation in anaerobic process is quite slow, requires bigger reactor. Process is very sensitive to environmental conditions. Often need further treatment before disposal.

2.7.2 Advantages

There are a few advantages of anaerobic digestion which are production of methane not higher than 120mg/l. The calcium accumulated in the biofilms increased in proportion to the calcium level in the feed. The biofilms for an increased input calcium concentration showed a trend of decreasing specific activity. The biofilms with a thickness of 100 to 120gm/l. The biofilms transferred from higher calcium medium to lower calcium meium were more susceptible to sloughing from their support surfaces, which indicates calcium's role in the stability structure (Gareth, 2001). The amount of sludge produces significantly less. Sludge id significantly well digested, easy to handle and no need to supply oxygen.

2.8 Acidogenesis

Anaerobic biofilms with dominantly acidogenic bacteria were grown infixed bed recycle reactors. The influence of calcium concentration in the culture medium on biofilm mass accumulation, immobilized calcium concentration and biofilm, specific activity was investigated. The results indicate that the biofilm mass accumulation was increased by the presence of the calcium in the growth medium when calcium concentration was less than 120mg/l.

2.9 Hydrolysis

The hydrilytic bacteria excrete extracellular enzymes to convert complex particulate matter into soluble compounds. In the digestion of particulate or polymeric waste, hydrolysis is often found to be the rate-limiting process (Archer and Kirsop, 1990).

2.10 Anaerobic Digestion

There are two types of anaerobic digestion used to day: the standard rate process and the high rate process. The standard rate process does not employ sludge mixing, but rather the digester contents are allowed to stratify into zones. Sludge feeding and withdrawal are intermitted rather than continuous. The digester is generally heated to increase the rate of fermentation and therefore decrease the required retention time. Retention time ranges between 30 to 60 days for heated digesters. The organic loading rate for a standard rate digester is between 0.48 and 1.6 kg total volatile solids per m^3 of digester volume per day. The major disadvantages of the standard rate process is the standard rate process is the large tank volume required because of long retention time, low loading rates and thick scum layer formation. Because of this limitation, systems of this type are generally used only at treatment plants having a capacity of $0.04m^3/s$ or less.

The high rate system evolved as a result of continuing efforts to improve the standard rate unit. In this process, two digesters operating in series separating the functions of fermentation and solids / liquid separation and residual gas extraction.

2.11 Methanogenesis

In this process, methane is the final product that comes from acetate or reduction of carbon dioxide by hydrogen utilizing acetotrophic and hydrogenotrophic bacteria respectively. Between the two, it was observed that in sewage treatment, acetotrophs were rate limiting, as their growth rate was much lower than that of the hydrogenotrphs.

Not only do the methanogens have slow growth rates, they are also sensitive to pH changes. Inhibition of methanogens will occur if the pH falls out of the range of 6.5 to 7.8 (Sixt and Sahm, 1987). Certain methanogens are also capable of converting other substrate to methane, as shown in the following Figure 2.1.

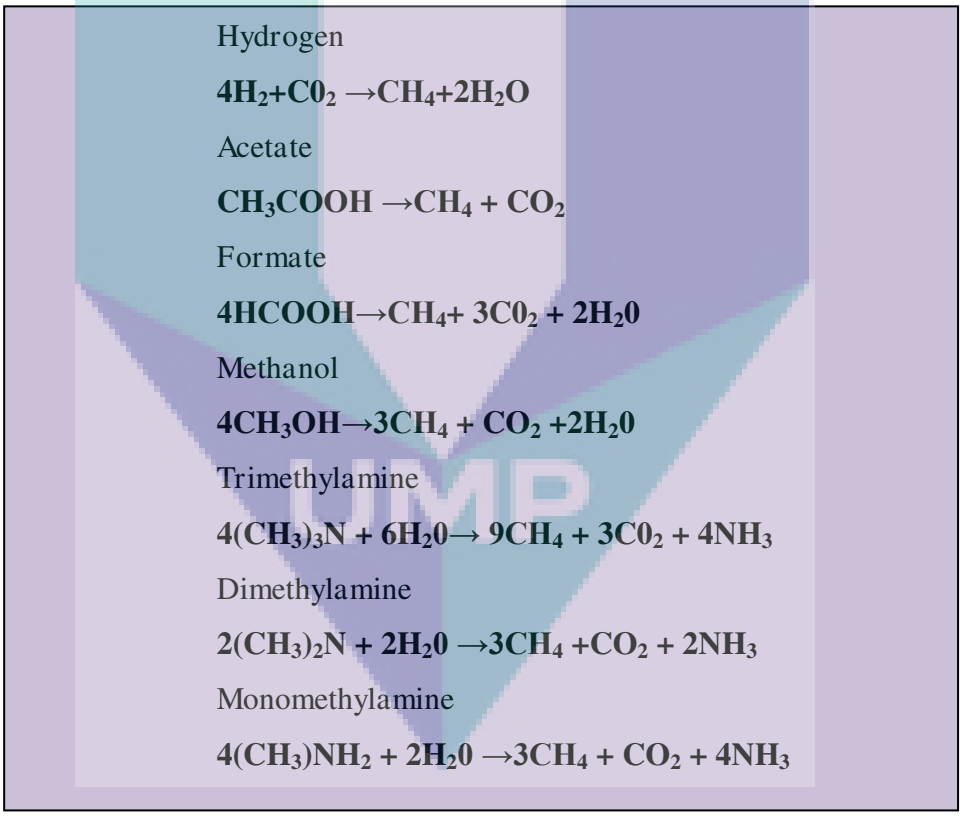


Figure 2.1: Methanogenesis Reactions.

The previous section hope to provide a general albeit arbitrary outline of the many possible metabolic pathways involved in a complete anaerobic digestion process. Hobson and Wheatly (1993) provided a good schematic of the main microbial reactions in anaerobic digesters.

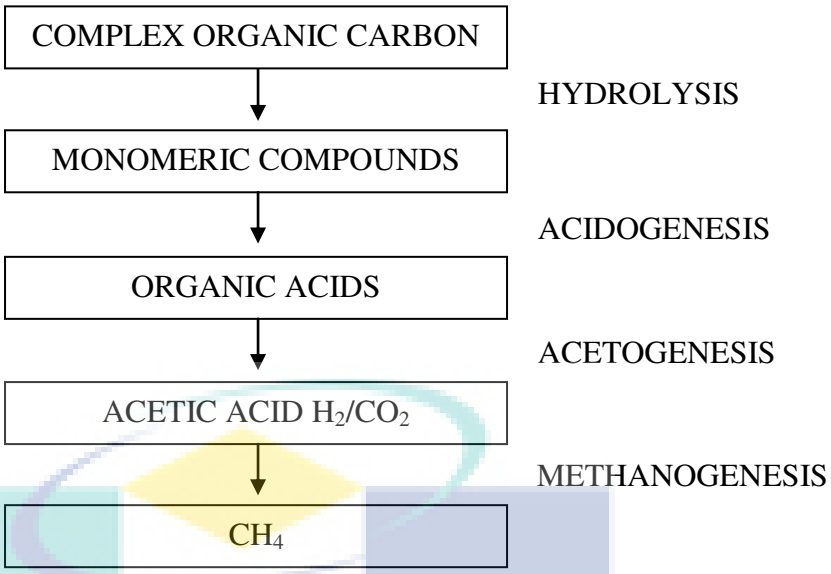


Figure 2.2: Major metabolic stages in methanogenesis from wastes.

2.12 Application of Anaerobic Process for Wastewater Treatment

There are many variations of existing digesters that generally fall under one of three processes shown in Figure 2.3. A major objective of digester development and design is to be achieving a high biomass content within the reactor in order to achieve a high methane production and yield, and a high COD reduction per unit of digester volume from high organic loading rates. At the same time, the digester should remain economically feasible, both in term of process energy requirements and digester costs.

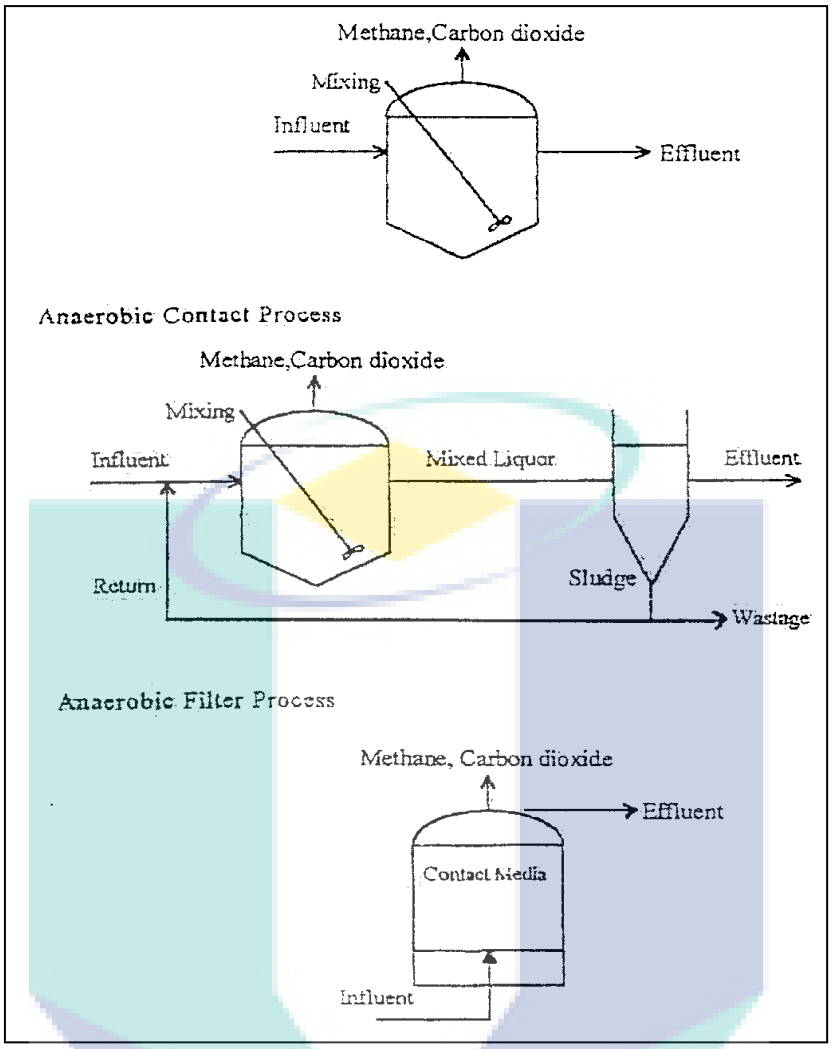


Figure 2.3 Schematic Diagram of Three Main Types of Anaerobic Treatment Process.

2.12.1 Anaerobic Contact Process

This process is used to treat high strength industrial wastewater. It is similar to activated sludge process except that there is no supply of oxygen. Settling characteristics of the biomass digester effluent will affect the suitability of this type of digester for different waste treatment. The anaerobic contact process is a relatively recent innovation in anaerobic waste water. The attractiveness of this process for treating strong (high COD) soluble industrial wastes is evident in considering the following advantages of anaerobic treatment (McCarty, 1986).

i. A high degree of waste stabilization is possible.

ii. The production of waste biological sludge is low, as are the nutrient requirements.

iii. Waste loading rates are not limited by oxygen transfer capabilities.

iv. A usable end product, methane, is produced.

2.12.2 Anaerobic Filter Process

The idea of retaining biomass independent of waste flow becomes a reality in the anaerobic filter process. The digester is filled up with contact or filter media on which the biomass remain trapped. The maintenance of a high concentration of biomass leads to very long solids retention time. However this process is more suitable for treating low suspended solid wastes. High suspended solids wastes tend to clog the media rapidly, which can be difficult to clean. The major worry of this process is the excessive biomass accumulation and blockage of the packed bed (Young et al., 1969).

2.12.3 Expanded Bed Process

In the case up flow anaerobic filter, the performance can be improved by allowing the media to fluidize. Biomass concentrations in excess of 15000 to 40000 mg/I have been reported. The process will maintain mission readness, improve effluent quality, and help meet new environmental regulations.

In addition, the process produces methane gas that could be used as fuel in place of natural gas. Although the methane require some cleanup (removal of carbon dioxide, sulfide, and water vapor), it represents a recovery of energy.

2.13 Kinetics and Modeling

The understanding of kinetics is important, in order to quantify and rationalize the digester operations. It appears that the foremost step in anaerobic treatment kinetics is to identify the rate limiting step. Identifying it is no easy task as the rate limiting step differs between types of waste, and even for the same waste, it

differs under different operating or digestion conditions. A slight change in condition can result in the lowest step changing from acetotropic methanogenesis to acetogenesis (Archer and Kirsop, 1990). However, process failure is always preceded by accumulation of volatile fatty acids and near cessation of methane production.

With the identifying of the limiting steps, the study of microbial kinetics can be preceded. The fundamental microbial kinetics are based on two fundamental relationships: growth rate and substrate utilization rate.

2.13.1 Microbial Growth Rate

For the large numbers and mixed cultured of microorganisms found in waste treatment system, it is convenient to measure biomass rather than numbers of organisms. In the log- phase, the rate expression for biomass increase as:

$$\frac{dy}{dx} = \mu X \qquad (2.1)$$

Where X= microorganism concentration (mg/l); t= time (day);

$$\mu = \left(\frac{1}{X}\right)\left(\frac{dx}{dt}\right) = \ Specific\ growth\ rate\ (day^{-1}) \qquad (2.2)$$

Taking microorganism decay (death of cell) into consideration, the net growth rate is:

$$\left(\frac{dx}{dt}\right) net = (\mu - b)X \qquad (2.3)$$

Where b= specific microorganism decay rate (day^{-1})

The microbial growth rate is proportional to the substrate utilization rate of a given waste by:

$$\frac{dx}{dt} = \ -Y\ (\frac{ds}{dt}) \qquad (2.4)$$

Where Y=growth yield coefficient (gVSS/gCOD)

From Equation (2.1) and (2.3) it can be shown that the relationship between the specific growth rate and growth yield coefficient can be expressed as:

$$U = \frac{\mu}{y} \qquad (2.5)$$

Where U=1/X (dx/dt) = specific substrate utilization rate (kgCOD/kg VSS/g)

Both Contois and Chen and Hashimoto models were expressed the predicted effluent substrate concentration, S as a function of influent substrate concentration, S_a. these are considered as improvement over the Monod model as they have explicitly account for organic loading which has been found to effect digester performance in some cases. Although Monod model is still applicable in other dogester. Monod model is also widely used due to its mathematical simplicity and relative ease of kinetic parameter estimation. Therefore, these three kinetic models as shown in Table 2.1.

Table 2.1 : Kinetics Models Used in Anaerobic Treatment.

Kinetic Models	A	B	C
Monod	$\mu = \frac{\mu^{\wedge} S}{K_s + S} - b$	$\frac{-ds}{dt} = \frac{\mu^{\wedge} XS}{Y(K_s + S)}$	$S = \frac{K_s\,(1 + B\theta)}{\theta_c\,(\mu_m - b) - 1}$
Contois	$\mu = \frac{U_m\,S}{BX + S} - b$	$\frac{-ds}{dt} = \frac{U_m XS}{Y(BX + S)}$	$S = \frac{BYS_o\,(1 + B\theta_c)}{BYS\,(1 + B\theta_c) + \theta_c\,(U_m - b)}$
Chen and Hashi-moto	$\mu = \frac{\mu^{\wedge} S}{KS_o + (1 - K)S} - b$	$\frac{-ds}{dt} = \frac{\mu^{\wedge} XS}{KX + YS}$	$S = \frac{KS_o\,(1 + b\theta_c)}{(K - 1)(1 + b\theta_c) + \mu^{\wedge}\theta_c}$

Pavlostathis and Giraldo-Gomez (1991)

Where X= time(day)

$\mu = \left(\frac{1}{X}\right)\left(\frac{dx}{dt}\right)$ + Specific growth rate (day $^{-1}$)

$\mu^{\wedge}$ = maximum specific growth rate (day^{-1})

b = specific microorganism decay rate (day^{-1})

Y= growth yield coefficient (gVSS/gCOD)

U =1/X (dx/dt) = specific substrate utilization rate (gCOD/gVSS/d)

S_o =influent substrate concentration (mg/l)

S = effluent substrate concentration (mg/l)

K_s =half-velocity coefficient (substrate concentration at one half maximum specific growth rate (mgCOD/l).

2.14 Digestion Operations

There are three main digestion operation which really important for this process. The operation consist of temperature, growth in mixed cultures and pH.

2.14.1 Temperature

Each species of bacteria reproduces best within a limited range of temperatures. Four temperature ranges are used to classify bacteria. Those that grow best at temperature below 20℃ are called Psychrophiles. Mesophiles grow best, at temperature between 25 ℃ and 40 ℃, between 45 ℃ and 60 ℃ the thermophiles grow best. Above 60℃ stenothermophiles grow best. Bacteria are single-cell protists. They utilize soluble food and in general, will be found whenever moisture and a food source are available. Their usual mode of reproduction is by binary fission.

Temperature and pH play a vital role in the life and death of bacteria, as well as in the other microscopic plants and animals. It has been observed that the rate reaction for microorganisms increases with increasing temperature. According to the temperature range in which they function best, bacteria may be classified as cryophilic or psychrophilic, mesophilic, and thermophilic. Typical temperature ranges for bacteria in each of these categories are presented in Table 2.2.

The growth range of facultative thermophiles extends from the thermophilic range into the mesophilic range. Bacteria will grow over a range of temperature and will survive at a very large range of temperatures. For example, Escherichia coli, classified as mesophiles, will grow at temperatures between 20°C and 50°C and will

reproduce, albeit very slowly, at temperatures down to 0°C. If frozen rapidly, they and many other microorganisms can be stored for years without a significant death rate. According to (Ma et al., 1993), a pilot anaerobic contact digester treating POME under thermophilic conditions apparently shown better digestion. Shorter hydraulic retention time was required and more biogas was obtained. (Borja and Banks, 1993) also reported higher percentage of methane composition in biogas.

Table 2.2: Typical temperature ranges for various bacteria

Type	Temperature, ^{o}C	
	Range	Optimum
Cryophilic*	2-30	12-18
Mesophilic	20-45	25-40
Thermophilic	45-75	55-65

*Also called Psychrophilic.

The pH of a solution is also a key factor in the growth of organisms cannot tolerate pH levels above 9.5 or below 4.0. Generally, the optimum pH for growth lies between 6.5 and 7.5.

2.14.2 Growth in mixed cultures

In wastewater treatment, as in natural, pure cultures of microorganisms do not exist. Rather, a mixture of species competes and survives within the limits set by the environment. Population dynamics is the term used to describe the time varying success of the various species in competition.

The prime factor governing the dynamics of the various microbial populations is the competition for food. The second most important factor is the predator-prey relationship. The relative success of a pair of species competing for the substrate is a function of the ability of the species to metabolize the substrate. The more successful 'species will be that metabolizes the substrate more completely.

2.14.3 pH

The digester bacteria have varying optimum pH for growth. In general, the fermentation of sugars takes places at relatively low pH values of 5 to 6. The hydrolysis and fermentation of polysaccharides, with the exception of starch, take place optimally at higher pH of 6.5 to 7 or over. The degradation of fatty acids and methane production is about 6.5 to 7.5 (Hobson and Whearly, 1993).

At a compromise, the pH should be held at some value, which allows the activity of all the bacteria, although not optimally for all. According to (Hobson and Wheatley, 1993), most digester systems are self-buffering at around pH 7. Therefore, the pH of the digester should be operated within the range of the optimum pH range of methanogens, i.e 6.5-7.8 (Sixt and Sahm, 1987) so as not to be inhibitive to the methanogens.

2.15 Membrane Separations

Effective product separation is crucial to economic operation in the process industries by using membranes (Howell, 1993). Membrane-separation technology comprises a range of innovative process engineering techniques that have been rapidly developed by materials Scientists, physical Chemists, and Chemical Engineers, and are applied to many conventionally difficult separations.

In simple terms, membrane separations may be considered as advanced filtration processes that use the separation properties of finely porous polymeric or inorganic films, operating over the colloidal to ionic size scales. The techniques offer the advantages of:

i. Relatively low capital and running costs
ii. Ambient temperature operation
iii. Highly selective separation
iv. Modular construction
v. Separation without any auxiliary materials
vi. Usually no phase change

vii. Continuous and automatic operation

viii. Concentration and purification may be achieved in one step

ix. Selectivity is good in many cases.

For well-established separation processes, such as distillation, there are reliable and general design methods available. These methods allow a prediction of the design and operation of, for example, a distillation column from acknowledge of the physic chemical properties of the substances to be separated. The design and operation of membrane separations in the process industries also requires quantitative methods for predicting separation performance, especially filtration rate and rejection (Bowen and Jenner, 1995). Membrane separation processes for liquid systems are conventionally classified in terms of size ranges of materials separated (Micro filtration, 10µm-0.1µm. Ultrafiltration, 0.1 µm -5nm; Nanofiltration, less than 5nm).

For such pressure driven processes, predictive methods must be based on the microhydro dynamics and interfacial events occurring at the membrane surface and inside the membrane. A membrane, as defined by (Howell, 1993), is a thin barrier between two fluids, which restricts the movement of one or more components of one or both fluids across the barrier. The selection of type of membrane process depends on the particle size that requires separation. The apparent dimensions of some particles are shown in Table 2.3 (Cheremisinoff and Cheremisinoff, 1993).

Table 2.3: Apparent Dimensions of Various Particles

Particle	Dimension (µm)
Yeast's, Fungi	1-10
Bacteria	0.3-10
Viruses	0.03-0.3
Protein (10^4 – 10^6 molwt)	0.002-0.1
Enzymes	0.002-0.005
Antibiotics, Polypeptides	0.0006-0.0012
Sugars	0.0008-0.001
Water	0.0002

(Cheremisinoff and Cheremisinoff, 1993)

2.16 Membrane Process

Membrane separation processes for liquid systems are conventionally classified in term of the size ranges of materials separated (Fane and Radovich, 1990), these processes, such as Microfiltration, MF (10 µm -0.l µm); Ultrafiltration UF (0.1 µm -5nm); and Reverse Osmosis (RO).

2.16.1 Microfiltration (MF)

Is a low - pressure membrane process for separating suspended solids from a feed stream. Water, salts, and select macromolecules pass through a semi permeable membrane, while suspended solids are retained and progressively concentrated (Cheremisinoff and Cheremiboff, 1993).

2.16.2 Ultrafiltration (UF)

Is a low pressure membrane process for separating high molecular weight species from a feed stream. Water, suspended solids are retained and progressively concentrated, in Ultrafiltration (UF), mainly due to its capacity to reduce formation of a concentration polarization layer, and consequently decreasing levels of fouling are pore clogging (Pradanos et al., 1995).

2.16.3 Reverse Osmosis (RO)

Is a high pressure membrane process for separating low molecular weight species from stream. Water selectivity passes through a semi permeable membrane, while salts, and macromolecules are retained and progressively concentrated.

2.17 Membrane Anaerobic System

As mentioned before, combination of membrane separation technology with anaerobic treatment processes is one of current research areas. The limitations of standard filtration are overcome by operating Ultrafiltration in what can be called "Crossflow Configuration". Performance and the economics of Ultrafiltration depend

on upon the rate of solvent passage through the membrane. Any accumulation of retained molecules or material at the surface a phenomenon often called concentration polarization (Pradanos at al. 1995), will 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 Figure 2.4.

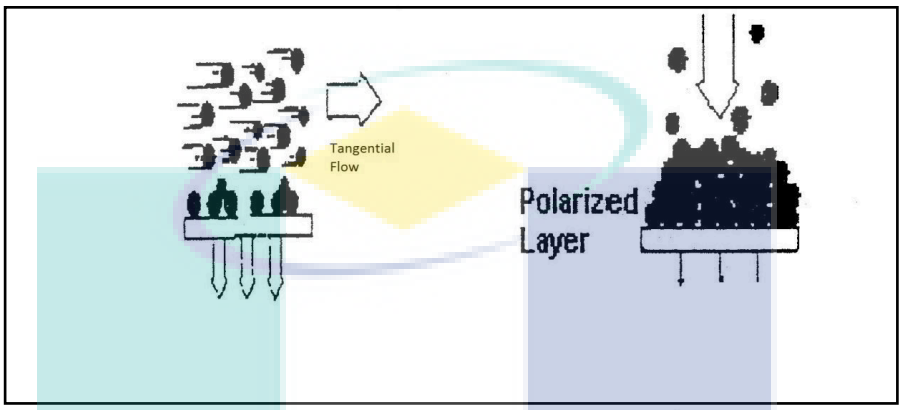


Figure 2.4: Effect of membrane separation surface in standard filtration

Although, it goes by different names, such as Crossflow UF Membrane Anaerobic Reactor (CUMAR) (Ince et al., 1995). The combination of anaerobic and membrane separation bioreactors have been used in treating various type of wastewater's a shown in Table 2.4 below.

Table 2.4: Application of Membrane Biological Reactors in Treating Several Type of Wastewater

Wastewater Type	Volume (m3)	HRT (h)	MLSS (kg/m3/l)	Influent COD (kg/m3)	OLR COD (kg/m3)	COD Removal %
Maize processing effluent	2610.0	120.0	21.0	3.0	15.0	97
Wheat starch wastewater	-	-	16.9	36.0	-	75.5
Brewery wastewater	0.05	12.0-19.2	50.0	6.7	15.0	96-99
High strength suspended solid	5.50	-	37.5-113.3	24.6-48.6	2.2-10.2	>98
High strength wastewater	5.0	12.0	7.6	-	35.5	93
Paper and pulp manufacturer wastewater	7.00	-	15.0	28.0	-	96
Industrial wastewater	2610.00	124.8	23.0	4.0-15.0	3.0	97
Synthetic wastewater	0.01	48-120	15.0	0.5	1.5-2.5	98

2.18 Introduction To Acoustic Theory

Acoustics is the branch of physics that is dedicated to the studies of sound, the generation, transmission, control, reception and effects of mechanical waves in solids, liquids and gases.There are several major sub-branches in this research field but the more prominent ones, in addition to ultrasonic, are environmental, architectural, musical and engineering acoustics.

Ultrasonic is the study of sound with a frequency higher than audible sound, environmental acoustics deals with noise control, architectural acoustics is the study of how sound waves and buildings interact, musical acoustics deals with the design and use of musical instruments and how they affect the listener and engineering acoustics concerns the recording and reproduction of sound, thus ultrasound are well established in most engineering application and material processing such as

sonochemistry, metal working, cleaning and many more, then each application have certain range of frequency, as will be showed in the Table 2.5 shown below.

Table 2.5: Frequency ranges and application

Frequency range	Application
Human detection	20Hz-20KHz
Industrial power Application	20KHz-100KHz
Control, cleaning, metal working, mixing	16-40KHz
Degassing, testing and diagnostic	1-10 MHz

The basic requirement of establishing an ultrasonic equipment are transducer (a device that can convert electric to wave) and medium within which sound could propagate, for sonochemical application the medium is mostly water, while transducers vary with application . In the following paragraphs some criteria and types of the existing transducers would be highlighted (Mason and Lorimer, 2002).

2.19 Transducer

Transducer is a device that can convert electrical current to sound wave or vise versa with reversible transducer can convert in both direction, and is fabricated from material that poses piezoelectric or magnetostructive properties. Currently there are around three main types of transducers, namely Gas driven transducer, Liquid driven transducer, and Electromagnatic transducer, Gas driven transducer is not used in sonochemical application, thus the other two types are discussed (Mason and Lorimer, 2002).

2.20 Liquid Driven Transducer

Its usefulness is nearly limited to mixing and homogenization process, and it constructed of mixing chamber that provided with a vibrating blade, then the material to be processed is usually driven to the chamber as a jet so when this high pressure driven jet hit the thin blade; it will start to vibrate this vibration and together with the venture effect would enhance the mixing process (Mason and Lorimer, 2002).

2.21 Electrochemical Transducer

These types of transducer are fabricated from specific material designated as ferroelectric that polarize as a respond to either pressure or electrical charges applied upon them. However some of Those materials are found in nature as large crystals such as quartz but the other are fabricated in combination with ceramics to form large crystals, according to this respond two types of transducer are produced from these material which are Piezoelectric and Magnetostructive transducers (Mason and Lorimer, 2002) in Figure 2.5.

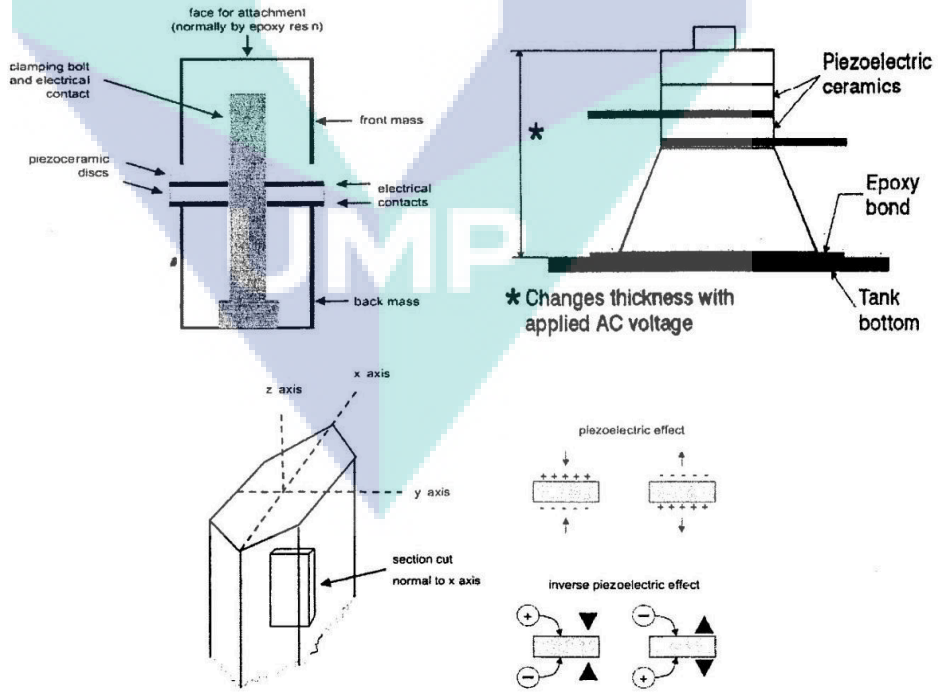


Figure 2.5: Piezoelectric effect of quartz (X cut), (Mason and Lorimer, 2002)

2.22 Piezoelectric Transducer

This type of transducer is fabricated from material have piezoelectric effects which best known by their single crystal which possess polar axis, such as quartz, tourmaline, lithium sulphate, cadmium sulphide, and zinc oxide. In fabricating the transducer the material cut to small disc, and an opposed pair of plane surfaces oriented at right angle to a certain specified axis is coated with thin metallic film (of silver or gold or aluminium) to serve as electrodes, when a thin element of a piezoelectric material is exposed to pressure, electric charge or in most cases an alternating current it will acquire equal and opposed charges in the two opposing surfaces this effects transmit vibrations from this thin surface to the medium in the form of ultrasonic wave whose frequencies (ranged between 25- 800KHz) are manipulated by adjusting the dimensions of the thin element, because the frequency is inversely proportional with the thickness of the thin element, mostly one element produces one frequency and that is why most of the current transducers have one frequencies only(Mason and Lorimer, 2002, Jeffery et al., 1997). Piezoelectric Transducer (Mason and Lorimer, 2002, Jeffery et al., 1997)

2.23 Magnetostrictive Transducer

A matter is Saied to have magnetostrictive properties, when it size will alternate if it is placed in magnetic field, hence in magnetostrictive transducers magnetism is applied to generate sound wave whose frequency range normally lies between 18-30 KHz, (Jeffery et al., 1997).

2.24 Ultrasonic Horn

There exists various ultrasonic apparatus and equipment, for laboratory as well as industrial use each of which is designed according to it is application such as cleaning bath, whistle reactor ultrasonic horn and many more unless in this research focus is more directed to ultrasonic horn since it might be used in designing the resonator to be used to carry out this research. The ultrasonic Horn is used I wide application, and it is characterized by fixed frequency and zero loss of power through walls since the tip is inserted directly to the sample, nearly its dimension and shape

are function of frequency and transducer materials as depicted in the Figure 2.6 (Mason and Lorimer, 2002).

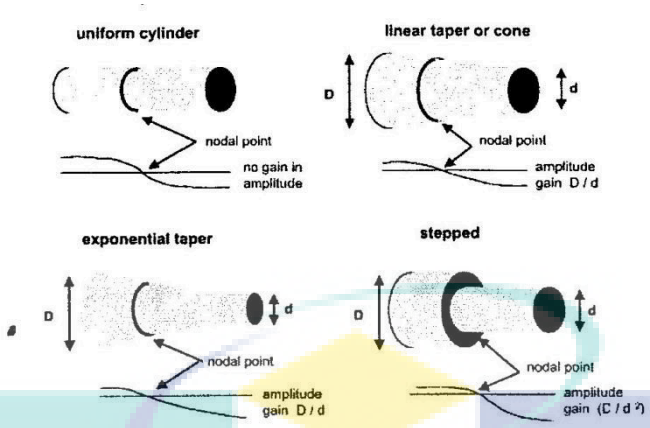


Figure 2.6: Shapes dimensions and magnification factor of Horn.

2.25 Transducer Operation and Wave Generation

The assembly of ultrasonic device is normally consists of two or three main components: designated as Generator, transducer and sample holder the later is optional for some application; Generator normally increases the electric power supplied to higher voltage (e.g 60 Hz electric power supply to 40 KHz) in order to met the capacity of the transducer which in turn depends on the size of the sample to be processed (Jeffery et al., 1997) Figure 2.7.Positive signals will induce expansion to a transducer while the negative signals will render it to contract, when this pattern is introduced to liquid it is the sound itself, propagates in the form of alternating compression (area of high pressure) and refraction (area of low pressure) wave.

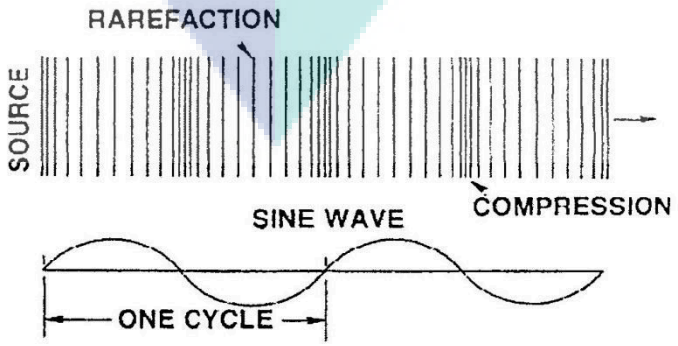


Figure 2.7: Transducer expands or contracts in accordance with the AC current signals producing sound wave (Jeffery et al., 1997)

2.26 Characteristics of Sound Waves

As was stated earlier; in general sound is generated in a material, as a result of some mechanical disturbance taking place on them. The disturbance may, for example, shock excitation, such as an explosion or the striking of a ball. On the other hand, the disturbance may take the form of continuous vibrations resulting perhaps, from speech, the playing of musical instrument, or the regular motion of a machine. In each case it can be shown that the source of sound is in the state of vibration (Jack Blitz, 1971).

Naturally sound waves are characterized by frequency, wave length, and velocity; moreover they are classified into four types on the basis of the mode of vibration of the particles of the medium with respect to the direction of the propagation of the waves, namely Longitudinal, Transverse, Surface and Lam waves. As long as the longitudinal waves are the only sound waves that can propagates in liquid medium, it would be the primary concern of this study and the other types cannot propagate in liquid medium and they are out of the scope of this study. Longitudinal waves propagate through a medium as, compressions and rarefactions along the direction of propagation of the wave.

Transverse waves, on the other hand, are oscillations perpendicular to the direction of propagation, such as waves on a string. Since longitudinal and transverse waves in most situations are governed by the same laws of physics and are described in the same way mathematically it is often convenient to think of sound waves as transverse waves (Subramanian et al., 2006). Longitudinal wave is the most widely used in liquid processing and this name because the particle vibration and wave motion are in the same direction. When acoustic wave propagates in medium it is characterized to induce either, particle displacement (y), or increase particle velocity (u), or impose pressure or stress (P). Those three characteristics are the fundamental with which the acoustic theory is applied in various industrial applications (Jack Blitz, 1971).

2.26.1 Particle Displacement(y)

The mathematical expression of the displacement of suspended particle excited by sound wave in y direction with tine is:

$$y(x, t) = A.\sin(wt - kx) \quad (2.6)$$

Where y represent the displacement at any time (t) , and w is the angular frequency defined as:

$$w=2\pi f \quad (2.7)$$

f is the frequencies of the wave (i.e. the number of complete periodic cycle undergone in unit second); and expressed in unit of hertz (Hz).The universal wave equation is the differential form of this displacement equation as:

$$\frac{\partial^2 y(x,t)}{\partial x^2} = \frac{1}{c^2}\frac{\partial^2 y(x,t)}{\partial t^2} \quad (2.8)$$

Where y represent the displacement at any time t, and w is the angular frequency defined as:

$$w=2\pi f \quad (2.9)$$

Vibrations are characterized by their frequencies, i.e. the number of complete periodic cycle undergone in unit time, e.g. one second. The unit of frequency is the hertz (Hz).

2.27 Particle Velocity

Is describing the speed with which an acoustically excited particle vibrate, this is different from the speed of sound in the medium and is given as:

$$u = u_0 \sin \omega(t - \frac{x}{c}) \quad (2.10)$$

u_0 is particle velocity amplitude

2.27.1 Pressure on the Particle

Since sound waves propagate in compressions and rarefactions forms in a medium; it is practical to express the wave function in gauge pressure form (Ahmad et al., 1996). The gauge pressure is the pressure above or below atmospheric pressure. Note the fact that the pressure function is phase shifted 900 compared to the displacement function, since sound wave are also known by their ability to increase or induce stress on the exposed materials this stress also is just a form pressure referred to as acoustic pressure (p) (Jack Blitz, 1971), which vary with location as follow:

$$p = p_0 \sin\omega \left(t - \frac{x}{c}\right) \quad (2.11)$$

p_0 Pressure amplitude

The aforementioned acoustic parameters are related to electrical parameters because similarities they share with the electrical quantities for example the pressure is analogous to electric voltage, velocity to electric current, and particle displacement to electrical charge and from the help of Ohm's law a quantity known as acoustic impedance (Z_a) is identified:

$$Z_a = \frac{p}{u} \quad (2.12)$$

It is similar to electrical impedance, but here as the wave are assumed not reflecting back thus the imaginary complex part will disappear, leaving a real quantity equal to electrical resistance (Ra), which given in the form of density of medium(p) and velocity of sound (c) (Jack Blitz, 1971).

$$R_a = \rho c \quad (2.13)$$

2.28 Acoustic Intensity

The intensity means magnitude of quantity (x) per area or volume, for instance the intensity of density of mass per volume, and intensity of pressure is force over volume and by the same token; the intensity of wave is given as energy of the wave per an imaginary plane surface in the medium oriented at right angle to the

direction of wave motion, and it is ultimate relation is given in accordance with the other acoustic quantities as:

$$I = \frac{p_0\, u_0}{2} = \frac{u^2 \rho c}{2} = \frac{p_0^2}{2\rho c} \qquad (2.14)$$

2.29 Measurement Scale

The amplitude of the sound wave produced by a vibrating body decays as the distance from the source is increased thus the amplitude in every motion is smaller than that of it's previous neighbor until it dies down to a resonance frequency where the vibrations are fixed for longer times, this concept is used to measure the acoustic parameters such as pressure, velocity and so on. Since the amplitude decays with time in exponential forms, the rate of decay is designated as damping coefficient or logarithmic decrement (δ):

$$\delta = \frac{2.303}{n} log_{10} \frac{A_0}{A_n} \qquad (2.15)$$

A_0, A_n are the initial amplitude and the amplitude after n complete cycles respectively. Similarly intensity may be calculated in a decibel scale in the same manner relative to some fixed intensity (Jack Blitz, 1971).

$$Intensity\ level = 10 log_{10} \frac{I}{I_o} \text{ Decibels (db)}$$

2.29.1 Sound Velocity in Material

Sound propagates in material as pressure wave with certain velocity (c) which varies from one sample to another, even within one sample its clamed to varies with frequency and sample composition and is calculated as the product of frequency (f) and wavelength (λ) .

$$c = f * \lambda \qquad (2.16)$$

With regard to the material characteristics sound velocity is also a strong function of material characteristics as shown in Table 2.6, thus another more relevant equation is used to predict the speed of sound in mixtures or emulsions (Garcia and Sinha, 2008)

$$c = \frac{1}{\sqrt{\rho_m^2 \, k_m}} \tag{2.17}$$

Where ρ_m^2 $k_m$are the density and compressibility of the mixture calculated from the mixing rule, some experimental values of various types of oil have been tabulated in Table 2.6 as shown below.

Table 2.6: Velocity of sound in some oils

Materials	API	Frequency	Sound velocity
Crude	31.52	1 MHz	1406.8 m/s
Crude oil	34.39	1 MHz	1391.9
Crude oil		1MHz	1330
Benzene	1320		1320
Nitrobenzene	Not specified	Not specified	1480
Olive oil			1400
Water			1490
Lubricating oil			1400
Motor oil			1700
Mineral oil			1430

The process of agglomeration and separation of suspended particles via ultrasonic is widely used in various industrial application, Phylis and coworkers have designed a 75 ml acoustic resonator to study the sedimentation of hybridoma cells suspended in a medium, by using composed transducer and Pyrex glass as a reflector, Coakely and coworkers have used the standing wave to manipulate a suspended eukaryote cells, in contrast to the previous researchers, others have investigated the effects of high power ultrasonic energy to dewater a slurry, however they have found that the high

power was not efficient in promoting agglomeration, but rather the ultrasonic energy which found to ply an important role in the dewatering process Franco et al. (2000), others have succeeded to apply the standing wave to collect a suspended particles in a porous medium incorporated with the resonating chamber. Similarly the concept of ultrasonically enhanced sedimentation of suspended particles for what so called an H-shaped separator was investigated, however it is resulted that the H-shaped apparatus was not efficient at high concentration of suspended particles (Franco et al. 2000).

2.30 Wave Motion

Mathematical expression of wave motion for one dimensional wave motion is:

$$y = A\cos\left(\frac{2\pi x}{\lambda} + \frac{\emptyset}{2}\right).\sin\left(\frac{2\pi x}{T} + \frac{\theta}{2}\right) \qquad (2.18)$$

Where, y is displacement at certain position (x) at time (t), A is the amplitude of the wave, λ is the wavelength, T is the period time and the phase shift, $\emptyset$ is the phase shift between the two travelling wave. The cosine and sine parts of the wave equation are responsible to describe the positional and time dependence of the wave.

2.30.1 Attenuation of Sound Wave

When sound waves propagate through a medium they are attenuated, means the intensity in the direction of propagation is reduced. Attenuation is caused by two processes, absorption of the sound waves and deviation of energy from the direction of propagation (Blitz, 1963). Through absorption, some of the mechanical energy of the waves is converted into heat by internal friction. Deviation of energy from the direction of propagation is caused by reflection, refraction, diffraction and scattering. In addition to the medium itself, suspended particles also contribute to the attenuation .

Beers-Lambert-Bouguer law, equation next, describes the attenuation process and also defines the frequency dependent absorption coefficient (Jack Blitz, 1963).

$$I = I_0 \exp(-2\alpha x) \qquad (2.19)$$

Where: I is the intensity of the wave after it has traveled the distance

x Through the medium

I_0 Is the intensity at $x = 0$ and α is the absorption coefficient.

In fluids, there are two main causes of absorption, viscosity and thermal conduction (Jack Blitz, 1963). The viscous losses can be regarded as friction losses between the molecules of the medium as they move relative to each other during the propagation of the sound waves through the medium. Thermal conduction losses arise during heat transport between the warmer compressed regions of the medium and the cooler rarefied regions. Relaxation phenomena can also affect the absorption characteristics but that is beyond the scope of this study.

Compared to fluids, there are more potential causes of attenuation of sound waves in solids (Jack Blitz, 1963). These are characteristic of the physical properties of the medium and can be categorized in a number of groups; losses characteristic of polycrystalline solids, absorption due to lattice imperfections, absorption in ferromagnetic and ferroelectric materials, absorption due to electron-photon interactions, absorption in single crystals due to thermal effects and absorption due to other possible causes, such as acoustoelectric effects, structural relaxation, thermal relaxation and nuclear magnetic resonance. The details of these processes are beyond the scope of this thesis.

2.30.2 Standing Wave

Interference between sound waves can generally be handled through super positioning, by adding the displacement of all the wave functions in every point. A special case of wave interference is when two travelling waves of equal amplitude and wavelength meet head on. The result is a phenomenon known as a standing or stationary wave. A standing wave has displacement nodes, where the medium

particles do not move, and displacement antinodes, where the particles move twice as much as in one of the travelling waves. Contrary to travelling waves, standing waves do not transfer energy, thus the net energy transport in both directions is zero, indeed in the case of standing the displacement and pressure terms are given without considering the displacement term since there is no motion in the standing wave pattern.

$$y(x,t) = A_{sw}\cos(\omega t).\sin(kx) \quad (2.20)$$

$$P = -P_{sw}\cos(\omega t).\sin(kx) \quad (2.21)$$

Where: $A_{sw}$and $P_{sw}$are the sums of the amplitude of the individual waves and k = $\frac{2\pi}{\lambda}$ is the wave number, w = $2\pi f$ is the angular frequency

The pressure and displacement functions are 90^0 out of phase with respect to position, but not with respect to time. Thus, pressure nodes will always the displacement antinodes and pressure antinodes will always be displacement nodes.

2.30.3 Acoustic Particle Manipulation

It is easy to picture that suspended particles are affected by forces when sound waves propagate through their suspending medium. The waves are disturbances in the positions of the medium particles and these consequently exert forces on both their neighbouring medium particles and the suspended particles as they move. However, in most cases these forces are very small or cancel each other out. Though, in some particular situations, as in standing waves, this is not always the case. Under certain conditions, acoustic standing wave forces make suspended particles move in a controlled fashion. The involved acoustic forces can be divided into several well defined categories; act in coherence to manipulate particles in suspended medium (Weiser, 1982).

During propagation acoustic wave travels in the form of pressure wave, when it strikes a particle a long the way, it exert pressure force or acoustic energy whose

magnitude depends on both medium and particle characteristics and expressed mathematically as:

$$F_r = \left(\frac{\pi P_0^2 V_c \beta_w}{2\lambda}\right) * \emptyset(\beta, \rho).\sin(\frac{4\pi x}{\lambda}) \quad (2.22)$$

$$\emptyset = \frac{5\rho_c - 2\rho_w}{2\rho_c - \rho_w} - \frac{\beta_c}{\beta_w} \quad (2.23)$$

Where:

β_c, β_w Compressibility of the medium and particles respectively

ρ_w, ρ_c Density of the medium and particles respectively

V_c Volume of the particle

Other researcher have further elaborated more on the various axial and transverse forces between the droplets and the incident acoustic wave hence they categorized them into three types the first one is the force exerted when the incident wave strikes a droplets in the medium and designated as Primary acoustic radiation force (Garcia and Sinha, 2008), which designated as the primary acoustic radiation force expressed mathematically as:

$$F = -4\pi R^3 k E_{ac} * \Phi(\beta, \rho) * \sin(\frac{4\pi Z}{\lambda}) \quad (2.24)$$

Where:

E_{ac} : Energy density of the acoustic wave

Z : Distance from the pressure node

R : Radius of the droplet

k : Wave number

Φ : Acoustic contrast factor

With regard to this acoustic contrast factor particles are normally derived to either pressure node or antinode depending on the sing of the acoustic contrast factor, hence they will go toward the pressure node in the case of positive contrast factor and to pressure antinode in the case of negative contrast factor (Garcia and Sinha, 2008) this concept is used to design the particle separator by generating a permanent standing wave pattern. However there is another force that will arise as a result of this primary force when any two droplets are in close proximity, this force termed as secondary acoustic radiation force and it's attractive in nature leading to the acceleration of aggregation and fusion of the droplets to form one big droplet indeed this force a strong function of the volumes of the droplets and given as:

$$F_s = \frac{k^2 E_a}{2\pi}\left(1 - \frac{\beta_p}{\beta_f}\right)^2 \frac{V_1 V_2}{d^2} \qquad (2.25)$$

V_1, V_2, d^2 are the volumes of the two interacting droplets and the separating distance between them respectively. Furthermore as the drop move through the liquid under these forces, they experience the hydrodynamic drag force (F_d):

$$F_d = -4\pi\left(\frac{1+\frac{2\hat{\mu}}{3}}{1+\hat{\mu}}\right)\mu R V^0 \qquad (2.26)$$

Where: μ is the viscosity of the fluid, and $\hat{\mu}$ is the ratio of the viscosities of the drop to the continuous phase and V^0 is the speed of the drop.

2.31 Previous Studies On Standing Wave Generation

Various studies have conducted lab experiment to apply the idea of standing wave resonators for different application but in the area emulsion it is still need further investigation to come up with a tremendous water oil acoustic separator, Guoxiang has applied 500 w generator, empowering 10KHz sonicator to design a standing wave chamber, thus his chamber was composed of tube filled with crude oil, an ultrasonic horn of Piezoelectric transducer and a reflection surface at the bottom of the vertical tube at shown in Figure 2.8, the total assembly of the chamber is 1) transducer, 2) Temperature controller, 3) Generator, 4) thermometer, 5)

resonator 6) insulator, 7) oscilloscope 8) Hydrophne. Other researchers reported that the frequency of more than 1 MHz (with $\lambda < 1.5$ mm) in water is preferred for cell and particles separation.

Gautam have conducted some experiment to separate oil droplets from aqueous solution (w/o emulsion) using acoustic chamber, and introduced a model to describe the manipulation of individual drops under the acoustic field based on the population balance model to track the sizes evolution under the influence of ultrasonic field (Garcia and Sinha, 2008)

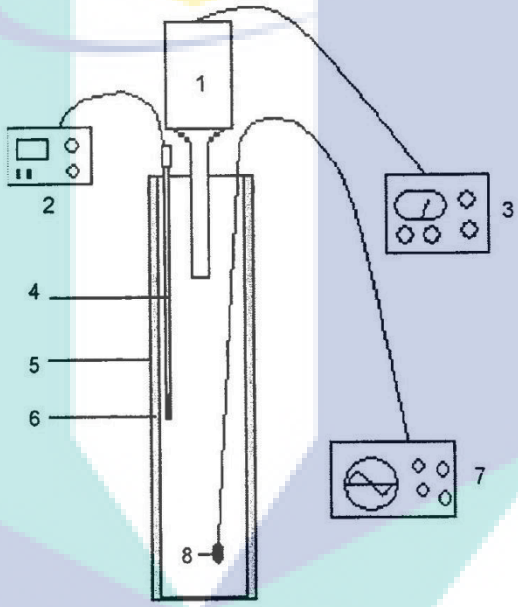


Figure 2.8: Acoustic resonating chamber (Garcia and Sinha, 2008)

2.32 General Evaluation Of Wave Motions

Waves are generated when a matter experience mechanical disturbance, and travel freely in the medium as a pressure wave in a compression refraction pattern. It will return to its original situation after the removal of the cause; however the general equation governing the wave motion is

$$\frac{\partial^2 \theta}{\partial x^2} = c^2 \frac{\partial^2 \theta}{\partial t^2} \qquad (2.27)$$

Where

c : Velocity

θ : disturbance

x : distance from the origin

t :time

Equation of wave motion:

For liquid and gas the motion is normally in x direction only and they are termed as Longitudinal waves and their motion are given by the following equation:

$$\frac{\partial^2 \xi_x}{\partial t^2} = \left(\frac{\lambda+2\mu}{\rho_0}\right)\frac{\partial^2 \xi_x}{\partial x^2} \quad (2.28)$$

$$c_1 = \sqrt{\frac{\lambda + 2\mu}{\rho_0}}\ The\ velocity\ of\ the\ longetidinal\ waves\ is\ given\ by$$

$$c_1 = \sqrt{\frac{\lambda + P_0}{\rho_0}}\ The\ velocity\ in\ liquid\ is\ generally$$

2.32.1 Ultrasonic and Agglomeration

The two main forces that could affect a suspended particle in liquid medium are believed by many researchers to be the primary and secondary acoustic radiation forces as would be elucidated mathematically as follows:

$$F_b = -4\pi R^3 k E_{ac}.\phi(\beta\rho)\sin\left(\frac{4\pi z}{\lambda}\right) \quad (2.29)$$

$$\phi(\beta\rho) = \left(\frac{5\rho_P - 2\rho_f}{2\rho_P + \rho_f}\right) - \frac{\beta_P}{\beta_f} \quad (2.30)$$

where

E_{ac}: energy density of acoustic field

Z : distance from the pressure node

R : Radius of the drop

K : wave number in the hosting fluid

$\beta = \frac{1}{\rho c^2}$ = For liquids

if ϕ have a negative values the droplet will move toward the pressure node and it will move to the pressure antinode when it will have a positive values.

Secondary acoustic radiation force:

When the droplets move toward the nodal planes with respect to primary radiation force they approach each other, then an attractive secondary radiation force will generate between any two approaching droplets that will ease their coalescence and can be expressed as:

$$F = -\frac{k^2 E_{ac}}{2\pi}\left(1 - \frac{\beta_P}{\beta_f}\right)^2 \frac{V_1 V_2}{d^2} \qquad (2.31)$$

Where V_1, V_2 are the volumes of the interacting droplets, d is the separation distance between the centers of the droplets. As the droplets move through the liquid under the influence of the various acoustic forces mentioned above they experience hydrodynamic drag which is given by the drag force F_d

$$F_d = -4\pi\left(\frac{1+2\hat{\mu}/3}{1\hat{\mu}}\right)\mu R V^o \qquad (2.32)$$

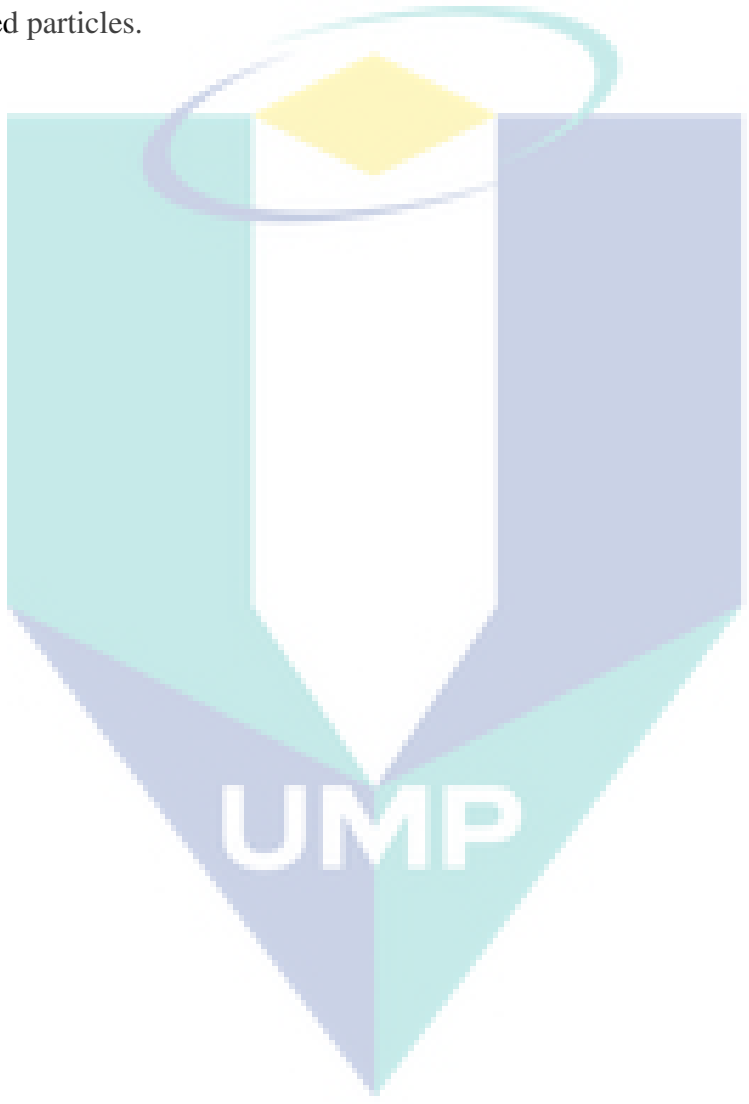
μ : Viscosity of the fluid

$\hat{\mu}$:Ratio of viscosity of drop to viscosity of continuous phase

V^o: speed of droplets

The process of agglomeration and separation of suspended particles via ultrasonic is widely used in various industrial application, Phylis and coworkers have designed a 75 ml acoustic resonator to study the sedimentation of hybridoma cells suspended in a medium, by using composed transducer and Pyrex glass as a reflector, Coakely and coworkers have used the standing wave to manipulate a suspended eukaryote cells, in contrast to the previous researchers, others have investigated the effects of high power ultrasonic energy to dewater a slurry, however they have found

that the high power was not efficient in promoting agglomeration, but rather the ultrasonic energy which found to play an important role in the dewatering process (Franco et al., 2006) others have succeeded to apply the standing wave to collect a suspended particles in a porous medium incorporated with the resonating chamber. Similarly the concept of ultrasonically enhanced sedimentation of suspended particles for what so called a H-shaped separator was investigated, however it is resulted that the H-shaped apparatus was not efficient at high concentration of suspended particles.



CHAPTER 3

ECONOMY ANALYSIS

In this project, Malaysia is currently the second world's producer and exporter of palm oil. Malaysia produces about 40% of the world's supply of palm oil. Figure 3.1 show that until December 2011, the total oil palm planted area in Malaysia are 5,000,109 hectare. Planted area of oil palm in Peninsular Malaysia is 2,546,760 hectare, Sabah, 1,431,762 hectare and Sarawak is 1,021,587 hectare.

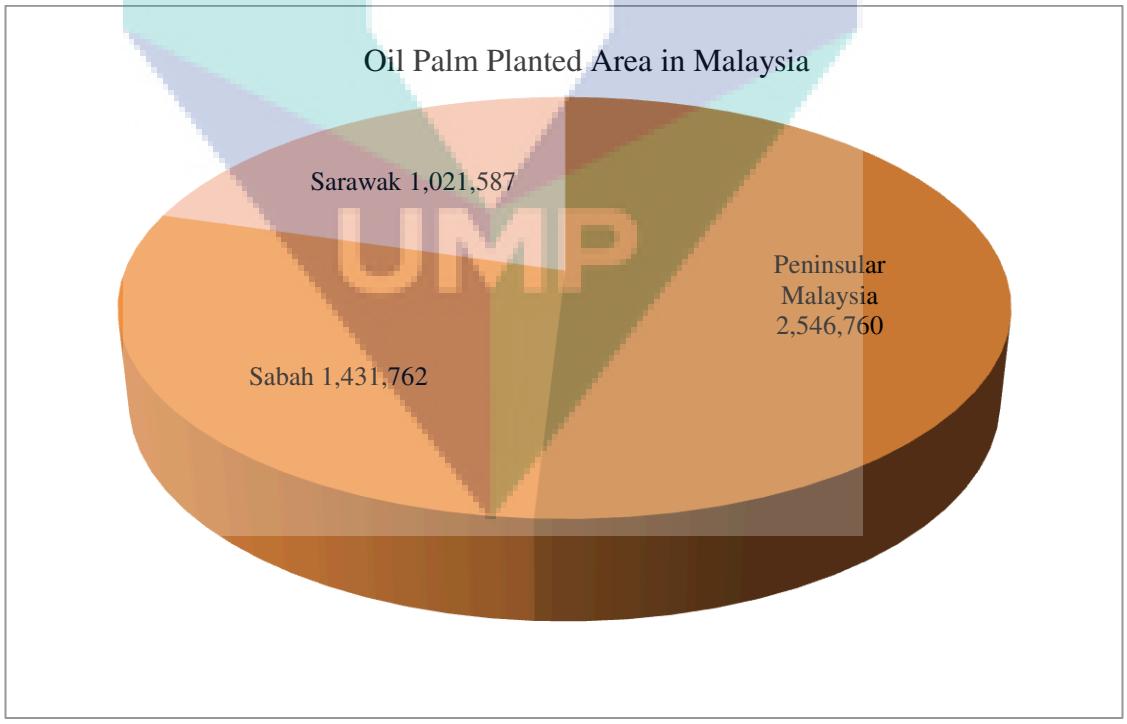


Figure 3.1: Total oil palm planted area in Malaysia (Malaysian Palm Oil Board (MPOB), 2011).

Oil palm industry in Malaysia was developed by Felda, Felcra, Risda, State Agencies, Private Estates and independent smallholders. The percentage of developer is show by Figure 3.2 below.

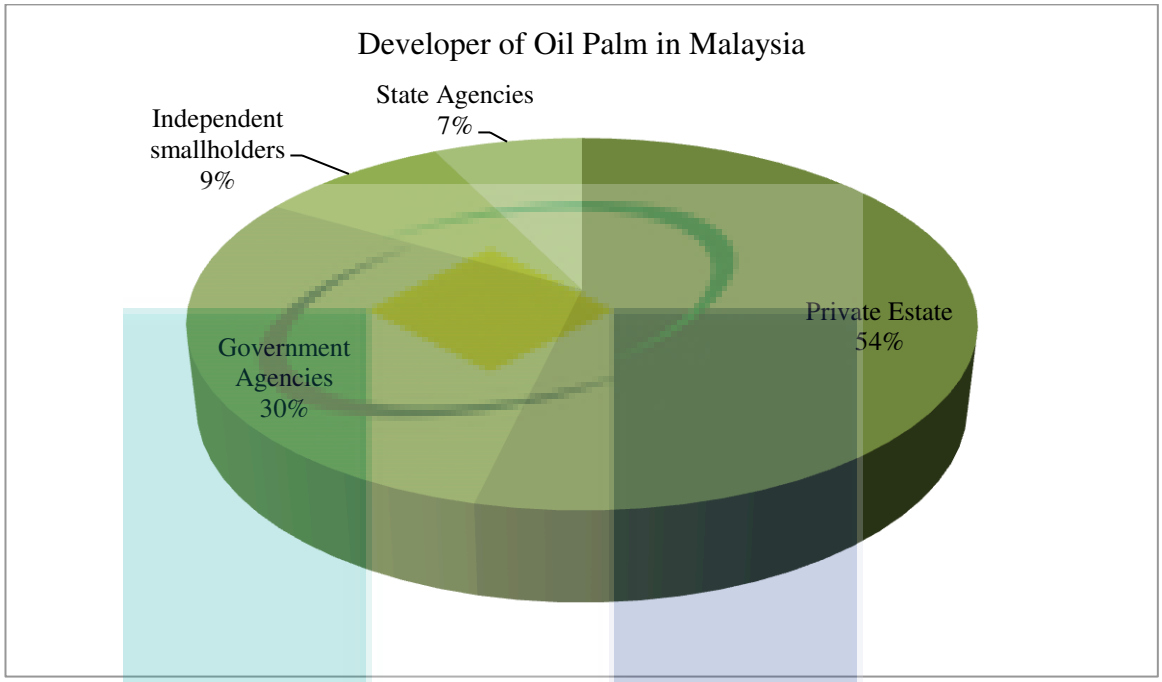


Figure 3.2: Developer of palm oil in Malaysia. (Malaysian Palm Oil Board (MPOB), 2011).

3.1 Demand of Wastewater Treatment System for POME

Wet process of palm oil milling consumes a large amount of process water and consequently, generates a larger amount of wastewater. Therefore, a larger amount of palm oil mill effluent (POME) is generated with high organic load. It was reported that for each ton of fresh fruit bunch (FFB) processed, 0.87 ton of POME is discharged with BOD as high as 50,000 mg/l (Prasertsan and Prasertsan,1996). Many studies suggested various water management approaches (Kittikun et al. 2000, Department of industrial works and GTZ 1997; Leong et al. 2002; Barrantes 2001), but a systematic approach was very rare. In recent years, the scarce of freshwater supply and the increasing wastewater treatment cost due to stringent environmental standards became the major problem of mills. It was found that the recycle of the waste streams had reduced the freshwater consumption and POME by 65% and 67%,

respectively. Due to that, the demand of wastewater treatment system is very high for the country such as Malaysia as a bigger producer of oil palm in the world.

Market research for 2011,the global market for water and wastewater treatment (WWT) products like delivery equipment, instrumentation, process equipment, and treatment chemicals will increase at a 10.4% compound annual growth rate (CAGR) to exceed $93 billion in 2016, from a 2011 value of nearly $57 billion (www.bccresearch.com). Malaysia also has a high demand for the wastewater treatment products to treat the POME. This is because the effluent must satisfy the standard parameters of Department of Environmental.

3.2 Demand of Biogas (Methane) from POME

Malaysia's palm oil industry is one of the important industries of the nation and it is the fourth largest contributor to the national economy and currently accounts for RM53 billion in Gross National Income (GNI). The Palm Oil National Key Economic Area (NKEA) is targeted to raise a total GNI contribution of RM125 billion to reach RM178 billion by 2020. As a major contributor to economic growth, the palm oil National Key Economic Area (NKEA) programme plans to implement eight cores Entry Point Project (EPPs) in spanning the palm oil value chain. One of the palm oil cores EPPs programme is EPP 5, build biogas facilities at mills across Malaysia (National Key Economic Areas (NKEA), 2010).

When Fresh Fruit Bunch (FFB) is processed, palm oil mill effluent waste (POME) is generated. In order to reduce the impact to the environment, the POME is treated before being discharged. It consists of several steps including cooling, oil removal, anaerobic and aerobic treatment (to reduce Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) to a level acceptable for irrigation or land application). The anaerobic decay of organic matter inside the ponds is accompanied by the production of biogas containing methane (which is a principal component of natural gas) that is released into the atmosphere.

This methane gas released during the milling process has given the palm oil industry a negative image due to its high potential for global warming where it is over 20 times more effective in trapping heat in the atmosphere than carbon dioxide over a 100-year period. As methane gas could be captured to generate electricity, mills can benefit from this new revenue source as well as from the carbon credit programme offered under the United Nations Framework for Climate Change Convention (UNFCCC).

The objective of this initiative is to ensure that mills capture methane gas to generate electricity for supply to the national grid or for their own use. Mills should start developing biogas plants immediately to capture additional income from the incentives offered by the Clean Development Mechanism (CDM) programme. Biogas plants will be developed at the 500 mills over the next 10 years. Of these, 250 mills will target to supply electricity to the national grid by 2020. Another 233 mills will capture biogas to be used as fuel for their own boilers. The balance of 17 mills will use the methane gas for both options (National Key Economic Areas (NKEA), 2010).

To accelerate the development of biogas plants, the electricity tariff for Renewable Energy Power Purchasing Agreement (REPPA) must be increased from the current RM0.21 per kilowatt hour to RM0.35 per kilowatt hour. To assist independent millers in funding the development of their biogas plants, an existing Green Technology Fund set up by the Ministry of Energy, Green Technology and Water is available.

This Entry Point Project (EPP) will be wholly funded by independent millers and plantation companies with a total estimated cost of RM2.8 billion. The investment will be targeted at three major areas for the construction and operation of biogas plants: building gas flaring facilities (worth RM1.7 billion), investing in connection of mills to the grid (worth RM845 million) and investing in gas burners (worth RM259 million) (National Key Economic Areas (NKEA), 2010).

This Entry Point Project (EPP) will generate an estimated RM2.9 billion in Gross National Income (GNI) in 2020 while creating 2,000 jobs and not requiring any incremental government funding (National Key Economic Areas (NKEA), 2010).

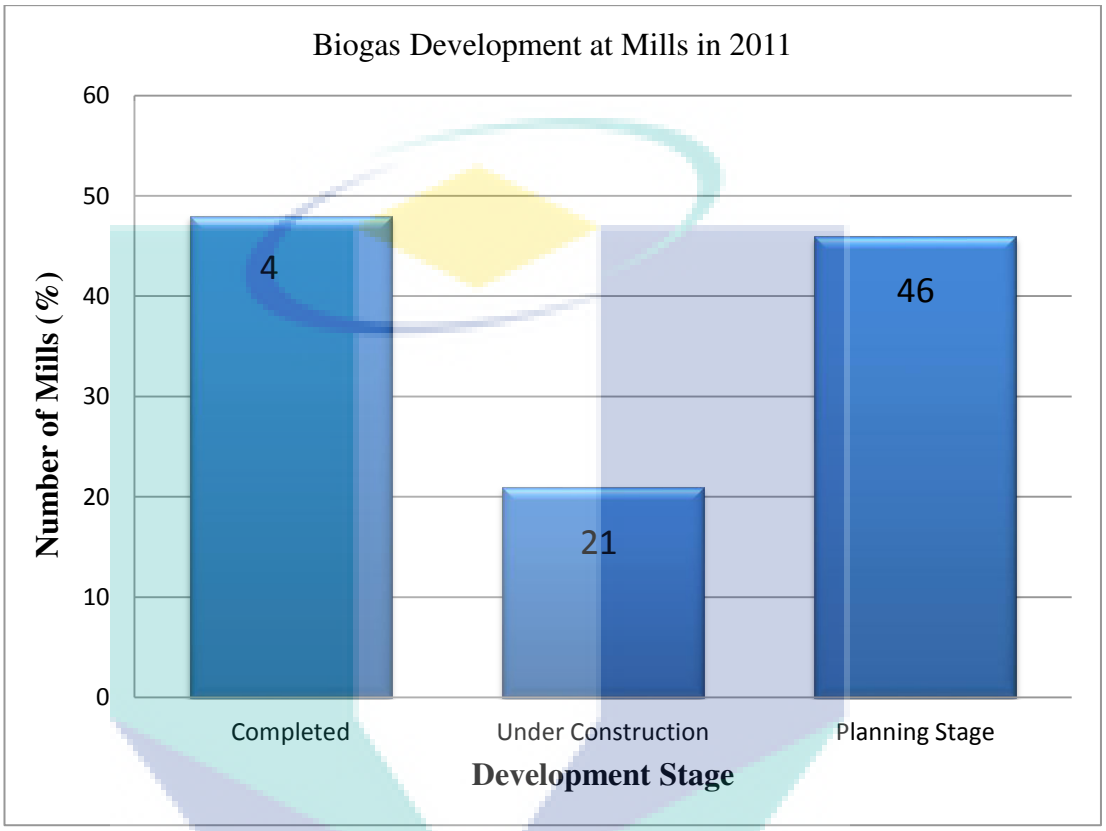


Figure 3.3: Biogas Development at Mills in 2011 (pemandu.gov.my).

It is most importance for the palm oil industry to capture biogas from POME. The reasons and benefits of biogas capture are many. These include additional revenues from sale of surplus energy and carbon credits. Furthermore, biogas capture will reduce the carbon footprint of palm oil production and enable competitive market access of palm products to environmentally sensitive markets such as the European country (EU) and United State (AS).

3.3 Market Opportunity

Currently, there are two Clean Development Mechanism (CDM) projects that have been registered to recover methane from palm oil mill effluent which are hosted by Kim Loong Power Sdn. Bhd. (Project, 0867) and United Plantations Bhd. (Project, 1153). As a develop country, Malaysia need more projects that can recover biogas from POME. Subsequent to this, investigation by (Yacob et al.,2006) on the methane emission from anaerobic pond shows that 1043.1 kg/day/ pond of methane gas is emitted. Based on the ponding system investigated, there were 4 anaerobic ponds, which in total produced 4172.4 kg/day of methane gas. It is estimated that approximately RM 1,027,975 per year (€ 228,438.9) can be generated as revenue if methane gas emitted from the anaerobic ponds are captured as renewable energy. Calculations are based on 300 working days and carbon credit price of € 10 per ton of carbon quoted by (Menon, 2007).

So, when the ultrasonic assisted membrane anaerobic system (UMAS) develops, it is the suitable time to attract developer of oil palm to change their current wastewater treatment system which is ponding system to ultrasonic assisted membrane anaerobic system UMAS. Payback period for the investment on anaerobic membrane system can be short if carbon credit prices remain high. Considering the revenue and advantages achieved through capturing methane gas, palm oil mills could switch to ultrasonic assisted membrane anaerobic system (UMAS).This is because UMAS specification was satisfy the need of developer. The comparison of the current system and ultrasonic assisted membrane anaerobic system (UMAS) are shows below table:

Table 3.1: Comparison of the current system and ultrasonic assisted membrane anaerobic system (UMAS).

Present Product	UMAS
A) Conventional Ponding System:	Ultrasonic-Assisted Membrane Anaerobic System (UMAS):
i) The system need a large land area.	i) Achieve a high COD removal efficiency (98.6%) in a short period of time.
ii) Long retention time (1-2 months).	ii) Reduced retention time from 60 days to 28 days.
iii) Low digestion rate of particles.	iii) Avoid fouling of membrane via intermittent ultrasonic application
B) Membrane Anaerobic System:	iv) Good alternative for treating high strength wastewater and for recovery of energy as methane (80%) that could be used to heat or produce hot water at the agricultural, industries and municipal waste.
i) Membrane fouling.	
ii) Need so much chemical solution to clean-up the membrane fouling.	
iii) Membrane fouling will interrupt the water production process.	v) Environmentally friendly
iv) Shorten the membrane life due to chemical erosion.	vi) The plant size can be reduced example from 50x50m to 10x5m.

3.4 Marketing Strategy

Marketing strategy will be to execute and communicate its value proposition of service and market segmentation advantage in providing ultrasonic assisted membrane anaerobic system (UMAS).

3.4.1 Pricing Strategy

The price that will be charged is depending to the volume of wastewater that industries produce per day. Wastewater and infiltration/inflow (I/I) volumes are used as design criteria for wastewater system facilities(Financing and charges for wastewater system, 2004). But as average the price of one package system including tank or reactor, membrane, ultrasonic system, valve and pump is about RM 200,000.00++. Wholesale prices have been established to encourage the quick formation of a dealership network. Dealers are afforded a 33% discount.

3.4.2 Promotion Strategy

The strategy how to promote the system can be done in many ways such as video advertisements, print advertisements and the concept of e-marketing and exhibition to introduce ultrasonic assisted membrane anaerobic system (UMAS) .

3.4.3 Strength, Weaknessess, Opportunities, Threats (SWOT) Analysis

Commercialized the product will facing a lot of challenges. So, by having a wide and thorough knowledge of the local manufacturing market and expertise, which will go towards penetrating the market. Below are the summarized strengths, weaknesses, opportunities and threats.

a) Strength

i) Strategic market segmentation and implementation strategies.
ii) Diversified market segments: ensuring the lack of dependency on one particular market.
iii) Combination of skills in directorship. The directors intend to jointly develop business strategy and long-term plans, having wide experience in product and business know-how.
iv) Establishment and maintenance of strong capital base.
v) An aggressive and focused marketing campaign with clear goals and strategies.

b) Weaknesses

i) Lack of a reputation in comparison to our competitors.
ii) The introduction of new organizational practices and personnel who have not previously worked together presents a challenge to the company.
iii) A limited financial base compared to the major players in the industry.
iv) Lack of clear-cut channels of distribution.
v) Establishment on the Internet will produce technological challenges.

c) Opportunities

i) Specific niche: Appreciation for high-quality of clean water.

- Reduce cost of maintenances.
- Reduce using of chemical solutions.

ii) Internet marketing and sales--though still in its infancy.

iii) Increasing number of industries looking at a quality system of wastewater treatment.

d) Threats

The present growth in the market may result in market saturation, through competition. This competition could emerge from a variety of given sources including:

i) Established mass-market companies' development of new lines and vertically integrating so as to be totally in control of supplies and products being sold on the respective markets.

ii) New marketing strategies and tactics by established products and companies.

iii) Existing competition.

iv) Other start-up companies generated by healthy economic growth nationwide.

v) Intolerable price increases by foreign suppliers may occur.

3.5 Financial Analysis

Financial plan is based on receiving several loans to purchase/fabricate the production equipments, provide initial operating capital, and establish the customer base. The profitability will be achieved early in the first year and due to the expected high growth rate, and must get a strong profit on sales by year three. Projected Profit and Loss, projected Cash Flow, Projected Balance Sheet and Break Even by a year will be disscussed below.

3.5.1 Projection of Profit and Loss

Every business needs to project a profit and loss statement for the next few years in order to help it better understand its needs. A projected profit and loss statement provides an analysis of the expected profitability of the business and often allows creditors to select among loan applicants. In this financial statement, the summarizations of the revenues, costs and expenses incurred are doing in specific period of time, usually a fiscal quarter or year. These records provide information that shows the ability of a company to generate profit by increasing revenue and reducing costs (Cornett M.M et.al.,2009). Analyzing business performance on a regular basis enables management to detect problems and solve them.

3.5.2 Projection of Cash Flow

Cash flow is essentially the movement of money into and out of your business; it's the cycle of cash inflows and cash outflows that determine a business' solvency. Cash flow analysis is the study of the cycle of the business' cash inflows and outflows, with the purpose of maintaining an adequate cash flow for the business, and to provide the basis for cash flow management. Cash flow analysis involves examining the components of the business that affect cash flow, such as accounts receivable, inventory, accounts payable, and credit terms (Cornett M.M et.al.,2009).

By performing a cash flow analysis on these separate components, it can be more easily identify cash flow problems and find ways to improve the cash flow. Besides that, projected cash flow is very important to most lenders because it provides an indication of whether the business will have enough cash to pay suppliers, vendors, and other creditors on time. This information also functions as a planning tool for the business. If his cash flow estimates show that the business will occasionally not have enough money to pay bills, arrangement in advance can do for other sources of funds to get through cash flow crunches. Projected cash flow statement also helps in facilitating better financial planning, project evaluation & fund control.

3.5.3 Projection of Balance Sheet

The balance sheet, also known as the statement of financial condition, offers a snapshot of a company's health. It tells you how much a company owns (its assets), and how much it owes (its liabilities). The difference between what it owns and what it owes is its equity, also commonly called "net assets" or "shareholders equity". The balance sheet tells investors a lot about a company's fundamentals such as how much debt the company has, how much it needs to collect from customers (and how fast it does so), how much cash and equivalents it possesses and what kinds of funds the company has generated over time. Assets, liability and equity are the three main components of the balance sheet (Katz J.A et.al,2011). Carefully analyzed, they can tell investors a lot about a company's fundamentals.

The balance sheet must follow the following formula:

Assets = Liabilities + Shareholders' Equity

3.5.3.1 Assets

There are two main types of assets: current assets and non-current assets. Current assets are likely to be used up or converted into cash within one business cycle usually treated as twelve months. Three very important current asset items found on the balance sheet are: cash, inventories and accounts receivables. (Katz J.A et.al,2011).

3.5.3.2 Liabilities

There are current liabilities and non-current liabilities. Current liabilities are obligations the firm must pay within a year, such as payments owing to suppliers. Non-current liabilities, meanwhile, represent what the company owes in a year or more time. Typically, non-current liabilities represent bank and bondholder debt.(Katz J.A et.al,2011).

3.5.3.3 Equity

Equity represents what shareholders own, so it is often called shareholder's equity. As described above, equity is equal to total assets minus total liabilities.

$$\text{Equity} = \text{Total Assets} - \text{Total Liabilities}$$

The two important equity items are paid-in capital and retained earnings. Paid-in capital is the amount of money shareholders paid for their shares when the stock was first offered to the public. It basically represents how much money the firm received when it sold its shares. In other words, retained earnings are a tally of the money the company has chosen to reinvest in the business rather than pay to shareholders. Investors should look closely at how a company puts retained capital to use and how a company generates a return on it(Katz J.A et.al,2011) .

3.5.4 Break Even Analysis

One of the most common tools used in evaluating the economic feasibility of a new enterprise or product is the break-even analysis. The break-even point is the point at which revenue is exactly equal to costs. At this point, no profit is made and no losses are incurred. The break-even point can be expressed in terms of unit sales or dollar sales. That is, the break-even units indicate the level of sales that are required to cover costs. Sales above that number result in profit and sales below that number result in a loss. The break-even sales indicates the dollars of gross sales required to break-even (Cornett M.M et.al.,2009). Figure 3.4 shown the break even chart.

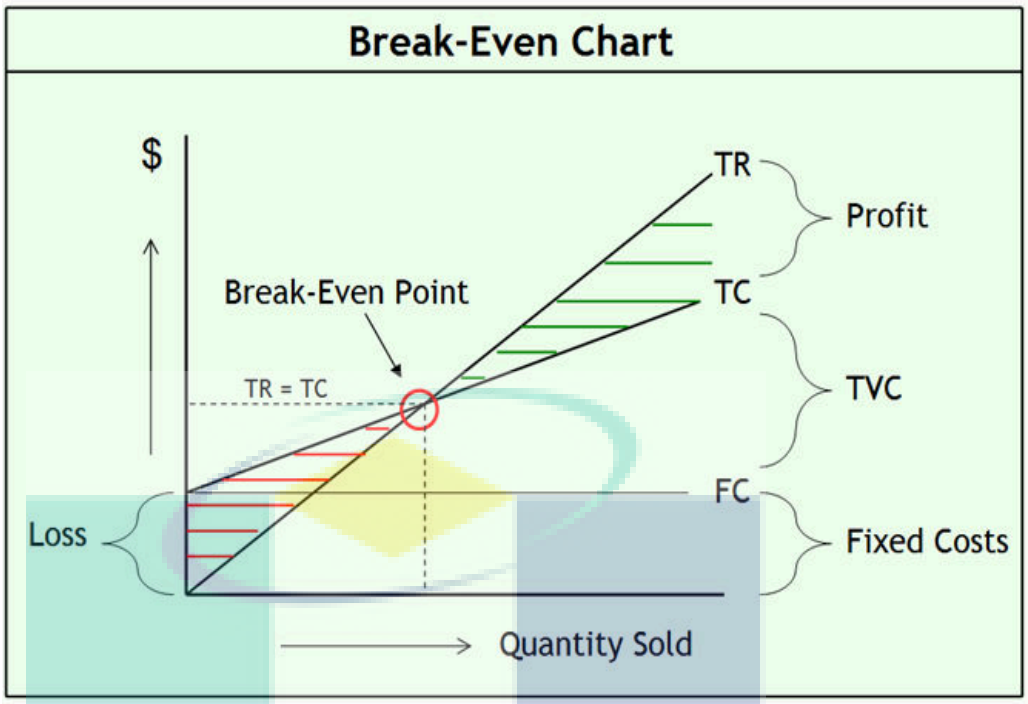


Figure 3.4 : Break even chart.

Where:

TR = Total Rrevenue

TC = Total Cost

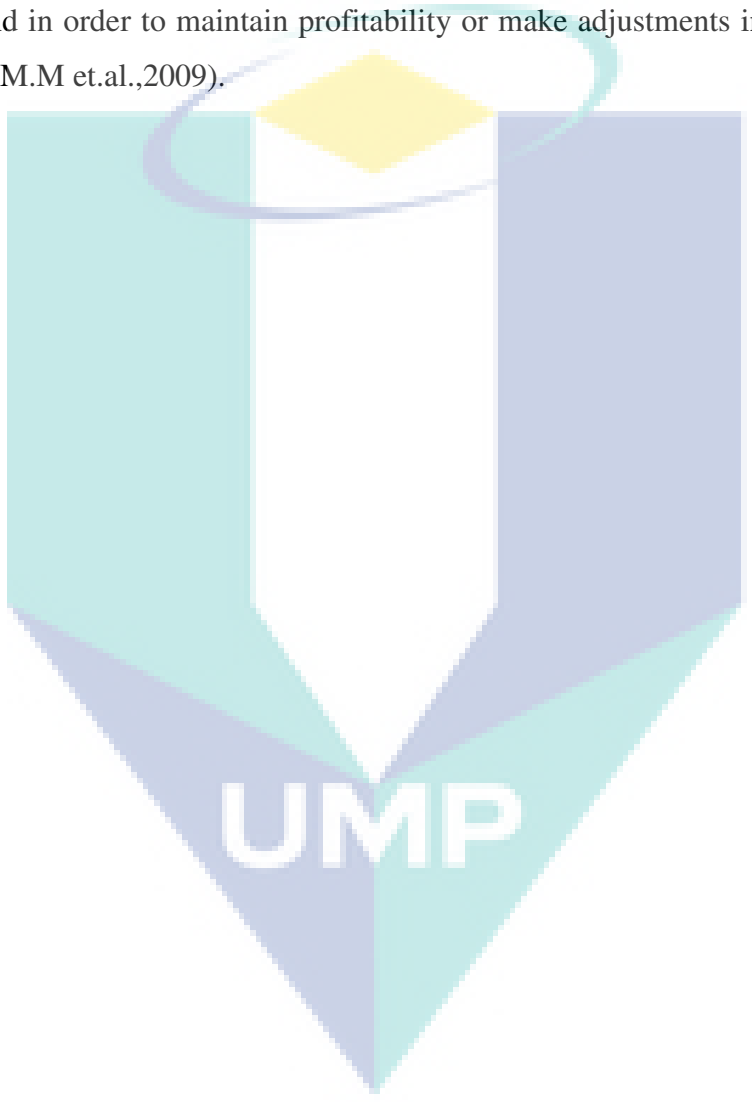
FC = Fixed Cost

TVC = Total Variable Cost

It is important to realize that a company will not necessarily produce a product just because it is expected to breakeven. Many times, a certain level of profitability or return on investment is desired. If this objective cannot be reached, which may mean selling a substantial number of units above break-even, the product may not be produced. However, the break-even is an excellent tool to help quantify the level of production needed for a new business or a new product.

Break-even analysis is based on two types of costs: fixed costs and variable costs. Fixed costs are overhead-type expenses that are constant and do not change as the level of output changes. Variable expenses are not constant and do change with the level of output. Because of this, variable expenses are often stated on a per unit

basis. Once the break-even point is met, assuming no change in selling price, fixed and variable cost, a profit in the amount of the difference in the selling price and the variable costs will be recognized. One important aspect of break-even analysis is that it is normally not this simple. In many instances, the selling price, fixed costs or variable costs will not remain constant resulting in a change in the break-even. And these changes will change the break-even. So, a break-even cannot be calculated only once. It should be calculated on a regular basis to reflect changes in costs and prices and in order to maintain profitability or make adjustments in the product line (Cornett M.M et.al.,2009).



CHAPTER 4

MATERIALS AND METHODS

Raw POME was treated by UMAS in a laboratory digester with an effective 200-litre volume. Figure 4.1 presents a schematic representation of the ultrasonic assisted membrane anaerobic system (UMAS) which consists of a cross flow ultra-filtration membrane (CUF) apparatus, a centrifugal pump, and an anaerobic reactor. Hence, the Figure 4.2 is shown the experimental setup for UMAS. 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.

The UF membrane module had a molecular weight cut-off (MWCO) of 200,000, a tube diameter of 1.25 cm and an average pore size of 0.1 µm. The length of each tube was 30 cm. The total effective area of the four membranes was 0.048 m^2. The maximum operating pressure on the membrane was 55 bars at 70 ℃, and the pH ranged from 2 to 12. The reactor was composed of a heavy duty reactor with an inner diameter of 25 cm and a total height of 250 cm. The operating pressure in this study was maintained between 2 and 4 bars by manipulating the gate valve at the retentate line after the CUF unit.

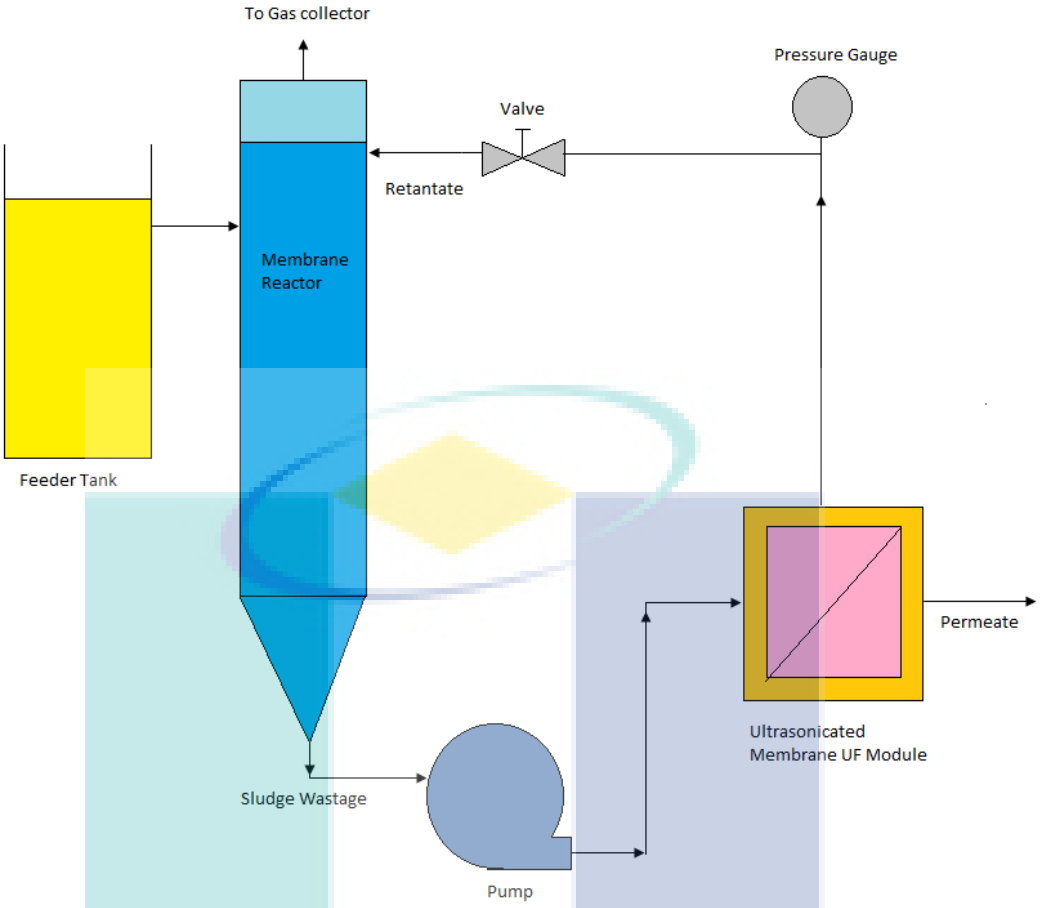


Figure 4.1: Experimental schematic for UMAS.

Figure 4.2: Experimental Set-up for UMAS.

4.1 Palm Oil Mill Effluent (POME)

Raw POME samples were collected from a palm oil mill in Kuantan-Malaysia. The wastewater was stored in a cold room at 4^{o}C prior to use. Samples analysed for chemical oxygen demand (COD), total suspended solids (TSS), pH, volatile suspended solids (VSS), substrate utilisation rate (SUR), and specific substrate utilisation rate (SSUR).

4.2 Bioreactor Operation

The ultrasonicated membrane anaerobic system, UMAS Performance was evaluated under six steady-states with influent COD concentrations ranging from (67,000 to 91,400 mg/l) and organic loading rates (OLR) between (0.5 and 9.5 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 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).

Table 4.1: Summary of results (SS: steady state).

Steady State (SS)	1	2	3	4	5	6
COD feed, mg/L	67000	79000	82400	86000	90000	91400
COD permeate, mg/L	980	1940	1650	1980	2200	3000
Gas production (L/d)	280.5	357	377	395	470	540
Total gas yield, L/g COD/d	0.29	0.38	0.65	0.77	0.82	0.88
% Methane	79	75.5	70.2	71.8	70.6	68.5
Ch_4 yield, l/g COD/d	0.29	0.32	0.50	0.54	0.56	0.59
MLSS, mg/L	12960	13880	15879	17700	20000	25600
MLVSS, mg/L	10091	10950	12624	14638	17000	22528
% VSS	77.86	78.89	79.50	82.7 0	85.00	88.00
HRT, d	480.3	76.40	20.3	8.78	7.36	5.40
SRT, d	860	320	132	32.6	14.56	10.6
OLR, kg COD/m^3/d	0.5	1.5	3	5.5	8.5	9.5
SSUR, kg COD/kg VSS/d	0.185	0.262	0.266	0.274	0.315	0.321
SUR, kg COD/m3/d	0.0346	0.8454	3.3028	5.6657	7.7753	9.4528
Percent COD removal (MAS)	**96.5**	**96.0**	**95.8**	**95.4**	**94.9**	**94.8**
Percent COD removal (UMAS)	**98.5**	**97.5**	**98.0**	**97.7**	**97.6**	**96.7**

Table 4.2: Results of the application of three known substrate utilisation models.

Model	Equation	R^2(%)
Monod	$U^{-1} = 2025\ S^{-1} + 3.61$ $K_s = 498$ $K = 0.350$ $\mu_{Max} = 0.284$	98.9
Contois	$U^{-1} = 0.306\ X\ S^{-1} + 2.78$ $B = 0.111$ $u_{Max} = 0.344$ $a = 0.115$	97.8
Chen & Hashimoto	$\mu_{Max} = 0.377$ $K = 0.519$ $U^{-1} = 0.0190\ S_o\ S^{-1} + 3.77$ $K = 0.006$ $a = 0.006$ $\mu_{Max} = 0.291$ $K = 0.374$	98.7

4.3 Determination of Biochemical Oxygen Demand (BOD)

Incubation bottles: 300mL bottles

BOD incubator

Volumetric flask, 1L.

Beaker, 500mL.

Dissolved oxygen meter.

1. Prepare reagents in advanced but discard if there is any sign of precipitation or biological growth in the stock bottles. Use reagents grade or better for all chemicals and use distilled or equivalent water.

   a) Phosphate buffer solution

   Dissolve 8.5 g KH_2PO_4, 21.75 g K_2HPO_4, 33.4 g $Na_2HPO_4\,7H_2O$ and 1.7 g NH_4CI in about 500 mL distilled water and dilute to 1L. The pH should be 7.2 without further adjustment.

   b) Magnesium sulfate solution

   Dissolve 22.5 g $MgSO_4\,7H_2O$ in distilled water and dilute to 1L.

   c) Calcium chloride solution

   Dissolve 27.5 g $CaCI_2$ in distilled water and dilute to 1L.

   d) Ferric chloride solution

   Dissolve 0.25 g $FeCI_3$ 6H2O in distilled water and dilute to 1L.

   e) Acid and alkali solutions, 1N for neutralization of caustic or acidic waste samples.

   i. Acid-Slowly and while stirring, add 28 mL concentrated sulfuric acid to distilled water. Dilute to 1 L.

   ii. Alkali-Dissolve 40 g sodium hydroxide in distilled water. Dilute to 1L.

2. Preparation of dilution water: Add 1 mL each of phosphate buffer, magnesium sulfate, calcium chloride, ferric chloride solution into 1L volumetric flask. Add distilled water to 1L.

3. Add 10mL wastewater sample into a 500mL beaker.
4. Add dilution water up to 30 mL into the same beaker.
5. Adjust pH value to 6.5 to 7.5 by adding acid/alkali.
6. Prepare 300mL dilution water as control in another 500mL beaker.
7. Put all prepared samples and control in 300mL-incubation bottle each.
8. Measure and record dissolved oxygen (DO) concentration for each sample using Dissolved Oxygen Meter.
9. Add water to the flared mouth of bottle and cover with an aluminum foil.
10. Put all the bottles in BOD Incubator for five days. Set the temperature at 20°C.
11. Measure final DO value after five days.
12. Calculate BOD5 according to the formula below:

BOD, mg/L $(D_1 — D_2) / P$ (4.1)

Where;

D1 = DO value in initial sample

D2 = DO value in final sample

P = Decimal volumetric fraction of sample used

Or

BOD, mg/L = $(D_1 — D_2)$ x Dilution factor

Dilution factor= Bottle volume (300mL) / Sample volume

4.4 Determination of Total Suspended Solids (TSS)

Glass fiber filter disk, 47 mm @ 70 mm — pre dry in the oven
Measuring cylinder, 100mL
Pipette, 1mL
Analytical balance
Oven — preheated to 103°C to 105°C
Desiccator
Buchner flask and funnel
Vacuum pump
Aluminum weighing dishes/Crucible dish

1. Dry the filter disk in the oven at 103°C to 105°C for 1 hour, cool in a desiccator and weigh.

2. Assemble filtering apparatus and filter and begin suction. Wet the filter with a small volume of distilled water to seat it.

3. Pipette 50mL of water sample (mixed to ensure homogeneity) onto centre of filter disk in a Buchner flask, using gentle suction (under vacuum).

4. Wash filter with three successive 1mL volumes of distilled water, allowing complete drainage between washings, and continue suction for about 3 mm after filtration is complete.

5. Carefully remove filter from filtration apparatus and transfer to aluminum weighing dish/crucible dish as a support.

6. Dry at least 1 hour at 103°C to 105°C in an oven cool in a desiccator to balance temperature and weigh.

7. Repeat the cycle of drying, cooling, desiccating, and weighing until a constant weight is obtained.

4.5 Determination of Chemical Oxygen Demand (COD)

Materials and Methods

COD Digestion Reactor
Spectrophotometer, HACH DR/2400 @ DR/2800
COD Digestion Reagent Vial LR @ HR
COD rack
Volumetric pipette, 2mL
Paper towel/Tissue

1. Homogenize 100 mL of sample for 30 seconds in a blender.
   *For samples containing large amounts of solids, increase the homogenization time.

2. For the 200-15,000 mg/L range or to improve accuracy and reproducibility of the other ranges, pour the homogenized sample into a 250-mL beaker and gently stir with a magnetic stir plate.
   *If the sample does not contain suspended solids, omit step 1 and step 2.

3. Turn on the COD Reactor. Preheat to 150°C. Place the safety shield in front of the reactor.

4. Remove the caps from two COD Digestion Reagent Vials.
   *Be sure to use vials for the appropriate range.

5. Hold one vial at a 45-degree angle. Use a clean volumetric pipette to add 2.00mL of sample to the vial. This is the prepared sample.

6. Hold a second vial at a 45-degree angle. Use a clean volumetric pipette to add 2.00mL de-ionized water to the vial. This is the blank.

7. Cap the vials tightly. Rinse them with de-ionized water and wipe with a clean paper towel.

8. Hold the vials by the cap over a sink. Invert gently several times to mix. Place the vials in the preheated COD Reactor.
   *The sample vials will become very hot during mixing.

9. Heat the vials for two hours.

10. Turn the reactor off. Wait about 20 minutes for the vials to cool to 120°C or less.

11. Invert each vial several times while still warm. Place the vials into a rack and cool to room temperature.

12. Touch Hach Programs. Select program 430 COD LR (Low Range) or 435 COD HR (High Range/High Range Plus). Touch Start.

13. Clean the outside of the vials with a damp towel followed by a dry one to remove fingerprints or other marks.

14. Install the 16-mm adapter. Place the blank into the adapter.

15. Touch Zero. The display will show: 0 mg/L COD.

16. When the timer beeps, place the sample vial into the adapter. Touch Read. Results will appear in mg/L COD.

CHAPTER 5

ANALYSIS AND RESULTS

5.1 Semi-continuous Ultrasonic-Membrane Anaerobic System (UMAS) performance

Performance of UMAS at six steady state was summaries in Table 4.1 which were established at different HRTs and influent COD concentrations. The kinetic coefficients of the selected models were derived from Equation 2 (Monod, 1949), Contois (1959) and Chen and Hashimoto (Chen et al., 1980) by using a linear relationship; the coefficients are summarised in Table 4.2. At steady-state conditions with influent COD concentrations of 67,000-91,400 mg/l, UMAS performed well and the pH in the reactor remained within the optimal working range for anaerobic digesters (6.7-7.8). At the first steady-state, the MLSS concentration was about 12,960 mg/l whereas the MLVSS concentration was 10,091 mg/l, equivalent to 77.9% of the MLSS. This low result can be attributed to the high suspended solids contents in the POME.

At the sixth steady-state, however, the volatile suspended solids (VSS) fraction in the reactor increased to 88% of the MLSS. This indicates that the long SRT of UMAS facilitated the decomposition of the suspended solids and their subsequent conversion to methane (CH_4). This conclusion supported by (Abdurahman et al., 2011) and (Nagano et al., 1992). The highest influent COD was recorded at the sixth steady-state (91,400 mg/l) and corresponded to an OLR of 9.5 kg COD/m^3/d. At this OLR the, UMAS achieved 96.7% COD removal and an effluent COD of 3000 mg/l. This value is better than those reported in other studies

on anaerobic POME digestion (Borja et al., 1993; Ng et al., 1985). The three kinetic models demonstrated a good relationship (R^2 > 99%) for the membrane anaerobic system treating POME, as shown in Figures 5.1 – 5.3. The Contois and Chen & Hashimoto models performed better, implying that digester performance should consider organic loading rates. These two models suggested that the predicted permeate COD concentration (S) is a function of influent COD concentration (S_o). In Monod model, however, S is independent of S_o. The excellent fit of these three models (R^2 > 97.8%) in this study suggests that the UMAS process is capable of handling sustained organic loads between 0.5 and 9.5 kg m^3/d.

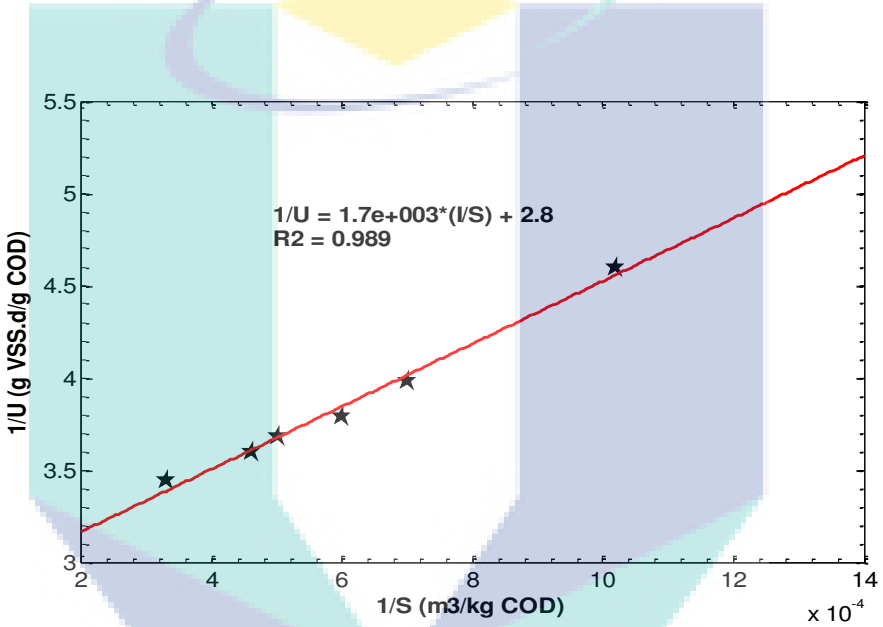


Figure 5.1: The monod model.

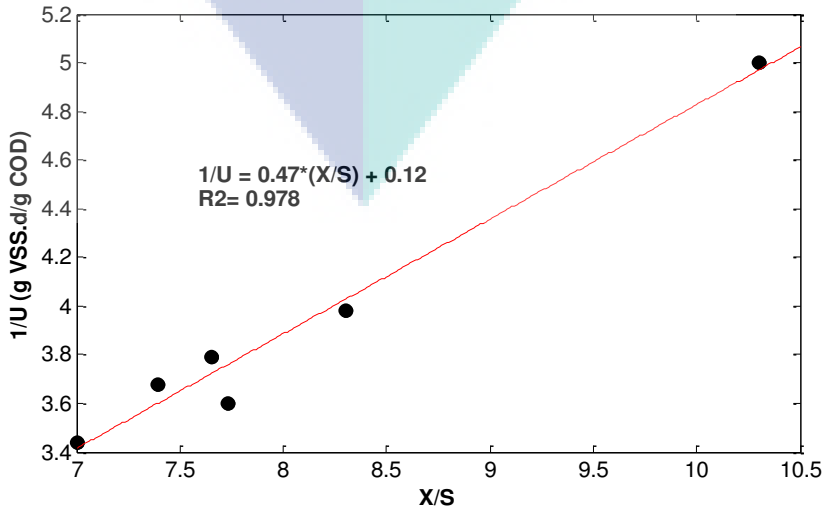


Figure 5.2: The Contois model.

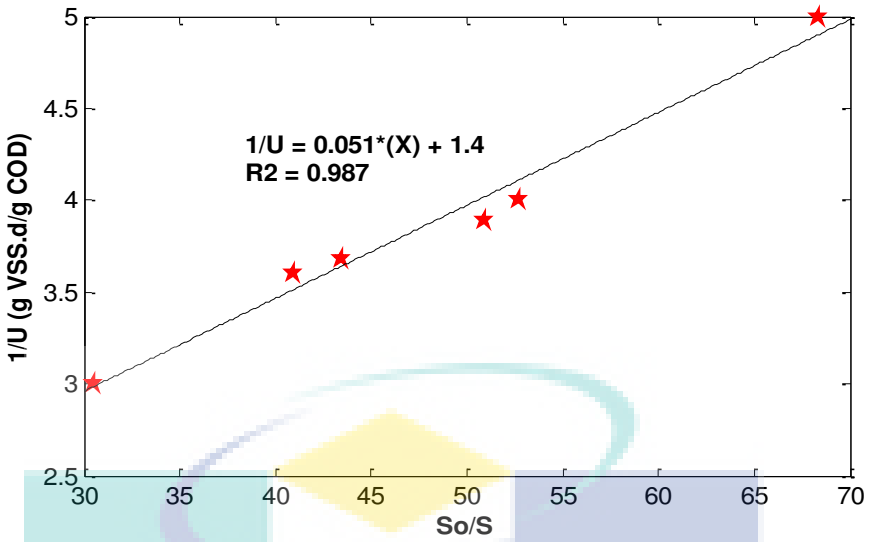


Figure 5.3: The Chen and Hashimoto model.

Figure 5.4 shown the percentages of COD removed by UMAS at various HRTs. COD removal efficiency increased as HRT increased from 5.40 to 480.3 days and was in the range of 96.7 % - 98.5 %. This result was higher than the 85 % COD removal observed for POME treatment using anaerobic fluidised bed reactors (Idris et al., 1998) and the 91.7-94.2 % removal observed for POME treatment using MAS (Fakhru'l-Razi et al., 1999).

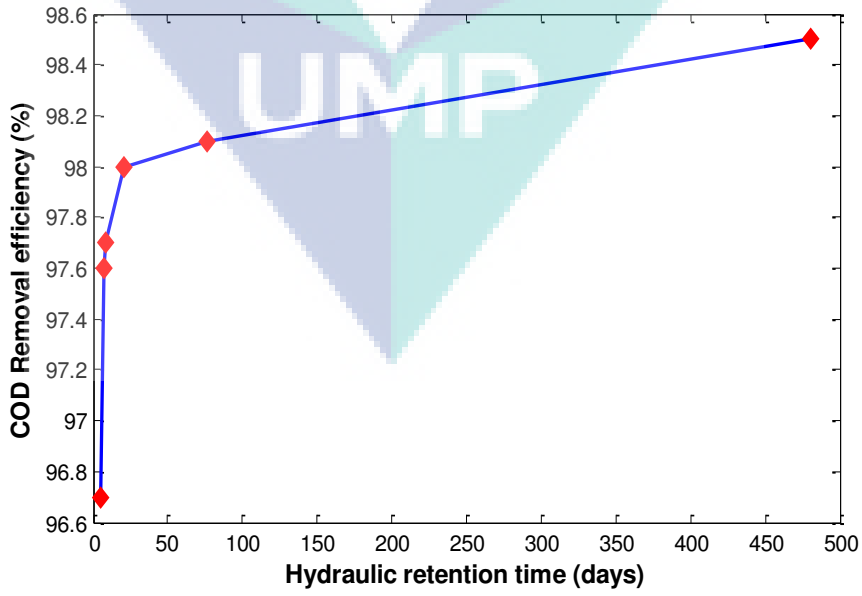


Figure 5.4: COD removal efficiency of UMAS under steady-state conditions with various hydraulic retention times.

The COD removal efficiency did not differ significantly between HRTs of 480.3 days (98.5%) and 20.3 days (98.0%). On the other hand, the COD removal efficiency was reduced shorter HRTs; at HRT of 5.40 days, COD was reduced to 96.7 %. As shown in Table 4.1, this was largely a result of the washout phase of the reactor because the biomass concentration increased in the system.

5.2 Determination of Bio-kinetic Coefficients

Experimental data for the six steady-state conditions in Table 4.1 in previous chapter were analysed; kinetic coefficients were evaluated and are summarised in Table 4.2., previous chapter is substrate utilisation rates (SUR); and specific substrate utilisation rates (SSUR) were plotted against OLRs and HRTs. Figure 5.5 shows the SSUR values for COD at steady-state conditions HRTs between 5.40 and 480.3 days. SSURs for COD generally increased proportionally HRT declined, which indicated that the bacterial population in the UMAS multiplied (Abdullah et al., 2005).

The bio-kinetic coefficients of growth yield (Y) and specific micro-organic decay rate, (b) and the K values were calculated from the slope and intercept as shown in Figure 5.6 and 5.7. Maximum specific biomass growth rates (μ_{max}) were in the range between 0.248 and 0.474 d^{-1}. All of the kinetic coefficients that were calculated from the three models are summarised in Table 5.2. The small values of μ_{max} are suggestive of relatively high amounts of biomass in the UMAS (Zinatizadeh et al., 2006). According to (Grady et al., 1980), the values of parameters μ_{max} and K are highly dependent on both the organism and the substrate employed. If a given species of organism is grown on several substrates under fixed environmental conditions, the observed values of μ_{max} and K will depend on the substrates.

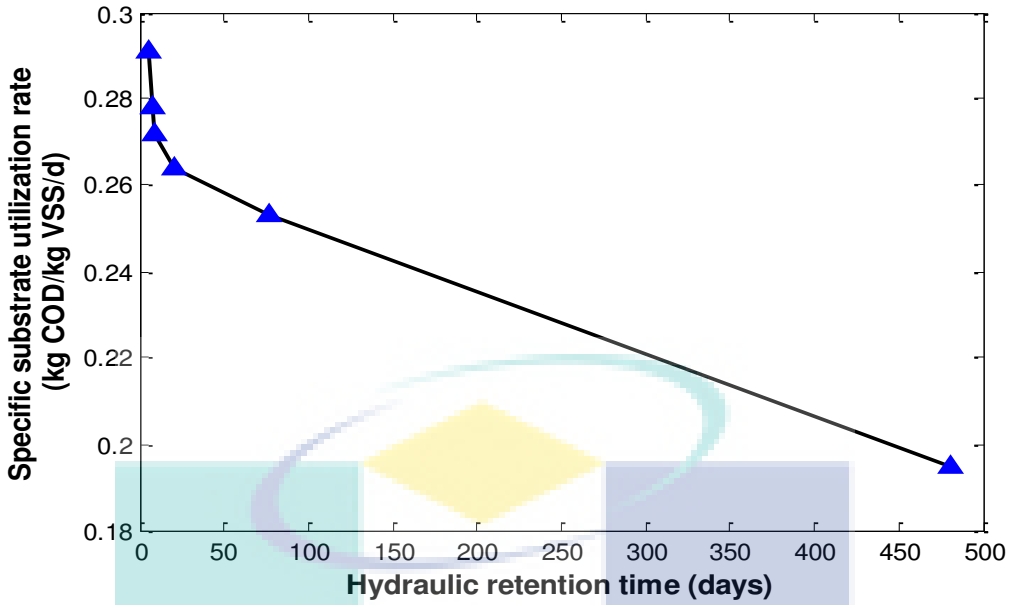


Figure 5.5: Specific substrate utilization rate for COD under steady-state conditions with various hydraulic retention times.

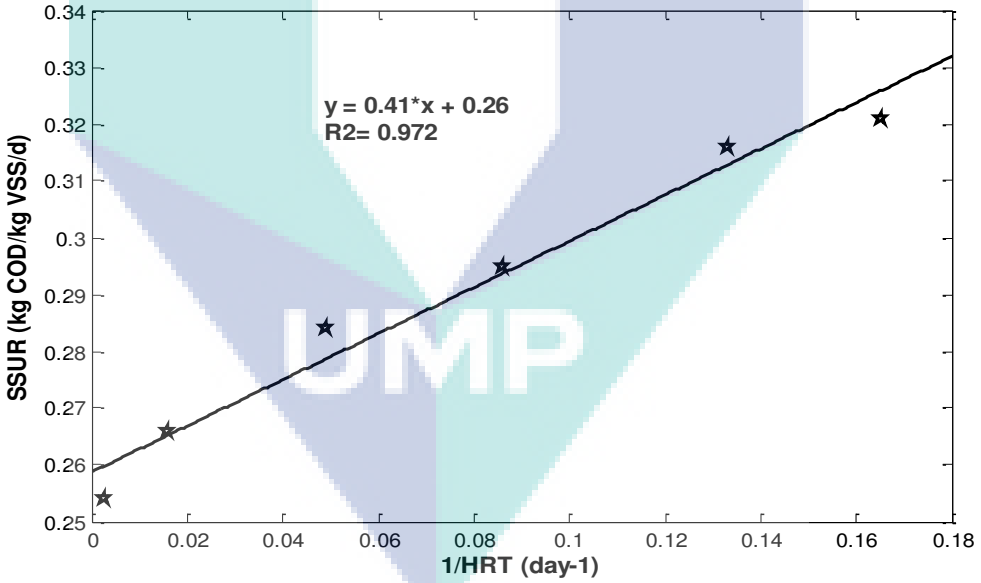


Figure 5.6: Determination of the growth yield, Y and the specific biomass decay rate,b.

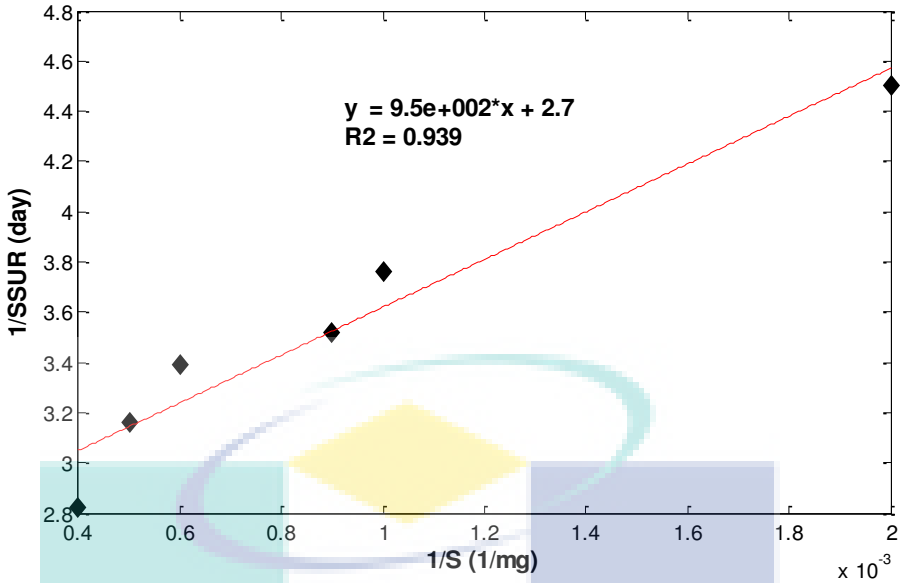


Figure 5.7: Determination of the maximum specific substrate utilization and the saturation constant, K.

5.3 Gas production and composition

Many factors must be adequately controlled to ensure the performance of anaerobic digesters and prevent failure. For POME treatment, these factors include pH, mixing, operating temperature, 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) 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. Figure 5.8 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 68.5% to 79% and the methane yield ranged from 0.29 to 0.59 CH_4/g COD/d. Biogas production increased with increasing OLRs from 0.29 l/g COD/d at

0.5 kg COD/m^3/d to 0.88 l/g COD/d at 9.5 kg COD/m^3/d. The decline in methane gas content may be attributed to the higher OLR, which favours the growth of acid forming bacteria over methanogenic bacteria. In this scenario, the higher rate of carbon dioxide; (CO_2) formation reduces the methane content of the biogas.

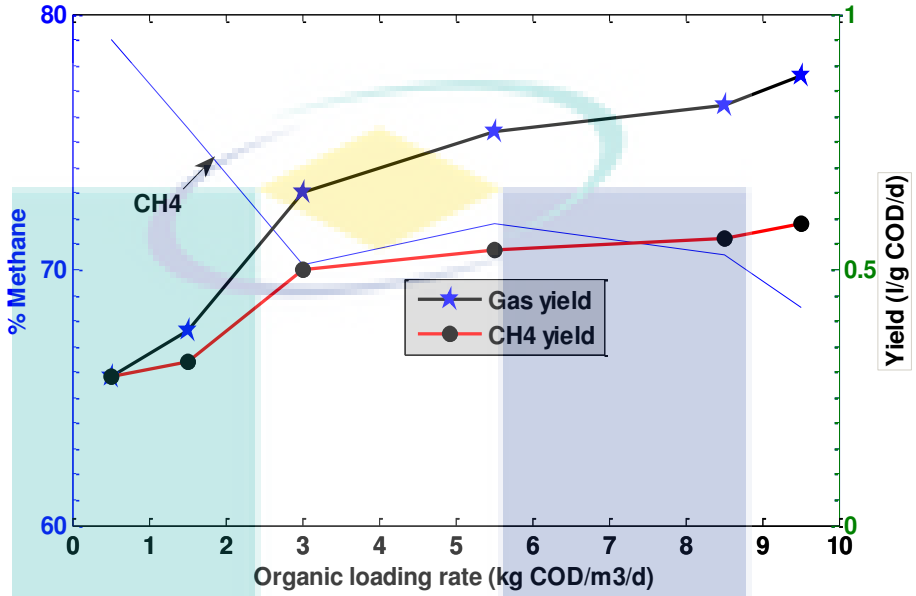


Figure 5.8: Gas production and methane content.

5.4 Projection of Profit and Loss

Based on Table 5.1 shows below, sales projected for year 1 is RM 1,121,168 and increaseD untill RM 5,108,918 at year 3. For the net profit , Year 1, the company will get RM 201,792, Year 2 is RM 603,000 and Year 3 is RM1,319,458. The projected profit and loss for shown that the company haS a good performance to market the ultrasonic assisted membrane anaerobic system (UMAS).

Table 5.1: Projection of Profit and Loss.

Description	Year 1	Year 2	Year 3
	RM	RM	RM
Sales	1,121,168	2,555,069	5,108,918
Direct cost of sales	122,550	297,853	612,688
Other Costs of goods	0	0	0
Total cost sales	122,550	297,853	612,688
gross margin	998,618	2,257,215	4,496,230
Gross margin%	89%	88%	88%
Operating Expenses			
Payroll	374,053	766,326	1,422,040
Sales and Marketing and Other Expenses	12,000	24,000	48,000
Depreciation	165,384	325,384	645,384
Rent	20,000	40,000	100,000
Utilities	18,000	36,000	72,000
Insurance	18,000	36,000	72,000
Payroll Taxes	56,108	114,949	213,306
Maintenance and Repair	4,800	9,600	20,000
Other	24,000	48,000	96,000
Total Operating Expenses	672,345	1,400,259	2,688,730
Profit Before Interest and Taxes	326,273	856,956	1,807,500
EBITDA	491,657	1,182,340	2,452,884
Interest Expenses	57,217	52,956	48,223
Taxes Accrued	67,264	201,000	439,819
Net Profit	201,792	603,000	1,319,458
Net Profit/ Sales	18%	24%	26%

5.5 Projection of Cash Flow

Table 5.2 below shows the projected cash flow for the business of ultrasonic assisted membrane anaerobic system (UMAS). The net cash flow shows that for Year 1 is RM 178,574, year 2 is RM 683,643 and year 3 is RM 1,595,696. The cash balance for Year1, Year 2 and Year 3 are RM 259,474, RM 943,117 and RM 2,538,813. From the table,the business still have adequate cash flow to maintaining the business. The business still have enough cash to pay the creditors on time.

Table 5.2: Projection of Cash Flow.

Description	Year 1 RM	Year 2 RM	Year 3 RM
Cash received			
Cash sales	448,467	1,022,028	2,043,567
Cash from receivables	542,495	1,366,516	2,768,762
Subtotal Cash from Operations	**990,962**	**2,388,544**	**4,812,329**
Additional Cash received	0	0	0
Sales Tax	0	0	0
New current borrowing	0	0	0
New other liabilities	0	0	0
New long-term liabilities	0	0	0
Sales of long term assets	0	0	0
New investment received	0	0	0
Subtotal cash received	**990,962**	**2,388,544**	**4,812,329**
Expenditures	**Year 1**	**Year 2**	**Year 3**
Expenditures from operations			
Cash spending	374,053	766,326	1,422,040
Bill payments	357,477	843,317	1,684,617
Subtotal Spent on Operations	**731,530**	**1,609,643**	**3,106,657**
Additional Cash spent			
Sales tax	0	0	0
Principal repayment of current borrowing	0	0	0
Other Liabilities Principal Repayment	0	0	0
Long term liabilities principal repayment	60,859	65,258	69,976
Purchase Other Current Assets	0	0	0
Purchase Long Term Assets	0	0	0
Dividends	20,000	30,000	40,000
Subtotal Cash spent	**812,389**	**1,704,901**	**3,216,633**
Net Cash Flow	**178,574**	**683,643**	**1,595,696**
Cash Balance	**259,474**	**943,117**	**2,538,813**

5.6 Projection of Balance Sheet

Table 5.3 below shows that the projected balance sheet. The total asset for Year 1, Year 2 and Year 3 are RM 1,064,710, RM 1,608,796 and RM 2,890,365 respectively. The total liablilities and equity are same as total asset which are for Year 1 is RM 1.064,710, Year 2 is RM 1,608,796 and Year 3 is RM 2,890,365. Through the balance sheet, it shows that the business have plenty of cash. The cash offers protection against tough times, and it also gives companies more options for future growth. Growing cash reserves often signal strong company performance. Indeed, it shows that cash is accumulating so quickly that management doesn't have time to figure out how to make use of it. Rather than that, it can increase the debtor's confident to further the business.

Table 5.3: Projection of Balance Sheet.

Deccription	Year 1	Year 2	Year 3
	RM	RM	RM
Assets			
Current Assets			
Cash	259,474	943,117	2,538,813
Account Receivables	130,206	296,731	593,320
Inventory	13,494	32,796	67,463
Other Current Assets	0	0	0
Total Current Assets	**430,174**	**472,644**	**799,597**
Long term Assets			
Long term Assets	826,920	1,626,920	3,226,920
Accumulated Depreciation	165,384	490,768	1,136,152
Total Long Term Assets	**661,536**	**1,136,152**	**2,090,768**
Total Assets	**1,064,710**	**1,608,796**	**2,890,365**
Liabilities and equity	**Year 1**	**Year 2**	**Year 3**
Current Liabilities			
Accounts Payable	35,957	72,301	144,387
Current Borrowing	0	0	0
Other Current Liabilities	0	0	0
Subtotal Current Liabilities	**35,957**	**72,301**	**144,387**
Long Term Liabilities	789,141	723,883	653,908
Total Liabilities	**825,098**	**796,184**	**798,294**
Paid in Capital	150,000	150,000	150,000
Retained Earnings	-112,180	59,612	622,612
Earnings	201,792	603,000	1,319,458
Total Equity	**239,612**	**812,612**	**2,092,070**
Total Liabilities and Equity	**1,064,710**	**1,608,796**	**2,890,365**
Net Worth	**239,612**	**812,612**	**2,092,070**

5.7 Break Even Analysis

Figure 5.9 below shows the break even point of ultrasonic assisted membrane anaerobic system (UMAS). The calculation besed on fixed costs, variable cost and selling price for year 1. Through the calculation, the break even point is 4 units of system per year. It means the company should sell the system only 4 units for year 1 to make its sales cover its expenses without making a profit or taking a loss. If it sells more, then it makes a profit but, if it sells less, it takes a loss.

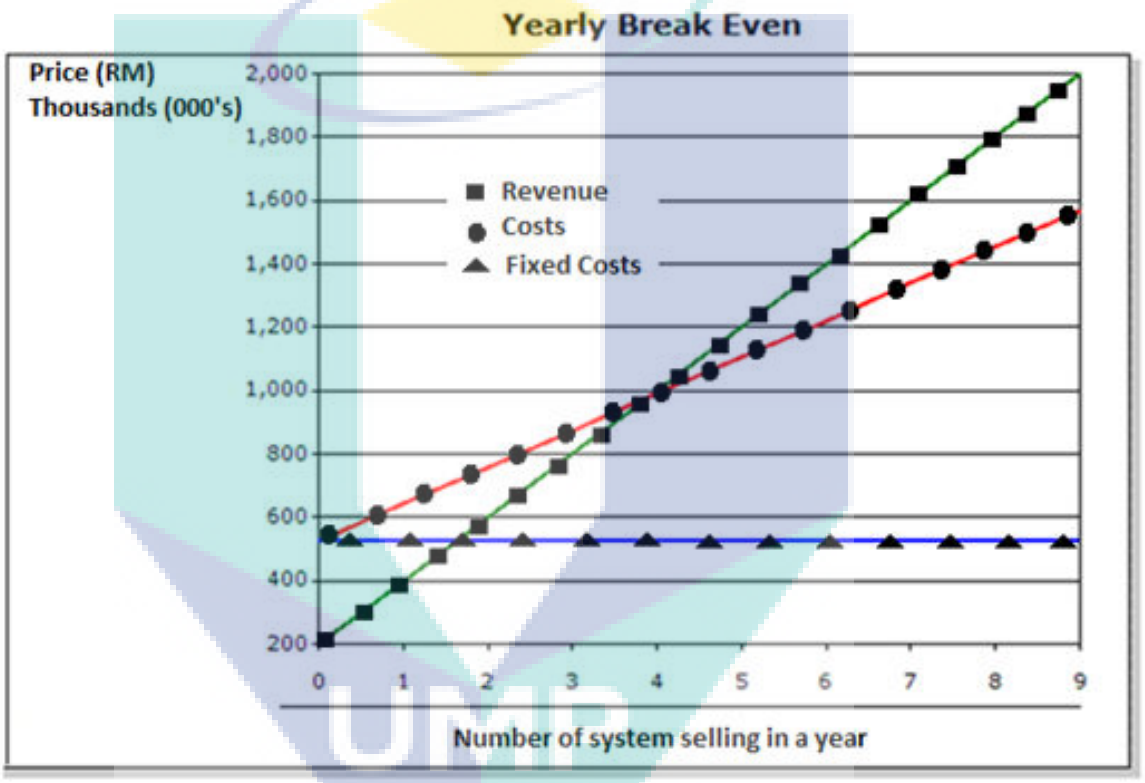


Figure 5.9: Yearly break even.

Table 5.4: Break Even Calculation by Year 1.

Description	Price (RM)
Fixed Cost	326,273
Variables Cost	
- Material	56,000
-Labor	60,000
Total Varaibles Cost	116,000
Selling Price	200,000
Break Even Point = 3.8 or 4 Units per year **= Fixed Cost /(Selling Price - Total Variables Cost)**	

Table 5.4 as above shows the manual calculation for break even point. From the calculation, even though without plotting a graph, still can calculate the unit which need to sell per year without get profit or loss.

CHAPTER 6

CONCLUSIONS

6.1 Conclusions

The ultrasonic assisted membrane anaerobic system, (UMAS) seemed to be adequate for the biological treatment of undiluted POME, 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). The overall substrate removal efficiency was very high-about 98.5%. The gas production, as well as the methane concentration in the gas was satisfactory and, therefore, could be considered as an additional energy source for the use in the palm oil mill.

Preliminary data of anaerobic digestion at 30 ℃ in UMAS showed that the proposed technology has good potential to substantially reduce the pollution load of POME wastewater. UMAS was efficient in retaining the biomass.The UMAS process will recover a significant quantity of energy (methane 79%) that could be used to heat or produce hot water at the POME plant. From the view of economy, the UMAS will get lots of opportunity in the market demand because of the great achievement in the process of the system. The system can compete with the other existed treatment system. Besides that, the projection of financial analysis showed that the system can generate a high profit when it marketed.

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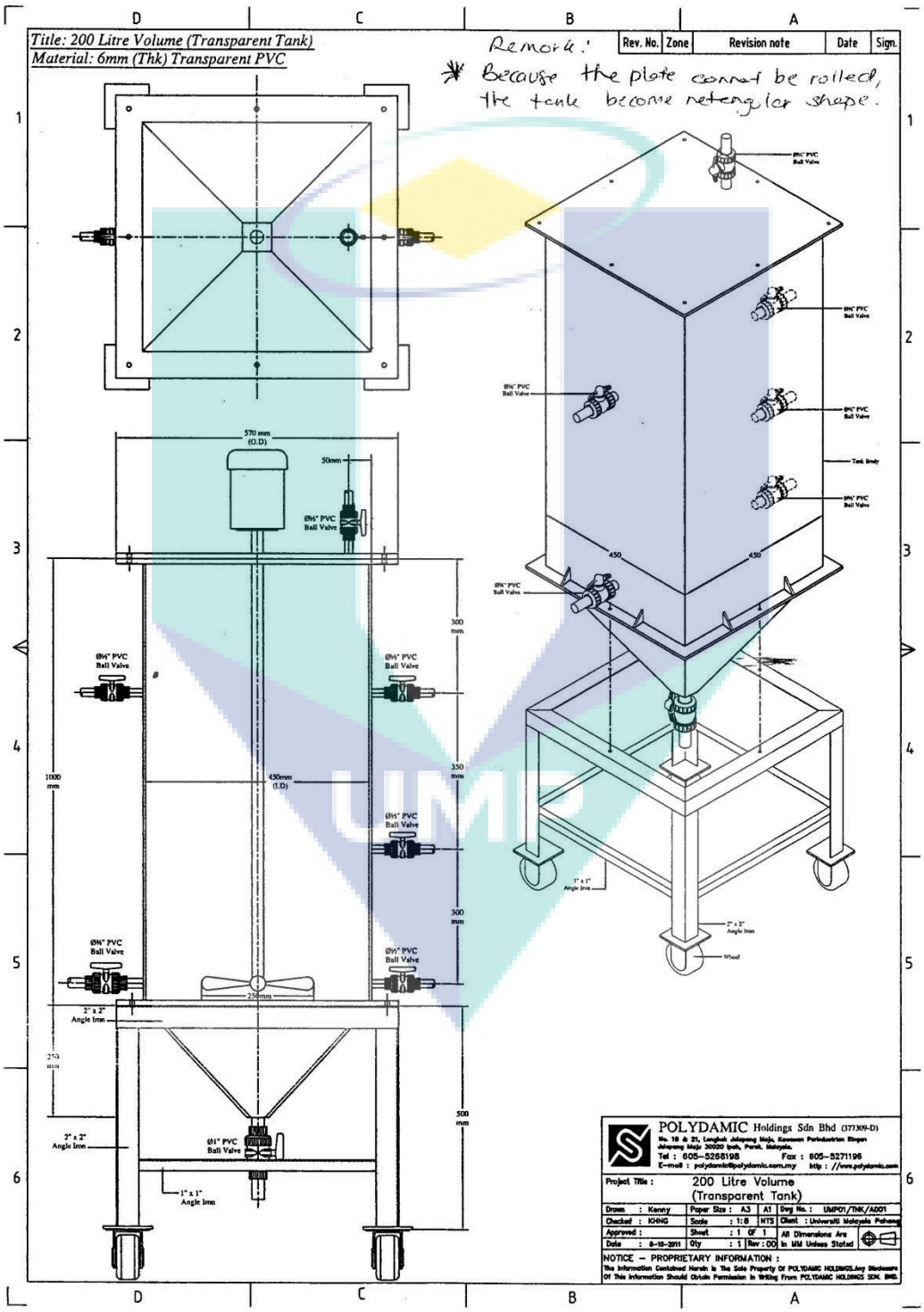
APPENDIX A

EXPERIMENTAL SET UP

FABRICATION OF TRANSPARENT TANK (TYPE A)



APPENDIX B

EXPERIMENTAL SET UP

FABRICATION OF TRANSPARENT TANK (TYPE B)