TREATMENT OF PALM OIL MILL EFFLUENT (POME) USING HYBRID UP FLOW ANAEROBIC SLUDGE BLANKET (HUASB) REACTOR

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ABSTRACT

Malaysia currently accounts for 51% of world palm oil production and 62% of world exports. In 2004, it was reported that Malaysia produces 14 million tons of palm oil planted on 38 000 square kilometers of land. This generates an enormous amount of liquid effluent known as palm oil mill effluent (POME) and consequently creates significant amount of pollution when released into rivers and lakes without proper treatment. Currently, the POME is treated using several methods such as cascade anaerobic ponds, anaerobic sludge fixed-film bioreactor and confined anaerobic digester. However, they have disadvantages of requiring vast land area, long hydraulic retention time (HRT) and low treatment efficiency. Besides that, the up-flow anaerobic sludge blanket (UASB) reactor has also been used to remove high pollutant loads of effluent from industrial wastewater. However in this study, hybrid upflow anaerobic sludge blanket (HUASB) reactors have been used to treat the POME. The aims of this research are to verify the performance of HUASB reactor and determine the optimum volumetric organic loading (OLR). Three reactors which are fixed with filter media of coarse gravels (R1), fine gravels (R2) and crushed glass (R3) were used to treat POME from Kian Hoe Plantation Sdn. Bhd. At the start of reactors operation, the OLR was fixed at 1.83 gCOD/L.d and HRT of 2.73 d until they reached steady state condition at 47 days for R1 and R2 and 42 days for R3. The OLRs were then gradually increased up to the loading of 9.17 gCOD/L.d for R1, 12.84 gCOD/L.d for R2 and 11.92 gCOD/l.d for R3. Whereas the HRTs were gradually decreased from 2.73 d to 0.55 d for R1, 0.39 d for R2 and 0.42 d for R3. The maximum efficiency of reactors in removing COD yields up to 97% with the loading of 5.5 gCOD/L.d for R1, 8.25 gCOD/L.d for R2 and 11.92 gCOD/L.d for R3. The use of packing materials in the HUASB reactors can avoid the floatation of poor settling particles and preventing washout of biomass from the reactors. This contributed to the increase in efficiency of the reactors.

ABSTRAK

Malaysia menghasilkan 51 % daripada keseluruhan penghasilan kelapa sawit di dunia. Pada tahun 2004, dilaporkan bahawa Malaysia telah menghasilkan 14 juta tan kelapa sawit daripada 38 000 km persegi tanah. Ini sekaligus menghasilkan sejumlah besar sisa effluen industri kelapa sawit atau dikenali sebagai POME. Penghasilan POME ini seterusnya memberi impak kepada pencemaran apabila disalirkan ke sungai atau tasik tanpa rawatan terlebih dahulu. Pada masa kini, POME dirawat menggunakan pelbagai kaedah seperti *cascade anaerobic ponds*, *anaerobic sludge fixed-film bioreactor* dan *closed anaerobic digester*. Walaupun begitu, penggunaan kaedah-kaedah ini mempunyai banyak kelemahan antaranya ialah memerlukan keluasan tanah yang besar, tempoh tahanan hidraulik yang panjang dan kadar kecekapan rawatan yang rendah. Selain itu, reaktor *Upflow Anaerobic Sludge Blanket* (UASB) juga digunakan untuk mengurangkan kepekatan bahan pencemar yang terdapat di dalam POME. Dalam kajian ini reaktor HUASB telah digunakan. Objektif utama kajian ini adalah untuk mengkaji kecekapan reaktor HUASB dan menentukan beban organik yang optimum. Tiga reaktor digunakan iaitu medium berkelikir kasar bagi R1, medium berkelikir halus bagi R2 dan medium pecahan kaca bagi R3 digunakan dalam reaktor HUASB bagi merawat sampel POME yang diambil dari Kian Hoe Plantation Sdn. Bhd. Operasi reaktor ini dimulakan pada beban organik 1.83 gCOD/L.d dan kadar tahanan hidraulik pada 2.73 hari. Pada permulaan operasi, R1 dan R2 mengambil masa selama 47 hari untuk mencapai keadaan stabil sementara R3 mengambil masa yang lebih singkat iaitu selama 42 hari. Keadaan beban organik ini ditingkatkan secara beransur-ansur sehingga mencapai beban 9.17 gCOD/L.d bagi R1, 12.84 gCOD/L.d bagi R2 dan 11.92 gCOD/L.d bagi R3. Sementara itu, kadar tahanan hidraulik pula semakin berkurangan kepada 0.55 gCOD/l.d bagi R1, 0.39 gCOD/L.d bagi R2 dan 0.42 gCOD/l.d bagi R3. Kadar kecekapan yang paling tinggi bagi ketiga-tiga reaktor adalah 97 % ketika R1 mencapai beban organik pada 5.5 gCOD/L.d bagi R1, 8.25 gCOD/L.d bagi R2 dan 11.92 gCOD/L.d bagi R3. Penggunaan medium penapis bagi reaktor HUASB ini dikenalpasti mampu menghalang berlakunya pengapungan partikel-partikel seterusnya dapat mengurangkan berlakunya reaktor tersumbat dan *washout* biomas daripada reaktor. Ini sekaligus meningkatkan kadar kecekapan reaktor.

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LIST OF ABBREVIATIONS

^0C	-	Degree Celsius
A	-	Area
Al	-	Aluminium
ANOVA	-	Analysis of Variance
B	-	Boron
BOD	-	Biochemical Oxygen Demand
Ca	-	Calcium
$CaCO_3$	-	Calcium Carbonate
CH_4	-	Methane
Cl	-	Chlorine
CO_2	-	Carbon Dioxide
COD	-	Chemical Oxygen Demand
Cu	-	Copper
Fe	-	Iron
HRT	-	Hydraulic Retention Time
HUASB	-	Hybrid Upflow Anaerobic Sludge Blanket
K	-	Potassium
kJ	-	Kilo Joule
kg	-	Kilogram
Mg	-	Magnesium
mg/L	-	Miligram per liter
mm	-	Milimeter
Mn	-	Manganese
N	-	Nitrogen
Na	-	Sodium
NaOH	-	Natrium Hydroxide
NH_3-N	-	Ammonia Nitrogen
NH_3	-	Ammonia
NO^-_3	-	Nitrate

OLR	-	Organic Loading Rate
O&G	-	Oil and Grease
pH	-	Hydrogen ion
PO^{-}_{4}	-	Phosphorus
POME	-	Palm Oil Mill Effluent
Q	-	Flow Rate
RTD	-	Residence Time Distribution
SEM	-	Scanning Electron Micrograph
Si	-	Silicon
SRT	-	Sludge Retention Time
S	-	Sulphur
TN	-	Total Nitrogen
TSS	-	Total Suspended Solid
TS	-	Total Solid
TVS	-	Total Volatile Solid
UASB	-	Upflow Anaerobic Sludge Blanket
v	-	Velocity
VFA	-	Volatile Fatty Acids
VSS	-	Volatile Suspended Solid
XRF	-	X-Ray Fluorescence
Zn	-	Zinc

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CHAPTER 1

INTRODUCTION

1.1 Background

The up-flow anaerobic sludge blanket (UASB) reactor was first introduced in 1980 for the treatment of industrial wastewater (Lettinga and Vinken, 1980). It was then developed by Lettinga and has gained popularity and been widely adopted for the treatment of medium to high strength industrial wastewater (Lettinga and Hulshoff Pol., 1991). But the first full scale application of anaerobic treatment was in a reactor resembling the septic tank in the 1860's, and was called "Mouras Automatic Scavenger". Then, the technological development proceeded via introducing the hybrid UASB; one of the alternative designs, which combines the advantages of UASB and Anaerobic Filter (AF) concepts have been developed. AF is one of the earliest types of retained biomass reactor developed by Young and McCarty in 1969. Starting in 1950's, the importance of the sludge retention concept for reducing the reactor size began to be recognized.

Full scale implementations of these developments have met with success and competitive installation will continue to take advantage of the new technology. One attempt is to use hybrid UASB, one of the newer designs, which combines the advantages of UASB and anaerobic filter (AF) concepts. The success of the anaerobic high-rate systems is due to the possibility of application of relatively high loading rate, while maintaining long SRT at relatively short HRT due to sludge immobilization. The wastewater in these systems flows through the anaerobic sludge where purification takes place through complex bio- physical – chemical interrelated processes. Organic matter is converted into biogas mainly methane and sludge (Metcalf and Eddy, 2004).

The HUASB is a reactor in which the upper 50% - 70% is filled with either floating or stationary materials to retain some of the escaping fine biomass. The HUASB is actually a combination of a UASB unit at the lower part and anaerobic fixed-film unit at the upper. This type of reactor is of particular value in a situation when the rate of sludge granulation is slow and there is a need to accelerate the reactor startup (Lee Jr., 2002). The packing of the material is fixed and the wastewater flows up through the interstitial spaces between the packing and bio-growth. Based on previous research, have been proved that HUASB design could be a very feasible and efficient alternative for the certain treatment such as distillery spentwash (Shivayogimath and Ramanujam, 1999) or phthalic (Tur and Huang, 1997) waste.

Palm oil processing is carried out using large quantities of water in mills where oil is extracted from the palm fruits. During the extraction of crude palm oil from the fresh fruits, about 50% of the water results in palm oil mill effluent (POME). It is estimated that for 1 tonne of crude palm oil produced, 5 - 7.5 tonnes of water ends up as POME (Ahmad, *et al*., 2003). The raw or partially treated POME has an extremely high content of degradable organic matter, which is due in part to the presence of unrecovered palm oil (Ahmad, *et al*., 2003). This highly polluting wastewater can, therefore, cause pollution of waterways due to oxygen depletion and other related effects as reported by Ahmad, *et al*. (2003). Thus, while enjoying a most profitable commodity, palm oil, the adverse environmental impact from the palm oil industry cannot be ignored.

1.2 Problem Statement of Research

Over the last three decades, the Malaysian palm oil industry has grown to become an important agriculture-based industry. Malaysian palm oil accounted for about 52% of the world palm oil output and this industry generated RM 13 billion in export earnings for the country. With increased cultivation and production of palm oil in the region, the disposal of the palm oil waste is becoming a major problem that must be appropriately addressed (Ahmad, *et al*, 2005).

The oil palm (*Elaeis Guineensis*) has been planted on about 5.5 M ha of land in Southeast Asia (Fairhurst and Hardter, 2003). The production of palm oil generates large amounts of polluted waste water known as palm oil mill effluent (POME). Palm oil industries worldwide are facing significant challenges in meeting the increasingly stringent environmental regulations in the disposal of POME.

Many waste products are generated by the oil palm processing mills. The most common one is the empty fruit bunch. Approximately 0.65 tonnes of raw POME is produced for every tonnes of FFB (Fresh Fruit Bunch) produced. In 2003, a total of 2,106,956 tonnes of FFB was processed, resulting in 1,369,521 tonnes of POME being produced (APOC, 2004). The empty bunch is a solid waste product of the oil palm milling process and has a high moisture content of approximately 55-65% and high silica content up to 25% of the total palm fruit bunch (Wambeck, 1999). They have a value when returned to the field to be applied as mulch for the enrichment of soil. However, it was noted that over application of the effluent must be avoided as it may result in anaerobic conditions in the soil by formation of an impervious coat of organic matter on the soil surface (Wambeck, 1999).

Raw POME is high in BOD of above 25,000 mg/L which makes it objectionable to aquatic life when introduced in relatively large quantities in waterways and rivers. Besides that, the effluent also acidic but non-toxic liquid with pH of around 4.0, viscous, high organic content and containing considerable amounts of plant nutrients (Shaji and Kamaraj, 2002). Many agricultural industries pose a serious hazard to the environmental by the pollution caused by effluent discharge. Anaerobic digestion of agro-industrial effluents is an environmental friendly way to combat both these problems (Shaji and Kamaraj, 2002). Wastewater is discharged from the palm oil extraction, by wet process, normally from the oil room. For instance, pollutant loads in wastewater discharged in four oil mills in Malaysia are as shown in Table 1.1 :

Table 1.1 : Average pollution load in wastewater discharged from four Oil Palm Mills in Malaysia.

Mills	Working Hours	(FFB) Fresh Fruit Bunch (tons)	Effluent flow (m^3/hr)	Effluent/FFB (m^3/t FFB)	COD (kg/t FFB)	BOD (kg/ton FFB)
Apa	19.56	464.60	10.05	0.44	47.51	25.88
SPb	17.60	437.53	21.53	0.94	62.54	27.59
Upc	24.00	220.00	10.79	1.18	47.81	26.62
UPOc	15.58	414.67	22.37	0.90	51.93	26.24
Mean	19.26	384.20	16.19	0.87	52.54	26.58
Std deviation	3.03	96.43	6.67	0.27	6.08	0.64

Source : Kittikun., et al.(2000) Department of Industrial Biotechnology, Faculty of Agro-Industry Prince of Songkla University, Hat Yai, Thailand.

Schmidt and Ahring, (1994), says that major advantage of the UASB reactor compared to other anaerobic treatment options is its ability to retain high biomass concentrations through granulation. However, it has some limitations. A major problem encountered is the long start-up period required for the development of granules. It usually takes 3-4 months or even longer before the process can be put in operation (Lettinga and Hulshoff Pol, 1991). To remedy this drawback, HUASB has been designed to minimize the limitations created by UASB reactor. Shortening of start-up time and higher removal efficiency bears practical significance as it can raise attractiveness of HUASB application in wastewater treatment. So, this study is basically to evaluate the performance of this HUASB approach in treating POME.

1.3 Objective of Research

During this research, some of the important objectives been considered to ensure the success of the research. The objectives are as follows :

a) to evaluate the effect of HUASB treatment on parameters such as pH value, chemical oxygen demand (COD), phosphate, ammonia nitrogen (NH_3-N), total solid (TS) and suspended solids (SS) by analysing the influent and effluent of the HUASB
b) to evaluate the development of sludge granulation and gas production in the HUASB reactor
c) to study the performance of Hybrid Up-Flow Anaerobic Sludge Bed (HUASB) reactor in treating POME and compare with performance of UASB.
d) to study the performance of HUASB reactor by using different packing materials in each reactor.
e) to study the effect of granulation and increase of organic loading rate (OLR) on the value of removal coefficients.

1.4 Scope of Research

The research focused on the laboratory investigations on anaerobic treatment of high-strength industrial wastewater namely palm oil mill effluent (POME) using HUASB reactor. The POME was taken from a palm oil factory, Kian Hoe Plantation Bhd. in Kluang. The raw sample taken has up to 50,000 - 60,000 of COD mg/l. The study of effluent characteristics such as COD, phosphate, ammonia nitrogen and TS will be done in the laboratory after the setup stage has been done. Besides gas production will also be determined in the process using the gas meter provided. The research is basically to determine the efficiency and performance of HUASB reactor in removing organic and inorganic pollutants in POME.

1.5 Importance and Contribution of Research

HUASB reactor is widely used high rate bio-reactors for bio-methanation of agro-industrial effluents. The 2 major disadvantages of conventional anaerobic processes such as process instability and slowness can be overcome by high rate reactors which employ cell immobilization techniques.

Many researchers reported that the HUASB reactor combined the advantages of both Up-flow Anaerobic Sludge Blanket (UASB) and Anaerobic Filter (AF). HUASB reactor was efficient in the treatment of dilute to high strength wastewater at high OLR (Organic Loading Rate) and short HRT (Hydraulic Retention Time). The use of packing material in the upper portion of HUASB reactor minimizes channeling problem and loss of biomass due to floatation associated with poorly performing UASB rectors. Additionally, the packing material enhanced the development of granular sludge (Shaji and Kamaraj, 2002).

A study by Najafpour, *et al*. (2006) evaluated the feasibility of shortening the start-up period of the UASB reactor and accelerating the formation of granular sludge, using a reactor with tubular flow behavior. Granular sludge was rapidly developed within 20 days, with the granule size gradually increasing to reach 2 mm diameter. The reactor had successfully treat POME with high organic load and suspended solids concentration. In addition, the packing material caused the flocculated biomass to precipitate over the sludge blanket to act as a suitable core for the development of granular sludge, while the biogas production was close to the theoretical yield. Other advantages including the reactor does not need granular sludge, stable and resilient to shocks, produces better effluent than UASB reactors on chemical wastewaters, superior for wastewaters with low sludge yield and excels on chemical wastewaters

HUASB reactor can be regarded as a grown-up technology, and so far is the most widely applied reactor concept. It has found as a potential application for a vast number of very different wastewater including industrial effluents.

1.6 Hypothesis

Several hypotheses can be derived through observation on an operation using Hybrid UASB reactor as follows:

i) determination of start up time for HUASB reactor should be shorter than ordinary UASB.
ii) HUASB will perform higher removal for every parameters been measured such as TS, TSS, COD, NH_3-N, PO^-_4 and many more.
iii) the maximum loading of HUASB reactor for this treatment of POME can achieve higher than UASB reactor.

iv) the rate of reaction or kinetic coefficient, k for each reactor increases as the organic loading rate increased.

v) flow pattern for HUASB reactor will be between an ideal plug flow and a complete mixed flow.

vi) the predominant bacteria on the surface of aggregated biomass are segmented filamentous type that has an important role in the aggregation of biomass.

vii) reactor with packing materials of fine gravels will show higher removal efficiency compared to coarse gravels and crushed glass.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

This chapter presents theoretical background of POME characteristics and studies on previous research of anaerobic treatment, specifically on HUASB reactor treatment on various types of wastewaters. Besides, it also provide different output of studies using UASB treatment in treating industrial wastewater, particularly those produced in agriculturally based industries.

2.2 Aerobic Treatment Process

Aerobic treatment process is a biological treatment that occurs in the presence of oxygen. Aerobic digestion actually refers to the use of aerobic bioreactors to stabilize particulate organic matter arising from primary clarification (predominantly biodegradable organic matter) and biological treatment (predominantly biomass) of wastewaters. Biodegradable particulate organic matter is hydrolyzed and converted into biodegradable soluble organic matter, releasing nutrients such as ammonia-N and phosphate. The biodegradable soluble organic matter is then converted into CO_2, water, active biomass through the action of heterotrophic bacteria (Leslie, *et al*, 1999).

2.3 Anaerobic Treatment Process

Anaerobic process is defined as biological treatment process that occurs in the absence of oxygen. Anaerobic treatment of wastewater is a complex biological process involving several groups of microorganisms (Cha and Noike, 1997). The anaerobic treatment process consists of two steps, occurs completely in the absence of oxygen and produces a useable by-product; methane gas (Man, *et al.*, 1986). In general complex wastes are stabilized in three basic steps; hydrolysis, acid fermentation and methanogenesis. Based on the previous research, a loading rate ranging from 1 to 50 kg.COD/m^3.d has been applied at various temperatures (from 10 to 65°C) and various hydraulic retention times (from a few hours to a few days) with COD reduction ranging from 70 to 90 % (Lettinga and Vinken, 1980, Cullimore and Viraraghavan, 1994, Speece, 1996 and Dague, *et al.*, 1998).

Referring to Metcalf and Eddy (2004), hydrolysis is a preparation in which solids and complex dissolved substrates are hydrolyzed into simple organic components. In the acid fermentation step, acid forming bacteria is used to convert the hydrolyzed organic material to volatile fatty acids (VFA) such as, acetic and propionic which are capable of being stabilized. While in methanogenesis, involves stabilization of these fatty acids by converting them to CO_2 and CH_4 by methanogens (Show, *et al.*, 2004). Substrate stabilization requires completion of the slower growing methane bacteria forming step because the initial steps do not remove the BOD or COD, rather they are converted to different species. Detention time and temperatures are dominant process variables.

2.4 Comparison Between Anaerobic and Aerobic Processes

Table 2.1 shows the differences between anaerobic and aerobic processes. The discussion focused on their organic loading rate (OLR), biomass yield, substrate utilization rate, start-up time, solid retention time (SRT), microbiology and environmental factors. The difference of both processes also shown in schematic diagram of Figures 2.1 and 2.2.

Table 2.1 : Comparison between Anaerobic and Aerobic Processes

	ANAEROBIC	*AEROBIC*
Organic Loading Rate	*High loading rates* : 10 – 40 kg COD/m^3-day (for high rate reactors)	*Low loading rates* : 0.5 – 1.5 kg COD/m^3-day (for activated sludge process)
Biomass yield	*Low biomass yield* : 0.05 – 0.15 kg VSS / kg COD (biomass yield is not constant but depends on types of substrates metabolized)	*High biomass yield* : 0.37 – 0.46 kg VSS / kg COD (biomass yield is fairly constant irrespective of types of substrates metabolized)
Specific substrate utilization rate	*High rate* : 0.75 – 1.5 kg COD / kg VSS-day	*Low rate* : 0.15 – 0.75 kg COD / kg VSS-day
Start- up time	*Long start-up* : 1 - 2 months for mesophilic 2 – 3 months for thermophilic	*Short start-up* : 1 – 2 weeks
SRT	Longer SRT is essential to retain the slow growing methanogens within the reactor	SRT of 4 – 10 days is enough in case of activated sludge process
Microbiology	Anaerobic process is multi-step process and diverse group of microorganisms degrade the organic matter in a sequential order	Aerobic process is mainly a one-species phenomenon
Environmental factors	The process is highly susceptible to changes in environmental conditions	The process is less susceptible to changes in environmental changes

(Source : Singh, 1999)

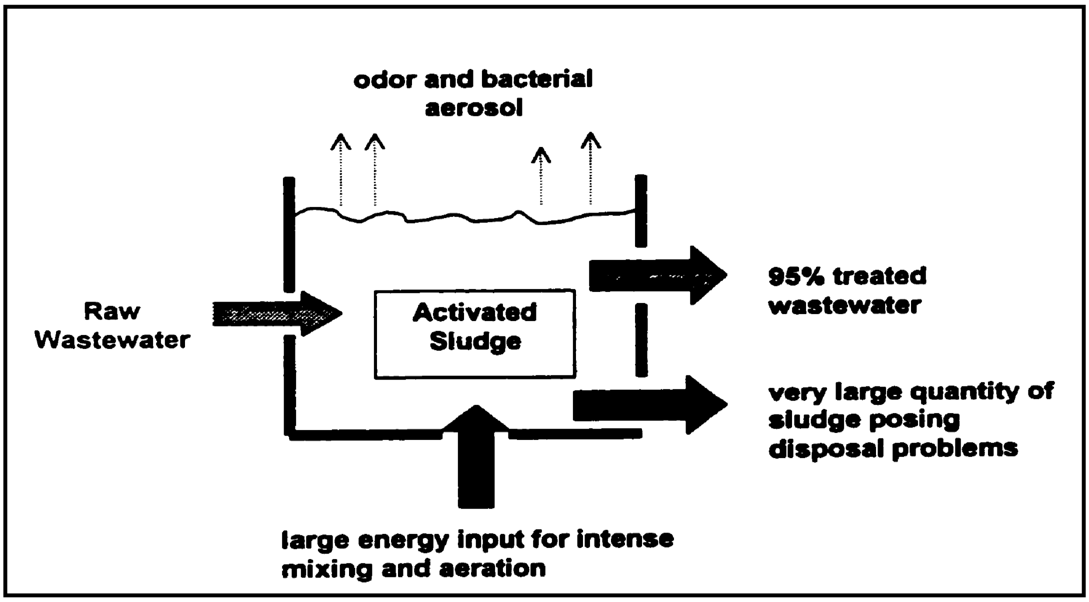

Figure 2.1 Aerobic wastewater treatment process (Singh, 1999)

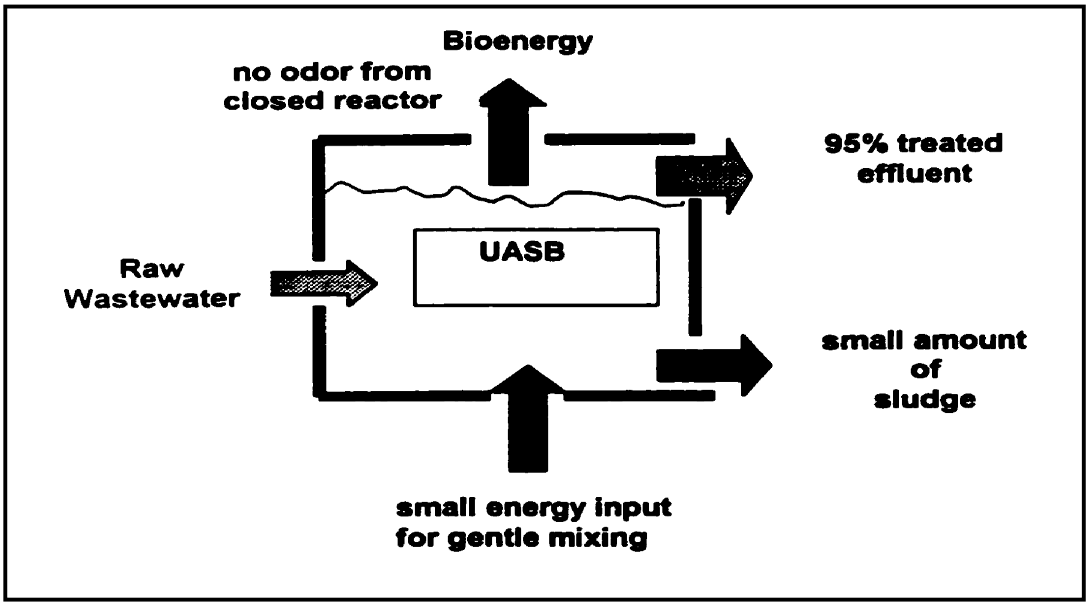

Figure 2.2 : Anaerobic wastewater treatment process (Singh, 1999)

It has been established that the anaerobic process is in many ways ideal for wastewater treatment. There are several significant advantages over other available methods especially aerobic treatment and is almost certainly assured of increase usage in the future. The advantages of anaerobic process is as listed below (Singh, 2009) :

a) Less energy requirement as no aeration is needed
b) Energy generation in the form of methane gas
c) Less biomass (sludge) generation
d) Less nutrients (nitrogen and phosphorus) requirement
e) Application of higher organic loading rate
f) Space saving because application of higher loading rate requires smaller reactor volume thereby saving the land requirement
g) Ability to transform several hazardous solvents including chloroform, trichloroethylene and trichloroethane to an easily degradable form

2.5 Palm Oil Mill Effluent (POME)

Palm oil mill effluent (POME) contains organic matter and plant nutrients that are excellent substitutes for organic fertilizer. POME comprises a combination of the wastewaters which are principally generated and discharged from the following major processing operations (DOE, 1999) :

i) Sterilization of FFB-sterilizer condensate is about 36% of total POME
ii) Clarification of the extracted crude palm oil-clarification wastewater is about 60% of total POME

iii) Hydrocyclone separation of cracked mixture of kernel and shell-hydrocyclone wastewater is about 4% of total POME

It is a colloidal suspension, which is 95 – 96 % water, 0.6-0.7 % oil, and 4-5 % total solids including 2-4 % suspended solids originating in the mixing of sterilizer condensate, clarifier and hydro cyclone wastewater (Ma, 2000). It is thick brownish in color liquid and discharged at temperature between 80 - 90° C (see Figure 2.3) (Ahmad, *et al*., 2003).

Figure 2.3 : Raw POME (brownish in color)

Raw POME is high in BOD and acidic with pH of around 4.0 (Ahmad, *et al*, 2003). It can be seen in the Table 2.2, that the BOD : COD ratio of raw POME is approximately 1 : 2, which means that POME is considered to be suitably treated by biological processes. While, the typical BOD : N : P ratio of 139 : 4 : 1 indicates the limitations of nutrient, which is required for bacterial growth and metabolic requirements of biomass to obtain optimum biological processes under aerobic conditions, which requires 100 : 5 : 1. Nutrient deficiency can lead to increasing the population of filamentous bacteria (Ujang and Lim, 2004). Application of anaerobic sludge in the oil palm fields carried out using the tractor-tanker system at the rate of 360 and 500 liters/palm/year for coastal and inland soils respectively (Ma, 2000).

Table 2.2 : Characteristic of Palm Oil Mill Effluent (POME)

GENERAL PARAMETERS		
PARAMETER	**MEAN**	**RANGE**
pH	4.2	3.5-5.2
Oil & Grease	6,000	150-18,000
Biochemical Oxygen Demand (BOD)	25,000	10,000-44,000
Chemical Oxygen Demand (COD)	50,000	16,000-100,000
Total Solids (TS)	40,500	11,500-79,000
Suspended Solids (SS)	18,000	5,000-54,000
Total Volatile Solids (TVS)	34,000	9,000-72,000
Ammonia Nitrogen (AN)	35	4-80
Total Nitrogen (TN)	750	80-1,400
Phosphorous	180	
Magnesium	615	
Calcium	440	
Boron	7.6	
Iron	47	
Manganese	2.0	
Copper	0.9	
Zinc	2.3	

All parameters in mg/L except pH

(Source : Industrial Processes & The Environment (Handbook No.3)-Crude palm Oil Industry,1999)

2.6 Environmental Quality Standard

After the enactment of the Environmental Quality Act (EQA), 1974 and the establishment of the Department of Environment in 1975, comprehensive environmental control of the crude palm oil industry was commenced. The Environmental Quality (Prescribed Premises) (Crude Palm Oil) Order, 1977 and the Environmental Quality (Prescribed Premises) (Crude Palm Oil) Regulations, 1977 were promulgated under the EQA, in order to regulate the discharge of effluent from the crude palm oil industry as well as to exercise other environmental controls (Laws of Malaysia, 2003). These were the first sets of industry specific subsidiary legislation to be promulgated under the EQA for industrial pollution control. Table 2.3 presented the current effluent discharge standard ordinarily applicable to crude palm oil mills.

Table 2.3 : Prevailing effluent discharge standard for crude palm oil mills

Parameters	Unit	Parameters Limits
Biochemical Oxygen Demand (BOD) (BOD; 3 days, 30°C)	mg/L	100
Chemical Oxygen Demand (COD)	mg/L	*
Total Solids (TS)	mg/L	*
Suspended Solids (SS)	mg/L	400
Oil & Grease (O&G)	mg/L	50
Ammonia Nitrogen (AN)	mg/L	150
Total Nitrogen (TN)	mg/L	200
pH	-	5-9
Temperature	°C	45

Note : * no discharge standard after 1984

(Source : Laws of Malaysia, 2003)

2.7 Up-Flow Anaerobic Sludge Blanket Reactor (UASB)

Lettinga and Vinken (1980) has been noted that anaerobic treatment processes, the UASB has become very popular in Western Europe and more recently in Asia. In UASB, anaerobic bacteria are immobilized by a process of spontaneous aggregation of the bacteria, resulting in densely packed biofilm particle (granules) (Chou and Huang, 2005). Thus, the UASB reactor can be operated at higher organic loading rate (OLR) and short hydraulic retention time (HRT). It is known that the loading rate of an anaerobic wastewater treatment system is dependent on the amount of active biomass present in the reactor (Lettinga, *et al.*, 1983). Therefore these upflow systems can accommodate organic loading rates several times higher than those of other anaerobic digesters.

Souza, 1986 has reported that the UASB adapts well to seasonal changes and interruptions in wastewater flow especially when compared to aerobic treatment systems. The UASB concept relies on the establishment of a dense sludge bed in the bottom of the reactor as in Figure 2.4, in which all biological process take place. This sludge bed basically formed by accumulation of incoming suspended solids and by bacterial growth. A major advantage of these up-flow systems is that their design permits the retention of a greater amount of active biomass in comparison with other anaerobic reactors. The ability of the upflow reactors to accumulate large amounts of biomass is the adhesion of bacterial cells to each other. The adhesion of bacteria to inert surfaces and the subsequent biofilm development have received considerable attention (Costerton, *et al.*, 1988, Kjelleberg,1984 and Paerl, 1980). The adhering bacteria form granules of biomass which can be several millimeters in diameter (MacLeod, *et al.*, 1990). Granules from successful UASB reactors are generally 0.1 - 4.0 mm in diameter (Grotenhuis, 1991 and Jih, *et al.*, 2003). Important parameters affecting the treatment efficiency of UASB reactors include the granulation process in the reactor and the characteristics of the wastewater to be treated. Among these parameters, the granulation process is to be the most critical one (Fang, *et al.*, 1994).

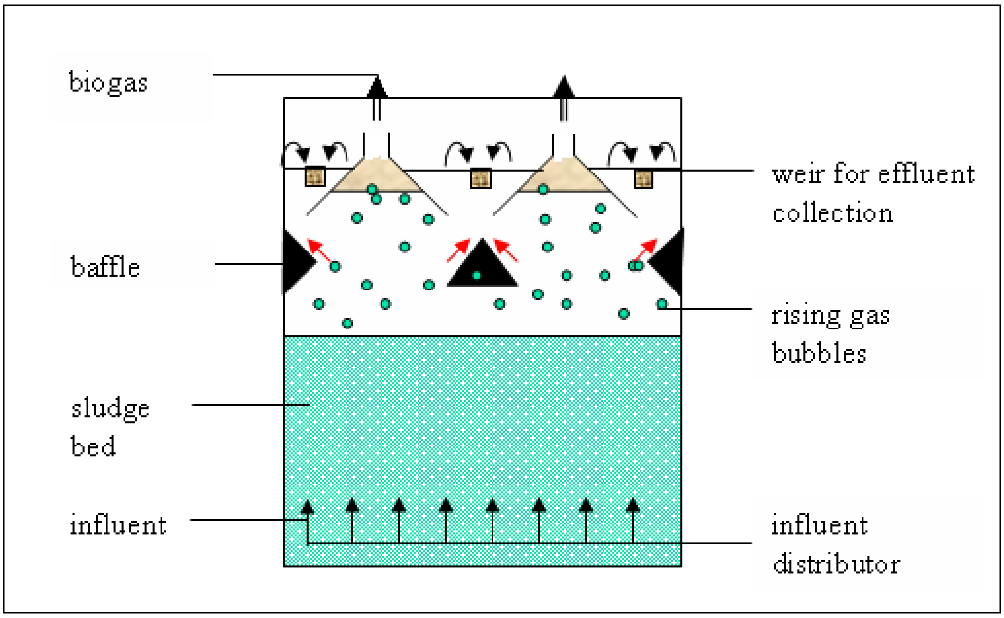

Figure 2.4 : Schematic diagram of UASB reactor (Khanal, 2002)

2. 8 Hybrid Up-Flow Anaerobic Sludge Blanket (HUASB)

The new anaerobic systems such as the HUASB (a combination of UASB and Anaerobic Filter) allow treatment of low strength wastes such as domestic wastewater by maintaining long solid retention time (SRT) independent of the hydraulic retention time (HRT). This reduces or eliminates the need for elevated temperatures (Lo, *et al.*, 1994). HUASB is of particular value in a situation when the rate of sludge granulation is slow and there is a need to accelerate the reactor startup. Where as, Shivayogimath and Ramanujam (1999), also operated a laboratory scale HUASB which operated under ambient conditions for 380 days.

Figure 2.5 shows the schematic diagram of HUASB reactor which is provided with their own packing material to place a different media as filtration. The HUASB reactors are frequently used for medium to high strength wastewater (2000 – 20000 mg/l COD), but have fewer applications to low strength wastewater (< 1000 mg/l COD). Hybrid system incorporates both granular sludge blanket (bottom) and anaerobic filter (top). Such approach prevents wash out of biomass from the reactor. Further additional treatment of wastewater was provided at the top bed due to the retention of sludge granules that escaped from the bottom sludge bed (Shaji, 2000). Study done by Tur and Huang (1997) shows that for hybrid reactor employed in their study prove that 86 % of the total biomass was accumulated in the sludge section and the other 14% accumulated in the biofilter section.

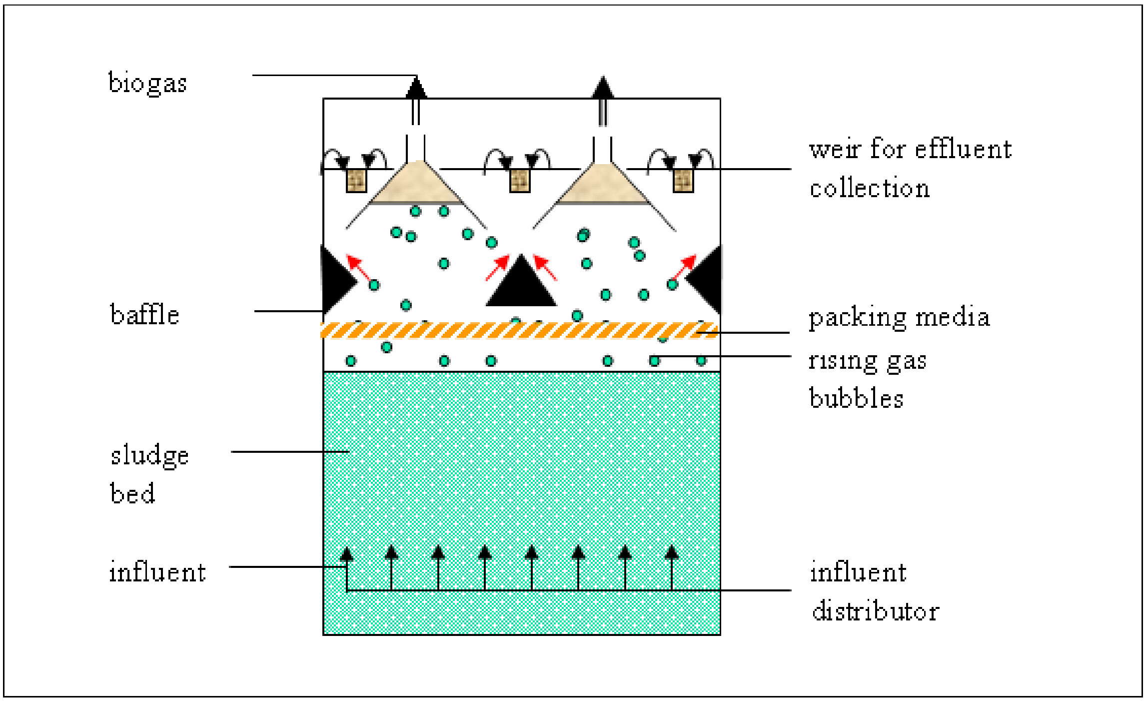

Figure 2.5 : Schematic diagram of HUASB reactor (Khanal, 2002)

2.8.1 Overview Reactor Performance

HUASB reactor exhibits positive features that make it as one of the most efficient treatment in wastewater. These have been proved by looking at a number of researches that have been carried out so far using HUASB reactor. Table 2.4 shows the number of research in many kind of wastewater using HUASB reactor within 10 years.

According to Table 2.4, Bello-Mendoza and Castillo-Rivera (1998) had treated coffee processing wastewater using volcanic rocks as filter media. This lab scale has been demonstrated in Mexico with the highest efficiency of 88.6%. While Borja, *et al.* (1998) and Elmitwalli, *et al.* (1999) used *polyurethane* foam with different temperature of 35 ºC and 13 ºC respectively. Both lab scale were demonstrated with efficiency of

93.4% and 61% respectively. The result showed that, higher temperature play their role in order to perform higher efficiency. In 1999 and 2000, Hutnan, *et al.* and Wu, *et al.* studied the treatment of synthetic wastewater with different filter media of tubular plastic carrier and raschig rings. Findings in Table 2.4 showed that by using raschig rings, the efficiency was higher in the range of 71% - 98% with HRT 5 – 60 hr and OLR, 1 – 24 kg.m^3.d.

Najafpour, *et al.* and Zinatizadeh, *et al.* investigated the performance of HUASB reactor using the same filter media, 90 pall rings in treating POME. Both operated at the same temperature of 38 ºC. Considering both lab scales were operated at HRT of 1.5d, study done by Zinatizadeh, *et al.* (2007) performed better at lower COD concentration of 9,750 mg/L COD (pre-settled POME) with efficiency of 93%. Overall, treating synthetic wastewater with COD concentration 5,000 mg/L COD under temperature of 35 ºC was able to reach efficiency of 98% by using raschig rings as filter media.

Table 2.4 : Previous researches using HUASB reactor

Researcher	Type of wastewater	Characteristics	Efficiency (%)
Bello-Mendoza & Castillo-Rivera (1998)	Coffee processing wastewater	- COD concentration = 2,030 mg/L COD - OLR : 0.21 – 2.59 kg/m^3.d - HRT : 10 - 59 hr - Temp. : 18 - 23 °C - Filter media :Volcanic rocks – 2/3 sludge blanket - Demonstration scale in Mexico	22.4 – 88.6
Borja, *et al.* (1998)	Slaughterhouse wastewater	- Volume : 3.74 – 10.41 g/L - OLR : 2.49 – 20.82 kg/m^3.d - HRT : 0.5 – 1.5 d - Temp : 35 ºC - Filter media : *Polyurethane* foam – 2/3 sludge blanket - Lab scale in Spain	90.2 – 93.4
Elmitwalli, *et al*. (1999)	a) Raw sludge b) Pre-settled	a) COD : 456 mg/L b) COD :344 mg/L - HRT : 8 h - Temp : 13 ºC - Filter media : Reticulated *polyurethane* foam sheets–500 m^2/m^3 - Lab scale in Netherlands	a) 66 b) 61

Table 2.4 : Previous researches using HUASB reactor

Researcher	Type of wastewater	Characteristics	Efficiency (%)
Hutnan, *et al.* (1999)	Synthetic wastewater	- COD concentration : 6,000 mg/L COD - OLR : 0.5 – 15 $kg/m^3.d$ - HRT : 0.4 - 12 d - Temp : 37 ºC - Filter media : Tubular plastic carrier – 544 m^2/m^3 - Lab scale in Slovakia	80 - 90
Wu, *et al.* (2000)	Synthetic wastewater	- COD concentration : 5,000 mg/L COD - OLR : 1 – 24 $kg/m^3.d$ - HRT : 5 – 60 hr - Temp : 35 ºC - Filter media : Raschig rings – 20%, 40%, 60% and 75% packing height - Lab scale in Singapore	71 - 98
Elmitwalli, *et al.* (2001)	Raw domestic sewage	- HRT : a) 4+8 hr b) 2+4 hr c) 3+6 hr - Temp : 13 ºC - Filter media :Vertical sheets of RPF – 2,400 m^2/m^3 - Pilot scale in Egypt	a) 70.9 b) 58.6 c) 63

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