The Performance Evaluation of Anaerobic Methods for Palm Oil Mill Effluent (POME) Treatment: A Review

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1. Introduction

Palm oil mill effluent (POME) is an important source of inland water pollution when released into local rivers or lakes without treatment. 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]. POME is a viscous brown liquid with fine suspended solids at pH ranging between 4 and 5 [Najafpour et al., 2006]. 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 biological treatment, consisting of anaerobic, facultative and aerobic pond systems [Chooi, 1984], and [N. 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 in Malaysia have adopted the ponding system for POME treatment [Ma et al., 1993], while the rest opted for open digesting tanks [Yacop et al., 2005]. These methods are regarded as a conventional POME treatment method involving long retention times and large treatment areas. High-rate anaerobic bioreactors have also been applied in laboratory-scaled POME treatment such as up-flow anaerobic sludge blanket (UASB) reactors [Borja el al., 1994a]; up-flow anaerobic filtration [Borja et al., 1994b]; fluidized bed reactors [Borja et al., 1995a], [Borja et al., 1995b] and up-flow anaerobic sludge fixed-film (UASFF) reactors [Najafpour et al., 2006]. Anaerobic contact digesters Ibrahim et al. (1984) and continuous stirred tank reactors (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] and [Fakhru'l-Razi, 1994].

2. Anaerobic digestion

Anaerobic digestion is the most suitable method for the treatment of effluents containing high concentration of organic carbon such as POME [Borja et al.,1996a]. Anaerobic digestion is defined as the engineered methanogenic anaerobic decomposition of organic matter. It involves different species of anaerobic microorganisms that degrade organic matter [Cote et al., 2006]. In the anaerobic process, the decomposition of organic and inorganic substrate is carried out in the absence of molecular oxygen. The biological conversion of the organic substrate occurs in the mixtures of primary settled and biological sludge under anaerobic condition followed by hydrolysis, acidogenesis and methanogenesis to convert the intermediate compounds into simpler end products as methane (CH_4) and carbon dioxide (CO_2) [Gee et al., 1994], [Guerrero et al., 1999], and [Gerardi, 2003]. Therefore, the anaerobic digestion process offers great potential for rapid disintegration of organic matter to produce biogas that can be used to generate electricity and save fossil energy [linke, 2006]. The suggested anaerobic treatment processes for POME include anaerobic suspended growth processes, attached growth anaerobic processes (immobilized cell bioreactors, anaerobic fluidized bed reactors and anaerobic filters), anaerobic blanket processes (up-flow anaerobic sludge blanket reactors and anaerobic baffled reactors), membrane separation anaerobic treatment processes and hybrid anaerobic treatment processes.

2.1. Anaerobic and alternative POME treatment methods

Currently available alternative methods for POME treatment are: aerobic treatment, membrane treatment systems and the evaporation method. The advantages and disadvantages of anaerobic and alternative treatment methods are shown in Table 1. In terms of energy requirement for POME treatment operation, anaerobic digestion has a greater advantage over the other alternative methods as it does not require energy for aeration. Furthermore, anaerobic POME treatment produces methane gas (CH_4) which is a value-added product to digestion that can be utilized in the mill to gain more revenue in terms of CER. For example, the open digesting tank for POME treatment without land application, the capital cost quoted by [Gopal et al., 1986] for a palm oil mill processing 30 tons FFB/h is RM 750,000. Based on the chemical Engineering Plant Cost Index [Ulrich et al., 2004] the capital cost for this system is estimated to be US 370,272 in 2006. Comparing this to the capital cost for a membrane system in POME treatment for a palm oil mill processing 36 tons FFB/h at RM 3,950,000 [Chong, 2007], it is obvious that the former anaerobic treatment has better advantage over other treatment methods in terms of capital cost. The disadvantages of anaerobic treatment are (a) long retention times and (b) long start-up period. However, the problem of long retention times can be rectified by using high-rate anaerobic bioreactors while the long start-up period can be shortened by using granulated seed sludge [McHugh et al., 2003], utilizing seed sludge from same process [Yacob et al., 2006b] or maintaining suitable ph and temperature in the high-rate anaerobic bioreactor for growth of bacteria consortia [Liu et al., 2002].

Treatment types	Advantages	Disadvantages	Reference
Membrane	Produce consistent and good water quality after treatment, smaller space required for membrane treatment plants, can disinfect treated water	Short membrane life, membrane fouling, expensive compared to conventional treatment	[Ahmad et al., 2006] [Metcalf et al., 2003]
Anaerobic	low energy requirements (no aeration),Producing methane gas as a valuable end product, generated sludge from process could be used for land applications	Long retention time, large area required For conventional digesters, slow start-up (granulating reactors)	[Metcalf et al., 2003] [Borja et al., 2006a]
Evaporation	solid concentrate from process can be utilized as feed material for fertilizer manufacturing	High energy consumption	[MA et al., 1997]
Aerobic	Shorter retention time, more effective in handling toxic wastes	High energy requirement (aeration), rate of pathogen inactivation is lower in aerobic sludge compared to anaerobic sludge, thus unsuitable for land applications	[Jr et al., 1999] [Doble et al., 2005]

Table 1. Advantages and disadvantages between anaerobic and alternative treatment methods

2.2. Anaerobic treatment methods

2.2.1. Anaerobic filtration

Anaerobic digestion has existed as a technology over 100 years. It gradually evolved, from an airtight vessel and a septic tank, to a temperature controlled, completely mixed digester, and finally to a high rate reactor, containing a density of highly active biomass. The microbiology of methane digestion has been examined intensively in the last decade. It has been established that three physiological groups of bacteria, converting hydrogen and carbon dioxide or acetate to methane. In contrast to aerobic degradation, which is mainly a single species phenomenon, anaerobic degradation proceeds as a chain process, in which several sequent organisms are involved. Anaerobic conversion of complex substrates requires the synergistic action of the micro-organisms involved. A factor of utmost importance, in the overall process, is the partial pressure of hydrogen and the thermodynamics linked to it. This fact has been recognized and discussed by researchers [Bryant et al., 1967]; [Boone and Bryant, 1980]; [McInerney et al. 1979]; [Hickey and Switzenbaum 1988]. Anaerobic filter were favor for wastewater treatment because (a) high substrate removal efficiency (b) it requires a smaller reactor volume which operates on a shorter hydraulic retention times (HRT), [Borja et al., 1994b], (c) the ability to maintain

high concentration of biomass in contact with the wastewater without affecting treatment efficiency [Reyes et al., 1999], [Wang et al. (2007)], and (d) tolerance to shock loadings [Reyes et al., 1999], [Van Der Merwe et al., 1993]. Besides, construction and operation of anaerobic filter is less expensive and small amount of suspended solids in the effluent eliminates the need of solid separation or recycle [Russo et al. 1985].

Another factor of fundamental importance has been the identification of new methanogenic species, and the characterization of their physiological behaviour. Of particular interest was the determination of the substrate affinity constants of both hydrogenotrophic and acetotrophic methanogens. While the first exhibit quite high substrate affinities and remove hydrogen down to ppm levels, the second group appears to contain species with only low substrate affinities [Zehnder et al., 1980]; [Huser et al., 1982]. This limited substrate affinity has,, an important consequence for anaerobic wastewater treatment.

A technological advance of utmost importance in anaerobic digestion has been the development of methods to concentrate methanogenic biomass in the reactor, especially in very low solids concentration in the wastewater, 1 - 2%. Such higher concentration of biomass can be achieved using of autoflocculation and gravity settling as, for instance, in the UASB reactor [Lettinga et al. 1983], by attachment to a static carrier (anaerobic filter) [Henze and Harremoes, 1982]; [Van Den Berg and Kennedy 1981]; [Young and McCarty 1969], by attachment to a mobile carrier (fluidized bed) [Binot et Heijnen 1984]; [Bull et al., 1984] or by growth in and on a matrix [Huysman et al., 1983]. All these different methods are in full development

Anaerobic filters have been applied to treat various types of wastewater including soybean processing wastewater [H-Q et al., 2002a], wine vinases [Nebot et al., 1995], [Perez et al., 1998], land fill leachate [Wang et al., 2007], municipal wastewater [Bodkhe, 2008], brewery wastewater [Leal et al., 1998], slaughterhouse wastewater [Ruiz et al., 1997], drug wastewater [Gangagni et al., 2005], and beet sugar water [Farhadian et al., 2007]. However, filter clogging is a major drawback in the continuous operation of anaerobic filters [Bodkhe, 2008], [Jawed et al. 2000], [Parawira et al., 2006]. Clogging of anaerobic filter has only been reported in the treatment of POME at an organic loading rate (OLR) of 20 g COD/l/day [Borja et al., 1995b] and also in the treatment of slaughterhouse wastewater at 6 g COD/l/day. This because the other studies were conducted at lower OLRs which had lower suspended solid content compared to POME. In general, anaerobic filter s are capable of treating wastewaters to obtain good effluent quality with at least 70% of COD removal efficiency with methane gas composition of more than 50%. Table 2 illustrates the COD removal efficiency of some treated wastewater using anaerobic filtration based on highest achievable percentage of methane in the generated biogas. In terms of POME treatment, the highest COD removal efficiency recorded was 94% with 63% of methane at an OLR of 4.5 kg COD/m3/day, while overall COD removal efficiency was up to 90% with an average methane gas composition of 60% [Borja et al., 1994b]. Investigations have been done to improve the efficiency of anaerobic filtration in wastewater treatment. [Yu et al., 2002a] found that operating at an optimal recycle ratio which varies depending on OLR will enhance COD removal. However, methane percentage will be compromised with increase in optimal recycle ratio. Higher retention of biomass in the filter will also lead to a better COD removal efficiency.

Types of Wastewater	Operating OLR range (Kg COD/m³/day)	COD removal efficiency (%)	Highest methane composition (%)	Reference
Slaughterhouse wastewater	1.0-6.5	79.9 (91.5)	51.1	[Ruiz et al., 1997]
POME	1.2-11.4	94.0 (94.0)	63.0	[Borja et al. 1994b]
Baker's yeast factory effluent	1.8-10.0	69.0 (74.0)	65.0	[Van der et al. 1993]
Distillery wastewaters	0.42-3.4	91.0 (93.0)	63.0	[Russo et al., 1985]
Landfill leachate	0.76-7.63	90.8 (90.8)	N/A	[Wang et al., 2007]

() - number in bracket denotes highest COD removal efficiency. N/A- data unavailable.

Table 2. Operating OLR range; COD removal efficiency in various wastewater treatments using anaerobic filtration based on highest % of methane production

2.2.2. Fluidized bed reactor

A fluidized bed reactor (FBR) is a type of reactor device that can be used to carry out a variety of multiphase chemical reactions. Fluidized bed reactor exhibits several advantages that make it useful for treatment of high-strength wastewaters. It has very large surface areas for biomass attachment [Borja et al., 2001], [Toldra et al., 1987] enabling high OLR and short HRTs during operation [Garcia et al., 1998], [Sowmeyan et al., 2008]. Furthermore, fluidized bed has minimal problems of channeling, plugging or gas hold-up [Borja et al., 2001], [Toldra et al. 1987]. Higher up-flow velocity of raw POME is maintained for fluidized bed reactor to enable expansion of the support material bed. Biomass will then attach and grow on the support on material. In this way, biomass can be retained in the reactor. Hickey and [Switzenbaum, 1988] reported on the development of the anaerobic expanded bed process, which was found to convert dilute organic wastes to methane at low temperatures and at high organic and hydraulic loading rates. This process was being evaluated in 1988, on a 10,000 gallons per day pilot scale, consisting of an anaerobic expanded bed followed by post- treatment. [Jeris, 1987] reported on a two year experiment, testing two pilot scale anaerobic fluidized bed reactors, treating primary effluent. One reactor used sand as a carrier, the other granular activated carbon (GAC). Seeding experiments indicated that the GAC developed a biofilm more quickly and had more attached biomass. In addition, better BOD removal was observed with the GAC reactor. He noted that removal efficiencies were essentially independent of organic volumetric loading rates. Over a twelve month period in temperate climates, effluent total BOD5 values were consistently around 40 mg/l.

Investigations have been done on the application of fluidized bed to treat cutting-oil wastewater [Perez et al., 2007]; real textile wastewater [Sen et al., 2003]; slaughterhouse wastewater [Toldra et al., 1987]; wine and distillery wastewater [Garcia et al. 1998], [Sowmeyan et al.,

2008]; ice-cream wastewater [Borja et al., 1995a], [Hawkes et al., 1995]; pharmaceutical efflu-ent [Saravanane et al., 2001], and POME [Borja et al., 1995b]. OLR ranges and COD removal efficiencies of various wastewater treatments using fluidized bed is tabulated in Table 3. Based on Table 3, it can be concluded that anaerobic fluidized bed can typically remove at least 65% and up to more than 90% of COD. Inverse flow anaerobic fluidized bed is capable of tolerating higher OLRs compared to up-flow configuration.

Types of Wastewater	Operating OLR range (Kg COD/m3/day)	COD removal efficiency (%)	Reactor configuration	Reference
Protein production from extracted				
Sunflower flour effluent	0.6-9.3	80.0-93.3	UF	[Borja et al., 2001]
POME	10.0-40.0	78.0-94.0	UF	[Borja et al., 1995b]
Ice-cream wastewater	3.2-15.6	94.4	UF	[Borja et al., 1995a]
Distillery effluent	6.11-35.09	80.0-92.0	DF	[Sowmeyan et al., 2008]
Brewery wastewater	0.5-70.0	80.0-90.0	DF	[Alvarado et al., 2008]
Real textile wastewater	0.4-5.0	78.0-89.0	UF	[Sen et al., 2003]

UF-upward flow; DF-downward/inverse flow.

Table 3. Operating OLR range; COD removal efficiency of various wastewater treatments using fluidized bed reactor

The type of support material in the fluidized bed plays an important role to determine the efficiency of the entire treatment system [Garcia et al., 1998], [Sowmeyan et al., 2008] for both inverse flow and up-flow systems. Studies using fluidized bed to treat ice-cream waste-water showed different COD removal efficiencies when different support materials were used. Researcher [Hawkes et al., 1995] found that fluidized bed using granular activated car-bon (GAC) gave about 60% COD removal while [Borja et al., 1995a] obtained 94.4% of COD removal using ovoid saponite. Thus suitable support material needs to be selected to obtain high COD removal efficiency in the system.

2.2.3. Up-flow Anaerobic Sludge Blanket (UASB) reactor

Up-flow anaerobic sludge blanket (UASB) technology, normally referred to as UASB reac-tor, is a form of anaerobic digester that is used in the treatment of wastewater. UASB was developed by [Lettinga et al., 1980] whereby this system has been successful in treating a wide range of industrial effluents including those with inhibitory compounds. The UASB re-

actor is a methanogenic (methane-producing) digester that evolved from the anaerobic clarigester. A similar but variant technology to UASB is the expanded granular sludge bed (EGSB) digester. The underlying principle of the UASB operation is to have an aerobic sludge which exhibits good settling properties [Lettinga, 1995]. So far, UASB has been applied for the treatment of potato wastewater [Kalyuzhnyi et al., 1998], [Lettinga et al., 1980], [Parawira et al., 2006]; domestic wastewater [Barbosa et al., 1989], [Behling et al., 1997]; slaughterhouse wastewater [Sayed et al., 1984]; POME [Borja et al., 1994c]. UASB has a relatively simple design where sludge from organic matter degradation and biomass settles in the reactor. Organic matter from wastewater that comes in contact with sludge will be digested by the biomass granules. Table 4 shows some performances of wastewater treatment using UASB system. For potato wastewater treatment [Kalyuzhnyi et al., 1998] and [Parawira et al., 2006] both observed foaming and sludge floatation in the UASB reactor when operating at higher OLRs (> 6.1kg COD/m3 day). The ability of UASB to tolerate higher OLR for potato wastewater investigated by [Lettinga et al., 1980] compared due to the fact that the latter two studies were conducted at laboratory scale. In general, UASB is successful in COD removal of more than 60% for most wastewater types except for ice-cream wastewater. Researcher [Hawkes et al., 1995] suggested that the lower COD removal percentage from ice-cream wastewater was due to design faults in the reactor's three phase separator and high contents of milk fat that were hard to degrade.

Types of Wastewater	Operating OLR range (Kg COD/m3/day)	COD removal efficiency (%)	Methane Composition (%)	Reference
POME single-stage two-stage	1.8-13.9	63.0-81.0	54.0-67.0	[Kalyuzhnyi et al 1998]
(based on methanogenic reactor)	1.5-6.1	92.0-98.0	59.0-70.0	[Parawira et al. 2006]
Domestic sewage	3.76	74.0	69.0	[Barbosa et al. 1989]
Ice-cream wastewater	0.5-50	50.0	69.6	[Hawkes et al. 1995]
Sugar – beet	4.0-5.0	95.0	N/A	[Lettinga et al. 1980]
Pharmaceutical wastewater	0.27-2.0	26.0-69.0	N/A	[Stronach et al. 1987]
Slaughter wastewater	7.0-11.0	55.0-85.0	65.0-75.0	[Sayed et al. 1984]
Confectionary wastewater	1.25-2.25	66.0	N/A	[Forster et al. 1983]

N/A – data unavailable.

Table 4. Performance of UASB in various wastewater treatments

POME treatment has been successful with UASB reactor, achieving COD removal efficiency up to 98.4% with the highest operating OLR of 10.63 kg COD/m3 day [Borja et al., 1994c]. However, reactor operated under overload conditions with high volatile fatty acid content became unstable after 15 days. Due to high amount of POME discharge daily from milling process, it is necessary to operate treatment system at higher OLR. UASB reactor is advantageous for its ability to treat wastewater with high suspended solid content [Fang et al. 1994]; [Kalyuzhnyi et al., 1998] that may clog reactors with packing material and also provide higher methane production [Kalyuzhnyi et al., 1996]; [Stronach et al., 1987]. However, this reactor might face long start-up periods if seeded sludge is not granulated.

2.2.4. Anaerobic contact digester

The anaerobic contact process is a type of anaerobic digester. Anaerobic digesters are the aerobic equivalents of activated sludge process and are currently used for treating effluents from sugar processing, distilleries, citric acid and yeast production, industries producing canned vegetables, pectin, starch, meat products, etc. This process has been implemented in POME [Ibrahim et al., 1984]; ice-cream wastewater, alcohol distillery wastewater [Vlissidis et al., 1993] and fermented olive mill wastewater treatment [Hamdi et al. 1991]. Concentrated wastewaters are suitable to be treated by anaerobic contact digestion since relatively high quality effluent can be achieved [Jr et al., 1999]. In the study of fermented olive mill wastewater treatment, anaerobic contact was capable of reaching steady state more quickly compared to anaerobic filter; however, more oxygen transfer in the digester (due to mixing) causes this process to be less stable.

2.2.5. Continuous Stirred Tank Reactor (CSTR)

CSTR run at steady state with continuous flow of reactants and products; the feed assumes a uniform composition throughout the reactor, exit stream has the same composition as in the tank. The mechanical agitator provides more area of contact with the biomass thus improving gas production. In POME treatment, CSTR has been applied by a mill under Keck Seng (Malaysia) Berhad in Masai, Johor and it is apparently the only one which has been operating continuously since early 1980's [Tong et al., 2006]. Other applications of CSTR on wastewater treatment include dilute dairy wastewater [Chen et al., 1996]; jam wastewater [Mohan et al., 2008] and coke wastewater [Vazquez et al., 2006].

The CSTR in Kek Seng's Palm oil mill has COD removal efficiency of approximately 83% and CSTR treating dairy wastewater has COD removal efficiency of 60%. In terms of methane composition in generated biogas, it was found to be 62.5% for POME treatment and 22.5-76.9% for dairy wastewater treatment.

2.2.6. Anaerobic contact digestion

Presently there are three categories of anaerobic treatment systems. The first category is the conventional anaerobic digester, which includes two basic designs and another that combines the two. The standard rate digester is the most basic treatment system. It mixes the

waste is solely by the movement of gas up through the solid matter and into the top of the tank; there is no external mixing. This process is highly inefficient, for it utilizes only 50 percent of the total waste volume, and requires a very long solid retention time (SRT), usually greater than 30 days; this process has been implemented in POME [Ibrahim et al., 1984]; ice-cream wastewater, alcohol distillery wastewater [Vlissidis et al., 1993] and fermented olive mill wastewater treatment [Hamdi et al., 1991]. Concentrated wastewaters are suitable to be treated by anaerobic contact digestion since relatively high quality effluent can be achieved [Jr et al., 1999]. In the study of fermented olive mill wastewater treatment, anaerobic contact was capable of reaching steady state more quickly compared to anaerobic filter; however, more oxygen transfer in the digester (due to mixing) causes this process to be less suitable.

2.2.7. Membrane separation anaerobic treatment process

Membrane separation has been considered for anaerobic reactors but the technology is still in a development stage. Several studies on membrane anaerobic processes for the treatment of various wastewaters including POME [Fakhru'l et al., 1999] have been performed [Fakhru'l et al., 1994]; [Nagano et al., 1992]; [Pillay et al., 1994]. For example, an ultrafiltration (UF) membrane with a molecular cut-off (MWCO) of 200,000 was used by [76] for biomass/effluent separation in conjunction with an anaerobic process for the treatment of POME. A lower operating pressure (1.5-2 bars) but a higher cross-flow velocity (2.3 m/s) was applied in this study in order to control fouling and to reduce solid deposition on the membrane surfaces. A high COD removal could be obtained in the membrane anaerobic system (MAS), but the permeate displayed a high color content with a low turbidity (less than 10 NTU), including that the color was due to dissolved solids with molecular weights lower than 200,000 g/mol. The particular organics retained in the reactor could be liquefied and decomposed because of the long solid retention time, which was independent of the HRT. The HRT was mainly influenced by the UF membrane flux rates which directly determined the volume of influent that could be fed to the reactor.

2.3. Clean Development Mechanism (CDM)

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change. The major feature of the Kyoto Protocol is that it sets binding targets for 37 industrialized countries and the European community for reducing greenhouse gas (GHG) emissions.These amount to an average of five per cent against 1990 levels over the five-year period 2008-2012.

The Clean Development Mechanism (CDM), defined in Article 12 of the Protocol, allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol (Annex B Party) to implement an emission-reduction project in developing countries. Such projects can earn saleable certified emission reduction (CER) credits, each equivalent to one tonne of CO_2, which can be counted towards meeting Kyoto targets.

The mechanism is seen by many as a trailblazer. It is the first global, environmental investment and credit scheme of its kind, providing a standardized emission offset instrument,

CERs. Besides helping to reduce carbon emission to the environment, CDM has the advantage to offer developing countries such as Malaysia to attract foreign investments to sustain renewable energy projects [Menon, 2002]. Thus, palm oil mills could earn carbon credits as revenue by the utilization of methane gas as renewable energy from anaerobic digestion of palm oil mill effluent. There is a lot of attention has been give to develop anaerobic treatment for POME since the implementation of CDM.

2.4. Comparison of various anaerobic treatment methods in POME treatment

Table 5 shows the performance of several of anaerobic digestion or treatment methods under both mesophilic and thermophilic conditions of POME. As can be seen from Table 5, the fluidized bed reactor has the ability to treat POME at very high organic loading rates; OLR with a short retention time, biogas capture is not emphasized using this process. Therefore, it can be concluded that USFF currently gives the best performance in POME treatment, achieving high COD removal efficiency and high OLR methane production at relatively short hydraulic retention time, HRT compared to conventional and other available anaerobic treatment methods.

retention (days)	Operating OLR (Kg COD/m³/day)	COD removal efficiency (%)	Hydraulic time	Methane composition (%)	Reference
Anaerobic pond 40	1.4		97.8	54.4	[Perez et al., 2001]
Anaerobic digester	2.16	80.7	20	36	[Yacop et al., 2005]
Anaerobic filtration	4.5	94.0	15	63	[Borja et al., 1994b]
Fluidized bed	40.0	78	0.25	N/A	[Borja et al., 1995b]
UASB	10.63	98.4	4	54.2	[Borja et al., 1994c]
UASFF	11.58	97	3	71.9	[Najafpour et al., 2006]
CSTR	3.33	80	18	62.5	[Tong et al., 2006]
Anaerobic contact process[a]	3.44	93.3	4.7	63	[Ibrahim et al., 1984]

N/A: data unavailable.

a In terms of BOD.

Table 5. Performance of various anaerobic treatment methods on POME treatment

Table 6 shows the advantages and disadvantages of each anaerobic treatment method. It can clearly seen that conventional methods are lacking in terms of treatment time, area required

for treatment and facilities to capture biogas. However, these methods are more economically viable and have the capacity to tolerate a wider range of OLR. High-rate bioreactors are more effective in biodegradation as shorter retention times are needed, producing higher methane yield while compromising the OLR, capital and operating cost.

Treatment processes	advantages	disadvantages	References
Ponding system	Reliable and stable Anaerobically digested POME from the ponds could be used to culture algae. Cheap, simple to construct, low maintenance costs, the energy needed to operate a ponding system is minimal.	large area of land are required, making it unsuitable for factories located in the near urban and other developed areas. no facilities to capture biogas long retention time.	[Chooi et al. 91984]
Anaerobic filtration	Small reactor volume Producing high quality effluent, short hydraulic times, able to tolerate shock Loadings, retain high biomass Concentration in the packing	lower methane emission, Clogging at high OLRs, High media and support cost Unsuitable for high suspended solid wastewater	[Borja et al., 1994b]
Fluidized bed	Most compact of all high-rate Processes, very well mixed Conditions in the reactor, large Surface area for biomass Attachment	high power requirements for bed fluidization, high cost of carrier media, not suitable for high suspended solid wastewaters	[Jr et al., 1997]
UASB	Useful for treatment of high suspended solid wastewater Producing high quality effluent No media required (less cost)	Performance dependent on sludge settleability, foaming and sludge floatation at high OLRs, long start up period if granulated, seed sludge is not used	[Lettinga, 1995]
UASFF	Higher OLRs achievable compared to operating UASB or anaerobic filtration alone, problems of clogging eliminated Higher biomass retention, more Stable operation, ability to tolerate Shock loadings, suitable for diluted Wastewater.	Granulation inhibition at high volatile fatty acid concentration Lower OLRs when treating suspended solid wastewaters	[Ayati et al., 2006]
CSTR	Provides more contact of wastewater with biomass through mixing, increased gas production compared to conventional method	Less efficient gas production at treatment volume. Less biomass retentio	Hamdi et al., 1991]

Table 6. Advantages and disadvantages of various treatment processes for POME

2.5. Factors influencing anaerobic digester performance

Biogas coming from biomethanization or anaerobic digestion represents an attractive strategy for both biomass waste treatment and recycling and is of great interest from an environmental point of view and may benefit society by providing a clean fuel source from renewable energy. This technology is accomplished by a series of biochemical transformations, which can be toughly separated into a first step where hydrolysis, acidification and liquefaction take a place and second step where acetate, hydrogen and carbon dioxide are transformed into biogas with methane content between 60-80%, which cover a large part of energy. Many factors govern the performance of anaerobic digesters where adequate control is required to prevent reactor failure. These factors are operating temperature, pH, mixing, nutrients for bacteria and organic loading rates into the digester.

2.5.1. Operating temperature

One of the most important factors affecting anaerobic digestion of organic waste is temperature. Anaerobic digestions can be developed at different temperature ranges including mesophilic temperatures (approximately 35ºC) and thermophilic temperatures ranging from 55 ºC to 60 ºC. Conventional anaerobic digestion is carried out at mesophilic temperatures (35–37 ºC), mainly because of the lower energy requirements and better stability of the process. POME is discharged at temperatures around 80-90 oC [Zinatizadeh et al., 2006] which actually makes treatment at both mesophilic and thermophilic temperature feasible especially in tropical countries like Malaysia. Effect of temperature on the performance of anaerobic digestion was investigated by [H-Q et al., 2002a] and found that substrate degradation rate and biogas production rate at 55 oC was higher than operation at 37 oC. Studies have reported that thermophilic digesters are able to tolerate higher OLRs and operate at shorter HRT while producing more biogas [Ahn et al., 2002], [Kim et al., 2006], and [Yilmaz et al., 2008]. However, failure to control temperature increase can result in biomass washout [Lau et al., 1997] with accumulation of volatile fatty acid due to inhibition of methanogenesis. At high temperatures, production of volatile fatty acid is higher compared to mesophilic temperature range [H-Q et al., 2002a].

2.5.2. pH

A pH (potential of Hydrogen) measurement reveals if a solution is acidic or alkaline (also base or basic). If the solution has an equal amount of acidic and alkaline molecules, the pH is considered neutral. The microbial communities in anaerobic digesters are sensitive to pH changes and methanogens are affected to a great extend [Jr et al., 1999]. Several cases of reactor failure reported in studies of wastewater treatment are due to accumulation of high volatile fatty acid concentration, causing a drop in pH which inhibited methanogenesis Parawira et al. (2006), [Patel et al., 2002]. Thus, volatile fatty acid concentration is an important parameter to monitor to guarantee reactor performance [Buyukkamaci et al., 2004]. It was found that digester could tolerate acetic acid concentrations up to 4000 mg/l without inhibition of gas production Stafford (1982). To control the level of volatile fatty acid in the system, alkalinity has to be maintained by recirculation of treated effluent [Najafpour et al., 2006], [Borja et al., 1996a] to the digester or addition of lime and bicarbonate salt [Gerardi, 2003].

2.5.3. Mixing

Distribution of bacteria, substrate, nutrients and temperature equalization by means of adequate mixing, are known to be crucial for the overall anaerobic digester (AD) process [Chapman, 1989]. Several investigations show that improvements in reactor performance can be achieved when changes in mixing intensity are imposed [Angelidaki et al., 2004]. According to [Gerardi, 2003] the main advantages of mixing in AD are: minimization of solids accumulation that may restrict reactor hydraulics, reduction of scum build up, elimination of temperature stratification and maintaining close contact between substrate particles and microbial communities. In a sequential experiment [Stroot et al., 2001] studied the feasibility of co-digestion of municipal solid waste, primary sludge and waste activated sludge (WAS) under mesophilic conditions in laboratory scale continuous stirred tank reactors (CSTRs) under different OLR and mixing conditions.

2.5.4. Organic loading rates

Organic loading rate is defined as the application of soluble and particulate organic matter. It's typically expressed on an area basis as pounds of BOD per unit area. Various studies have shown that higher OLRs will reduce COD removal efficiency in wastewater treatment systems [Torkian et al., 2003], [Sanchez et al., 2005]. However, gas production will increase with OLR until a stage when methanogens could not work quick enough to convert acetic acid to methane.

3. Conclusions

The performance of anaerobic treatment for POME and effects of organic loading rates were thoroughly reviewed. The palm oil industry is an indisputable source of pollution in Malaysia. In order to counteract the negative impact of this source, anaerobic digestion is an advantageous method for POME treatment as it generates valuable and product that can be exchanged into revenue when registered as a clean development mechanism CDM project. Furthermore, research can be done to develop a thermophilic anaerobic bioreactor with minimal control to ease system operation. Moreover, intensity of mixing in the thermophilic range should be investigated to obtain an optimum mixing rate that will keep microbial consortia in close proximity and at the same time improve the system efficiency. Furthermore, operation costs can be reduced through utilization of biogas for heat or electricity energy generation in the plant.

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