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PALM OIL MILL EFFLUENT (POME) TREATMENT USING HYBRID UPFLOW ANAEROBIC SLUDGE BLANKET (HUASB) REACTORS : IMPACT ON COD REMOVAL AND ORGANIC LOADING RATES

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ABSTRACT

Processing of palm oil fruit into palm oil produced high strength wastewater which is known as palm oil mill effluent (POME). POME contains high concentrations of chemical oxygen demand (COD), total solids (TS), and suspended solids (SS). Before POME can be discharged to the environment, it has to be treated to the level conforming to the discharge standards. Currently, most palm oil mills in Malaysia are using anaerobic ponds to treat POME. This is very conventional and often creates environmental pollution themselves. Therefore, the aim of this study is to assess a more suitable treatment method to overcome the limitations and disadvantages of anaerobic ponds. In this study, three hybrid up-flow anaerobic sludge blanket (HUASB) reactors, treating POME with COD of ±5000 mg/L at room temperature were operated. Coarse gravel, fine gravel and crushed glass were applied as filter media in three reactors (R1, R2 and R3). The reactors were operated at organic loading rate (OLR) of 1.83 g COD/L.d and hydraulic retention time (HRT) of 2.73d for the start up operation. Experimental results indicated that POME can be treated more effectively by using HUASB reactors because HUASB was able to retain more biomass in the filter media in addition to the high concentration of biomass in the sludge blanket. Efficiency of treatment up to 98 % removal was observed. It was also shown that the HUASB reactors have shortened the start up period from 60 days as in UASB (up-flow anaerobic sludge blanket) reactors (in previous study) to 47 days to achieve steady state.

Keyword: HUASB; OLR; POME; steady state.

INTRODUCTION

The up-flow anaerobic sludge blanket (UASB) reactor was first introduced in the Netherlands in the late 1970s. In 1980, the reactor was used for the treatment of industrial wastewater. 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 & Hulshoff Pol, 1991). 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. AF is one of the earliest types of retained biomass reactor developed by Young and McCarty in 1969.

The success of the anaerobic high-rate systems is due to the possibility of application of relatively high loading rate, while maintaining long sludge retention time (SRT) at relatively short hydraulic retention time (HRT) due to sludge immobilization. Organic matter is converted into biogas (mainly methane) and sludge (Metcalf & Eddy, 1991). 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. 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. The HUASB reactors are frequently used for medium to high strength wastewater (2000 – 20,000 mg/l COD), but have fewer applications to low strength wastewater (< 1000 mg/l COD). Study done by Tur & Huang (1997), showed that 86 % of the total biomass accumulated in the UASB section and the removing 14% accumulated in the bio-filter section.

Ahring & Schmidt (1993), 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 & 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.

MATERIALS AND METHODS

This study was a comparative investigation of reactor's performance in three laboratory scale HUASB reactors designated as R1, R2 and R3. Reactor 1, Reactor 2 and Reactor 3 have been setup with the packing material of fine gravel, coarse gravel and crushed glass respectively. Three 7.85 L plexiglass HUASB reactors with an internal diameter of 100 mm and a height of 1000 mm were used in this study (see Figure 1). Early study of hybrid UASB reactor set up by Shivayogimath and Ramanujam (1998) has an internal diameter 0.10 m, overall height 0.77 m and the total liquid volume was 5 L. The standard reference for performing wastewater testing is contained in Standard Methods for the Examination of Water and Wastewater, 21st Edition (AWWA, APHA, 2005).

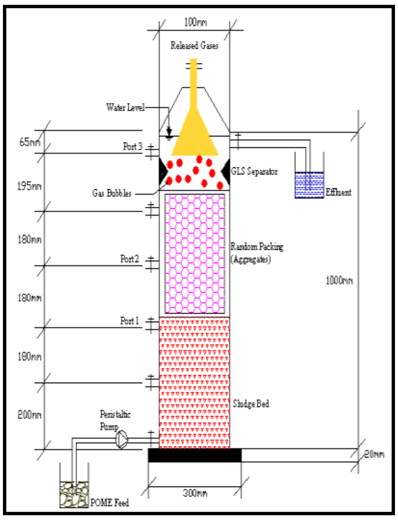

FIGURE 1 : Schematic diagram of HUASB reactor

Wastewater and seed sludge preparation

POME was collected from local palm oil mill Kian Hoe Plantation Private Limited Kluang, Johor. The POME was first acidified (pH = 2.0) with H_2SO_4 and diluted using tap water. The diluted sample was stored in a refrigerator that has been set at 4ºC in order to prevent premature degradation. The influent tube that carries the POME from feed tank to the reactor must be long enough to ensure that the influent had been warmed up to room temperature prior to entering the reactors (Kuan et al, 2004). All reactors were inoculated with 40% of digested sludge having initial COD concentration of 50,000 mg/L to 55,000 mg/L. The sludge was obtained from the anaerobic treatment pond of Kian Hoe Plantation. The granular sludge sample was then screened with sieve to remove foreign materials (Feng & Chiu, 2003).

Reactor system

The reactors were placed in the laboratory under room temperature of 24 ± 1 ºC. The column consisted of three sections; bottom, middle and top. The bottom part, with a height of 470 mm, consists of an active sludge bed. The middle part with a height of 180 mm was installed with random packing of materials to act as medium for a fixed-film attached growth and the top part of the reactor served as a gas-solid-liquid separator (GSL). The GSL separator function to separate solids from effluent as well as to ease the withdrawal of gas out of the reactor. The 180 mm middle section of the column which was mentioned earlier was packed with coarse gravel for R1 and fine gravel for R2 while another reactor (R3) packed with crushed glass to act as a filter. An inverted funnel-shaped gas separator was used to facilitate the withdrawal of biogas to a gas collection system. The POME was pumped into the reactor inlet by peristaltic pumps (Cole-Parmer, MasterFlex® L/S™).

Influent feed concentration was maintained by controlling the delivering flow at 2 mL/min. The OLR and HRT for all the reactor at the beginning of operation were 1.83 g COD/L.day and 2.73 days. The start-up operation continued until the steady state operation achieved (evidenced by constant gas production; ± 5 % and COD removal; ± 90 % for one week). Steady gas production was used to ascertain that reactors could be loaded to the next OLR. The organic loading rate was subsequently step increased to the next higher rate through shortening of HRT (Speece, 1996). In order for pH values to remain neutral (6.5<pH<7.5) in the influent, appropriate volume of $NaHCO_3$ were added to feed tank. The time taken for each reactor to reach steady state is presented in Table 2.

Monitoring and Analytical Methods

The performance of the reactor was monitored frequently. Chemical Oxygen Demand (COD) test was performed on the influent and effluent samples in order to evaluate the efficiency of the reactor. The COD concentration will be analyzed using DR 5000 spectrophotometer and was carried out in accordance with the Standard Methods for the Examination of Water and Wastewater, 21st Edition (AWWA, APHA, 2005).

RESULTS AND DISCUSSION

Characterization of Palm Oil Mill Effluent

Various batches of POME samples were tested to determine the characteristics of the wastewater. The characteristic of raw POME and the effluent after treatment by UASB, anaerobic pond and HUASB reactor are summarized in Table 1.

TABLE 1 : POME Characteristics

PARAMETERS	* STANDARD LIMIT (DOE)	* POME STANDARD CONCENTRATION	RAW POME	** UASB (eff.)	*** ANAEROBIC POND (effluent)	**HUASB REACTOR** (eff)		
						R1	R2	R3
pH	5 -9	4.7	3.8	7.96	-	6.82	6.88	6.82
COD	-	50,000	53,590	796	1725	1126	967	663
TS	-	40,500	15,544	4879	-	2017	1849	2314
TSS	400	18,000	7066	1791	-	1933	1019	1387
TVS	-	-	3906	765	-	709	590	986
NH_3-N	150	750	100.5	53	115	25.5	27.6	23.4
PO_4	-	-	242	-	60	76	43.8	150
NO_3^-	-	-	506	-	5	71	67	75

- *All parameters unit in mg/L except pH* • *Note : eff - effluent*
- *Sources : * J. Haniff (1994) ** N.N. Jidin (2006) *** K.K. Chin et al (1996)*

Organic Loading Rate (OLR) and Hydraulic Retention Time (HRT)

Based on Table 2 below, all three reactors R1, R2, and R3 were started with an OLR of 1.83 g COD/L day an increased stepwise to 2.72, 3.66, 4.6 and 5.5 g COD/L day every time when the COD removal efficiency reached > 90% (ie. steady state). It is critical to select a reasonably high OLR during start-up, to ensure rapid granulation and a stable treatment process. The OLR for the reactors were increased by reducing the hydraulic retention time (HRT). Time needed for R1 and R2 to reach every steady state was nearly the same from first start up until third steady state. This was due to the characteristic of both reactors of using the same packing material but of different sizes for filtration. Starting from 3rd steady state with OLR of 3.66 g COD/L.d until OLR of 6.42 g COD/L.d, R2 showed a significant acceleration towards attaining steady state condition with only 93 days taken compared to R1 and R3 with 136 days and 97 days respectively.

Generally, the time taken to achieve steady state is getting lesser from 1st steady state to another for every reactor. But for certain cases such as in 2nd steady state, the time taken was higher than the 1st steady state from 47 days to 56 and 52 days for R1 and R2 respectively as well as R3, from 42 days to 55 days due to biomass washout and the clogging of the tube.

Table 2 also showed that R1, R2 and R3 failed when the reactors reach OLR of 9.17 g COD/L.d, 12.84 g COD/L.d and 11.92 g COD/L.d respectively. It can be summarized that reactors with fine gravel packing material presented the most efficient treatment. This clearly demonstrated that the use of fine gravel as packing material was able to extend the period of the treatment compared to the others due to the ability of the filter to prevent lighter fraction of biomass being washed out off the reactor. The surface area of fine gravel in the filter packing material has created more biomass to be attached which provided efficient secondary treatment. The treatment was terminated on day 290, 303 and 292 due to the failure of the reactors.

TABLE 2 : Time (in days) for Each OLR to Achieve Steady State Condition

Steady State	OLR (gCOD/l.d)	HRT	FLOW RATE (ml/min)	*REACTOR 1* Days	*REACTOR 2* Days	*REACTOR 3* Days
1st (Start up)	1.83	2.73	2	47	47	42
2nd	2.72	1.84	3	56	52	55
3rd	3.66	1.36	4	40	38	21
4 th	4.6	1.09	5	38	27	21
5 th	5.5	0.91	6	32	14	34
6 th	6.42	0.78	7	26	14	21
7 th	7.34	0.68	8	28	28	17
8 th	8.25	0.61	9	14	19	17
9 th	9.17	0.55	10	9	17	18
10 th	10.09	0.49	11	na	14	20
11 th	11.01	0.45	12	na	9	16
12 th	11.92	0.42	13	na	11	10
13 th	12.84	0.39	14	na	13	na

Note : na – not available

Efficiency of COD removal

The efficiency of treatment in all reactors increases as loading increased, due the formation of more granular sludge. In the early stage of the treatment (start-up of reactor), COD of the effluent for all reactors showed fluctuating pattern with large variation due to instability of the system and excessive volatile fatty acids (VFA) concentration that was discharged in the effluent (Sun *et al.*, 2004). Figure 2 demonstrated that steady state condition was achieved at each hydraulic loading. The steady state (based on the dotted line in Fig. 2), shows that the reactors were very efficient in COD removal. Towards the end of operation, as the loading rate reaches 8.25 g COD/L.day, 11.92 g COD/L.day and 11.01 g COD/L.day respectively for R1, R2 and R3 the removal efficiency starting to drop from more than 90% removal to only 68% for R1, 39% for R2 and 64% removal for R3. At all OLRs, fine gravels added in R2 provided the highest COD removal with 99% at OLR of 8.25 g COD/L.d.

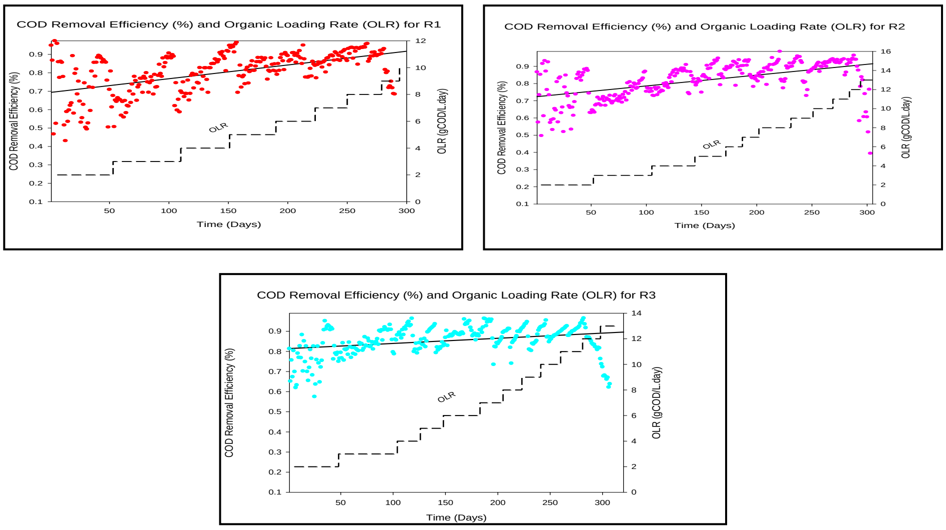

FIGURE 2 : COD Removal Efficiency of R1, R2 and R3

CONCLUSION

This study reveals that the treatment of POME using the HUASB reactor as a hybrid bioreactor with high organic load and SS concentration was successfully achieved. The use of HUASB reactor was a good strategy to accelerate anaerobic granulation and to achieve high COD removal efficiency in a short period of time. The reactor was very efficient in the treatment of diluted and high strength POME at high OLR and short HRT. The study was done continuously for about 220 days at various OLRs. A successful start up was achieved when the reactor achieve steady state at day 47. Steady state is said to be achieved after the efficiency of treatment reached 90% or more in COD removal. The COD removal efficiency was achieved over 90 % at OLR 1.833 g COD/L.d with HRT of 2.73 d during the start-up time. The highest COD removal efficiency also achieved at 98% for R3 at loading rate of 5.5 g COD/Ld.

The use of packing media in the middle portion had reduced channeling problem and loss of biomass due to flotation associated with poorly performing UASB reactors. It has been proved in this study when the washout rarely happened for R1, R2 and R3 with filter media installed compared to the control reactor which has no filter installed. It can be summarized that all reactors are feasible in treating POME especially in reducing COD concentration up to 98% removal. Reactor 2 which was installed with fine aggregates filter media achieve the shortest time to achieve steady state as well attaining the highest efficiency with the ability to reach OLR up to 12.84 g COD/L.day.

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