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The Start-up of Hybrid, Anaerobic up-Flow Sludge Blanket (HUASB) under a Range of Mesophiclic and Thermophilic Temperatures

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Abstract

We have examined the effect of gradual increase of the temperature on the performance of anaerobic process of palm oil mill effluent (POME), and sludge granules development. Two hybrid up-flow anaerobic sludge blanket (HUASB) reactors R1 and R2 were employed to be run at 27±2 and 37±1°C, respectively. R1 was kept at room temperature for the whole experiment, where the temperature of R2 was increased up to 49ºC (3ºC after every steady-state occurrence). Maximum COD removal of 91% was obtained in R2 at optimum temperature of 46°C, while 84% was recorded in R1. Additional parameters were applied to evaluate the performance of the process, i.e. total suspended solids (TSS), Turbidity, and Color. The imaging of sludge aggregate has revealed the effect of temperature on granulation development during the experiment. Throughout the operation period, it can be seen that the microbial growth rate was significantly affected by temperature. Hence, the use of HUASB reactor could be productively implemented for POME treatment as an efficient system under the mesophilic and thermophilic temperatures.

Keywords: anaerobic treatment; HUASB reactor; temperature; sludge granules; maximum specific microbial growth rate

1. Introduction

Industrial wastewater is enormously contaminated with several organics that may generate hydrogen which contributes to green house gases emissions (Wongtanet & Prapagdee, 2008). Therefore, anaerobic wastewater treatment has been introduced as a clean technology due to its efficient feasibility for the treatment of high strength wastewater (Alshafei, 2009), in addition to low to medium wastewater (Banu, Kaliappan, & Yeom, 2007) with lowest sludge production. Furthermore, anaerobic technology is of high economic advantages in comparison with aerobic technology (Lew, Tarre, Belavski, & Green, 2004). In the past few decades, the hybrid up-flow anaerobic sludge blanket HUASB bioreactor has been successfully introduced as a clean-efficient technology (Lettinga & Hulshoff, 1991). The HUASB reactor is a combination of the up-flow anaerobic sludge blanket (UASB) and the up-flow anaerobic filter (UF) reactors. This technology has shown high treatability for industrial effluents (Shivayogimath & Ramanujam, 1999; Anushuya & Sudhir, 2008). As POME is very strong effluent in terms of the main contaminants (COD of 54000 mg/L and TSS 19000 mg/L), discharging the unprocessed POME will create an adverse impact to the environment. Thus, Series of physical, chemical, and biological processes are essential to remove the contaminant substances, i.e. particles, wastewater color, turbidity, odor, heavy metals, dissolved organic materials, and nutrient (Lorestani, 2006; Noophan, Paopuree, Kanlayaras, Sanya, & Techkarnjanaruk, 2009). In biological reactors, contaminants can effectively be removed if appropriate operational conditions are applied (i.e. Organic loading rate (OLR), hydraulic retention time (HRT), and temperature). Temperature range is of high importance for the treatment performance. However, operation of high rate reactors has been applied either in temperate or cold ambience (Van Lier, Martin, & Lettinga, 1996), whereby bacterial growth potentials have been reported under psychrophilic, mesophilic and thermophilic conditions (Dague, Banik, & Ellis, 1998). The aim of this study is to evaluate the reactor performance under temperature increments from mesophilic to thermophilic conditions with considerable acceleration in the organic loading rates increment, in addition to investigating the feasibility of oil palm shell (OPS) as filter support material.

2. Materials and Methods

2.1. Seed sludge

In this study, reactors were seeded with anaerobic sludge collected from the anaerobic pond of a palm oil plantation due to its contents of anaerobic microbial life. The raw sludge was screened to remove the coarse solids and debris which may inhibit the anaerobic suspended growth (Costerton, Irving, & Cheng, 1981). It was also screened through a 600 μm sieve before seeding (Yu, Tay, & Fang, 2001; Hang & Byeong, 1990). The concentration of the existing sludge was estimated to be 12000 mg/L volatile solids.

2.2. Wastewater

Palm oil mill effluent (POME) was used as feed in this study. It was collected monthly from Kian Hoe palm oil plantation, Kluang, Johor, Malaysia. It was then kept in a cold room at temperature of 4°C to avoid further biodegradation. Due to the solid contents of POME, raw sample was screened (Table 1) with a sieve of 150 μm diameter (Park, So, Lee, Jun, Yoon, & Park, 2007), and it was neutralized to pH 7±0.4 using 6N sodium hydroxide NaOH (Zhang, Show, Tay, Liang, & Lee, 2008).

2.3. Experimental set-up

Two perspex laboratory-scale HUASB reactors R1 and R2 were used in this experiment, and were fabricated in exact duplicate. The internal diameter was 10 cm and the total height of 100 cm. The total volume of the reactor was 7.85 L, while the working volume was 7.22 L. The sludge blanket was placed at the bottom of reactors to provide suspended growth process. In addition to that, packing media was provided at the upper part of reactors to implement the attached growth of microorganisms (Metcalf & Eddy, 2003). OPS support media was packed in R1 and R2 to occupy one third of the active reactor volume with 31 cm of height (Anushuya & Sudhir, 2008). The gas-liquid solid (GLS) was built in the top of each reactor to cope with the phenomenon of biomass washout and to guide gas escape. On the other hand, water bath system was provided to control the temperature of R2. Moreover, the operation temperature of R1 was kept at room temperature of 27±2°C. Continuous operation was performed via daily feeding of the reactors for study duration of 173 days for R1, and 160 days for R2.

Table 1. POME characteristics

Characteristic	*Unit*	*Raw POME Average*	*Sieved POME Average*
COD	mg/L	49000	47750
TSS	mg/L	14505	9225
Color	Pt-Co	7150	5975
Turbidity	NTU	9225	5887
pH	-	4.55	4.45

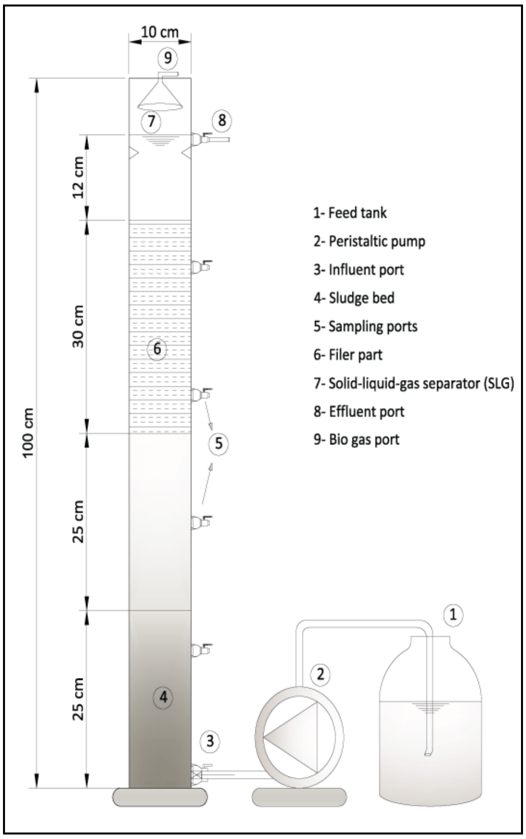

Figure 1. Schematic diagram of HUASB reactor

2.4. Start-up period

The first feed flow rate was regulated at an OLR of 1.85 kg/m^3.day, and a HRT of 2.6 days, it was maintained until the first steady-state achievement. Rationale of maintaining a long HRT was to obtain a high-rate microorganisms' development as well as to prevent biomass washout phenomenon during sludge acclimatization. At the early stages of reactors' start-up, the biomass particles tended to aggregate as a result of microbial cells excretion and corruption as well as organic materials debris (Costerton, Irving, & Cheng, 1981). On these occasions, initial bacterial aggregation can be considered as highly sensitive process which is sensitive to operational parameters' shocks, including temperature, OLR and HRT shocks. Raw POME was screened, and diluted to around 10 times at the beginning to provide an influent COD concentration of 4700±100 mg/L. A decrease of the dilution factor was applied after each steady-state to obtain higher loading for the next operation. This experiment was conducted on the reactors R1 and R2 for the duration of 170 and 163 days, respectively. The operation conditions were

Table 2. Operational conditions of process

Reactor	*Steady-states (times)*	*operation (days)*	*OLR (kg/m^3. day)*	*HRT (days)*	*Up-flow velocity (m/day)*	*Temperature (°C)*
Reactor 1	1	53	1.85	2.62	0.37	28
	2	45	3.16	1.67	0.55	27
	3	32	4.68	1.25	0.73	26
	4	23	6.70	0.98	0.92	25
	5	20	9.37	0.84	1.10	25
Reactor 2	1	55	1.85	2.62	0.37	37
	2	43	3.16	1.67	0.55	40
	3	28	4.68	1.25	0.73	43
	4	19	6.70	0.98	0.92	46
	5	15	9.37	0.84	1.10	49

turned steeply after each steady-state condition (Table 2). Rationale was to examine the reactors' tolerance against operational parameters shocks.

2.5. Sampling and analysis

Influents and effluents of each reactor were collected three times a week, and were transferred to the laboratory for analysis of chemical oxygen demand (COD), total suspended solid (TSS), color, turbidity, and pH. Samples analysis was performed according to the standard method of water and wastewater examination (APHA, 1998). The stated parameters have been tested to evaluate the behavior of each reactor due to its condition. Furthermore, light microscope (OLYMPUS BX60M) was employed to reveal the morphology of sludge granules.

3. Results and discussion

3.1. The influence of temperature on reactors performance

Both of the reactors R1 and R2 were started under specific operation conditions of OLR and HRT, while various temperatures were applied as mentioned in the previous section. Comparable performance during the first 30 days was observed for both of the reactors, whereas the efficiency of parameters removal was slightly increased. COD removal of R1 reached 81% at day 55, while in R2, it reached 88% at the same day of operation (Fig. 2). During the five steady-state conditions, higher COD removal of 90% was observed in R2 than that of 82% in R1. This indicated the stability of system under mesophilic and thermophilic temperatures, where optimal removal was recorded at the thermophilic temperature of 46°C. In previous studies, COD removal efficiencies of (80-90%) were found at low OLRs and low temperatures (Ilter, Turkdogan-Aydinol, Yetilmezsoy, Comez, & Bayhan, 2010; Lew, Tarre, Belavski, & Green, 2004), whereas at extreme OLRs and treatment temperature of 40°C, a 80% COD removal was obtained (Shivayogimath & Ramanujam, 1999).

The pH of influents was adjusted at 7.5±0.2. However, the effluents pH was below 6.5 at first operation (Fig. 3). That was mainly attributed to the instability of the sludge bed within the first fifty days of run. During the operation, the pH of R2 has tended to neutralize and was increased with the OLR increment as well as by temperature rise. However, pH profile for this study was higher in comparison with previous studies (Anushuya & Sudhir, 2008; Shivayogimath & Ramanujam, 1999).

The solids indication of this experiment was represented by total suspended solids (TSS). An increment of

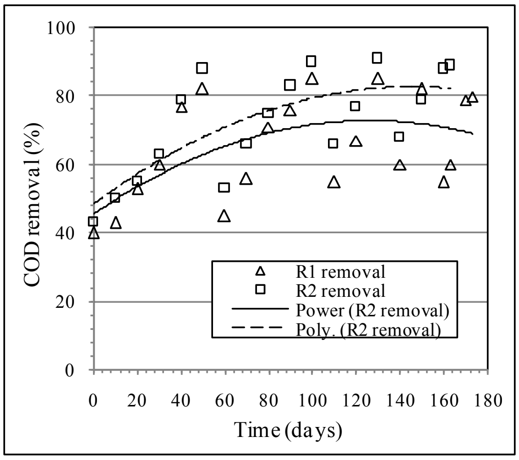

Figure 2. COD removal tendency of R1 and R2

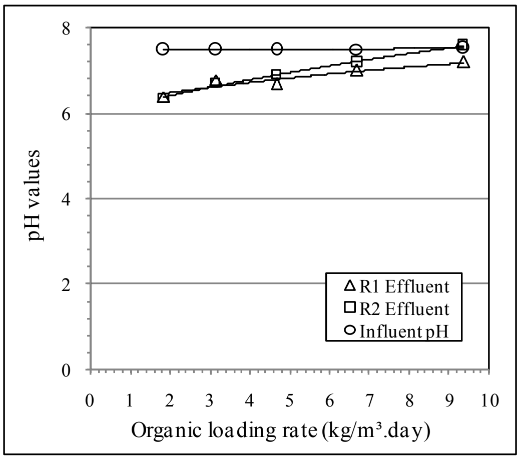

Figure 3. pH profile during reactors operation

TSS removal from 58 to 89% was reported in R2, while it was from 54 to 80% in R1. When HRT was reduced, the TSS of R2 effluent was more stable than that of R1 (Fig. 4). High TSS removal efficiency was attributed to the favourable role of filter packing media as has been demonstrated earlier (Mohd Noor, Ahmad, & Abdul Halim, 1989; Rajakumar & Meenambal, 2008).

As observed from the experiment, both of the reactors were not essentially efficient for removing the rest of the parameters such as turbidity and color. However, it can be concluded that further treatment is of imperative role to achieve optimum processes in which superior treatment of POME would be accomplished.

3.2. The influence of temperature on bacterial aggregations and activities

Organisms' development to granules has been considered as an important key towards successful operation of anaerobic bioreactors (Hulshoff, Lopes, Lettinga, & Lens, 2004). It was noticed that a relationship between sludge granulation development and reactors removal efficiency has essentially been proved during the experiment. Irregular and rough surface of granules has been observed through digital imaging. Granule formation has been explained by several theories such as the bacterial cells bridging or adhesion (Hulshoff, Lopes, Lettinga, & Lens, 2004). At the mesophilic to thermophilic conditions in R2, there was darker aggregation than that in R1 (Figs. 5-6). This was due to the high rate of iron and sulphur (as ferrous sulphide precipitate) on the surface of R2 (Hulshoff, 1989). It was also noticed that the aggregation in R2 is bigger than that in R1, this was attributed to higher activities that have been recognized with the overall process efficiencies in R2.

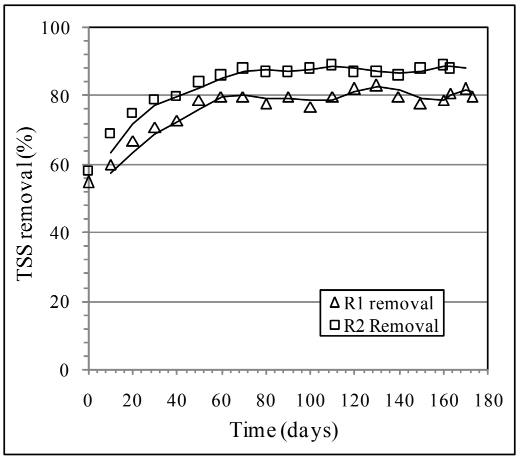

Figure 4. Suspended solids removal in R1, and R2

OLR shocks were also applied beside the regulated increase of temperature in R2 to examine the tolerance of each reactor. The results were in agreement with the fact that a considerable relationship between maximum specific microbial growth rate and temperatures between 20-60°C has been established (Equation. 1) based on previous work (Chen & Hashimoto, 1978).

$$\mu m = 0.013T- 0.129 \text{.........................} (1)$$

Where, μ_m is the maximum specific microbial growth rate (day^{-1}), and T is the temperature (°C). In one

Figure 5. Sludge aggregation image in R2

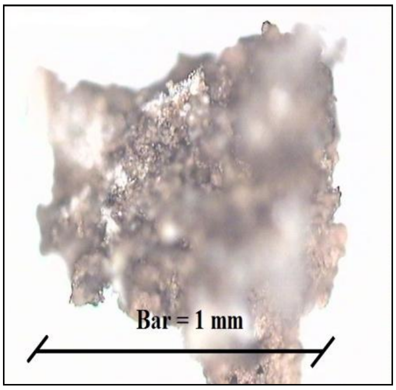

Figure 6. Sludge aggregation image in R1

experiment, it has indicated that bacterial activity which in accordance with process performance was dropped when a decrease of operation temperature from 35 to 25°C was applied (Yetilmezsoy, 2008). However, essentially stops (μ_{m} (10°C) = 0.001 day^{-1}) below 10°C has been reported (Yetilmezsoy, 2008). That relationship has been widely applied to give an indication of the systems kinetic aspects. Fig. 7 shows the maximum specific microbial growth rate (SMR) of R1 and R2. It can be noticed that SMR in R2 increased due to the increase of its operation temperature after each steady-state condition. By considering the overall removal rates of the reactors, SMR tendency in the graph would reflect a successful relationship between microbial growth and temperature. Hence, temperature increment can be considered as a significant positive parameter for improving the treatment.

4. Conclusions

According to this study, it can be concluded that the HUASB reactor can be successfully represented as feasible alternative of POME treatment. In this novel hybrid bioreactor, high organic contamination and COD concentration of POME was effectively treated. R1 showed efficient results during its whole operation of 173 days. However, R2 was run for 160 days only, and it was improved gradually by increasing the temperature reaching to the thermophilic temperature of 49°C. The stepwise increment of temperature has provided high stability and maximum specific microbial growth rate of 0.508 day^{-1}. Furthermore, the sharp rise of influent organic load has essentially showed the effect of higher temperature in providing more stability. The results showed good removal for both of the reactors beside the shorter time of R2 to reach comparable conditions with higher COD removal of 91% compared to R1 where it was 84%. Referring to the sludge granules morphology in R2 which was darker and bigger than that in R1, it can be realized that granules growth is of significant role on the anaerobically treatment using HUASB reactor.

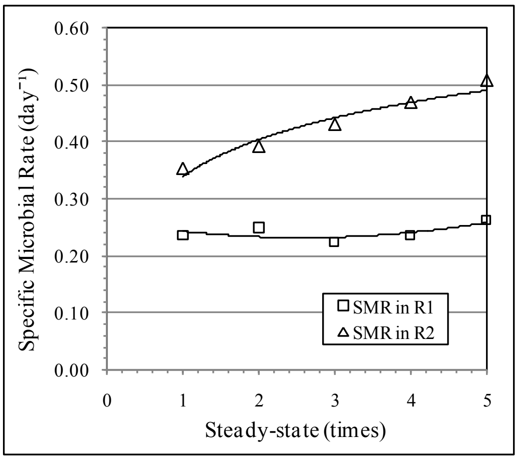

Figure 7. The maximum specific microbial growth rate (SMR) of R1 and R2

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