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A biodegradation and treatment of palm oil mill effluent (POME) using a hybrid up-flow anaerobic sludge bed (HUASB) reactor

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Abstract
Generally, anaerobic treatment has become a viable alternative in support of industrial wastewater treatment. Particularly, it is used in common to treat the palm oil mill effluent (POME). This study was carried out to assess the start-up performance of a bioreactor hybrid up-flow anaerobic sludge blanket (HUASB). Whereby, three identical reactors of 7.85-l capacity R1, R2, and R3 were operated for 57 days in order to provide two alienated comparisons. Identical operation conditions of organic loading rate (OLR) and hydraulic retention time (HRT) of 1.85 $kg.m^{-3}.day^{-1}$, and 2.6 day, respectively. R1 was operated in room temperature of 28±2°C, and packed with palm oil shell as filter medium support. R2 was set with room temperature but packed with course gravel. R3 was provided with water bath system to adjust its temperature at 37±1°C mesophilic, while its filter material had to be palm oil shell. During the whole operation period R3 was more efficient for organic materials, where a chemical oxygen demand (COD) removal efficiency of 82% was registered, while R1 and R2 were relatively less efficient of 78%, and 76%, respectively. Furthermore, TSS removal of R3 was also higher than R1, and R2 as registered 80%, 77% and 76%, respectively. On the other hand, turbidity and colour removal were not efficient and needed a post treatment. The seeded sludge was developed in each reactor as illustrated in this paper. Therefore, all reactors show favorable performance of anaerobic treatability of POME as well as good response of microbial species development.

Keywords: Biological treatment; HUASB; POME; Nutrients; Mesophilic temperature.

1. Introduction
A laboratory investigation on the biologically treatment of palm oil mill effluent (POME) was conducted in this study. This is generally considered as high contaminated industrial wastewater. The high-rate anaerobic bioreactor HUASB has successfully recorded elevated results of organic removal efficiencies as well as stability operation system. Recently, various studies were concentrated on the use of hybrid up-flow sludge technology as an alternative of wastewater treatment reactors, whereby one study was carried out by Shivayogimath & Ramanujam conducted for 380 days in continuous operation of the hybrid UASB reactor [1]. It was reported that the operational conditions were in term of low OLR increasing gradually to reach 36 kg $COD.m^{-3}.d^{-1}$ and a short HRT of 6 hour. The COD removal efficiency raise to 80% at maximum value of the experiment, according that the biogas production was contained high rate of 80% methane. Another experiment has done subsequently by Lew, B et al., [2]. The experiment involved an investigation of the feasibility of each hybrid UASB and UASB reactors for

the treatment of domestic wastewater as well as the application of various temperatures for the both systems. It is indicated that constant values of COD removal efficiencies of 80% have been registered for each reactor in case of operation temperature up to 20ºC and reaching to 28ºC [2]. However, the low temperatures of less than 20ºC have relatively showed a better performance of UASB than hybrid UASB, where the COD removal efficiencies were 70% and 60% respectively. Subsequently other study have conducted by Rajakumar, R and Meenambal, T [3] to investigate the performance for each hybrid UASB reactor and anaerobic filter (AF) reactor, where the comparison of this study was mainly compared the start-up interval as well as the reactors COD removal efficiencies. The hybrid UASB reactor was better in the process performance where it showed a shorter start-up period of 120 days with a high organic removal efficiency of 80% with minimum biomass washout, whereas anaerobic filter in same operational conditions showed an organic removal efficiency of 70% and the start-up period required more than 145 days of continuous operation to reach steady-state [3]. Another group of researchers found that the hybrid UASB reactor can tolerate as well as cope with the high phenolic pollution wastewater more than other anaerobic reactors [4]. Whereby, since its beginning, this hybrid reactor has been studied by many researchers and it found that HUASB reactor is incredibly efficient in treating dilute to medium strength wastewaters [5, 6].

2. Materials and methods

2.1 Experiment set-up

Schematic diagram of the experimental setup is conclusively described in Figure 1. Three laboratory scale Hybrid up-flow anaerobic sludge blanket HUASB reactors were employed in this assay to provide more than one comparison R1, R2, and R3. Cylindrical outline of Perspex were the reactors made of, whereby each reactor was fabricated as per the guidelines given by Lettinga and Hulshoff, considering that the mentioned researchers have developed that system [13]. It was with internal diameter and total height of 10 cm, and 100 cm respectively. Furthermore, this was providing a total volume of 7.85-l while the liquid volume was found to be 7.22-l in depth. In addition of placing the sludge blanked at the bottom of reactors where this provided suspended growth process, packing media was provided at the upper part of reactors to implement the attached growth of microorganisms [7]. Fine gravel was packed in R2, while palm oil shell was provided in R1, and R3. Identical volumes of packing media were estimated in each reactor to be one third of the active reactor volume with 31 cm of height [4]. The gas-liquid solid GLS was placed at the top of each reactor to cope with phenomenon of solid washout. On the other hand, water bath system was provided to control the temperature of R3 in mesophilic range of 37±1°C. On the opposite side, the operation temperature of R1 and R2 were kept at room temperature of 28±2°C. Continuous operation was conducted via daily feeding of reactors for the start-up duration of 57 days with fixed organic loading rate OLR and hydraulic retention time of $1.85 kg.m^{-3}.day^{-1}$, and 2.6 day respectively.

2.2 Wastewater characteristics

The industrial wastewater, palm oil mill effluent POME has been used for the present study. It was collected monthly to be kept in samples storing room at 4°C avoiding any changes of its characteristics. It was obtained from Kian Hoe, palm oil plantation, Kluang, Johor, Malaysia. Due to the solid contents of POME it was necessary to screen the raw sample to reduce a bulky intake of solids. The characteristics of POME before and after screening were listed in Table 1.

2.3 Seed sludge

The sludge used for the present experiment was collected from the anaerobic pond, due to its contents of anaerobic microbial life [8]. On these, sludge was obtained from Kian Hoe, palm oil plantation, Kluang, Johor, Malaysia. The seeded sludge was screened to remove the entire course suspended solids and large debris which may inhibit anaerobic suspended growth [9]. Furthermore, the existing granular debris was also removed. The estimated concentration of the provided sludge was 106 g/l COD, and 173 g/l TS.

2.4 Start-up period

The first feed flow rate was regulated at $1.85 kg.m^{-3}.day^{-1}$. Besides, a hydraulic retention time of 2.6 day was maintained during the reactors start-up operation period. The long HRT was used in order to obtain a good development of microorganism as well as to prevent sludge washout phenomenon. At the earlier stage of reactors start-up the sludge particles starting to aggregate as a result of microbial cells excretion and corruption as well as organic materials debris [9]. On these, initial bacterial aggregation can be considered of high sensitive process which is extremely affected by operational conditions in addition of such parameters shocks occurrence e.g. Temperature, OLR, and HRT shocks. Raw POME was screened to release the clogging elements as well as inorganic particles. Dilution rate was around 10 times to ensure influent COD concentration of 4700±100 mg/l. This experiment was conducted for 57 days, where the operation conditions were maintained without increasing to compare the entire reactors performance.

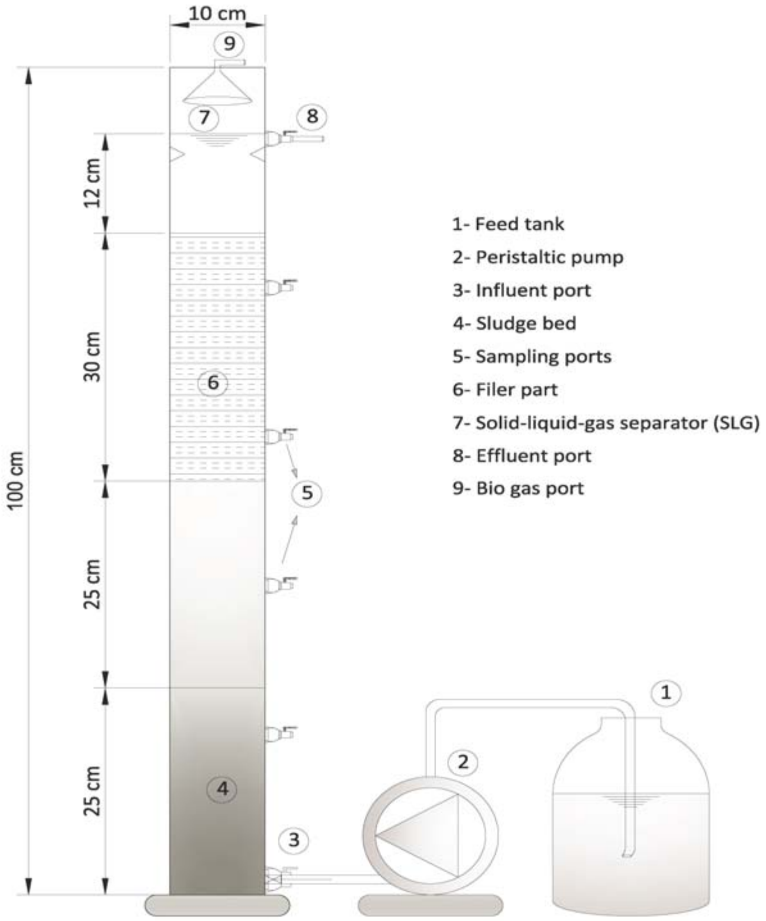

Figure 1. Schematic diagram of HUASB reactor

Table 1. Raw and screened POME characteristics

Parameters	Raw POME range	Average	Screened POME range	Average
COD	37000-61000	49000	35000-60500	47750
TN	745-935	840	710-925	817.5
TP	255-342	298	228-317	272.5
TSS	13630-15380	14505	8600-9850	9225
Colour	6500-7800	7150	5500-6450	5975
turbidity	7400-11650	9225	4800-6975	5887
PH	4.2-4.9	4.55	4.2-4.7	4.45

2.5 sampling and analysis

The collection of reactors effluents was done daily to be transferred to the analysis laboratory for parameters analysis. The related parameters were observed and analyzed daily are Chemical Oxygen Demand (COD), Total Nitrogen (TN), Total Phosphorus (TP), Total Suspended Solid (TSS), Colour, Turbidity, and pH. All the mentioned parameters were analyzed according to the standard method of water and wastewater examination [10]. The bacterial growth in sludge bed was also observed by using PAXcam system connected with light microscope. The stated parameters have been tested to analyze the behavior of each reactor due to its condition.

3. Result and discussion

3.1 Reactors performance

At the earlier start-up period the COD removal of the entire reactors tended to increase slightly, where started at low percent of less than 20%. It can be attributed to the fact that reactors microbial communities were not exceedingly populated [11]. Slightly increment of COD removal for the entire reactors was registered as illustrated in Figure 2 during the first month of start-up period. After day 40th, an increase of COD removal has been observed where R3 showed better stability as well as removal efficiency of 82% during the start-up operation than that in R1 and R2, which were 78% and 76%, respectively. The SS removal efficiency were started with more than 30% in each reactor, where that was due to the efficient role of filter media in capturing the rising solids from influent as well as sludge particles. R3 has showed higher TSS removal of 80% than that of 77% and 76% in R1 and R2, respectively. As demonstrated in Figure 3, the relationship of the reactors total suspended solids removal where it was stable with continuous increment during the reactors operation period. The turbidity removal was slightly low of about 45% at the end of operation in R3, where Figure 4 presented the turbidity tended of each reactor. That was due to the fact that such anaerobic treatment has absolutely needed to post treatment involved more quality aspects processes, where anaerobic treatment has deemed more appropriate of chemical oxygen demand and high suspended solids wastewater treatment [12].

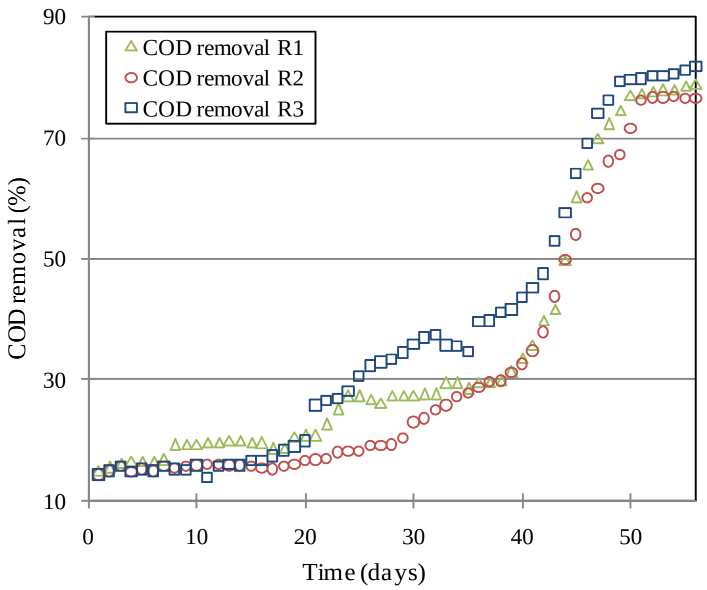

Figure 2. COD removal in R1, R2, and R3

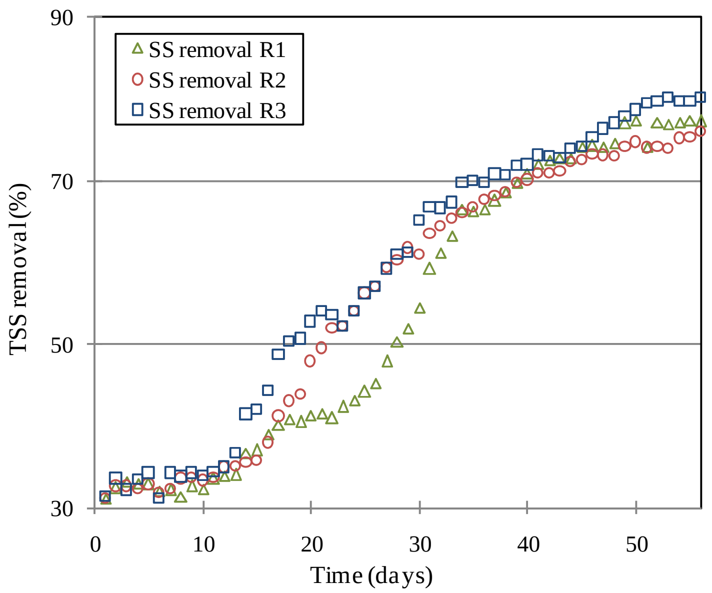

Figure 3. TSS removal in R1, R2, and R3

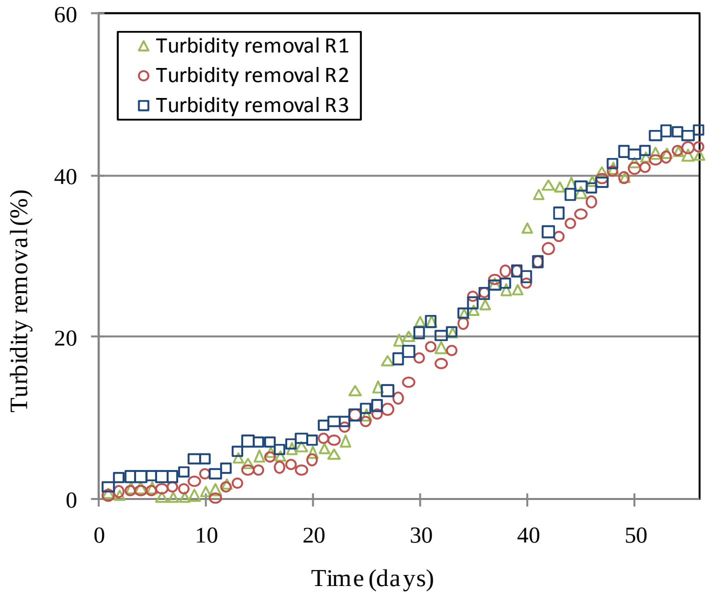

Figure 4. Turbidity removal in R1, R2, and R3

3.2 Nutrient consumption

Referred to Table 1 information, the pretreated POME that used as reactors influent was with the COD: N: P ratio of 175:2.8:1, which is relatively in agreement with Ronnachai et al. [14]. Furthermore, nutrient ratio is considered adequate for the anaerobic degradation process inside each reactor. The nutrient's consumption in the entire reactors is separately described in each of Figures 5, 6, 7. Whereby, it shows a slightly increase in the beginning interval reaching to the day 35 due to insufficient degradation of organics. However, when bacterial activities were improved, a rapidly increment in nutrient's consumption has been reported after day 40th. R3 consumption of nutrient was of 87% nitrogen, and 85.5% phosphate. It was slightly higher than that in R1, and R2.

3.3 sludge bed growth

Microorganism's growth in such anaerobic reactors as HUASB reactor has been considered as the most responsible key of the successful anaerobic treatment process[15]. There was slow growth of the sludge beds in each reactor. However, the sludge bed presented an improvement in both reactors with only 57 days. The evolution of sludge bed particles was illustrated in Figure 8. Where, R3 microbial communities were extremely more aggregated than that in R1, and R2.

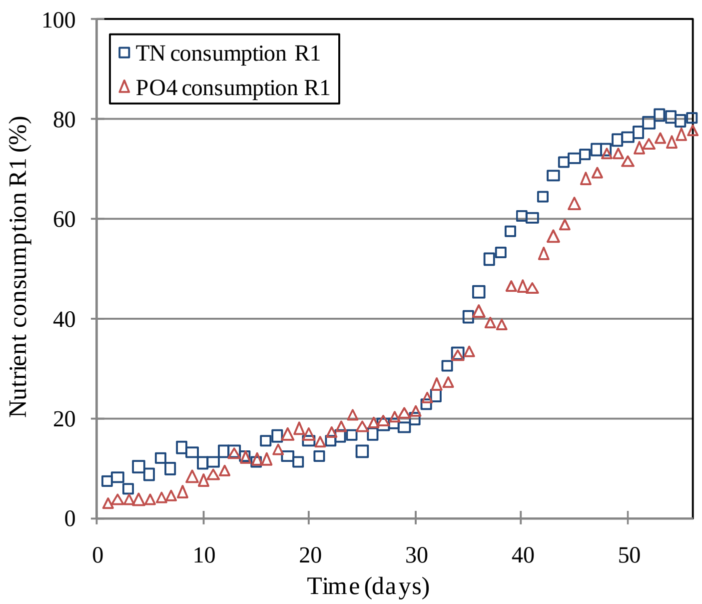

Figure 5. Nutrient consumption in R1

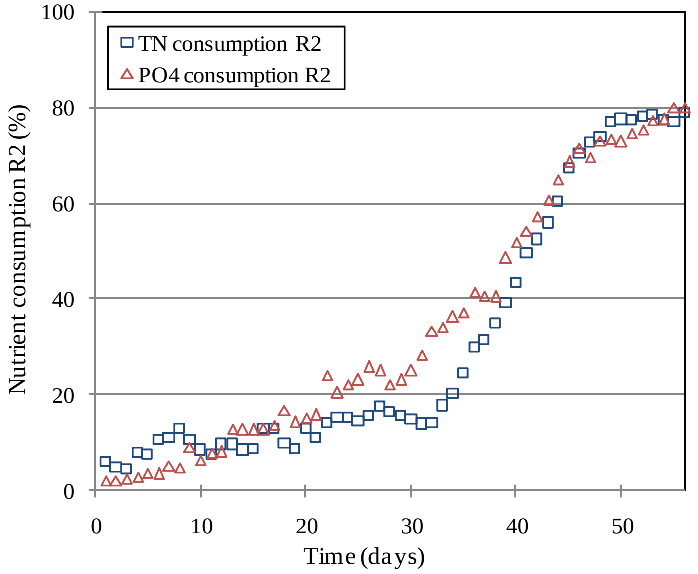

Figure 6. Nutrient consumption in R2

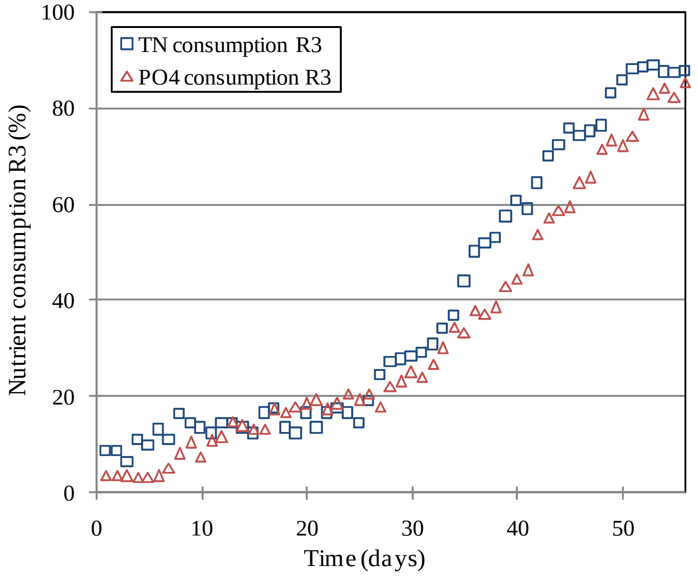

Figure 7. Nutrient consumption in R3

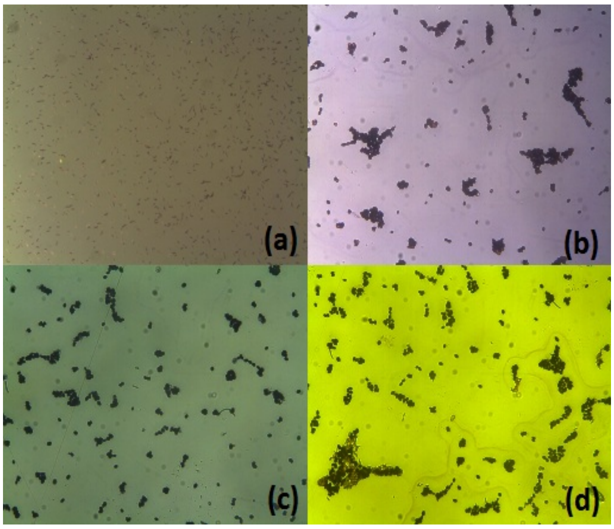

Figure 8. Bacterial aggregation in sludge bed (a) the initial sludge used in HUASB reactors. (b) R1 bacterial development. (c) R2 bacterial development. (d) R3 bacterial development

4. Conclusion

Standing on the conducted experiment, the fast response of the reactors proves the feasibility of using such anaerobic system like HUASB reactor for POME treatment. The microorganism's tolerance as well as development was slightly rapid due to the suitability of POME as treated wastewater in the entire treatment. On the other hand, palm oil shell as filter packing media showed the optimization case of the conducted study with using the mesophilic temperature of 37°C for the treatment. Whereby, this case was presented in R3 which is showing high efficiencies comparing to R1, and R2. Besides, a low organic loading rate of $1.85 kg.m^{-3}.day^{-1}$ accelerated the performance of reactors as well as picking a long hydraulic retention time of 2.6 days was also improved the treatment. On these, diluted POME can be efficiently treated in HUASB technology with using the mentioned conditions above. Furthermore, high COD and SS removal efficiencies were obtained during the operation period of 82%, and 87% respectively in R3. Turbidity and colour removal were not efficient and needed a post treatment. It can be concluded that the new technology of hybrid UASB reactor still needs R&D to make clear its entire concept and the most factors that affecting the process, whereby it has stated that at low temperature conditions of treatment, unstable performance has been reported. Finally it is believed that the new offered bioreactor may be employed as an alternative of the anaerobic reactors for treating several kind of wastewater such as industrial or municipal effluents.

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