International Journal of Integrated Engineering, Vol. 6 No. 1 (2014) p. 35-39

Sludge Bed Granules' Growth in the HUASB Reactor Treating High Strength Industrial Wastewater

Sinan Abood Habeeb[1,*], Ab. Aziz Abdul Latiff[2], Zawawi Daud[2], Zulkifli Ahmad[2]

[1]Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Johor, MALAYSIA.
[2]Department of Water Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Johor, MALAYSIA.

Abstract: The development of anaerobic sludge granules in a hybrid up-flow anaerobic sludge bed (HUASB) reactor in terms of granular size and solids content was observed. After appropriate pre-treatment of the palm oil mill effluent (POME), it was continuously fed to the HUASB reactor under room temperature condition (27°C). Particle size analysis and solids content examination were conducted for 196 days. A volatile solid ratio was ranging from 0.36 to 0.51 which was quite low, and granules particle size of less than 1 mm diameter was reported during the operating period. Results obtained in this study indicated that sludge bed development based on the sludge particle size distribution and the volatile solid ratio, was quite slow due to the bulk solids that entering the reactor resulting in certain inhibition of the anaerobes' activity. It has been concluded that anaerobic wastewater treatment process in anaerobic reactors such as the HUASB reactor, can be significantly affected by the organic loading rate, hydraulic retention time applied to the reactor and the wastewater characteristics.

Keywords: Anaerobic wastewater treatment, HUASB, reactor start-up, sludge granules, solids content

1. Introduction

Anaerobic wastewater treatment has become an attractive method due to its advantages of low energy required, low sludge production, small construction area and high treatability [1]. The concept of anaerobic wastewater treatment was initially implemented around one hundred years ago. However, one of the main problems with using anaerobic systems is the long term start-up operation. Recent researches have endeavored to produce a more efficient reactor for the anaerobic treatment of wastewater, with new technologies being introduced that proved successful in operation and removal, although the cost of these systems is formidable.

Anaerobic wastewater treatment processes are now considered as one of the most popular treatment methods in tropical countries [2]. It has been identified as a very sensitive process that could easily be affected by several operational factors e.g. temperature, hydraulic retention time (HRT), organic loading rate (OLR), pH and mixing. The key factor that ensures high performance in anaerobic reactors is the right selection of operational conditions [1,3]. Therefore, the success of the anaerobic processes would totally depend on their operational parameters.

A new design derived from the idea of combining the up-flow anaerobic sludge bed (UASB) reactor and the anaerobic filter (AF) has recently been introduced as a high efficient bioreactor. The advantages of each reactor have been incorporated into a new technology to offer a hybrid up-flow anaerobic sludge bed (HUASB). The concept is based on the UASB reactor with the filter media set approximately at the top middle part of the reactor. The main advantage of adding the filter media is to retain the washed out biomass as well as to reduce the rate of solids in effluent [4]. The successful treatment in HUASB reactor is principally attributed to the formation of anaerobic granular in sludge bed [5], where the microbial communities digest the substrates to its simplified compounds end up to biogas. The details of the granulation and the microbial community form a complex science and are difficult to explain exhaustively. Seed sludge that is used for the HUASB reactor start-up period to be upgraded to granules can be provided from any source containing appropriate bacterial flora. Normally, the seed sludge may be obtained from anaerobic ponds sediments, fresh water sediments, septic tank sludge, manure, digested sewage sludge and anaerobic treatment plants [6].

The objectives of this study were to investigate the development of sludge bed granules as the main agent of wastewater treatment and to identify the most significant factors that would positively or negatively affect the anaerobic treatment process.

2. Materials and Methods

The heart of the experimental set-up was the HUASB reactor, in which the POME was treated. The schematic diagram is demonstrated in Fig. 1. The reactor has been designed precisely according to the guidelines given by Lettinga and Hulshoff [7]. The sludge blanket was positioned at the bottom of the reactor. The sludge height was 30 cm which gives a biomass volume of 2.36 L. In addition to that, packing media was provided at the upper part of reactors to implement the attached growth process

*Corresponding author: sinancivil@engineer.com
2014 UTHM Publisher. All right reserved.
penerbit.uthm.edu.my/ojs/index.php/ijie

of microorganisms [8]. Fine gravel support material was packed in the reactor to occupy one third of the active reactor volume with 30 cm height [4]. Gas-liquid-solid (GLS) separator was built at top of the reactor to guide the gas escape as well as to prevent solids washout with effluent.

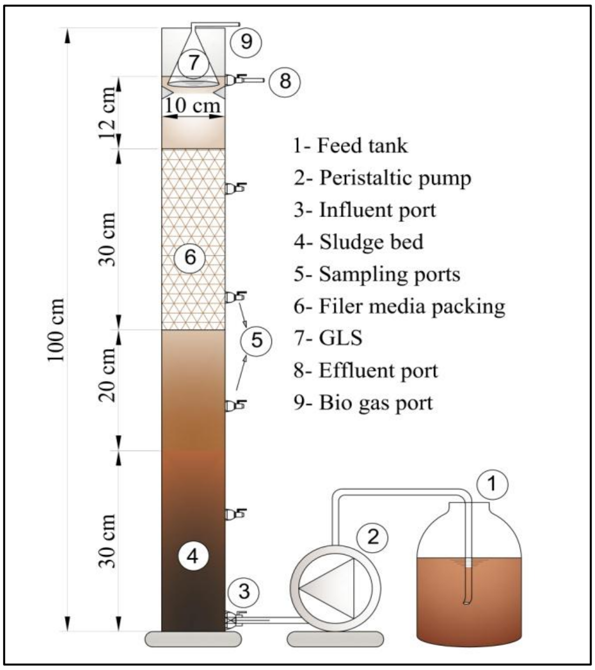

Fig. 1 Schematic diagram of the HUASB reactor.

The POME was obtained from Kian Hoe, palm oil plantation, Kluang, Johor, Malaysia. Samples were collected monthly and stored at 4°C prior to use to prevent any change of characteristics or further degradation [8]. POME was diluted ten times with tap water in the start-up operation to obtain a range of 4.5±0.3 g.L^{-1} as influent COD concentration, then pH was neutralized to 7.4±0.2 using 6N sodium hydroxide NaOH [4]. It was also essential to further screen the raw wastewater with a sieve of 150 µm diameter. The seeding sludge used for the present experiment was taken from the anaerobic pond of palm oil mill treatment plants, as it contains anaerobic microbial life [6]. The raw sludge was screened through a 600 µm sieve to remove the coarse debris and particles before seeding. The concentration of the existing sludge was estimated to be 11,000 mg.L^{-1} volatile suspended solids.

The first feed flow rate was regulated at 1.87 kg COD.m^{-3}.day^{-1}. Besides, a hydraulic retention time of 2.51 day was maintained during the reactors start-up operation for the first steady-state condition occurrence. A step increase of OLR was continuously applied by decreasing the hydraulic retention time (HRT) and also by increasing the feed concentration after each steady-state operation according to Table 1.

Analytical methods have included several tests in order to reveal the factors affecting the sludge development process. Particle size determination and sludge granule imaging were performed in this study by the use of a particle size analyser (CILAS 1180) and a light microscope (OLYMPUS BX60M), respectively. The measurement ranges provided by the system were from 0.04 to 2,500 µm. Besides, sludge volatile ratio is the ratio of the biomass content to the total content of solids in the sludge bed, or equivalently the ratio of the mixed liquor volatile suspended solid (MLVSS) to the mixed liquor suspended solids (MLSS). MLVSS and MLSS tests were performed according to the procedure given in the standard book of water and wastewater examination [9].

Table 1 The reactor operational conditions during the experiment

Steady-states (times)	Operation (days)	OLR (kg COD. m^{-3}. day^{-1})	HRT (days)	Up-flow velocity (m.day^{-1})	temperature (°C)
1	57	1.87	2.51	0.37	28
2	48	3.12	1.67	0.54	27
3	35	4.69	1.25	0.73	26
4	22	6.70	1.01	0.92	25
5	19	9.37	0.84	1.10	25
6	16	10.93	0.72	1.28	26

3. Results and Discussion

Samples for determination of sludge granular profile were taken from the bottom of HUASB reactor at regular intervals (after 40th, 80th, 142nd, and 185th day of operation) corresponding the OLRs of 1.87, 3.12, 6.70, and 10.93 kg COD.m^{-3}.day^{-1}, respectively. Fi. 2 shows the particle size distribution for the HUASB reactor. For the raw sludge sample, particle size distribution has indicated particle size ranges from 0.04 to 200 µm, while particle sizes in the range of 200-500 µm were not yet present in the raw sample. It was noticed that the proportion of 81.5% (small flocs sizes of 0.04-50 µm diameter) decreased over time and with the OLR increment, to be 27.9% at 185th day of operation. At the opposite side, the proportions of bioparticle sizes (50-1,000 µm diameter) witnessed an increase from 18.5% (at the start of operation) to 72.1% (after 185th day of operation). That strongly indicates the growth of small-sized bioparticles into larger particles over time. An obvious development of sludge bed granules has observed, especially in the last observation, where large size bioparticles in HUASB reactor appeared with higher proportions.

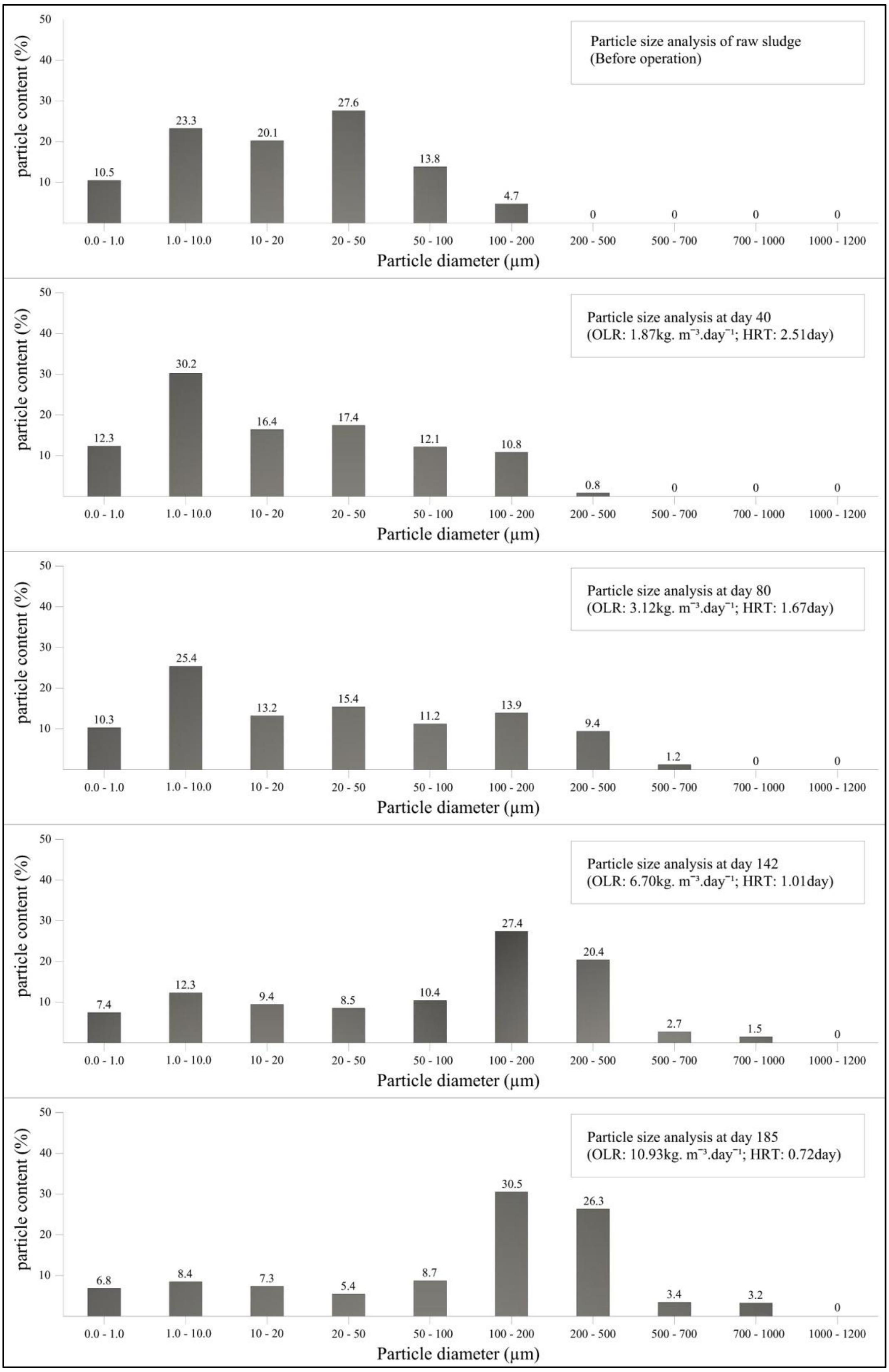

Fig. 2 The particle size distribution for the developed sludge aggregation.

On the other hand, sludge granule imaging has been examined using a light microscope (OLYMPUS BX60M) to reveal the exterior characteristics of sludge granules. Fig. 3 shows the image analysis of sludge granules in the reactor. It has been observed that irregular and rough surface of granules have been observed through digital imaging analysis that could classify the granules between the categories of granular and flocculent (pallets) according to Bellouti et al [10], and granules according to Yu [6], with the latest seeming more sensible, since these granules obtained in the present study have performed well in terms of contaminant removal (COD: 67%, TSS: 58%, TS: 50%, VSS: 62% and nutrient: 40%). Granule formation has been attributed to the bacterial bridging or adhesion which ends up in the form of granules [5]. Small cavities appeared in the granules of reactor.

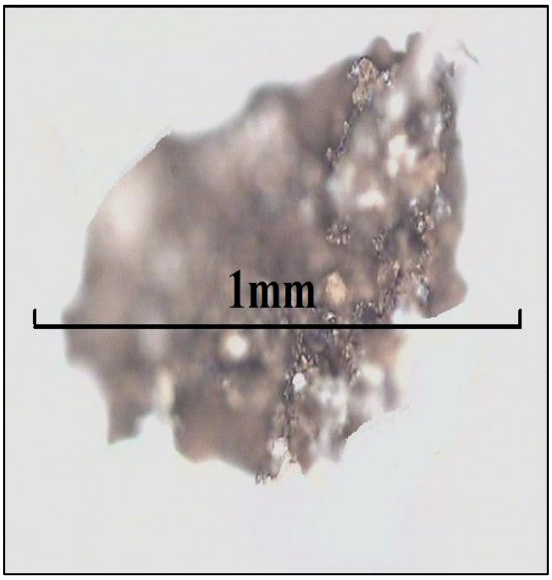

Fig. 3 Sludge granule image.

The examination of biomass concentration was performed based on the mixed liquor volatile suspended solid (MLVSS) and mixed liquor suspended solid (MLSS). This section discusses the biomass developed at each steady-state operation condition involving 6 data points for the HUASB reactor. Initial MLVSS of raw sludge to be seeded into the reactors was around the value of 11,000 mg.L^{-1}. Concentrations of MLVSS are presented as shown in Fig. 4. It has been notices that the concentrations of MLVSS were observed to drop for the entire operation, excluding the increase recorded (higher MLVSS of 12,300 mg.L^{-1}) at the first steady-state operation (OLR of 1.87 kg COD.m^{-3}.day^{-1} and HRT of 2.51 day). However, biomass concentration obtained in the present study (in term of MLVSS) was relatively lower than that reported in literature using the HUASB for the treatment of POME [11]. In another investigation, it has been reported that MLVSS was estimated to be 2000 mg.L^{-1} using municipal wastewater [12]. It can thus be concluded that MLVSS is a variable parameter that depends mainly on the characterisation of the feed substance and the biomass characteristics.

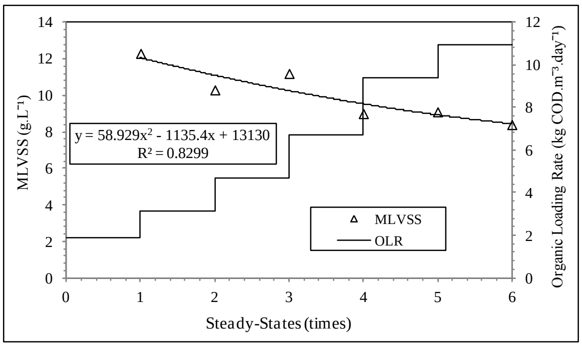

Fig. 4 The development of biomass concentration (for 196 days of operation) in term of MLVSS.

Mixed liquor suspended solid (MLSS) was determined in this study to obtain the ratio of MLVSS over MLSS, which appraises the level of biodegradation process in the sludge bed. Fig. 5 shows the concentrations of MLSS observed during the period of operation. After the start of operation of the reactor, an increase of the MLSS value was observed until the second steady-state (OLR of 3.12 kg COD.m^{-3}.day^{-1} and HRT of 1.67 day) was achieved. After that, a drop in MLSS concentrations was recorded for the rest of operation period, until the last observation of 23,200 mg.L^{-1} at the sixth steady-state (OLR of 10.93 kg COD.m^{-3}.day^{-1} and HRT of 0.72 day). Comparing the results obtained in this study with those obtained by other researchers; there is good agreement with results obtained from the treatment of sewage using UASB reactor, with MLSS values ranging from 20,000 to 30,000 mg.L^{-1} [4]. It can be concluded that the values of MLVSS and MLSS are not quite significant as the ratio of MLVSS/ MLSS.

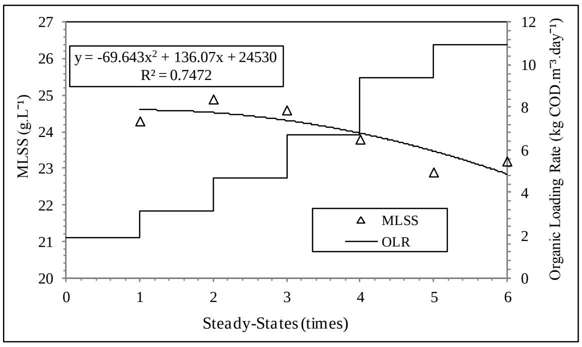

Fig. 5 The development of biomass concentration (for 196 days of operation) in term of MLSS.

The ratio MLVSS/MLSS in the sludge bed of anaerobic bioreactors can be represented by the mass of the suspended solids to the volatile mass in the mixed liquor. Suspended solids can involve minerals, inorganic solids, organic matters, live and/or dead microorganism groups, and debris of microorganism cells. While, volatile suspended solids would include organic matters, and live or dead microorganism groups only. The MLVSS/MLSS ratio can thus be considered an important indicator for the biodegradation process, with higher ratio meaning higher active biomass for better biodegradation process. In this study, the MLVSS/MLSS ratio has been discussed as its significance was properly explained. Fig. 6 illustrates the MLVSS/MLSS ratios observed during this study. The MLVSS/MLSS ratio ranged from 0.36 to 0.51 and from in the operating reactor. One study investigated the MLVSS/MLSS ratio of around 0.7 using the UASB reactor [11]. Another investigation revealed a MLVSS/MLSS ratio of 0.52 during the treatment of municipal wastewater using the UASB reactor also [12]. The literature results were in good agreement with the current results obtained in this study. In general, the reason for the relatively low ratios obtained in this study can be mainly attributed to the high inhibitory matters content in POME i.e. fats, oil, and grease. These substances likely inhibit the biodegradation process by providing higher suspended solid content, as is shown in a study that observed the negative effect on anaerobic granulation [5].

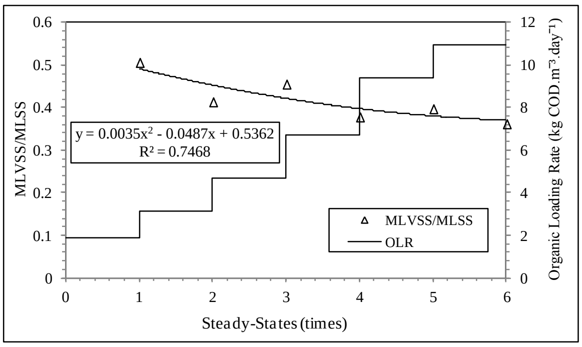

Fig. 6 MLVSS/MLSS Ratio (for 196 days of operation).

4. Conclusion

The viability of POME treatment using HUASB reactors with several operational conditions was assessed in this study in long term operation (196 days). Besides, the sludge bed development based on the sludge particle size distribution and the volatile solid ratio in the sludge, was quite slow because of the bulk solids that entering the reactor resulting in certain inhibition to the anaerobes' activity. However, it has been concluded that high OLR (9.37 kg COD.m^{-3}.day and above) applied had a very adverse impact on the sludge bed development resulting in less active granules (volatile solid ratio of <0.4 and granules particle size of less than 1 mm diameter) formed under the applied condition. Finally, it can be concluded that anaerobic wastewater treatment process in anaerobic reactors such as the HUASB reactor, can be significantly affected by two main factors: the operating parameters such as organic loading rate and hydraulic retention time applied to the reactor; and the wastewater characteristics such as the solid content.

References

[1] Saleh, M.A., and Usama, F.M. UASB/EGSB application for industrial wastewater treatment. *International Water Technology Conference*, Volume 7, (2003), pp. 335-344.

[2] Van Lier, J.B. High-rate anaerobic wastewater treatment: diversifying from end-of-the-pipe treatment to resource-oriented conversion techniques. *Water Science and Technology*, Volume 42, (2008), pp. 1137-1148.

[3] Schmidt, J.E., and Ahring, B.K. Granular sludge formation in up-flow anaerobic sludge blanket (UASB) reactors. *Journal of Biotechnology and Bioengineering*, Volume 49, (1996), pp. 46-55.

[4] Rajakumar, R., and Meenambal, T. Comparative study on start-up performance of HUASB and AF reactors treating poultry slaughterhouse wastewater. *International Journal of Environmental Research*, Volume 2, (2008), pp. 401-410.

[5] Hulshoff, P.L.W., Lopes, S.I.D., Lettinga, G., and Lens, P.N.L. Anaerobic sludge granulation. *Water Research Journal*, Volume 38, (2004), pp. 1376-1389.

[6] Yu, L., Hai-Lou, X., Kuan-Yeow, S., and Joo-Hwa, T. Anaerobic granulation technology for wastewater treatment. *World Journal of Microbiology and Biotechnology*, Volume 18, (2002), pp. 99-113.

[7] Lettinga, G., and Hulshoff Pol, L.W. UASB-process design for various types of wastewaters. *Water Science and Technology Journal*, Volume 24, (1991), pp. 87-107.

[8] Metcalf and Eddy. *Wastewater engineering, treatment, disposal and reuse*. 4thed, McGraw-Hill, (2003), New York, USA.

[9] APHA. *Standard methods for the examination of water and wastewater*. 20thed, APHA, (1998), Washington DC, USA.

[10] Bellouti, M., Alves, M.M., and Novais, J.M. Flocs vs. granules: differentiation by fractal dimension. *Water Research*, Volume 31, (1997), pp. 1227-1231.

[11] Najafpour, G.D. High rate anaerobic digestion of palm oil mill effluent in an upflow anaerobic sludge-fixed film bioreactor. *Process Biochemistry*, Volume 41, (2006), pp. 370-379.

[12] Von Sperling, M., Freire, V.H., and Lemos Chernicharo, C.A. Performance evaluation of a UASB-activated sludge system treating municipal wastewater. *Water Science and Technology*, Volume 43, (2001), pp. 323-328.