Reaktor

p-ISSN 0852 – 0798
e-ISSN 2407 – 5973

Acredited: SK No.: 60/E/KPT/2016
Website : http://ejournal.undip.ac.id/index.php/reaktor/

Reaktor, Vol. 19 No. 3, September Year 2019, pp. 111-116

The Performance of a Pilot-Scale Anaerobic Hybrid Bioreactor on Palm Oil Mill Effluent Treatment

Adrianto Ahmad [1*], Bahruddin [1], David Andrio [1], and Amir Hamzah [2]

[1] Department of Chemical Engineering, Faculty of Engineering, Universitas Riau
Kampus Binawidya KM. 12,5 Panam, Pekanbaru
[2] Department of Electrical Engineering, Faculty of Engineering, Universitas Riau
Kampus Binawidya KM. 12,5 Panam, Pekanbaru

*) Corresponding author: adri@unri.ac.id

(Received: August 14, 2019 Accepted: October 17, 2019)

Abstract

Contemporarily, Indonesia and Malaysia are the largest contributors of crude palm oil (CPO) in the world by up to 40%, and 37.3%, respectively. Furthermore, its production value this year reached 19.7 million tons, where each generates 2.5 m^3 of wastewater. Meanwhile, of all the provinces in Indonesia specifically, Riau is the largest supplier for exports by up to 38%, generated from 225 palm oil mills, where a total of 6.3 million tons resulting in the generation of about 15.75 million m^3 of wastewater, with organic content between the range of 30,000-60,000 mg COD/l. In addition, one of the uses of this wastewater includes anaerobic processes, with the double benefit of reducing COD concentrations, subsequently applying it as fertilizer, and also in the production of methane gas, as an alternative source of energy. The purpose of this study, therefore, is to observe the effect of bioreactor volume, scale-up on the performance of anaerobic hybrid bioreactors, in the treatment of mill effluents. The technology examined in this study was the anaerobic hybrid bioreactor with the dimensions of length 22 m, width 10 m, and depth 1.5 m, and a total volume of 330 m^3, which is impermeable to oxygen, and a 250 m^3 effective working volume. This was built and operated at a hydraulic retention time of 1 day, in the Palm Oil Mill of Riau, and the results showed the environmental conditions to range from a pH of 7.2 to 8.0, with temperatures from 32^{0}C to 35^{0}C, acetic acid of 774 mg/l to 1,180 mg/l, and alkalinity of 2,149 mg/l up to 2,400 mg/l. Furthermore, the performance of these reactors are shown by the highest COD removal efficiency of 77.8%, and a biogas test for the propensity of being applied as an alternative energy source obtained a methane gas concentration of 54%.

Keywords: *anaerobic; bioreactor; biogas; wastewater; performance; palm oil mill effluent*

How to Cite This Article: Ahmad, A., Bahruddin, Andrio, D., and Hamzah, A. (2019), The Performance of a Pilot-Scale Anaerobic Hybrid Bioreactor on Palm Oil Mill Effluent Treatment, Reaktor, 19(3), 111-116, http://dx.doi.org/10.14710/reaktor.19.3.111-116.

INTRODUCTION

Contemporarily, Indonesia is the largest contributor of crude palm oil (CPO) in the world by up to 40% and closely followed by Malaysia which supplies 37.3% worldwide. However, its production this year reached 19.7 million tons, and each creates 2.5

m^3 of wastewater. Furthermore, Riau Province is the largest contributor to CPO exports by 38%, which is generated from 225 palm oil mills, with a total of 6.3 million tons generated. Therefore, the resulting wastewater reaches 15.75 million m^3, with organic content between 30,000-60,000 mg COD/l, and one of its utilization is performed by using an anaerobic process. This has the double benefit of decreasing COD concentrations, facilitating its use as liquid fertilizer, and also in the manufacture of methane gas, to serve as an alternative energy source. Handling wastewater palm oil mill in the Indonesia mostly use the anaerobic then continued with anaerobic pond. This System is able to removed the content of BOD to 95%, but in the run long for 55 days to 110 days (Thanh, 1980).

Research conducted by Ahmad et al (2010) reported an anaerobic hybrid bioreactor with a volume of 2.5 m^3 is capable of converting palm oil mill effluent into biogas, with a retention time of 1 day. Furthermore, the apparatus possessed a volume of 12.5 m^3 (2013), and 50 m^3 (2016), and the results showed that an elevation in its scale, using the capacity of 50 m^3/day, is able to provide good prospects for development. Therefore, the increase from 12.5 m^3, further, escalated the amount of biogas produced at a flow rate of 19 l/min.

The innovation of an anaerobic hybrid bioreactor technology lies in the merging of suspended and inherent growth bioreactors, through the use of solid media as cell immobilization media for excellent biomass wash-out control. In addition, up to 3,800 kg of palm shells are applied as a medium for cell immobilization, in an attempt to reduce pollution from palm oil mill solid waste. This system, however, has the advantage of possessing a one-day retention time, which is relatively shorter than the existing treatment plant of 219 days, with an open pond system. Moreover, there is also a probability to use the methane gas released into the atmosphere as fuel gas, therefore, reducing the effect of greenhouse gases. In addition, the resulting liquid fertilizer saves the need for external varieties in the oil palm plantations. The purpose of this study, therefore, is to observe the effect of bioreactor volume, scale-up on the performance of anaerobic hybrid bioreactors, in the treatment of mill effluents, at a flow rate of 250 m^3 per day.

MATERIALS AND METHODS

Wastewater Source

The wastewater used was generated from wastewater following a deolization process that occurred in the palm oil mill.

Bioreactor used

The anaerobic hybrid bioreactor used has a length of 22 m, the width of 10 m, and depth of 1.5 m, with a total volume of 330 m^3, which was impermeable to oxygen, and an effective volume of 250m^3. In addition, a continuous operation was performed with a hydraulic retention time of 1 day, and a flow rate of 250 m^3 daily. Furthermore, the bioreactor is shown in figure 1: The parameters observed include pH, temperature, chemical oxygen demand (COD), volatile fatty acids (VFA), alkalinity, and total solids (TS), while the analysis method was conducted according to APHA (2005).

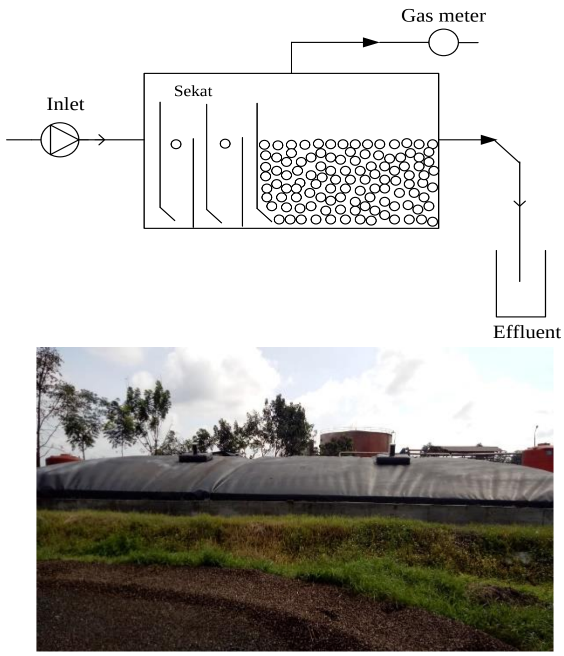

Figure 1. Anaerobic hybrid bioreactor set-up

RESULTS AND DISCUSSIONS

Wastewater Characteristics

The results of analyzing the characteristics of palm oil mill effluents are presented in Table 1. Table 1 shows the organic content, expressed with the COD parameter of 50,000 mg/l, and the appropriate bioconversion process used was anaerobic. According to Malina and Pohland (1992), similar materials containing values above 3,000 mg/l are better processed anaerobically because the bioconversion of the aeration process requires a large amount of energy. According to Rahayu et al (2015) that untreated palm oil mill effluent in ranged COD 15,100 to 34,280 mg/l compare with the maximum limit for discharge 350 mg/l (PERMENLH No. 5, 2014). Therefore, need to do processing palm oil mill effluent before discharged into water.

Table 1. Measurement Results of Palm Oil Mill Effluent Characteristics

No.	Parameter	Value
1.	pH	5.6
2.	volatile fatty acids	250.8 mg/l
3.	Alkalinity	114 mg/l
4.	Total Solids (TS)	7,100 mg/l
5.	Total Suspended Solids (TSS)	7,000 mg/l
6.	Total Suspended Volatile Solids (TVS)	3,530 mg/l
7.	Volatile Suspended Solids (VSS)	1,700 mg/l
8.	Total COD	50,000 mg/l

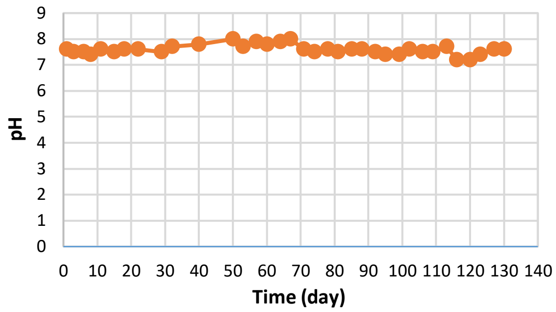

Figure 2. pH conditions during the bioreactor operational process

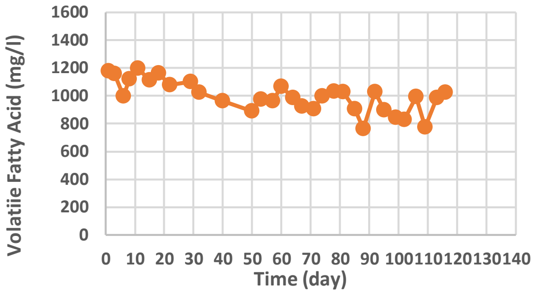

Figure 3. Volatile Fatty Acids during the bioreactor operational process

Environmental Conditions of Bioreactors

Maintaining the optimal environmental conditions needed to control the process conducted in anaerobic biodegradation, includes the regulation of pH, volatile fatty acids, alkalinity, total solids, COD, and methane gas.

pH Conditions in Bioreactor Environment

The pH conditions are shown in Figure 2. Figure 2 shows pH fluctuations during operation, which indicates the simultaneous stages of acidogenesis and methanogenesis, causing a relatively constant pH of 7.2 to 8.0 that returns to stability (7.5) after 71 days. This means that the microorganisms are capable of adapting properly, which is in line with the statement of Speece (1996) that anaerobic processes occur stable in a range of pH 6.5 to pH 8.2. In addition, the fluctuations of up to 8.0 are possibly influenced by the alkalinity observed to affect the pH system. However, the role of volatile fatty acids is also very important, as well as the relative acidic wastewater. According to Benefield and Randall (1980), bacterial methane highly sensitive to change pH. The rate of methane fermentation relative constant span pH 6.0 to 8.5, but declining very quickly out of range. According to Sahm (1984) that activity bacterial methane relative constant span pH 6 to pH 8. According to Ghosh and Klass (1978) that the pH below 6.5, activity bacterial methane very low and estimated case of death to bacteria. Labib et al (1992) reported that concentration hydrogen can increase methane production and hampering reduction of the etanol, propionic acid and butyric acid. Rahayu et al (2015) stating that a pH range of 6.5–7.5 results in good performance and stability in anaerobic syatems, while Zhang et al (2011) obtain methane gas optimum pH range of 8.5-9.0.

Volatile Fatty Acid Conditions in Bioreactors

The concentration of volatile fatty acid in the anaerobic hybrid bioreactor is shown in Figure 3 below. Figure 3 shows the fluctuation of volatile fatty acids during operation to be an indication of ongoing acidogenesis reactions that are responsible for its production in the system, at a concentration ranging from 774 mg/l to 1,180 mg/l. According to Benefield and Randall (1980), its optimum concentration in an anaerobic process takes place within the range of 50 to 500 mg/l. Therefore, the formed volatile fatty acids are neutralized by the alkalinity produced in the anaerobic system, which is partially converted to biogas in the methanogenesis reaction. Range concentration volatile fatty acid on this research relatively less than researchers other (Ng et al., 1985; Ahmad and Setiadi, 1993). Ng et al (1985) obtains volatile fatty acid of 5,458 mg/l on hydraulic retention time 1 day, while Ahmad and Setiadi (1993) obtain volatile fatty acid of 2,026 mg/l hydraulic retention time 2 days.

Alkalinity Condition of in Bioreactors

The concentration of alkalinity in the anaerobic hybrid bioreactor is shown in Figure 4 below. Figure 4 shows the fluctuation in alkalinity formed during the operation process, which indicates an ongoing reaction with volatile fatty acids in the system. The value in palm oil mill effluent is relatively low, although it becomes higher in the anaerobic biodegradation process, while the concentration of fatty acids reduces. Therefore, the alkalinity formed ranges from 3,100 mg/l to 2,149 mg/l, although stability is achieved at a concentration of 2,400 mg/l. This is in line with Benefield and Randall (1980), stating that optimum alkalinity concentration takes place within the range of 2,000 to 3,000 mg/l, which is capable of neutralizing the excess acetic acid, and further maintain the pH of operation. Stability bioreactor reviewable of the relationship between volatile fatty acid with alkalinity. According to Grady and Lim (1980) that ratio volatile fatty acid with alkalinity optimum under 0.4. This research shows stability high because ratio volatile fatty acid and alkalinity average of 0.37.

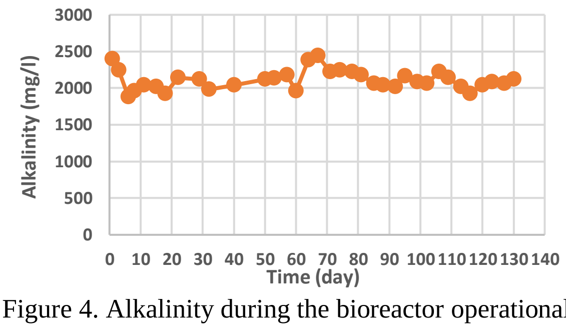

Figure 4. Alkalinity during the bioreactor operational process

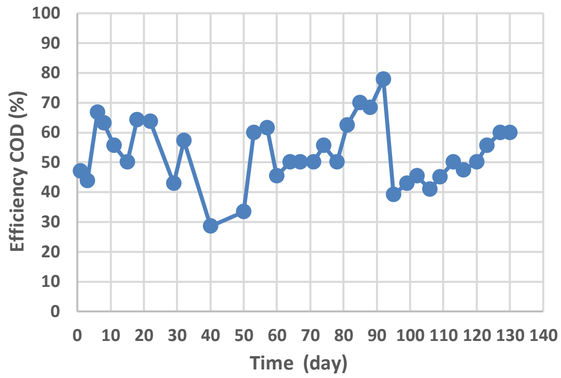

Figure 5. COD removal efficiency during the bioreactor operational process

Anaerobic Hybrid Bioreactor Performance

Bioreactor Efficiency

An anaerobic hybrid bioreactor is able to convert organic compounds contained in palm oil mill effluent into biogas, at a highest COD removal efficiency of 77.8%, as shown in Figure 5.

Figure 5 shows that the removal efficiency of organic matter fluctuates during the operational process, with the highest allowance value obtained on the 92nd day, at 77.8%, for more organic material set aside in steady conditions. The efficiency of organic matter removal shows the ability of biodegradation into methane gas and CO_2 by anaerobic bacteria. In addition, a higher value leads to a greater increase in the changes observed, which, further, causes the formation of more methane gas and subsequently decrease CO_2. This is due to the elevation in organic compounds being broken down into volatile fatty acids, and the consecutive transition into the substrate, for the growth of methanogenic bacteria. Moreover, Malina and Pohland (1992) stated the possibility of anaerobic bioreactors, with a removal efficiency of above 80%, to properly degrade the organic components. Meanwhile, the value obtained in this current study is relatively lower, in comparison with that obtained by Ahmad, et al. (2010) which was 84%, using the same system, although with the immobilized media of palm fronds. Furthermore, it is also higher than those which employed the use of empty fruit bunches (Ahmad, et al. 2010). Thanh (1980) use anaerobic pond with efficiency allowance of 95% higher than the research, but requires time processing very long namely 15 to 20 days. It also earned on high-rate anaerobic pond with efficiency allowance of 95% for 15 days, whereas on research was conducted with hydraulic retention time 1 day. Ng et al (1985) use two-phase anaerobic digester able to 70% of the processing for 11 days, while Fitrah et al (2019) report that highest COD removal efficiency obtained by 78,87%.

COD Removal of Palm Oil Mill Effluent

The COD profile during the bioreactor operation is shown in Figure 6.

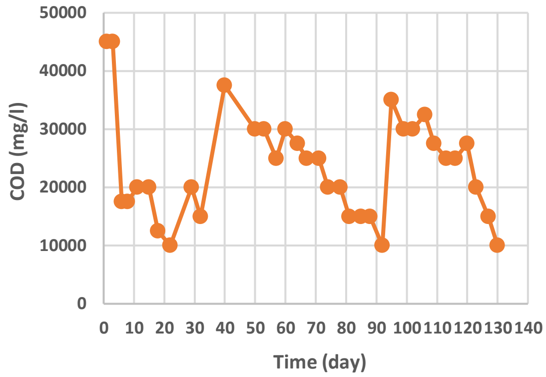

Figure 6. COD during the bioreactor operational process

Figure 6 shows the fluctuation of COD concentration from the initiation of each process to range from 45,000 to 10,000 mg/l. Meanwhile, during operation, bioreactors obtain relatively high organic loads that enhanced the ability of anaerobic bacteria to convert volatile fatty acids into biogas (Malina and Pohland, 1992). These results indicate the capability of the microorganisms to degrade the organic compounds contained in palm oil mill effluent into methane gas and CO_2, with the COD value being low as 10,000 mg/l (Ahmad et al, 2013)

Solids Removal of Palm Oil Mill Effluent

The total solid profile during the bioreactor operational process is shown in Figure 7. Figure 7 shows a decrease in TS from 4.25 mg/l to 1.54 mg/l at the initiation of operation. However, from day 20 to 130, the concentration of solid also relatively declined because it has broken down into simple organic compounds within the plant. This, further, reduces the organic matter, depending on the biodegradation ability of the anaerobic bacteria (Malina and Pohland, 1992), therefore, illustrating the ability of the microorganism to reproduce itself, further forming a floc with high activity. Therefore, the organic solids contained in palm oil mill effluents relatively high concentrations are degraded by anaerobic bacteria. Removal TS obtained by 64%.

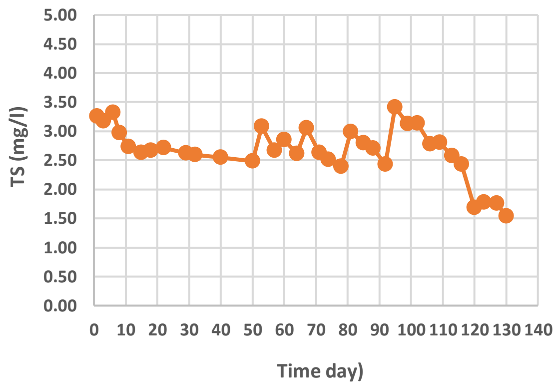

Figure 7. TS during the bioreactor operational process

Table 2. Biogas Composition

No.	Biogas	Concentration
1.	CH_4	54.0%
2.	CO_2	6.6%
3.	O2	2.5%
4.	Bal.	36.9%

Biogas Production

Based on the performance of anaerobic hybrid bioreactors in the conversion of organic materials into biogas, the efficiency of removal reached 77.8%, and further produced biogas with a methane content of 54%, as shown in Table 2.

Table 2 shows the composition of the biogas formed to be 54% CH_4, 6.6% CO_2, 2.5% O_2, while H_2S was not detected, due to the damage observed in the indicator. Panjaitan et al (2012) in research obtain composition gas metan by 58.5%, while Zhang et al (2011) obtain by 46% and Fitrah et al (2019) obtain by 46.1%.

CONCLUSIONS

Based on the results, the following was concluded:

1. The bioreactor operation was carried out with environmental conditions ranging from a pH 7.0 to 7.8, temperatures of 30^0C to 34^0C, volatile fatty acid concentrations of 774 mg/l to 1,180 mg/l, and alkalinity value of 2,149 mg/l to 2,400 mg/l.
2. The performance of an anaerobic hybrid bioreactor is indicated by the highest COD removal efficiency, which was 77.8%.
3. The resulting biogas to be used as an alternative energy source contained 54% methane

.

ACKNOWLEDGEMENT

This research was funded by the Director-General of Strengthening Innovation, Ministry of Research, Technology, and Higher Education, in the 2019 Industrial Innovation research scheme. Therefore, the authors are grateful for financially backing the study that was capable of producing this scientific work.

REFERENCES

Ahmad, A., Bahruddin, Andrio, D., and Hamzah, A., (2016), *Increase Capacity Biogas Power Plant of Capacity Bioreactor 12.5 m^3 be 50 m^3 per day on Palm Oil Mill Sei Pagar PTPN V Riau*, Final Report INSINAS Research 2016, KEMENRISTEKDIKTI RI, Jakarta

Ahmad, A., Bahruddin, and Hamzah, A., (2013), *Increase Performance Biogas Power Plant Based Palm Oil Mill Effluent by Scale-up Anaerobic Hibryd Bioreactor of 2,5 m^3 to be 12,5 m^3 per day*, Report Insinas Research 2013, KEMENRISTEK RI, Jakarta

Ahmad, A., Bahruddin, Amraini, S. Z., and Andrio, D., (2010), *Bioconversion Palm Oil Mill Effluent into Energy Fuel Alternative in Anaerobic Bioreactor*, Final Report RUSNAS Batch I 2010, DP2M KEMDIKNAS RI, Jakarta

Ahmad, A., and Setiadi, T., (1993), Application Two-stage Anaerobic Fluidised Bed Bioreactor, *Proceeding National Industry Biotecnology Conference*, PAU-Bioteknologi ITB Bandung

APHA (American Public Health Association) (2005) *Standard Methods for the Examination of Water and Wastewater,* American Public Health Association/American Water Work Association/Water Environment Federation, Washington DC, USA, Edisi ke-20.

Benefield, L. D., and Randall, G. W., (1980), *Biological Process Design for Wastewater*, Prentice-Hall, Inc., Englewood Cliffsw

Fitrah, R., Ahmad, A., and Amri, I., (2019), Enhanced biogas production by mesophilic and thermophilic anaerobic co-digestion of palm oil mill effluent with empty fruit bunches in expanded granular sludge bed reactor, *IOP Conf. Ser.: Mat. Sci. Eng*., 550

Ghosh, S., and Klass, D.L., (1978), Two-Phase anaerobic digestion, *Proc. Biochem.,* 13, 15-24

Grady Jr, C.P.L., and Lim, H.C., (1980), *Biological wastewater treatment. Theory and applications,* Marcel Dekker Inc., New York, 833-886

Labib, F., Ferguson, J.F., Benjamin, M.M., Merigh, M., and Ricker, N.L., (1992), Anaerobic butyrate degradation in a fluidized bed reactor: effects of increased concentration of H_2 and acetate, *Environ. Sci. Technol.*, 26(2), 369-376

Malina, J. F., and Pohland, F. G., (1992), Design of Anaerobic Process for the Treatment of Industrial and Municipal Waste, *Water Quality Management Library*, vol. 7

Ng, W. J., Wong, K. K., and Chin, K. K., (1985), Two-Phase Anaerobic Treatment Kinetics of Palm Oil Waste, *Wat. Res*, 19(5), 667-669

Panjaitan, S. D., Sukandar, Sitorus, B., and Yandri, (2012), *Technology biogas power plant purification of derived from domestic waste*, Proceeding INSINAS 2012. KEMENRISTEK

Peraturan Kementerian Lingkungan Hidup No. 5, tahun 2014

Rahayu, A. S., Karsiwulan, D., Yuwono, H., Trisnawati, I., Mulyasari, S., Rahardjo, S., Hokermin, S., and Paramita, V., (2015), *Handbook POME to Biogas, Project Development in Indonesia*, 2^{nd}, USAID-WINROCK International

Rittmann, B. E., and McCarty, P. L., (2001), *Environmental Biotechnology: Principles and Applications*, McGraw-Hill International Editions, Singapore

Sahm, H., (1984), Aaerobic Wastewater Treatment, *Advanc. Biochem. Engg. Biotechnol*, 29, 83-115

Speece, R.E., (1996), "*Anaerobic Biotechnology for Industrial Wastewaters*", ArchaePress, Nashville, Tennessee, USA.

Thanh, N.C., (1980), High organic wastewater control and management in the tropics, *Water Pollution Control Conference,* CDG, AIT-ERL, Bangkok, Nov.

Zang, Ye, Zheng, Zhang, and Yan, (2011), High-rate mesophilic anaerobic digestion of palm oil mill effluent in Expanded Granular Sludge Bed Reactor, *Advances in Biomedical Engineering,* 3(5).