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Startup of expanded granular sludge bed reactor treating undiluted palm oil mill effluent

Startup of expanded granular sludge bed reactor treating undiluted palm oil mill effluent

A Ahmad, I Amri and R Fitrah

Department of Chemical Engineering, University of Riau
HR Subrantas Rd. km 12.5 Pekanbaru 28293

E-mail: adri@unri.ac.id

Abstract. A lab-scale Expanded Granular Sludge Bed (EGSB) Reactor was used to the treatment of undiluted Palm Oil Mill Effluent (POME) with the COD mean value of 53,333.33 mg/l. The startup was done at a mesophilic temperature of 35 ± 2^0C for 12 days with two days Hydraulic Retention Time (HRT) as a pre-study of enhanced biogas production by mesophilic and thermophilic anaerobic co-digestion of POME with Empty Fruit Bunches (EFB) in EGSB Reactor. The steady state was achieved at 8th to 12th day of continuous operation. The effluent COD at steady state was vary from 10,000 to 11,500 mg/l, COD removal 78.44 – 81.25 %, Methane content was 43.89 % and total biogas volume achieved was 2.760 ml (0.1486 – 0.1503 m^3 CH_4/kg COD removed). There were several operational problems met in the experiment and corresponding countermeasures were also discussed.

1. Introduction

Riau province was the biggest CPO producer in Indonesia, achieving 7.33 tons or equal to 34,904,761 tons of FFB in 2016. It was followed by a large amount of liquid waste or Palm Oil Mill Effluent (POME) estimated by 20,942,857 m^3 (0.6 m^3/tons FFB processed). POME was mainly consisted of processed sludge, condensate from sterilizing, processed water from clarification, Hydrocyclone /Clay bath and spent water from plant's cleaning activity. POME was relatively high in organic materials and non-toxic because no chemicals were used in the extraction process of palm oil.

POME's physical appearance was brown-colored, contain residual oil, dissolved solids, and suspended colloidal form with high temperature, high level of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Such characteristics would harm the environment when openly discarded into bodies of water. High level of BOD would reduce oxygen levels in the water thus threatened the aquatic ecosystem [1]. [10]. Most of CPO producer treated POME by using open ponds system which consists of a de-oiling tank, facultative aerobic and anaerobic ponds [2]. [11]. The number of ponds used varies that depends on the capacity of the palm oil mill.

Anaerobic pond for 54 tons FFB/hour Palm Oil Mill sized from 60 x 29.6 x 5.8 m (length x width x Depth) [3]. [12]. The size also depended on how many vacant areas could be used as open ponding system. Anaerobic ponds have the longest retention time among any other ponds in the ponding system, which vary from 20 to 200 days [2]. [11]. The drawbacks of this system was a long HRT, required vast areas, and the released of GHG in the form of Biomethane which cannot be collected thus harming the environment. Concerned researchers were trying to solve these problems by utilizing biogas from POME for power plants

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To shorten the HRT, lessen the area required, and utilizing the biogas produced at the same time, researchers were studied various type of high-rate bioreactors such as Expanded Granular Sludge Bed (EGSB) [4] [5], tank digester [5] [19], anaerobic filter by [6] [13], anaerobic fluidized reactor [7] [14], anaerobic baffled reactor [8] [20], and upflow anaerobic sludge bed reactor (UASB)[9]. [15]. EGSB was a variant of the UASB reactor with a typical characteristic of a slender body. This design was aimed for improving the substrate-biomass contact time in granular sludge bed [4]. [5]. Upflow movement from the substrate would expand the sludge bed, releasing biogas bubbles that were trapped in between granular sludge as well as mixing the substrate with biomass.

Yejian *et al.* (2008) studied start-up of EGSB at 35^0C using a diluted POME with a constant level COD of 30,000 mg/l [4] [5]. The EGSB reactor used was 21,560 ml in total volume and 20.500 ml in effective volume. Highest COD removal was 91%, at two days HRT and 1.45 to 17.5 kg COD/m^3 of Organic Loading Rate (OLR). Yejian *et al.* (2011) studied another use of EGSB reactor in treating POME to generate biogas [10]. [4]. The reactor was operated continuously at a mesophilic temperature of 35^0C with the OLR was increasing in the range of 1.45 to 16.5 kg COD/m^3-day. The highest Biomethane Yield achieved was 46.00% at a temperature of 35^0C, HRT of 3 days, OLR of 10 kg COD/m^3, and pH 8.5 – 9.0.

Ohimain and Izah (2014) reviewed the biogas production and performance from many different types of anaerobic biodigester by using Nigeria's POME - Potential Biogas data from 2004 until 2013 [11]. [2]. The study revealed that EGSB reactor exhibits the highest Biomethane production in the shortest HRT compared to other types of the anaerobic biodigester.

This study was performed to review the startup of EGSB reactor treating undiluted POME at a mesophilic temperature of 35 ± 2^0 C and Hydraulic Retention Time (HRT) of 2 days. This study was also a pre-study of enhanced biogas production by mesophilic and thermophilic anaerobic co-digestion of POME with Empty Fruit Bunches (EFB) in EGSB Reactor.

2. Materials and methods

The materials used in this study were POME obtained from Sei Galuh Palm Oil Mill, PT. Perkebunan Nusantara V, granular sludge obtained from UASB reactors of PT. Insansandang Internusa treating textile wastewater, Nitrogen, and NaCl solution. Other supporting materials i.e.; $K_2Cr_2O_7$ 0.05 M; Ag_2SO_4 0.05 M; FAS; H_2SO_4 0.02 N; NaOH 0.1 N; indicator Ferroin, PP and MO.

The EGSB reactor series used in this research were presented in figure 1 below.

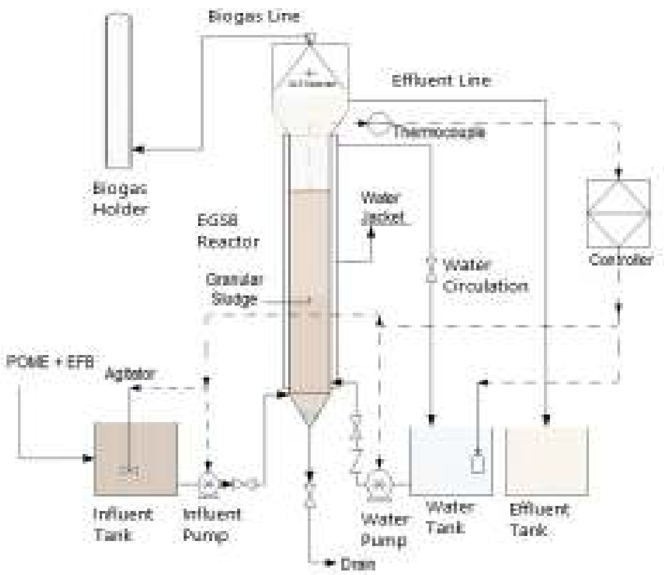

Figure 1. Schematic diagram of the EGSB reactor.

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EGSB reactor used in this study was made of PVC pipe with 4 in ID and 6 in OD. The space between two pipes was used for a water jacket. The diameter to height ratio was 1:15 minimum, so the reactor's height (not including the head and bottom) is 190 cm. The reactor divided into three parts, namely the bottom, body, and head. All of these parts were joined by two pcs of 4 in PVC coupling. Inside the head section of the reactor, there was an inverted cone-shaped Gas-Liquid-Solid separator, which served as biogas capture. The lower part of the reactor served as influent distribution area. The total volume of the EGSB reactor was 30,570 ml and the effective volume was 19,820 ml.

All of the instruments used, i.e., influent pump, a water circulation pump for the water jacket, coil heater, and thermocouple were connected to a single control panel. The biogas outlet was connected to an inverted 2000 ml measuring glass, containing 10% NaCl solution to measure the amount of biogas generated. Other tools were test tubes, 250 ml Erlenmeyer, and a burette to perform the titration. Research variables were reactor's effective volume of 19,820 ml, HRT of 2 days, and temperature of 35 ± 2^0 C [10, 12]. [4] [18].

2.1. Material preparations:

POME obtained from the bottom outlet of Fat Pit in Sei Galuh Palm Oil Mill, PTPN V. Granular Sludge took from UASB reactor treating textile wastewater in PT. Insansandang Internusa. Microbial consortia on the granular sludge mainly consisted of *Micrococcus sp Nitrosomonas sp, Nitrobacter sp, and Methanobacter sp.*

2.2. POME characteristics

POME's characteristics were analyzed in the Material Testing Lab of Dinas Bina Marga, Riau Province**.** The COD level measured using the titration method, while biogas content was analyzed using a portable gas analyzer (Biogas Geotech 5000).

3. Results and discussion

POME's characteristic was presented in table 1.

Table 1. Characteristic of POME obtained from Sei Galuh Palm Oil Mill, PTPN V.

Parameters	Value	Threshold*
pH	4.58	6.0 – 9.0
BOD5 (mg/l)	-	100
COD (mg/l)	55.000	350
TSS (mg/l)	-	250
Total Alkalinity (mg/l)	1.220	N/A
Volatile Fatty Acid (mg/l)	180	N/A
Total Nitrogen (mg/l)	-	50
Max. Debit (m^3/ton CPO)	-	2.5

**Indonesia's Ministry of Environment Regulation No. 5,2014*

3.1. Influent's COD level

Influent's COD level analysis was used as the basic calculation of EGSB reactor's COD removal. This value was the average values of influent's COD samples result per run with three repetitions. Influent's COD level analysis was presented in table 2 below:

Table 2. Influent's COD level in mg/L.

Sample 1	Sample 2	Sample 3	Average
55.000	50.000	55.000	53.333

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3.2. Start-up preparation

3.2.1. Influent pump calibration. Before the startup was started, influent's pump was calibrated to ensure that HRT achieved in 2 days. Influent's pump capacity was set in the control panel. Once the pump ready, the step continued by calibration of the temperature.

3.2.2. EGSB reactor temperature calibration. Reactor's temperature was set to 35 ± 2^0 C by starting the heater coil to warm up the circulating water inside the water jacket. Once the temperature inside of the reactor reached 37^0C, the control panel will cut off the power to coil heater and water pump. The two instruments will back to work when the temperature of the reactor was 33^0C. This process repeats during continuous operation of the reactor.

3.2.3. Startup EGSB reactor. The startup begins with the mixing of 9 liters granular sludge and POME which has been prepared in advance. POME and granular sludge mixture were stirred and then fed into the reactor. Reactor's temperature was controlled at 35 ± 2^0C (Mesophilic). The use of freshly obtained granular sludge from another fully operated reactor aimed to shorten startup time [13, 14]. [16 - 17].
Make sure that all parts of the reactor, i.e., the hose inlet-outlet, pumps and instruments are correctly installedproperly, and then fed the Nitrogen gas into the reactor to ensure the reactor was in anaerobic condition. After this stage was completed, the reactor operated in a batch-mode for two days [4]. [5]. After the second day, Biogas bubbles was generated and attached to the inner side of the measuring glass containing 10% of NaCl solution. Formation of Biogas bubbles indicated the microbial consortia was digesting POME [4]. [5].
The next step was reactor operated in continuous mode. Influent's pump switched on to fed POME into the reactor. The continuous-mode was staged for 12 days. During the 4th day in continuous-mode, the effluent's hose and the GLS separator were clogged by scum. As a result, granular sludges were carried over the effluent's tank and Biogas outlet [4]. [5].
Some improvements were made in the head section and the Biogas outlet of the reactor to prevent the recurrence of similar incidents. Startup phase was restarted to ensure the reactor's operational excellence in the next step. The second startup attempt was also failed due to the limited volume of biogas holder. The biogas volume generated during the 4th day was much higher than the biogas holder volume. The third attempt of the start-up stage was quite a success. The batch-mode operation for two days, followed by continuous-mode for the next ten days went smoothly. During ten days of operation, the samples were taken from POME's preparation tank and effluent's outlet hose to determine the COD level.

3.3. COD removal
The effluent's samples were taken in 2 days of intervals. The COD removal during the startup stage was presented in figure 2:

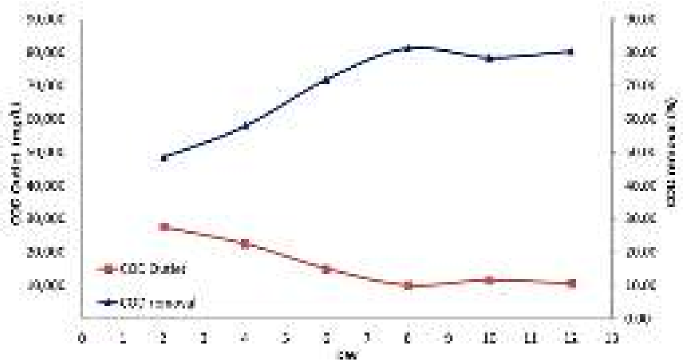

Figure 2. The COD removal during startup.

Figure 2. showed that the reactor was steady on day 8 to 12, where the COD level was relatively stable at 10,000 to 11,500 mg/l. The effluent's COD level on the second day was removed for 48.44% compared to the influent's level. Effluent's physical appearance still looks dark brown and there was a bit granular sludge carried away to the effluent outlet. The effluent's color tends to fade over the increase of COD removal during the start-up stage. The effluent's COD level was decreasing from 27,500 to 10,000 mg/l on day 2 to 8. The reactor was on steady condition starting from day 8 to 12. The effluent's dark brown color was faded, effluent's COD levels were stable at 10,000 to 11,500 mg/l, and COD removal vary from 78.44 to 81.25%.

3.4. The biogas volume

During the start-up stage, biogas volume was measured with inverted glass tube containing 10% NaCl solution. The volume of biogas during startup was presented in figure 3:

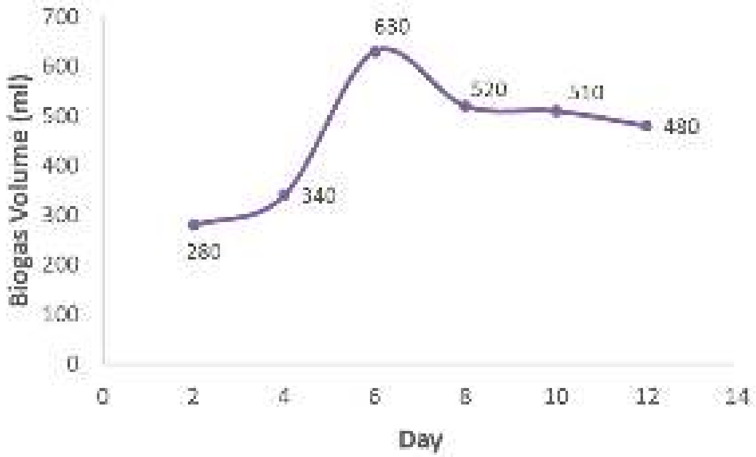

Figure 3. Biogas volume during the startup stage.

Figure 3. showed that biogas volume increased from 4th to 6th day, they tend to be stable in the range of 480 – 520 ml on day 8 to 12. Biogas was formed from the beginning of 2 days of batch-mode. Biogas volumes increased over days during the start-up stage. Observation during the startup stage showed that the biogas volume increased when the sludge bed was expanded by influent's pump operational pressure [14]. [17]. The biogas volume varied from 480 to 630 ml on day 6 to 12.

The total biogas volume generated during the start-up stage was 2,760 ml with 43.89% of Biomethane. The Biogas content was analyzed using Geotech Biogas 5000. The Biomethane yield during the startup stage was 0.1486 – 0.1503 m^3 CH_4/kg COD. The detailed experimental data showed in table 3.

Table 3. Detailed experimental data.

Parameters	Day					
	2nd	4th	6th	8th	10th	12th
COD influent (mg/l)	53.333					
COD effluent (mg/l)	27.500	22.500	15.000	10.000	11.500	10.500
COD removal (%)	48.44	57.81	71.88	81.25	78.44	80.31
Biogas volume (ml)	280	340	630	520	510	480
	2.760					

3.5. Scum formation

Undiluted POME which fed into EGSB reactor were taken directly from the bottom outlet of Fat Pit in Sei Galuh Palm Oil Mill. Scum formation occurred due to the high content of oil in POME digested by microbial consortia in granular sludge. The thickness of scum will continue to grow along with the high content of oil and fats in POME.

Scum layer could block the biogas. The thicker the scum layer, more difficult for biogas bubbles to pass through. In this study, a scum formed hinder the GLS separator outlet. To overcome this constraint, GLS separator can be modified, i.e., by adding a scum breaker. Development of GLS separator with scum breaker could be an interesting research topic in the near future.

3.6. Effluent's outlet blockage

The blockage of the effluent's outlet hose occurred due to scum carry over. The increased scum deposit in the outlet line could block the outlet flow. This blockage would failof GLS separator. The remaining scum could also stick to the inner wall of the hose, thereby reducing the effluent's outlet volume. In this study, the constraint was corrected by modified the GLS separator and increased the size of the effluent's outlet hose.

3.7. Granular sludge carry over

Granular sludge carry-over occurred on 1st to the 2nd day of continuous-mode operation. This was caused by the high pressure of influent's pump when it was run for the first time. Granular sludge was not fully settled yet, even after the two days of batch-mode operation. It was slowly disappeared after the 4th day of continuous-mode operation. On day 8, the carryover was stopped, granular sludge has already settled.

4. Conclusion

EGSB reactor can be used in the anaerobic digestion of raw and undiluted POME to generate Biogas at mesophilic condition (temperature 35 ± 2^0C). EGSB reactor start-up stage achieved the steady state on day 8 to 12 of continuous-mode operation with COD removal 78.44 to 81.25%. The Biogas volume generated during 12 days of start-up stage was 2,760 ml (0.1486- 0.1503 m^3 CH_4/kg COD).

References

[1] Ahmad A, Shah, Othman and Abdullah 2014 Enhanced palm oil mill effluent treatment and biomethane production by co-digestion of oil palm empty fruit bunches with Chlorella sp. *Can J Chem Eng* **92** 1636–42

[2] Chan and Choi 1984 Ponding system for palm oil mill effluent treatment. *Proceedings of the Regional Workshop on Palm Oil Mill Technology & Effluent Treatment* p 185–92

[3] Yacob, Hassan, Shirai, Subash, and Wakisaka 2006 Baseline study of methane emission from anaerobic ponds of palm oil mill effluent treatment *Sci Total Environ* **366** 187–96

[4] Yejian Z, Li Y, Lina C, Xiuhua L, Zhijian M and Zhenjia Z 2008 Startup and operation of anaerobic EGSB reactor treating palm oil mill effluent *J. Env. Sci.* **20** 658-63

[5] Ho C C and Tan Y K 1985 Anaerobic treatment of palm oil mill effluent by tank digesters *J. Chem. Technol. Biotechnol.* **35** 155–64

[6] Borja R, and Banks C J, 1994, Treatment of palm oil mill effluent by upflow anaerobic filtration, *J. Chem. Technol. Biotechnol.* **61** 103–09

[7] Borja R, and Banks C J 1995 Response of an anaerobic fluidized bed reactor treating ice-cream wastewater to organic, hydraulic, temperature and pH shocks *J. Biotechnol.* **39** 251–59

[8] Setiadi T, Husaini and Djajadiningrat A 1996 Palm oil mill effluent treatment by anaerobic baffled reactors:Recycle effects and biokinetic parameters *Water Sci. Technol.* **34**(11) 59–66

[9] Borja R and Banks C J 1996 Anaerobic treatment of palm oil mill effluent in a two-stage up-flow anaerobic sludge blanket (UASB) reactor *J. Biotechnol.* **45** 125–35

[10] Yejian Z, Hairen Y, Xiangyong Z, Zhenjia Z, and Li Y 2011 High-rate mesophilic anaerobic digestion of palm oil mill effluent (POME) in Expanded Granular Sludge Bed (EGSB) reactor *Int. Confer. Agricul. Natural Res. Engine. Adva. Biomed. Engine*. **3-5** 214-19

[11] Ohimain E I and Izah S C 2014 Potential of biogas production from palm oil mill effluent in

Nigeria *Sky Journal of Soil Science and Environmental Management* **3** 50–58
[12] Kim H S, Choi S, Ju H and Jung J 2013 Mesophilic co-digestion of palm oil mill effluent and empty fruit bunches, *Environmental Technology* **34**(13-14) 2163–70
[13] Goodwin, Forster, and Wase, 1992, Pre-granulated seeds for UASB reactors: how necessary are they? *Bioresour. Technol.* **41** 71–79
[14] Poh and Chong 2009 Development of anaerobic digestion methods for palm oil mill effluent (POME) treatment *Bioresour. Technol.* **100** 1–9

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