Bioresource Technology xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Performance comparison between mesophilic and thermophilic anaerobic reactors for treatment of palm oil mill effluent

Joo-Young Jeong, Sung-Min Son, Jun-Hyeon Pyon, Joo-Yang Park *

Department of Civil and Environmental Engineering, Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul 133-791, Republic of Korea

HIGHLIGHTS

- Anaerobic combined system was used to treat fresh POME in Sumatra, Indonesia.
- Fresh POME was mechanically pretreated by using screw decanter.
- Total COD removal was 90–95% in both conditions at the OLR of 15 kg [COD]/m^3/d.
- Thermophilic was better for COD removal and biogas production than mesophilic.
- Maximum biogas production was 20.0 l/d at 15 kg [COD]/m^3/d OLR in thermophilic.

ARTICLE INFO

Article history:
Received 10 January 2014
Received in revised form 3 April 2014
Accepted 4 April 2014
Available online xxxx

Keywords:
Anaerobic digestion
Organic loading rate
Palm oil mill effluent
Mesophilic
Thermophilic

ABSTRACT

The anaerobic digestion of palm oil mill effluent (POME) was carried out under mesophilic (37 °C) and thermophilic (55 °C) conditions without long-time POME storage in order to compare the performance of each condition in the field of Sumatra Island, Indonesia. The anaerobic treatment system was composed of anaerobic hybrid reactor and anaerobic baffled filter. Raw POME was pretreated by screw decanter to reduce suspended solids and residual oil. The total COD removal rate of 90–95% was achieved in both conditions at the OLR of 15 kg [COD]/m^3/d. The COD removal in thermophilic conditions was slightly better, however the biogas production was much higher than that in the mesophilic one at high OLR. The organic contents in pretreated POME were highly biodegradable in mesophilic under the lower OLRs. The biogas production was 13.5–20.0 l/d at the 15 kg [COD]/m^3/d OLR, and the average content of carbon dioxide was 5–35% in both conditions.

1. Introduction

Palm oil is one of the most popular vegetable oils in the world and its consumption has increased steadily (Lim and Teong, 2010). Palm oil mill effluent (POME) is wastewater generated from palm oil milling process. About 5–7 tons of water are required to produce 1 ton of crude palm oil and half of water used in the milling process is turned into POME. Raw POME contains 0.6–0.7% residual oil and 2–4% of suspended solids, which are mainly debris of palm fruit mesocarp. POME is a colloidal suspension of brownish color which has very high concentrations of chemical oxygen demand (COD) due to low carbon numbers (8–20) of amino and fatty acids dissolved in it. Therefore, the discharge of untreated POME is a great threat to surrounding watershed and water body (Wu et al., 2009; Yeoh et al., 2011).

The aerobic process is not suitable for treatment of POME due to unbalanced nutrient content. On the other hand, anaerobic treatment is favorable for POME treatment since POME contains high concentration of COD (Chin et al., 1996). The ponding system is the most commonly used conventional anaerobic method for the treatment of POME (Yacob et al., 2005). The ponding system requires low operational costs; however, it needs a long retention time and large treatment area. Furthermore, the generated biogas such as methane and carbon dioxide is released directly into the atmosphere from the open pond that accelerates global warming (Gobi et al., 2011). To solve these problems, closed anaerobic digesters such as the up-flow anaerobic sludge blanket (UASB) and anaerobic filter (AF) has been investigated for developing of an efficient process (Poh and Chong, 2009; Fang et al., 2011). The up-flow anaerobic sludge-fixed film was used for treating POME, and a COD removal efficiency of 89–97% was achieved (Najafpour et al., 2006). Zhang et al. (2008) obtained a COD removal efficiency of 91% using expanded granular sludge bed. The sequential anaerobic treatment system composed of UASB and down flow

---

* Corresponding author. Tel.: +82 2 2220 0411; fax: +82 2 2220 1945.
E-mail address: jooypark@hanyang.ac.kr (J.-Y. Park).

http://dx.doi.org/10.1016/j.biortech.2014.04.007
0960-8524/© 2014 Elsevier Ltd. All rights reserved.

Please cite this article in press as: Jeong, J.-Y., et al. Performance comparison between mesophilic and thermophilic anaerobic reactors for treatment of palm oil mill effluent. Bioresour. Technol. (2014), http://dx.doi.org/10.1016/j.biortech.2014.04.007

anaerobic filter was investigated to treat confectionery wastewater under mesophilic condition at 25–35 °C (Beal and Raman, 2000). In the last case, the total COD removal efficiency was 98% at the organic loading rate (OLR) of 12.5 kg [COD]/m^3/d, and this result indicated that high efficiency can be achieved with the sequential anaerobic treatment system in comparison with that obtained from a single process.

The operating temperature is one of the key factors which affect the COD removal efficiency of anaerobic treatment. In general, it is known that thermophilic digester can be operated at high OLRs and can produce more biogas than that generated from mesophilic digester (Dinsdale et al., 1997; Yu et al., 2002). Several research projects have conducted investigations to find the effect of operating temperature on anaerobic digestion by using various wastewaters (Choorit and Wisarnwan, 2007; Ramakrishnan and Surampalli, 2013). However, the accumulation of volatile fatty acid (VFA) frequently occurred on account of washout biomass at thermophilic condition.

A higher substrate degradation rate and biogas production rate have been commonly reported as advantages in the thermophilic anaerobic POME digestion. Raw POME discharged at high temperatures around 80–90 °C was expected to be treated by thermophilic anaerobic condition without difficulty. From this point of view, several researchers have validated the feasibility of the thermophilic anaerobic process with various conditions (Khemkhao et al., 2012, 2011; Chou et al., 2010; Chan et al., 2010). Nevertheless, the mesophilic condition still can be preferable due to greater process stability. In addition, usually raw POME was collected in palm oil refinery then brought to the laboratory then stored until it was used in all cases. During this time, the characteristics of collected POME can be changed.

In this study, the combined anaerobic digestion system was examined for comparison between mesophilic and thermophilic conditions. The combined anaerobic digestion system was composed of two hybrid reactors for stable operation. The primary digester, anaerobic hybrid reactor (AHR), consists of UASB and AF. In AHR, the wastewater was treated in two steps; by the microorganisms from the sludge bed at the lower part of the reactors and by a biofilm formed on the filter media in the upper part of the reactors. Additionally, the media prevents the washout of the granule. The secondary digester, anaerobic baffled filter (ABF), was made of plug flow reactor with a vertically installed baffle which is a combination of anaerobic baffle reactor and AF. In comparison with a previous study conducted by Beal and Raman (2000), ABF showed better performance than that of anaerobic downflow filter in terms of accumulated sludge collection. Therefore, ABF could facilitate high solids removal and long biomass retention. Also, ABF may have resilience to both hydraulic and organic shock loadings. Finally, the objectives of this study were to compare and to evaluate the performance of combined system of AHR and ABF under mesophilic and thermophilic anaerobic condition for POME treatment.

2. Methods

2.1. Characteristics of the raw POME

The raw POME was sampled from Amagra palm oil plantation on Sumatra Island, Indonesia. To prevent chemical change of samples such as acidogenesis, all experiments were performed in the next building of palm oil refinery. High concentrations of suspended solids (SS) in the POME can lead to problems, such as producing scum and clogging (Latif et al., 2011). The residual oil in the POME also causes a problem in anaerobic treatment by coating the surface of anaerobic granule. In this study, in order to avoid these problems, the raw POME was pretreated by a screw decanter to remove the SS and residual oil. Thus, considerable amount of SS (around 90%) was removed. The characteristics of the POME are presented in Table 1. The suitable ratio of COD:N:P in anaerobic digestion was reported to be 300–500:5:1 (Annachhatre, 1996). Since the pretreated POME in this study had an appropriate content of nitrogen and extra surplus content of phosphorous, the addition of nutrients during treatment was not necessary.

2.2. Reactor design and configuration

The schematic diagram of experimental set-up is shown in Fig. 1. Exactly the same set-up was used to operate the anaerobic treatment at two different temperatures: 37 °C and 55 °C. The feed flows were closely controlled to maintain same OLR using one peristaltic pump with silicon tubes (I.D. 8 mm, Masterflex®). The primary reactor, AHR, was made from acrylic resin so as to have a volume of 3 l (H: 60 cm × I.D. 8 cm). The upper zone (20% of reactor volume) of AHR was filled with media (Tri-pack, polyethylene, diameter: 1 in., surface area: 85 ft^2/ft^3, specific gravity: 0.95, volume void space: 90%, Solmaro Trading & Engineering Company, South Korea) for tri-phase separation as well as prevention of washout. The surge tank (H: 20 cm × I.D. 5 cm) with a volume of 0.4 l was located next to AHR in order to recycle the accumulated VSS to the AHR again. The recycle flow rate was maintained consistently 30 times of influent flow rate for mixing of AHR. The secondary reactor, ABF was made from acrylic resin with a volume 1.5 l (H: 30 cm × I.D. 8 cm). The vertical baffle (H: 20 cm) in ABF forces the POME to flow under and over to improve the degradation. 80% of ABF volume was filled with the same media of AHR. All reactors except the surge tanks were equipped with water jacket to keep constant the temperatures (37 °C or 55 °C).

2.3. Inoculum

The mesophilic seed slurry was acquired from a brewery in South Korea. The total suspended solids (TSS) and volatile suspended solids (VSS) of slurry containing granule were 53–59 g/l and 33–35 g/l, respectively. The mesophilic seed slurry was used directly for the initial thermophilic start-up. After failure of the start-up, the seed slurry had been re-circulated at 55 °C for 4 weeks without any feed for its acclimation to thermophilic conditions. After filling the reactors with fresh water, anaerobic reactors, except surge tanks, were inoculated with the seed slurry: 0.9 l (30% of the reactor volume) for AHR and 0.225 l (15%) for ABF.

2.4. Experimental method

The OLR was increased incrementally from 2 to 15 kg [COD]/m^3/d in consideration of the criteria for steady states suggested by Wu et al. (2000). The inflow rate was fixed to 0.73 and 0.77 l/d the OLR of 2–4 and 6.5–15 kg [COD]/m^3/d, respectively. The total hydraulic retention time of combined systems were 5.8

Table 1
The characteristics of the POME used in this study.

Parameter	Fresh POME	Pretreated POME
pH	3.7–4.4	3.7–4.3
COD	71,800–98,000	58,480–59,520
Total suspended solids	25,380–34,900	3,400–3,860
Volatile suspended solids	22,820–27,910	2,040–2,536
Total nitrogen	570–1,120	380–880
Total phosphorus	628–2,370	182–1,200

Note: All parameters are in mg/l except pH.

Please cite this article in press as: Jeong, J.-Y., et al. Performance comparison between mesophilic and thermophilic anaerobic reactors for treatment of palm oil mill effluent. Bioresour. Technol. (2014), http://dx.doi.org/10.1016/j.biortech.2014.04.007