International Biodeterioration & Biodegradation 95 (2014) 89–92

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

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

Performance evaluation of a field-scale pilot bioreactor for anaerobic treatment of palm oil mill effluent

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ARTICLE INFO

Article history:
Received 15 January 2014
Received in revised form
1 May 2014
Accepted 3 May 2014
Available online 24 May 2014

Keywords:
Anaerobic treatment
Hybrid reactor
Combined system
Start-up
Palm oil mill effluent
Field-scale

ABSTRACT

A combined system of anaerobic reactors was applied in a field-scale pilot bioreactor to treat palm oil mill effluent (POME) from the Amagra palm plantation in Sumatra Island, Indonesia. The initial start-up of this system failed due to shock loads of suspended solids, organics, and flow rates. After adjusting for influent conditions and operation variables, the second start-up successfully proceeded, where 70% of chemical oxygen demand (COD) was removed at 6 kg m^{-3} day^{-1} of the organic loading rate. Nutrients such as N or P were not added. An addition of alkalinity was made at the initial start-up and later found to be not necessary because amino and fatty acids were rapidly removed in this high rate system.

1. Introduction

Palm oil is a valuable resource in tropical areas, particularly in Indonesia and Malaysia. Approximately 80% of palm oil is used for food purposes. Over the past three decades, there has been a significant growth in the global consumption of vegetable oil. Palm oil production involves the generation of a huge amount of highly concentrated organic wastewater called palm oil mill effluent (POME). Treatment of POME still depends greatly upon a conventional pond system that consists of anaerobic and facultative ponds followed by polishing ponds. Open digesting tanks are also frequently adopted due to their convenience in removing scum and bottom sludge (Najafpour et al., 2006). In both methods, methane gas is released directly to the atmosphere, which produces serious concerns for global warming due to POME (Yacob et al., 2005). In addition, the infiltration of untreated POME of high organic content into surrounding water has caused serious water pollution problems (Wu et al., 2010).

Closed anaerobic digesters are very effective in preventing greenhouse gas emissions. There has been great improvement in developing high rate anaerobic reactors. The most successful processes are upflow anaerobic sludge blanket (UASB) reactors and anaerobic filters (AF). The disadvantages of these reactors are washout of sludge in UASB and clogging in AF (Wu et al., 2000; Bodkhe, 2008). Hybrid reactors have also been developed, combining the advantages of both reactors. Recently, a combined system of an anaerobic hybrid reactor (AHR) with an anaerobic baffled filter (ABF) was developed. A laboratory pilot of this system was used to investigate its applicability for POME treatment and proved its effectiveness and stability in treating highly concentrated organic waste (Choi et al., 2013). One of the drawbacks in anaerobic treatment is the difficulty of start-up (Yacob et al., 2006). Start-up of an anaerobic reactor takes a longer time due to the low growth yield of microorganisms.

Recently, research has been done on the anaerobic digestion of POME. However, only a few studies are available for the field application of high rate anaerobic reactors to POME. In this study, a combined system of AHR and ABF was scaled up to a field-scale pilot bioreactor to treat 16 m^3 day^{-1} of 55000 mg L^{-1} of POME. The field pilot was constructed in a palm oil mill plant in Sumatra Island, Indonesia. The objective of this study was to investigate the performance of the combined system at a field scale for anaerobic high rate treatment of POME, especially at the start-up period.

2. Materials and methods

2.1. Palm oil mill effluent

Raw POME from the Amagra palm plantation in Sumatra Island, Indonesia was examined to contain 4–5% of total solids (TS), 2–4%

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http://dx.doi.org/10.1016/j.ibiod.2014.05.005
0964-8305/

Table 1
Characteristics of the POME used in this study.

Parameters	Value
pH	4.0–5.6
COD (mg L^{-1})	32,300–63,200
TSS (mg L^{-1})	2,060–24,720
VSS (mg L^{-1})	2,040–20,360
T-N (mg L^{-1})	380–880
T-P (mg L^{-1})	182–1,500

suspended solids (SS), 0.6–0.7% of residual oil and 95–96% of water. High concentrations of SS and oil can cause serious operational problems such as excessive scum build-up and clogging in high rate anaerobic treatment processes (Latif et al., 2011). The raw POME was pretreated using a three-phase screw decanter. Table 1 shows the characteristics of the pretreated POME. Further treatment using air flotation was also performed to prevent scum build-up. When the pH in AHR decreased below 5.5, $NaHCO_3$ was added at the rate of 250 mg L^{-1} at the beginning of start-up. No nutrients such as N or P were added.

2.2. Reactor design and configuration

A schematic diagram of the field-scale reactor used in this research is shown in Fig. 1. Anaerobic processes consist of a primary reactor (AHR) and secondary reactor (ABF). The AHR was made of reinforced concrete with internal epoxy coating to have an octagonal pillar shape, of which the volume was 60 m^3 (height, 8.6 m; cross sectional area, 7 m^2). The upper zone of the AHR was packed with Tri-Pack media up to a depth of 2.6 m from the top (polyethylene, Solmaro Trading & Engineering Company, South Korea; diameter, 3.5 in; specific gravity, 0.95; specific area, 38 ft^2 ft^{-3}; porosity, 95%). The surge tank was placed just after the primary reactor to recycle the effluent. Recycling for AHR was intended to improve buffering capacities for pH and shock loads.

The second reactor was made in the same manner to have half of the volume of the primary reactor (volume, 30 m^3; height, 7.64 m; cross sectional area, 4 m^2). The ABF was designed to have a longer flow path using a vertical baffle. The ABF was packed with the same Tri-Pack from the top to a depth of 5.32 m (70%, H H^{-1}).

Fig. 2. A picture of the field pilot located in Riau province of Sumatra Island, Indonesia.

Generated biogas flowed through water traps to prevent back-flow of gas. The height of the trap was about 50 cm, and then biogas flowed to a dry desulfurizer. The desulfurizer was filled with a powdered activated carbon to adsorb H_2S gas generated from the reactors. A front view of the high rate anaerobic reactors (HRARs) system in Indonesia is shown in Fig. 2.

2.3. Start-up and experimental methods

The reactors were operated at mesophilic temperatures between 32 and 37 °C. Organic loading rates (OLR) to the reactors were altered by changing the flow rate (Table 2). A step at the same OLR lasted from 6 to 55 days. The intended OLR at the same step was not maintained due to fluctuations in water quality of the POME from the field. A slurry of mesophilic anaerobic granules from a UASB reactor in a brewery plant in South Korea was seeded as 5 m^3 for AHR and 1 m^3 for ABF. Chemical oxygen demand (COD) concentrations were measured using the reactor digestion method (HACH, method 8000, range: 20–1500 mg L^{-1}). Total suspended solids (TSS) and volatile suspended solids (VSS) were measured

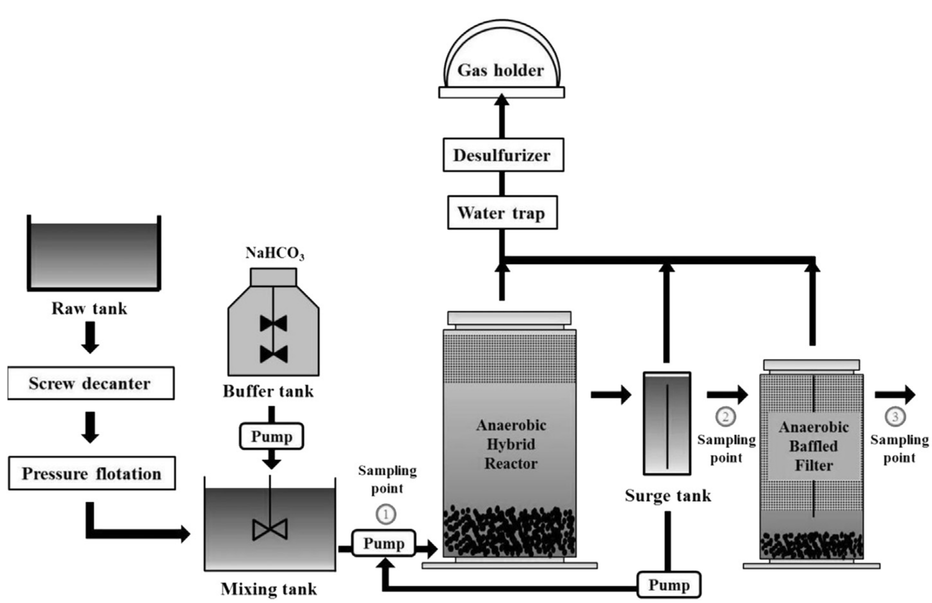

Fig. 1. Schematic of the field pilot, showing the anaerobic reactors combined with AHR and ABF to treat POME.