Journal of Environmental Management 146 (2014) 217–225

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Treatment of agro based industrial wastewater in sequencing batch reactor: Performance evaluation and growth kinetics of aerobic biomass

J.X. Lim, V.M. Vadivelu*

School of Chemical Engineering, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Penang, Malaysia

ARTICLE INFO

Article history:
Received 7 April 2014
Received in revised form
18 July 2014
Accepted 21 July 2014
Available online

Keywords:
Biological treatment
Sequencing batch reactor
Palm oil mill wastewater
Growth kinetics
Aerobic biomass

ABSTRACT

A sequencing batch reactor (SBR) with a working volume of 8 L and an exchange ratio of 25% was used to enrich biomass for the treatment of the anaerobically treated low pH palm oil mill effluent (POME). The influent concentration was stepwise increased from 5000 ± 500 mg COD/L to 11,500 ± 500 mg COD/L. The performance of the reactor was monitored at different organic loading rates (OLRs). It was found that approximately 90% of the COD content of the POME wastewater was successfully removed regardless of the OLR applied to the SBR. Cycle studies of the SBR show that the oxygen uptake by the biomass while there is no COD reduction may be due to the oxidation of the storage product by the biomass. Further, the growth kinetic parameters of the biomass were determined in batch experiments using respirometer. The maximum specific growth rate (μ_{max}) was estimated to be 1.143 day^{-1} while the half saturation constant (K_s) with respect to COD was determined to be 0.429 g COD/L. The decay coefficient (b_D) and biomass yield (Y) were found to be 0.131 day^{-1} and 0.272 mg biomass/mg COD consumed, respectively.

1. Introduction

Various effluent treatment schemes have been proposed and used to treat palm oil mill effluent (POME). Although many studies on physical–chemical methods (such as membrane separation, adsorption and coagulation–flocculation treatments) for the treatment of POME have shown great performance, previous works have been limited to the laboratory scale (Ahmad et al., 2009; Chaiprapat and Laklam, 2011). The application of these treatments in industry is limited due to the high equipment cost and mechanical energy consumption required for treatment. Thus, more than 85% of POME is treated by biological systems (Jalani et al., 2000). Generally, biological treatment carried out in open pond system which consists of an anaerobic ponds followed by an open tank digester, coupled with extended aeration in the pond to further reduce the amount of COD (Poh and Chong, 2009).

The open pond system used in the treatment of POME possesses several drawbacks, including its requirement of large land area, poor sludge settling ability, the sensitivity of biomass to temperature and pH changes and the emission of unpleasant odor (Poh and Chong, 2009). Furthermore, the biological treatment pond for POME has a relatively high hydraulic retention time (HRT) of approximately 10–120 days (Igwe and Onyegbado, 2007). Considering the amount of POME generated during this period, effective treatment requires a very large land area to contain the wastewater. Additionally, the biomass in the aerobic pond needs an adequate supply of oxygen in order to effectively degrade the organic contents of POME. Therefore, the depth of the pond must be shallow so that oxygen can penetrate to the bottom of pond to ensure effective treatment. Thus, the overall area of the pond needs to be increased to compensate for the loss of depth (Henze et al., 2008). Due to the large size and configuration of the treatment ponds, it is difficult to control and maintain the efficiency of the treatment process.

In addition to the problem of the large land area required, conventional biological pond systems tend to have a poor separation between the treated effluent and biomass (Liu et al., 2003). The flush-out of biomass from the treatment system reduces the treatment efficiency and can affect the ecosystem of the effluent receiving water bodies. Therefore, bioreactors such as the upflow anaerobic sludge blanket reactor (UASB) or the UASB integrated with upflow fixed film (UFF) have been used to improve the separation of solid (biomass) and liquid (treated effluent) (Borja and Banks, 1994). Besides, due to the acidity and unique composition of POME, biological treatment systems' performance is variable, leading to inconsistent effluent quality. To improve the

* Corresponding author. Tel.: +60 4 5996460; fax: +60 4 5941013.
E-mail address: chvel@usm.my (V.M. Vadivelu).

http://dx.doi.org/10.1016/j.jenvman.2014.07.023
0301-4797/

performance of biological treatment, POME usually undergoes a neutralization process before being transferred to the biological treatment system. The use of additional chemicals might increase the operating cost of the treatment system.

Alternatively, the sequencing batch reactor (SBR) has gained the attention of researchers studying POME treatment due to its proven performance in treating both domestic and industrial wastewater. SBR technology has been reported to achieve organic carbon, phosphorus (P) and nitrogen (N) removal and, in some cases, biological removal of heavy metals (Pijuan et al., 2004; Sirianuntapiboon and Hongsrisuwan, 2007). Owing to its flexible reactor operation, highly effective performance and relatively reduced land area requirement, SBR technology is being used increasingly for the biological treatment of industrial wastewater. The viability of the utilization of SBR for POME treatment was investigated in some works and achieves high percentage of COD removal (Chaiprapat and Laklam, 2011; Chan et al., 2010; Gobi and Vadivelu, 2014). Detailed studies of the aerobic biomass treating POME in an SBR, however, have not yet been performed. Therefore, the performance of the biomass and growth kinetics involved in the aerobic treatment of POME using an SBR was investigated in the present study.

2. Materials and methods

2.1. Palm oil mill effluent and seed sludge

The POME used in this study was collected from the anaerobic pond of Elegant Palm Oil Mill, Bagan Serai, Perak and stored in a cold room at a temperature of 4 ± 1 °C. The required volume was warmed to room temperature (28 ± 2 °C), filtered to remove debris and diluted to the desired concentration using tap water before it was fed into the SBR. The seed sludge was obtained from the aerobic pond of the same palm oil mill.

2.2. Reactor setup and operation

A 10 L SBR with an effective working volume of 8 L was used to enrich the biomass. The SBR operates in a 6-h cycle with 4 phases: filling (10 min), aerobic reaction (340 min), settling (1 min) and decanting (9 min). In each cycle, 2 L of POME were fed into the reactor for an HRT of 1 day. The reactor was operated at room temperature (28 ± 1 °C), and the pH was not controlled. The DO concentration in the reactor was maintained within the range of 4.0–5.5 mg/L with an ON/OFF controller. The acidic POME was the only feed to the reactor, and the pH of the wastewater was not adjusted. The feed concentration to the SBR was increased stepwise from 5000 ± 500 mg COD/L to 11,500 ± 500 mg COD/L.

The operation of the POME treatment using the SBR was monitored by long-term reactor performance and weekly cycle studies. Liquid and solid mixture samples were taken from the SBR to evaluate the performance of the reactor. The performance of the SBR was determined on the basis of COD removal as well as biomass concentration (MLVSS) and sludge volume index (SVI).

Analytical determinations of COD and SVI were carried out in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA, 2012). Mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) were determined according to Standard Methods 2540E.

3. Growth kinetic parameters determination

The biomass from parent SBR operating under steady state condition (stable MLVSS concentration, constant COD removal and repeatable cycle profiles) treating POME with the influent COD concentration of 5000 mg/L was used to evaluate the growth kinetic parameters. Batch experiments were carried out using respirometer (BM-Advance, Surcis). The data collected were analyzed using mathematical equation to determine the growth kinetic parameters, namely, maximum growth rate, half saturation constant, biomass yield and decay coefficient. Each of the experiments was repeated at least three times in order to calculate the mean values and the standard deviation.

3.1. Determination of decay coefficient (b_D)

At the beginning of each batch test, the respirometer was filled with a known amount of mixed liquor (consisting of biomass) taken from parent SBR (just before the settling phase to ensure there is no remaining soluble COD from the feed) and filled with distilled water to give a total operating volume of 1 L. Samples were taken to determine the initial biomass and COD concentration in the reactor. The DO concentration of the respirometer reactor was maintained within 4.0–5.5 mg/L. The batch test was conducted for a period of 6 h and samples were taken out at an interval of 30 min for COD concentration measurement. DO concentrations throughout the test were measured and OUR was calculated. The value of decay coefficient (b_D) can be obtained by performing calculation on the change of oxygen uptake rate (OUR) over time.

In a batch bioreactor where there is only biomass with no soluble substrates input, the usage of oxygen is solely due to the decay of biomass. Hence, the correlation between OUR and decay can be stated as in Equation (1) (Grady et al., 2011):

$$\mathrm{OUR_D} = (1 - f_D) \cdot b_D \cdot X_{H,t} \tag{1}$$

where $\mathrm{OUR_D}$ = oxygen uptake rate due to biomass decay; b_D = decay coefficient of biomass; $X_{H,t}$ = MLVSS concentration at t time; f_D = fraction of active biomass contributing to biomass debris.

The OUR change over time at a prolonged cultivation period (where all the biodegradable soluble COD is completely consumed) with no addition of external substrate is considered as the endogenous respiration (Grady et al., 2011). The decrease of respiratory oxygen uptake with time corresponds to the decay of the biomass since there is no substrate supplement for the growth of biomass. By performing a mass balance on the active biomass in the bioreactor at this stage, the changes of biomass due to time are stated in Equation (2):

$$\frac{dX_H}{dt} = -b_D \cdot X_H \tag{2}$$

$$\int_0^{X_{H,t}} \frac{1}{X_H} dX_H = \int_0^t -b_D dt$$

$$\ln\left|\frac{X_{H,t}}{X_{H,0}}\right| = -b_D t$$

$$X_{H,t} = X_{H,0} \cdot e^{-b_D t} \tag{3}$$

By substituting Equation (3) into Equation (1), the resultant Equation (4) is obtained:

$$\mathrm{OUR_D} = (1 - f_D) \cdot b_D \cdot X_{H,0} \cdot e^{-b_D t} \tag{4}$$

By performing log natural on both sides of Equation (4) and rearranging the oxygen uptake rate as function of time can be defined as in Equation (5) (Grady et al., 2011):