Bioresource Technology 172 (2014) 461–466

Contents lists available at ScienceDirect

Bioresource Technology

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

Short Communication

Anaerobic digestion of municipal wastewater sludges using anaerobic fluidized bed bioreactor

Nizar Mustafa [a], Elsayed Elbeshbishy [b], George Nakhla [a,c,*], Jesse Zhu [c]

[a] Department of Civil and Environmental Engineering, University of Western Ontario, London, Ontario N6A 5B9, Canada
[b] Department of Civil and Environmental Engineering, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada
[c] Department of Chemical and Biochemical Engineering, University of Western Ontario, London, Ontario N6A 5B9, Canada

HIGHLIGHTS

- Performance of AnFBR for treating primary and waste activated sludges was evaluated.
- Different organic loading rates (OLRs) ranged from 4.2 to 93 kg/m^3-d were evaluated.
- 70% solids destruction of primary sludge was achieved at OLR of 19 kg/m^3-d.
- 56% solids destruction of waste activated sludge was achieved at OLR of 8 kg/m^3-d.
- First-order coefficient for primary sludge was higher than waste activated sludge.

ARTICLE INFO

Article history:
Received 7 July 2014
Received in revised form 16 September 2014
Accepted 17 September 2014
Available online 28 September 2014

Keywords:
Anaerobic digestion
Fluidized bed bioreactor
Primary sludge
TWAS

ABSTRACT

The anaerobic digestion of primary sludge (PS) and thickened waste activated sludge (TWAS) using an anaerobic fluidized bed bioreactor (AnFBR) employing zeolite particles as the carrier media was investigated at different organic loading rates (OLRs). PS was tested at OLRs from 4.2 to 39 kg COD/m^3-d corresponding to hydraulic retention times (HRTs) from 1.0 to 8.9 days. The highest COD removal and VSS destruction efficiencies for primary sludge of 85% and 88%, respectively, were achieved at an HRT of 8.9 days and OLR of 4.2 kg COD/m^3-d. For TWAS, VSS destruction efficiencies varied from 42% at an HRT of 2.6 days and OLR of 13.1 kg COD/m^3-d to 69% at an HRT of 8.8 days and an OLR of 4.2 kg COD/m^3-d. The first-order COD biodegradation rates in the AnFBR for PS and TWAS were 0.4 d^{-1} and 0.1 d^{-1}, respectively, almost double the rates in conventional high-rate digesters.

1. Introduction

The primary challenge associated with the anaerobic treatment of biosolids in conventional systems is the slow rate of biodegradation not only requiring very long retention times and large reactor volume but also achieving low solids destruction efficiencies (Bunrith, 2008). The common low rate digestion system is continuously stirred tank reactor (CSTR), and high rate systems are upflow anaerobic sludge bed (UASB), expanded granular sludge bed (EGSB), fluidized bed bioreactor (FBR), anaerobic membrane bioreactor (AnMBR) (De Mes et al., 2003). Although high rate anaerobic digesters such as UASB, AnMBR, EGSB, and FBR are not suitable for high solids or thickened wastes, high rate systems can be used as a part of multi-stage system for treating high solids wastes (Angelidaki et al., 2003). Typically conventional completely mixed anaerobic digesters (CAD) treating municipal wastewater sludge have solids retention times (SRT) of 15 days or more and are characterized by relatively low organic solids destruction efficiencies of less than 50%. Grady et al. (1999) observed that a lower SRT limit of 10 days at a temperature of 35 °C is sufficient to ensure an adequate safety factor against washout of the methanogenic population, and incremental changes in volatile solids destruction are relatively small for SRT values above 15 days. Fluidized bed reactors have been used as a substitute for the conventional bioprocesses in various biotechnological applications e.g. fermentation, production of enzymes, and bioconversions (Grady et al., 1999). The structure and physical properties of natural zeolite such as channel and pore cavities, high specific surface area, low bulk density, high exchange (CEC) and adsorption capacities make it ideal for use in biological purification wastewater processes (Christidis, 1998; Wong and Yeung, 2007; Carretero and Pozo, 2009; Marty et al., 2010; Park et al., 2010). Consequently, the use

* Corresponding author at: Department of Civil and Environmental Engineering, University of Western Ontario, London, Ontario N6A 5B9, Canada.
E-mail address: gnakhla@eng.uwo.ca (G. Nakhla).

http://dx.doi.org/10.1016/j.biortech.2014.09.081
0960-8524/

of natural zeolite in different wastewater biological treatment processes has increased significantly over the past few years (Montalvo et al., 2012). An Anaerobic fluidized bed reactor (AnFBR) with zeolite as carrier media (425–610 μm) developed by Nakhla and coworkers of the University of Western Ontario (Andalib et al., 2012a), was recently tested for the treatment of stillage with TCOD of 120 g/L and TSS of 60 g/L (Andalib et al., 2012b). The AnFBR showed up to 88% TCOD and 78% TSS removal at organic and solids loading rates (OLR and SLR) of 29 kg COD/m^3 d and 10.5 kg TSS/m^3 d respectively and hydraulic retention time (HRT) of 3.5 days (Andalib et al., 2012b). The main objectives of this study were to test the performance of the AnFBR with more challenging municipal waste e.g., primary sludge (PS) and thickened waste activated sludge (TWAS) and bench-mark it against CAD at the lab-scale. In this study, two anaerobic fluidized bed bioreactors (AnFBR) with zeolite particles as carrier media (610–825 μm) were used to digest municipal wastewater sludge under high OLRs. To the best of the authors' knowledge, this is the first study which evaluated the capability of treating municipal wastewater biosolids in an anaerobic fluidized bed.

2. Methods

The schematic diagram of the mesophilic AnFBR is presented in Fig. 1. The details of the set-up and operation of the lab-scale AnFBR can be found elsewhere (Andalib et al., 2012b). Anaerobic digested sludge (TSS and VSS concentrations of 17,500 and 13,400 mg/L) from the secondary digester was collected from the St. Mary wastewater treatment plant (Ontario, Canada) and used as the seed sludge for the acclimatization of the AnFBRs. The reactors were started by feeding synthetic solution containing 10,000 mg/L acetate and 5000 mg/L glucose, at a flow rate of 3.4 L/d corresponding to a volumetric OLR of 3.2 kg/m^3-d based on the 16 L AnFBR liquid volume. Details of composition of the synthetic feed are presented elsewhere (Andalib et al., 2012a). After the acclimatization period, the PS and TWAS were fed to the AnFBR. The operating conditions for the AnFBR over the course of the study are presented in Tables 2 and 3 for the PS and TWAS, respectively. Samples were analyzed for different water quality parameters such as TSS, VSS, TCOD, SCOD, VFA, and alkalinity and the gas production as well as the gas composition was monitored daily. The analytical techniques of the aforementioned parameters are presented elsewhere (Andalib et al., 2012b).

Attached biomass concentrations (biosolids) were measured using APHA Standard Method No. 2540G (APHA, 1998). Biomass detachment rate constant was calculated using the following equation:

$$\text{Biomass detachment rate constant}(b) = \frac{Q_{\text{effluent}} * \text{VSS}_{\text{effluent}}}{M_{\text{media}} * B_{\text{d}}} \quad (1)$$

where b is the first-order detachment rate constant (d^{-1}), $Q_{effluent}$ is the effluent flow rate (L/d); M_{media} is the mass of zeolite particles (g); and B_d is the attached biofilm concentration (mg/g).

3. Results and discussion

3.1. Performance of AnFBR treating adelaide WWTP primary sludge

Table 2 summarizes the steady-state performance of the AnFBR treating PS over the five testing phases. PS feeding to the AnFBR was started at an OLR of 4.2 kg COD/m^3-d and increased gradually to 19 kg COD/m^3-d to 39 kg COD/m^3-d in Phase IV, prior to reduction to 28 kg COD/m^3-d in phase V. During the first three phases, both COD and VSS removal efficiencies decreased gradually with increasing the OLRs. The VSS removal efficiencies of 88%, 79% and 70% were achieved at OLRs of 4.2, 9.5 and 19 kg COD/m^3-d, respectively. Increasing the OLR to 39 kg/m^3-d in Phase IV resulted in sharp deterioration in performance as evidenced by COD removal efficiency of 30% and VSS destruction efficiency of 31% (Table 3) due to sudden doubling of OLRs. Reducing the OLR to 28 kg COD/m^3-d in phase V resulted in slight improvement in the system performance, with both COD and VSS removal efficiencies increased to 42%. The VFA-to-alkalinity ratio (α) is a widely accepted measure of anaerobic digestion stability (Chen et al., 2007). The steady-state VFA (as acetate)-to-alkalinity ratio (α) were consistently below 0.2 in phases I–IV, although during the transition from one phase to another α increased due to sudden doubling of OLRs. However, in phases IV and V, an increase in α value to 0.5 was observed due to the accumulation of the VFA. The widely variation of α value between 0.29 and 0.41 clearly suggesting that digestion stability at OLR of 28–39 kg/m^3-d was compromised.

3.2. Performance of the AnFBR treating TWAS

The steady-state performance data of the AnFBR treating TWAS is presented in Table 3. The operation of the AnFBR2 was over four phases corresponding to various OLR. In phase I, at an OLR of 4.2 kg COD/m^3-d, COD removal and VSS destruction efficiencies were 68% and 69%, respectively (Table 3). The VSS destruction efficiencies decreased to 56% at OLR of 8.1 kg COD/m^3-d. Increasing the OLR to 13.1–18.2 kg/m^3-d resulted in a sharp a drop in performance as evidenced by COD removal efficiency of 34–42% and VSS destruction efficiency of 33–42% (Table 3). Methane yields ranged from 0.5 to 0.54 m^3/kg VSS destroyed. VFA-to alkalinity ratios (α) were consistently below 0.3 in Phases I and II. However, in Phases III and IV, α values varied more widely between 0.35 and 0.45 clearly indicating that digestion stability at OLR of 13.1–18.2 kg/m^3-d (Phases III and IV) is compromised.

3.3. Volatile solids destruction modeling

In general, volatile solids destruction efficiencies range from 40% to 55% depending on the characteristics of the sludge and the operating conditions such as the HRT, SRT and OLR. The following empirical equation (Liptak, 1974) is applied for high-rate digestion systems, with SRT of 15–20 days.

$$V_{\text{d}} = 13.7\text{Ln}(\text{SRT}) + 18.9 \quad (2)$$

where V_d is the volatile solids destruction efficiency (%) and SRT is the SRT of the system in days. Based on the AnFBR performance, Eqs. (3) and (4) describe the kinetics of VSS destruction efficiency as a function of SRT for PS and TWAS, respectively.

$$V_{\text{d}} = 20.7\text{Ln}(\text{SRT}_{\text{d}}) + 35.4 \quad (3)$$

$$V_{\text{d}} = 17.8\text{Ln}(\text{SRT}_{\text{d}}) + 19.7 \quad (4)$$

Fig. 2 shows the volatile solids destruction as a function of time for both AnFBRs using Liptak equation and the measured volatile solids destruction at each corresponding SRT. It is evident that the Liptak model significantly underestimated the AnFBR performance at all OLRs. Discrepancies between the model and the measured VSS destruction efficiencies varied from 55% of the model to 110% of the model for primary sludge while for TWAS deviations from the model ranged from 3% to 27%. As expected, the first-order VSS destruction coefficient for PS was higher than for TWAS.

3.4. First-order COD degradation rates

Since in a fixed-film process like the AnFBR, determination of SRT is complicated, the COD and correspondingly VSS degradation