Applied Energy 204 (2017) 807–818

Contents lists available at ScienceDirect

Applied Energy

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

Ultrasonically enhanced anaerobic digestion of thickened waste activated sludge using fluidized bed reactors

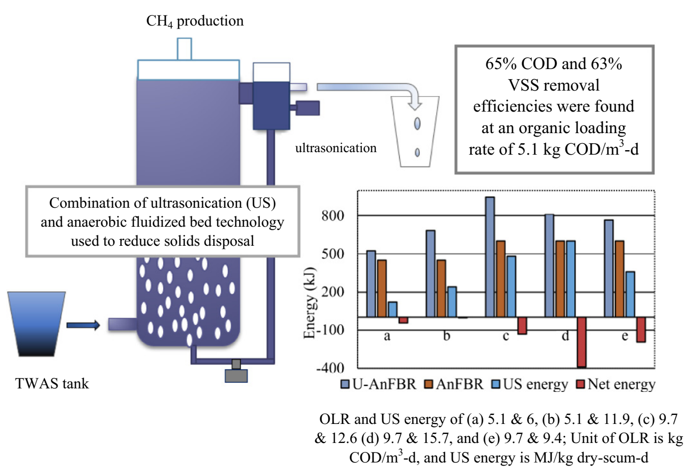
M.M.I. Chowdhury [a], G. Nakhla [a,b,*], J. Zhu [b]

[a] Civil and Environmental Engineering, University of Western Ontario, London, ON N6A 5B9, Canada
[b] Chemical and Biochemical Engineering, University of Western Ontario, London, ON N6A 5B9, Canada

HIGHLIGHTS

- Combination of ultrasonication and anaerobic fluidized bed technology used.
- Ultrasonication significantly reduces disposal and dewatering costs.
- Energy neutrality was observed which reduced 82% of scum.
- 65% COD, and 63% VSS removal efficiencies were noted for the U-AnFBR.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 4 April 2017
Received in revised form 4 July 2017
Accepted 15 July 2017

Keywords:
Anaerobic digestion
Thickened waste activated sludge
Anaerobic fluidized bed reactor
Ultrasonication

ABSTRACT

This study aimed at assessing the impact of ultrasonication on the anaerobic digestibility of thickened waste activated sludge (TWAS) in an anaerobic fluidized bed reactor (AnFBR). Two lab-scale AnFBRs treating TWAS were studied to explore the impact of ultrasonication (US) in the dispersing and reuse of scum for methane production. Our current work applied ultrasound energy at 120–600 kJ/d for 2 s per 30 s corresponding to ultrasonication densities of 6–15.7 MJ/kg dry-scum-d. At an organic loading rate (OLR) of 5.1 kg COD/m^3-d and US energy of 11.9 MJ/kg dry-scum-d, scum decreased by 82% from 20.2 gm/d to 3.7 gm/d, and COD and VSS destruction efficiencies were 65% and 63%, respectively roughly 20% higher than the control reactor without US. Scum reduction varied linearly with US energy about 25 kJ/g TS was required to break the scum. The energy balance also indicated that the aforementioned US energy of 11.9 MJ/kg dry-scum-d was optimum because of energy neutrality. Specific methanogenic activity (SMA) tests showed that the activity-based sludge retention time (SRT) is higher for the ultrasonicated AnFBR (U-AnFBR) (7.1 days) compared to AnFBR (5.1 days). Furthermore, a higher rate of maximum specific biogas production (R_m) was observed in the U-AnFBR of 26.7 ml/gmVSS-hr as compared to 15.7 ml/gmVSS-hr for the control AnFBR, with respective suspended biomass activities of 2 ml/gmVSS-hr and 4.1 ml/gmVSS-hr i.e. confirming that US improved methanogenic activity in the reactor and reduced the detachment of active methanogens.

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

http://dx.doi.org/10.1016/j.apenergy.2017.07.057
0306-2619/

1. Introduction

The use of wastewater biosolids not only opens a window of opportunities for clean, renewable and CO_2 neutral energy source but also minimizes the use of fossil fuels and lessens global warming. Anaerobic digestion (AD) for biogas production from organic waste is one of the most efficient technologies for providing clean and renewable energy and has the potential to reduce greenhouse gas (GHG) emissions [1]. AD technology is able to treat high-strength, wastewaters due to its capability of sustaining higher volumetric loadings, low nutrient requirements, low biomass yield, and additional biogas (hydrogen, methane) production [2]. Additionally, AD can reduce waste volume, enhance nutrient recovery, and simultaneously produce renewable energy as well as reduce treatment cost [3–5]. On the other hand, disposing the thickened waste activated sludge (TWAS) is difficult and expensive. Rather than disposing, TWAS can be an excellent alternative for generating energy since it has abundant carbon and nutrients [6]. However, a serious issue for the broad implementation of anaerobic digestion for biosolids using conventional technologies is its inability to operate at high organic loading rates, and the long hydraulic retention time (HRT) of 20–40 days [7,8]. Additionally, the slow growth rate of the methanogens coupled with the performance fluctuation due to their highly sensitive characteristics remain as major obstacles in anaerobic digestion [9,10]. Anaerobic digestion (AD) of wastewater biosolids is limited by slow biodegradation rates ensuing from slow biomass hydrolysis, and resulting in low solids destruction efficiencies which ultimately necessitate large footprint and high capital costs.

Recently the anaerobic fluidized bed bioreactor (AnFBR) has been successfully demonstrated for biosolids digestion, despite the widely accepted problems of handling high solids in fluidized bed reactors because of its enhanced mass and heat transfer rates, stability under shock loadings, high treatment efficiency at high organic loading rates, and a uniform distribution within the liquid phase [11]. Andalib et al. have investigated the treatability of thin stillage as a by-product of bioethanol production using AnFBR and reported 88% TCOD and 78% TSS removal at very high organic loading rate (OLR) of 29 kg COD/m^3-d, solids loading rate of 10.5 kg TSS/m^3-d, and an HRT of 3.5 days [12]. However, one of the major problems of this technology and conventional digestion systems is the generation of scum in the digester. Wang et al. have found that the scum in the AnFBR was about 6% of dry solids caused operational and maintenance problems, and also reduces overall efficiency [11]. Hence one of the main challenges of AD is the minimization of scum generation in the reactor.

In order to enhance the energy production, effects of combined calcium peroxide (CaO_2) and microwave pre-treatments on the anaerobic digestion of WAS was investigated by Wang and Li and observed that percentage of CH_4 in biogas increased by 25.4% because of the enhanced growth of hydrogenotrophic methanogens (*Methanospirillum* sp.) and acetate-utilizing methanogens (*Methanosaeta* sp.) [4]. Yin et al. have conducted an experiment to evaluate the anaerobic biomethane production potential with enzymatically pretreated mixed sludge and food waste and observed that the bio-methane yield of mixed waste pretreated with fungal mash was found to be 2.5 times higher than activated sludge without pre-treatment [5]. However, utilization of ultrasonication as a pre-treatment have demonstrated success to enhance the methane production [13] as well as digester performance [3,14]. Total methane production, net energy, and energy benefit were observed at 186 mL/g TS (total solid), 6.04 kJ/g TS, and 2.88 kJ/g TS, respectively during the digestion of a mixture of the dairy manure and ultrasonically pretreated wheat straw [13]. An increase of dehydrogenase activity and adenosine triphosphate content by 257%, and 374%, respectively was found when ultrasonication was used in methanogenic granules to evaluate the performance of UASBr [3]. Xie et al. have applied low-intensity ultrasonication at 0.2 W/cm^2 for 10 min in anaerobic sludge and found that the activity of anaerobic sludge was enhanced with a simultaneous 30% increase in organic removal efficiency [15]. However, the aforementioned study investigated an ultrasonic cleaning bath in which anaerobic sludge was taken in a 100 ml serum bottle. The bath had a fixed frequency of 35 kHz and variable power from 0 to 80 W [15]. Application of low strength ultrasound in upflow anaerobic sludge blanket reactor (UASBr, 1 s per min, 0.05 W/ml of US density) successfully enhanced the CH_4 production from brewery wastewater at an OLR of 2 kg COD/m^3-day by 38% and 19% at ambient and mesophilic conditions, respectively [16]. Moreover, in the aforementioned study was applying ultrasonication (2 s per 30 s, 0.0025 W/ml of US density) in a dry digestion system at the same OLR of 2 kg COD/m^3 reported that methane production increased by 40% by decreasing the solids content from 12% to 10% indicating that high solids content reduced the US effect. A different sludge yield was observed in the aforementioned study i.e. 86.1% and 94.3% of the $COD_{removed}$ were converted to CH_4, while the remaining 13.9% and 5.7% were presumably converted to biomass in the control and sonicated UASBr. Elbeshbishy and Nakhla have investigated five different mesophilic systems to evaluate the effect of ultrasonication on the anaerobic biodegradability of food waste and found that sonication inside the reactor showed superior results compared to pretreatment [16]. The aforementioned study reported 67% VSS removal efficiency and a methane production rate of 3.2 $LCH_4/L_{reactor}$d at an OLR of 11.7 kg COD/m^3-d. The aforementioned study reported that methane production increased by 28% at an input energy of 500 kJ/kgTS and that utrasonication was a more effective pretreatment process for hog manure with higher TS content than WAS and primary sludges. Table 1 summarizes the AnFBR performance and the impact of sonication in different treatment.

Based on the above studies, no research so far has explored the combination of US and anaerobic fluidized bed technology to reduce solids disposal. The current work developed a novel anaerobic fluidized bed digestion incorporating ultrasonication for enhanced biogas production due to dispersing and reuse of scum. The main concept was to utilize the high scum COD to enhance overall performance.

2. Materials and methods

2.1. System setup and operation

Two identical lab-scale anaerobic fluidized bed reactors (AnFBRs) one as a control without US and the other with US (U-AnFBR) were used to test the TWAS, as shown in Fig. 1. TWAS from the Adelaide Wastewater Treatment Plant (a single-stage nitrifying wastewater treatment plant with an SRT of 6–8 days), London, Ontario. The plexiglass reactors consisted of a 16-liters liquid volume main anaerobic column (3.6 m height, 8.9 cm long and 5.1 cm width) and a liquid-solids separator (0.9 m height, 18 cm long, and 8 cm width) from which the digested sludge was separated and circulated to the bottom of the AnFBR for fluidization. An ultrasonic cell disrupter (VCX 500, Sonic and Material Inc., Newtown, USA) was installed in upper level at 3.2 m from the bottom of the reactor and 0.2 m below the effluent tube. The ultrasonic Vibracell was supplied by Sonic and Materials, Newtown, USA (model VC-500, 500 W, and 20 kHz). A wet tip gas meter (Rebel wet-tip gas meter company, Nashville, TN, USA) was connected to each reactor at the top of the column for measuring