WATER RESEARCH 66 (2014) 430–446

Available online at www.sciencedirect.com

ScienceDirect

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

High pressure homogenization and two-phased anaerobic digestion for enhanced biogas conversion from municipal waste sludge

Abdullahil K. Wahidunnabi, Cigdem Eskicioglu *

UBC Bioreactor Technology Group, School of Engineering, University of British Columbia, Okanagan Campus, 3333 University Way, Kelowna, BC V1V 1V7, Canada

ARTICLE INFO

Article history:
Received 28 March 2014
Received in revised form
26 August 2014
Accepted 27 August 2014
Available online 6 September 2014

Keywords:
Two-phased anaerobic digestion
High pressure homogenization
Sludge pretreatment
Biogas
Total coliform
Sludge solubilization

ABSTRACT

This study compared advanced anaerobic digestion combining two-phased anaerobic digestion (2PAD) with high pressure homogenization (HPH) pretreatment to conventional anaerobic digestion of municipal sludge at laboratory scale. The study began with examination of thickened waste activated sludge (TWAS) solubilization due to HPH pretreatment at different pressure (0–12,000 psi) and chemical dose (0.009–0.036 g NaOH/g total solids). Homogenizing pressure was found as the most significant factor (p-value < 0.05) for increasing solubilization of particulate chemical oxygen demand (COD) and biopolymers in TWAS. Based on the preliminary results, a pretreatment with chemical dose of 0.009 g NaOH/g total solids and pressure of 12,000 psi was selected for digester studies. Upon acclimation of anaerobic inocula to pretreatments, a total number of twelve lab-scale digesters were operated under scenarios including single-stage (control), 2PAD, and HPH coupled with 2PAD (HPH + 2PAD) at sludge retention times (SRTs) of 20, 14 and 7 days. Between mesophilic and thermophilic temperatures, mesophilic digestion was found to benefit more from pretreatments. Relative (to control) improvements in methane yield and volatile solids (VS) removals increased noticeably as SRT was shortened from 20 to 14 and 7 days. HPH + 2PAD system was found to achieve the maximum methane production (0.61–1.32 L $CH_4/L_{digester}$-d) and VS removals (43–64%). Thermophilic control, 2PAD and HPH + 2PAD systems resulted in significant pathogen removals meeting Class A biosolids requirements according to Organic Matter Recycling Regulations (OMRR) of British Columbia (BC) at 20 d SRT. Energy analysis indicated that all the digestion scenarios attained positive energy balance with 2PAD system operated at 20 d SRT producing the maximum net energy of 4.76 GJ/tonne COD_{added}.

1. Introduction

Population growth and upgrades in wastewater treatment processes to secondary treatment have resulted in production of significant amount of wastewater sludge to be disposed in the environment. Thus waste sludge treatment/disposal has now become a solid waste management challenge. In Canada, more than 0.66 million dry metric tonnes of

* Corresponding author. Tel.: +1 250 807 8544; fax: +1 250 807 9850.
E-mail addresses: cigdem.eskicioglu@ubc.ca, cigdem.eskicioglu@gmail.com (C. Eskicioglu).
http://dx.doi.org/10.1016/j.watres.2014.08.045
0043-1354/

sludge is produced per year and about 6.5 million dry metric tonnes of sludge per year is generated in the United States (Spinosa and Vesilind, 2001), whereas annual sludge generation in the European Union is about 10.0 million dry metric tonnes (Pérez-Elvira et al., 2006). Anaerobic digestion is the most common process exercised for sludge treatment as it not only offers stabilization and volume reduction of sludge for disposal, but also causes the reduction of pathogen and odor potential. In addition, anaerobic digestion does not require oxygen and produces methane, making it less energy intensive process. However, there are scopes for improvement with some aspects of anaerobic digestion. Anaerobic digestion is a multi-step process which involves hydrolysis, acidogenesis, acetogenesis and methanogenesis. Hydrolysis achieves disintegration and conversion of particulate organic matter to simpler substrates such as sugar, amino acids and long chain fatty acids by the extra-cellular enzymes. Usually, hydrolysis is the rate-limiting step in anaerobic digestion of complex particulate waste (Siegert and Banks, 2005) which leads to a higher sludge retention time (SRT) (20–30 d) requirement and low organic matter removal efficiency (30–50%) (Lin et al., 2009). Particularly with waste sludge, waste activated sludge containing extracellular polymeric network (EPS) and microbial cells is resistant to biodegradation. Microbial cell walls prevent extracellular and hydrolytic enzymes from working efficiently in the hydrolysis step of anaerobic digestion (Park et al., 2004). As a consequence, anaerobic digestion results in poor biodegradation and can achieve only 35–45% volatile solids (VS) reduction of the sludge (Gossett and Belser, 1982).

Significant improvement in anaerobic digestion can be achieved by enhancing hydrolysis of sludge through pretreatment techniques (Zheng et al., 2009). Pretreatments aim to increase sludge biodegradability, which results in higher methane production per unit mass of sludge, as well as reduced amount of solids for final disposal. Different types of pretreatments, such as physical, chemical, and biological processes, as well as combinations of these, have been studied so far with various levels of success (Eskicioglu et al., 2007; Appels et al., 2008; Sandino et al., 2010; Strong et al., 2011). Among these pretreatment options, two-phased (acid phase-methane phase) anaerobic digestion (2PAD) has become popular for its ability to produce higher amounts of biogas, better solids reduction (Bolzonella et al., 2012; Riau et al., 2010) and significantly higher pathogen reduction compared to conventional mesophilic digestion processes. 2PAD can include thermophilic–thermophilic or thermophilic–mesophilic acid and methane phase digestion. The latter is commonly known as temperature phased anaerobic digestion (TPAD). Several researchers have demonstrated the potential of TPAD system to produce digestates that meet Class A biosolids requirements (Cheunbarn and Pagilla, 2000; Vandenburgh and Ellis, 2002; Riau et al., 2010). Moreover, the energy requirement is relatively less as it can implement partial thermophilic digestion (Han and Dague, 1997). According to the Land Application Guidelines for the Organic Matter Recycling Regulation (OMMR) and the Soil Amendment Code for Practice by BC Ministry of Environment (OMRR, 2008), biosolids are categorized as Class A or Class B. This classification is based on the quality criteria in terms of fecal coliforms, trace heavy metals and vector attraction (38% or more VS removal). Class A biosolids must contain a fecal coliform density less than 1000 most probable number (MPN)/g of dry total solids or *Salmonella* sp. density less than 3 MPN/4 g of dry total solids (EPA, 1999).

A mechanical pretreatment technique, high-pressure homogenization (HPH), has been reported as a less energy intensive process and can bring improvement in anaerobic digestion performance (Stephenson et al., 2005). HPH involves externally applied pressure on sludge flocs and microbial cells. The homogenizer has a positive displacement air pump which pressurizes the sludge samples through a narrow orifice. The homogenizing pressure is regulated by adjusting the homogenizing valve. The homogenizing valve provides an abrupt pressure drop which causes high fluid shear within the sludge. When the external pressure exceeds the internal resistance of the flocs or microbial cells, the sludge particles break and cell membrane ruptures releasing the intra-cellular substances (Müller et al., 1998; Stephenson et al., 2005; Zhang et al., 2012). A recent study by Sandino et al. (2010) with demonstration-scale HPH plant showed that HPH pretreatment was able to enhance the biogas production by 11–18% over conventional mesophilic mixed sludge digestion at SRTs between 7 and 20 days.

Although combination of two or more different pretreatments is not something new, very few studies have been reported on combination of pretreatments with 2PAD. To the best of our knowledge, being an only study, performance of 2PAD system in combination with microwave pretreatment was investigated by Coelho (2012). However, HPH pretreatment has not yet been studied in combination with a 2PAD system in laboratory or larger scale for municipal sludge digestion. From the literature, both HPH and 2PAD system alone was found to provide enhanced biogas production and VS removal over un-pretreated sludge. The authors of this paper propose a hypothesis that a combined HPH and 2PAD system can achieve higher overall anaerobic digestion performance and net-energy production than HPH or 2PAD alone as it will combine the advantages of both digestion process enhancements. The second hypothesis of this research is that the level of enhancement by pretreatments (HPH and 2PAD) on thermophilic, un-pretreated, single-stage (control) digesters will be less discernable than that of mesophilic digesters as thermophilic controls will already be benefitting from operating at elevated temperatures compared to their mesophilic partners. To validate these hypotheses, this study investigated the effects of HPH and 2PAD systems as separate single pretreatment systems and their combination (HPH + 2PAD) for enhancing anaerobic digestion of municipal sludge.

2. Materials and methods

2.1. *Sludge samples*

Fermented primary sludge (FPS) and thickened waste activated sludge (TWAS) samples were collected from Kelowna Wastewater Treatment Plant (KWWTP), BC Canada. The