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Evaluation of continuous mesophilic, thermophilic and temperature phased anaerobic digestion of microwaved activated sludge

*Nuno Miguel Gabriel Coelho**, *Ronald L. Droste*, *Kevin J. Kennedy*

University of Ottawa, Department of Civil Engineering, Ottawa, Ontario K1N 6N5, Canada

ARTICLE INFO

Article history:
Received 21 September 2010
Received in revised form
5 December 2010
Accepted 25 February 2011
Available online 12 March 2011

Keywords:
Sludge pretreatment
Microwaves
Anaerobic digestion
Thermophilic
Mesophilic
Two-stage digestion

ABSTRACT

The effects of microwave (MW) pretreatment, staging and digestion temperature on anaerobic digestion were investigated in a setup of ten reactors. A mesophilic reactor was used as a control. Its performance was compared to single-stage mesophilic and thermophilic reactors treating pretreated and non-pretreated sludge, temperature-phased (TPAD) thermophilic-mesophilic reactors treating pretreated and non-pretreated sludge and thermophilic–thermophilic reactors also treating pretreated and non-pretreated sludge. Four different sludge retention times (SRTs) (20, 15, 10 and 5 d) were tested for all reactors. Two-stage thermo–thermo reactors treating pretreated sludge produced more biogas than all other reactors and removed more volatile solids. Maximum volatile solids (VS) removal was 53.1% at an SRT of 15 d and maximum biogas increase relative to control was 106% at the shortest SRT tested. Both the maximum VS removal and biogas relative increase were measured for a system with thermophilic acidogenic reactor and thermophilic methanogenic reactor. All the two-stage systems treating microwaved sludge produced sludge free of pathogen indicator bacteria, at all tested conditions even at a total system SRT of only 5 d. MW pretreatment and staging reactors allowed the application of very short SRT (5 d) with no significant decrease in performance in terms of VS removal in comparison with the control reactor. MW pretreatment caused the solubilization of organic material in sludge but also allowed more extensive hydrolysis of organic material in downstream reactors. The association of MW pretreatment and thermophilic operation improves dewaterability of digested sludge.

1. Introduction

Anaerobic digestion is commonly used in wastewater sludge treatment. However, low biodegradability of sludges, particularly waste activated sludge (WAS) is an issue. Hydrolysis is a rate limiting step when degrading this type of complex organic material, and most of the biodegradable material is either enclosed inside the microbial cell wall (Park et al., 2004) or enmeshed in a extracellular polymeric matrix (Neyens and Baeyens, 2003), which further contributes to limit the biodegradability of these sludges to 35–45% reduction in volatile solids (VS) (Bolzonella et al., 2005; Bhattacharya et al., 1996).

Microwaving is a novel method to thermally pretreat sludges that increases digestion efficiency and decreases

* *Corresponding author*. University of Ottawa, Department of Civil Engineering, 161 Louis Pasteur, Room A106, Ottawa, Ontario K1N 6N5, Canada. Tel.: +1 613 562 5766.
E-mail address: nuno.coelho@uottawa.ca (N.M.G. Coelho).
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doi:10.1016/j.watres.2011.02.032

pathogen content. It is an energy efficient method, since it eliminates heat losses that occur in energy transmission in conventional heating. MWs can also provide rapid increases in the inner temperature of bulk liquids, decreasing pretreatment time (Metaxas and Meredith, 1983). Hong (2002) applied MW radiation to different types of sludge in order to check the effect on biodegradability. The effect in solubilizing chemical oxygen demand (COD) was effective in activated sludge since the fraction of soluble COD (sCOD) to total COD (tCOD) increased from 8.5 to 18%. The pretreatment consisted of heating the sludge to a temperature of 70 °C. The increase in this ratio for primary sludge was only 1%. For higher pretreatment temperature (100 °C) the digestion of sludge showed an increase in the amount of methane produced of 23% for primary sludge (PS) and 15% for activated sludge (Hong, 2002). Eskicioglu et al. (2007a,b) investigated the effects of MW intensity, temperature and sludge concentration on the solubilization of WAS (taken from an activated sludge unit operating at 5 d SRT). It was reported that the MW intensity was not a significant factor influencing digestion but temperature of pretreatment and sludge concentration did show an influence on both WAS solubilization and biogas production. Sludge irradiated to 96 °C had a greater production of biogas than sludge irradiated to 75 °C and this sludge in turn produced more biogas than sludge irradiated to 50 °C. Sludge pretreated to 96 °C showed an increase of 20% in biogas production compared to the control in the assays at 3% total solids (TS). For the assays at 1.4% TS the increase in biogas production was 15%. The authors also performed a study based on the ultrafiltration membrane fractionation of the soluble fraction of the pretreated sludge that confirmed that digesters treating high molecular weight materials resulted in smaller biodegradation rate constants. Toreci et al. (2009) tested MW pretreatment at temperatures above the boiling point (175 °C) and reported increase of 31% in biogas production in mesophilic anaerobic digestion compared to controls without pretreatment. The authors noted also the occurrence of inhibition in the early stages of digestion. In previous experiments the same authors reported higher percentages of solubilization of tCOD at MW pretreatment temperatures of 175 °C than those obtained at pretreatment below boiling point (Toreci et al., 2008).

The dual-stage thermophilic/mesophilic process or temperature-phased anaerobic digestion (TPAD) has gained some interest due to the fact that it tries to combine the advantages of thermophilic systems in terms of pathogen control and VS reduction, makes use of process optimization due to staging, and it is still economical to operate because the bulk of the digestion takes place in the mesophilic stage (Han et al., 1997; Sung and Santha, 2003). Some of the reasons proposed to explain better performance of dual-stage TPAD include the setting of optimal conditions for two different bacterial populations (mesophilic methanogens and thermophilic hydrolytic/acidogenic) in terms of pH, temperature and residence time. It is known that the methanogens and hydrolytic/acidogenic bacteria have different optimal pH, and the thermophilic acidogens growth rate is higher than mesophilic methanogens (Kiyohara et al., 2000). Also, some compounds that are inhibitory to methanogenesis such as phenol or unsaturated fatty acids, are less inhibitory after being acidified (Kobayashi et al, 1989). Finally, a lower pH in the first reactor may cause a different distribution of the VFA produced by the acidogenic bacteria, one that includes a smaller proportion of more difficult to degrade VFAs, such as propionate (Breure and van Andel, 1984; Azbar and Speece, 2001).

Very few studies have been published that report the use of pretreatment methods prior to TPAD or two-stage digestion. Toreci et al. (2009) tested high temperature MW pretreatment (175 °C) combined with two-stage mesophilic digestion for three different SRTs (20, 10 and 5 d) with somewhat inconclusive results. Although MW pretreatment alone improved biogas production and VS removal for all SRT in comparison with non-pretreated sludge, and dual-stage digestion alone showed greater biogas production and higher VS removal, MW pretreatment associated with dual-stage digestion did not show any advantages regarding VS removal and biogas production. Variations on the composition of sludge, the type of sludge being tested, viz., the SRT and MW pretreatment process, particularly MW intensity and pretreatment duration, may have interacted and caused the observed results.

The combination of two different techniques or two different pretreatment methods is not original. However, microwaving has not yet been used in combination with other methanization enhancement techniques (either other pretreatment options, or digestor set-ups other than mesophilic single or two-stage). So, there is an interest to evaluate what a novel pretreatment technology that is energy efficient and has proved to increase digestion efficiency can provide in terms of methane production or solids reduction when combined with another pretreatment technique or variations in digestion setup from the conventional mesophilic digestor.

Given the aforementioned results by previous authors and in order to tackle insufficient or nonexistent experience and results with MW pretreatment and TPAD, a set of tests was devised to evaluate the influence of these parameters in global digestion performance.

2. Materials and methods

A total of 10 semi-continuous reactors were setup to study the effect of MW pretreatment, staging, digestion temperature and SRT in process performance. The experimental setup is depicted in Fig. 1.

The reactors used were 1000 mL Schott borosilicate glass bottles, with a useful volume of 800 mL. The reactors were sealed with black butyl rubber stoppers (VWR, Montreal, QC) with two holes: one to sample, waste and feed the reactors and the other to collect and measure the biogas. Biogas was collected in 2 L Tedlar bags. The tedlar bags (Chromatographic Specialties Inc., ON) were equipped with on/off valves and a septum fitting that was used for gas composition sampling. The volume of biogas produced daily was measured using a manometer.

The mesophilic reactors receiving pretreated sludge were inoculated with acclimatized sludge. This sludge was taken from the anaerobic reactors of the Ottawa, ON municipal wastewater treatment plant [Robert O. Pickard Environmental Center (ROPEC)] that digest primary and secondary sludges at