Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

An investigation of ultrasound effect on digestate solubilization and methane yield

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ARTICLE INFO

Article history:
Received 30 October 2016
Revised 4 March 2017
Accepted 12 March 2017
Available online xxxx

Keywords:
Ultrasound
Digestate
Anaerobic digestion
Methane

ABSTRACT

In this study, different ultrasound power intensities of 0.05–0.21 kW/L (4.13–16.52 kW h/kg TS) were applied at a frequency of 20 kHz and for durations of 5–20 min to digestate obtained from a domestic wastewater treatment plant. The ultrasonic effect on digestate solubilization was revealed by increased levels of soluble Chemical Oxygen Demand (sCOD), soluble Total Organic Carbon (sTOC), and soluble Total Nitrogen (sTN) released into the solution. The highest material release was achieved at an ultrasonic energy intensity of 0.21 kW h/L. Furthermore, the ultrasonic effect on CH_4 production was studied using the anaerobic digestion process. The application of ultrasound at 0.05–0.21 kW h/L provided 1.6–2.3-fold increase in net CH_4 production. Analysis of the energetics of the system showed that only about 4 and 11% of the energy input was recovered in terms of additional CH_4 production at 0.21 and 0.05 kW h/L, respectively. A comprehensive cost-benefit analysis of the system is required for making a conclusion on the feasibility of the system, and such analysis should include environmental, economic, and societal benefits of the system, among others.

1. Introduction

The production of sludge is one of the main challenges in the wastewater industry. Some of the challenges include stabilizing the sludge to eliminate unpleasant odor, reducing the water content and sludge volume, reducing the amount of harmful microorganisms, and recovering important nutrients such as nitrogen and phosphorous (Rulkens, 2004). Anaerobic digestion is one of the main methods used for stabilizing the organic matter in sludge. The process has been used for close to a century; however, it still has limitations. One of the key challenges associated with the process is the low extent organic matter mineralization. The process was reported to achieve volatile solids (VS) reductions in the range of 35–50 percent (Tchobanoglous et al., 2003), passing through 50–65 percent of organic matter measured as VS in the resulting digestate – the residue from anaerobic digestion. The quantity of biogas, hence methane, production is also directly related to VS destruction; hence the process underutilizes a valuable fuel source, which is disposed of at landfills.

A number of process modifications had been proposed and implemented to address this challenge, resulting in several types of anaerobic digestion systems – single-stage, multi-stage, fixed-film, low-rate, and high-rate among others. In the last few years, however, more emphasis was placed on improving the biodegradability of the feed sludge, developing proprietary sludge pretreatment technologies. Recent technology innovations in the area include BIODIET®, MicroSludge™, Sonolyzer™, and OpenCEL among others (USEPA, 2006). Some of the methods enhanced the rate of VS destruction, but no significant improvement in the extent of VS destruction and/or in the quantity of biogas production has been achieved. Consequently, some of these technologies were abandoned, although millions of dollars were spent on their development and commercialization or acquisition. Moreover, some companies are left with huge financial obligations for technologies that were implemented at full-scale, but failed to meet performance specifications.

The lack of significant improvement in the extent of VS destruction and/or in the quantity of biogas production has necessitated a closer look at the digestate resulting from anaerobic digestion of sludge. Data on the chemical composition of digestate is scant, however, the limited data available reveals that long-chain organics – palmitic, stearic and oleic acids, lignin, hemicellulose, and cellulose – are the major components of organic matter in digestate (Table 1). Prior studies have shown that these compounds are very difficult to biodegrade (Angelidaki and Ahring, 1995; Kotzé et al., 1969).

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http://dx.doi.org/10.1016/j.wasman.2017.03.021
0956-053X/

Table 1
Some of the relevant physical and chemical characteristics of digestate.

Item	Concentration	Units	Reference
TS	1.5–13.2	%	Makádi et al. (2012), Moller and Muller (2012), and Neczaj et al. (2012)
VS	59.9–77.6	%TS	Neczaj et al. (2012)
pH	7.3–9.0	–	Moller and Muller (2012) and Song et al. (2004)
Alkalinity	5870–7420	mg/L as $CaCO_3$	Song et al. (2004)
Soluble COD	2062–6644	mg/L	Song et al. (2004)
VFA	19–9260	mg/L	Neczaj et al. (2012) and Song et al. (2004)
Organic Matter	55–80	%TS	Moller and Muller (2012)
Palmitic Acid	5.2–22.0	mg/L	WRAP (2013)
Stearic Acid	32.6–71.3	mg/L	WRAP (2013)
Oleic Acid	10.0–13.8	mg/L	WRAP (2013)
Lignin	243–280	g/kg TS	Makádi et al. (2012)
Hemicellulose	42–54	g/kg TS	Makádi et al. (2012)
Cellulose	68–79	g/kg TS	Makádi et al. (2012)
Total N	3.1–18.1	%TS	Makádi et al. (2012) and Moller and Muller (2012)
Total C	36.0–45.0	%TS	Moller and Muller (2012)
Total P	0.6–1.7	%TS	Makádi et al. (2012) and Moller and Muller (2012)
Total K	1.9–4.3	%TS	Makádi et al. (2012) and Moller and Muller (2012)

Considering these facts, the pre-treatment of sludge may not necessarily be effective. This is because pre-treating a sludge mixture, containing about 50% of readily biodegradable organic matter (Williams, 2013), is not efficient since the pre-treatment methods employed are nonselective, *i.e.*, the methods act both on readily biodegradable and non-biodegradable organic matter. We hypothesize that the treatment of digestate can release organic matter into the solution, making them more amenable to anaerobic digestion process. Therefore, the goal of this research is to investigate the feasibility of ultrasound treatment of digestate to enhance methane production. Prior studies have shown that sonication improved solubilization of digestate and its anaerobic digestion (Cesaro et al., 2014; Boni et al., 2016). At pilot-scale and full-scale demonstrations, we envision that the treated digestate can be (a) recycled back to anaerobic digester (AD1) from which it was produced or (b) used as feedstock for another anaerobic digester (AD2); see the schematic representation in Fig. 1.

2. Materials and methods

2.1. Materials

The digestate and inoculum used in the research were collected from San Elijo Water Reclamation Facility (Cardiff By Sea, CA). The digestate was collected before the addition of polymers, which are added to promote sludge particle aggregation for easier dewatering. The inoculum was collected from an anaerobic digester tank operated at 37 °C. The digestate and inoculum were transported to the lab in a cooler with dry ice. The digestate was collected on the same day as the start of the experiment, and it was characterized upon arrival in the lab (Table 2). On the other hand, the inoculum was collected in advance and incubated at 37 °C for a week prior to the start of the anaerobic digestion experiment. It was also degassed daily to avoid the influence of accumulation of gases on the physiology and metabolism of the seed bacteria. The inoculum was also characterized at the end of incubation period by average total solids (TS) content of 12.3 ± 0.31 g/L and VS content of 8.1 ± 0.09 g/L. Chemicals and reagents used in the research were obtained from Fischer Scientific (Pittsburgh, PA) and Sigma-Aldrich Co. (St. Louis, Mo).

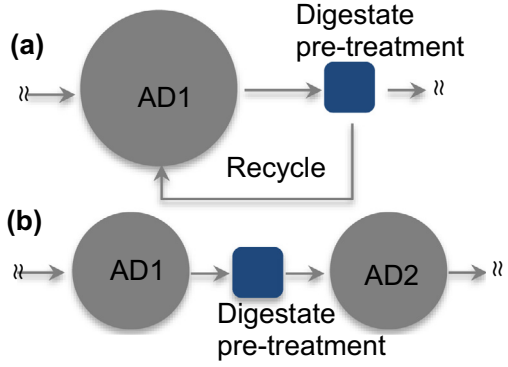

Fig. 1. Integration of digestate pre-treatment with anaerobic digestion [Not To Scale].

2.2. Experimental set-up

2.2.1. Pre-treatment of digestate

Ultrasound treatment of digestate was conducted using a Qsonica Q55 sonotrode system (20 kHz) with a 3.175-mm micro-tip immersed midway in 80 mL of sample in a 100-mL beaker. Treatment was performed at a setting of 100% (55 W) for 5, 10, 15, and 20 min. The temperature of the digestate was monitored using a thermometer to check for overheating (Table 3). After ultrasound treatment, the digestate samples were centrifuged at 10,000*g* for 10 min and then the supernatant was analyzed for sCOD, sTOC, and sTN.

The ultrasonic energy intensity, E_I, was calculated using the following equation:

$$E_I = \frac{P * t}{V}$$

where E_I is the ultrasonic power intensity in kW h/L, p is the power of ultrasound, which is 0.055 kW, t is the sonication time in s, and V is the volume of the digestate in L. In addition, the specific energy, E_S, can be estimated using the following equation:

Table 2
Some of the physical and chemical characteristics of digestate used in the study.

Parameter	Unit of measurement	Average	Std. deviation
pH	–	7.1	0.10
TS	g/L	12.6	0.15
VS	g/L	8.1	0.13
sTOC	mg/L	133.9	3.36
sCOD	mg/L	473.3	17.49
sTN	mg/L	1044.5	13.87
Alkalinity	mg/L as CaCO3	2450.0	50.00

Please cite this article in press as: Garoma, T., Pappaterra, D. An investigation of ultrasound effect on digestate solubilization and methane yield. Waste Management (2017), http://dx.doi.org/10.1016/j.wasman.2017.03.021