Energy Conversion and Management 119 (2016) 444–452

Contents lists available at ScienceDirect

Energy Conversion and Management

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

The effect of ultrasonic pretreatment on biogas generation yield from organic fraction of municipal solid waste under medium solids concentration circumstance

Mazdak Rasapoor [a,*], Yahya Ajabshirchi [a], Mehrdad Adl [b], Reza Abdi [a], Arash Gharibi [c]

[a] Department of Bio System Engineering, University of Tabriz, 5166616471 Tabriz, Iran
[b] Energy Division, Materials and Energy Research Center, 3177983634 Karaj, Iran
[c] Department of Physics, Shanxi Normal University, Linfen 041004, China

ARTICLE INFO

Article history:
Received 22 February 2016
Received in revised form 8 April 2016
Accepted 19 April 2016
Available online 26 April 2016

Keywords:
Ultrasonic
Biogas yield
Anaerobic digestion
OFMSW

ABSTRACT

Hydrolysis is the most rate limiting step in almost all anaerobic digestion systems. To tackle long time duration, ultrasonic pretreatment proved that it can effectively improve biogas yield efficiency by effecting on soluble particles. In this study, the effect of three different ultrasonic power densities (0.2 W/mL, 0.4 W/mL and 0.6 W/mL) at three different times (10 min, 20 min and 30 min) on biogas yield of organic fraction of municipal solid waste (OFMSW) at three different total solid content (6%, 8% and 10%) were analyzed. Results showed significant ($p < 0.01$) effect of both sonication density and time of sonication on biogas final yield and biogas yield after 72 h digestion with the 6% TS content. Parameters like specific energy input and total volatile fatty acid (TVFA) content were also evaluated to find the best sonication treatments for OFMSW. For lower TS contents (6% and 8%), sonication treatment significantly ($p < 0.01$) increased TVFA concentration before digesting. It is also proved that specific energy input between 5000 kJ/kg TS and 10,000 kJ/kg TS can effectively increase the biogas yields, especially for 6% TS content, and caused maximum biogas yield produced after 72 h of digestion.

1. Introduction

Biological treatment represents the main option for the organic fraction of municipal solid waste (OFMSW), especially when collected separately or sorted at the garbage processing facilities [1]. Amongst biological processes, anaerobic digestion, which decomposes organic matter by employing a variety of anaerobic microorganisms into methane and some other inorganic byproducts, is one of the most attractive treatments for OFMSW and nowadays, researchers are very much concentrated on anaerobic digestion systems and procedures, aiming to improve the efficiency and accelerate the process rate [2,3]. Biogas as a main product of anaerobic digestion can be used as fuel to produce heat, as fuel in a combined heat and power plant (CHP plant), and/or as vehicle fuel [4]. Anaerobic digestion process takes place in four main reactions: 1 – hydrolysis: It is the first step of the process. During this phase, the complex organic matter (polymers) is broken down into smaller units (mono- and oligomers). 2 – acidogenesis: The intermediates from the hydrolysis are degraded into acetate, carbon dioxide and hydrogen. 3 – acetogenesis: During this phase, the products from the acidogenesis that cannot be transformed into methane in the next step of the process (long-chain VFA and alcohols) are converted into acetic acid and hydrogen. 4 – methanogenesis: This last step actually runs in parallel to acetogenesis so that the acetic acid and the mixture between hydrogen and carbon dioxide are transformed into methane and either carbon dioxide or water [5–7]. It is generally accepted that hydrolysis is the rate limiting step during anaerobic digestion of OFMSW. Due to the chemical and physical structure of lignocelluloses, their microbial hydrolysis is a slow and difficult process [6]. Therefore, adequate pretreatments favoring disintegration and solubilization of high molecular compounds can effectively improve digestion yield [8].

Ultrasonic pretreatment is no doubt recognized as the most powerful method, if compared with other pretreatments (thermal, acid and bacterial product). Ultrasonic process proved to be the most versatile, as it was effective with different kind of fat-predominant solid substrates, coming from meat processing. During sonication, microbubbles are formed due to high pressure application to liquid [9]. High pressure applications cause a violent collapse and high amounts of energy are released in a small area [10]. Consequently, due to extreme local conditions, some radicals

* Corresponding author.
E-mail address: Mazdak.rasapoor@gmail.com (M. Rasapoor).

http://dx.doi.org/10.1016/j.enconman.2016.04.066
0196-8904/

can form and react with the substances in the water [11]. The main working parameters of sonication are sonication power, sonication frequency and sonication time [12]. Show et al., found that an increase in sonication intensity decreased the main particle size, which indicated further break- up of flocs [13]. An overview on the literature suggests that; reducing the process time of anaerobic digestion and increasing the biogas yield at the same time, are the main objectives of ultrasonic pretreatment. However, ultrasonic treatment is an energy intensive process, which causes great concerns on its practical application [14,15].

The ultrasound-induced structural changes in lignocellulosic biomass depend on the ultrasonication power and duration. Longer ultrasonication times that increased the dissolved carbohydrate concentration depend on ultrasonic power and frequencies. Hay et al., found that excess time of ultrasonication (over 45 min) can cause an inverse effect of final products [16]. These results contribute to particle size changes due to sonication effects. The increase in the particle size at higher sonication time is due to the re-flocculation phenomena between the particles. The flocs are initially reduced but an increased sonication time further induces more release of intercellular polymers due to cell lysis that are favorable for re-flocculation [17–21]. The effect of ultrasonic power density ranges on particle size, hydrolysis and methane generation were studied in scientific literatures. Particle size reduction increased with an increase in sonication densities from 0.22 W/mL to 0.52 W/mL. Mao et al., reported that the hydrolysis rate increased by 19–75% for digesters fed with sonicated sludge at different sonication densities between 0.18 and 0.52 W/mL. Gronoors et al., found that 0.3 W/mL at 30 min time of ultrasonic power density can increase the methane production by 20% compared to the control sample [22].

Scientific literature contains several studies on the impact of ultrasonic pretreatment on biogas yields of sludge, but just in a few studies have the results been obtained using OFMSW. The aim of this research was to investigate the effect of total solids (TS) content, sonication power and sonication time on both biogas yield and biogas generating acceleration. Furthermore, conducting an energy analysis was adopted by the purpose of selecting the most energy efficient approach on performing ultrasonic pretreatment for the OFMSW under the medium TS circumstance (TS between 6% and 10%).

2. Materials and methods

2.1. Inoculum and substrate

Food wastes were acquired from the kitchen of the Institute of Materials and Energy, Karaj, Iran. The materials were shredded and screened to less than 3 mm mesh size after collection for the purpose of improving the matter solubilization and increasing contact with the enzymes [23]. The samples were stored at 4 °C before applying further treatment, as suggested previously [24]. In order to consider the effect of ultrasonic power density, the food waste was diluted with pure water to reach the total solids (TS) content of 6%, 8% and 10%. Inoculum was prepared from an existing anaerobic digestion plant for MSW located in the eastern part of Tehran and incubated at 35 °C until required for the usage in experiments [2]. The food waste to inoculum ratios were adjusted at approximately 0.78 (VS basis) at the beginning of anaerobic process. This ratio was acceptable according to the Haider et al. report. They studied the substrate to inoculum rates between 0.25 and 2 and found that ratios between 0.5 and 1 have the highest cumulative biogas generation [25]. During the experiment, food waste sample analysis performed 9 times, according to number of experiment runs. The characteristics of the food wastes and inoculum are mentioned in Table 1.

2.2. Ultrasonic pretreatment

The ultrasonic pretreatment was carried out with a low frequency (20 kHz) bench lab sonicator, model LABSONIC*P made by Sartorious Stedium®, with a power ranging from 0 to 400 W, equipped with a 14 mm titanium tip as shown in Fig. 1. The mixture to be treated was put in a cylindrical Pyrex beaker with the ultrasonic probe placed in the center and immersed up to 2 cm.

Materials with different total solid contents were treated in 3 ranges of 0.2, 0.4 and 0.6 W/mL in 3 different sonication times, 10 min, 20 min and 30 min. After the ultrasonic pretreatment, materials were prepared for digesting by mixing them with inoculum and putting the mixture into the laboratory bottle digester. Table 2 reports the different levels of treatment parameters.

By combination of each set of three factors and considering the control samples, which includes samples without pretreatments, 36 different treatments were analyzed as triplicates. The specific energy input (SE) required during ultrasonication was calculated according to the following formula:

$$SE = \frac{P \cdot t}{V \cdot TS} \quad (1)$$

where SE is the specific energy input kJ/kg TS, P is the power input (kW), t is the ultrasonication time (s), V is the sludge volume (L), and TS is the total solids concentration (g/L) [26].

2.3. Digester setup

The digesters used in this paper were retrieved from the laboratory scale digesters described in McLeod et al. [27]. The biogas measurement setup shown briefly in Fig. 2 included a small anaerobic digestion reactor, a biogas storage bottle and a liquid displacement bottle. Laboratory glass bottles of 100 mL volume were used as the digester. In order to seal the digester, a silicone rubber sheet was added to the upper region of the laboratory bottle between the cap and gas outlet port. The digesters seeded with the inoculum and then, before fastening the caps, the bottles were flushed with Nitrogen gas (purity: 99.9%) for 2 min to create an anaerobic environment. A laboratory bottle of 1000 mL volume which was filled with water, connected to the 100 mL digester bottle with a connecting silicon rubber tube and then sealed with a silicone rubber sheet like the first one. Due to biogas generation, the pressure inside the 100 mL digester caused water displacement from the

Table 1
General characteristics of the utilized raw materials in AD experiments.

Material		TS content (wt.% wet basis)	VS content (wt.% TS basis)	Total volatile fatty acids at initial (mg/kg wet as CH_3COOH)	Initial pH prior to digestion process
Inoculum	Sample variations	23.7 ± 0.8	41.5 ± 0.6	1150 ± 33	7.21 ± 0.15
Food wastes	Sample variations	18.4–26.3	88.3–94.6	2414.5–5683.5	3.60–4.54
	Mean value	22.7	90.8	4126.7	4.12
	Std. deviation	1.4	1.1	318.3	0.22