Renewable Energy 77 (2015) 550–557

Contents lists available at ScienceDirect

Renewable Energy

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

Effects of thermal pretreatment on acidification phase during two-phase batch anaerobic digestion of kitchen waste

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ARTICLE INFO

Article history:
Received 14 January 2014
Accepted 24 December 2014
Available online 10 January 2015

Keywords:
Thermal pretreatment
Anaerobic digestion
Kitchen waste
Acidification

ABSTRACT

The effect of thermal pretreatment (55–160 °C) on the degradation characteristics of kitchen waste during anaerobic fermentation at medium temperature was investigated. The breakdown of both organics and inorganics and the enhancement of biogas production in batch tests caused by thermal pretreatment during subsequent anaerobic fermentation were examined. Considering the effect of the acidification products and ammonia nitrogen in the acidification phase on subsequent biogas production, the influencing factors and related characteristics of various fermentation types were investigated. The results indicate that thermal pretreatment cannot only promote the anaerobic degradability of KW and the biogas production from KW but can also reduce the retention time necessary for anaerobic acidification by five days. At 50–70 °C and 140–160 °C, the biogas production and organic removal rates of the subsequent anaerobic digestion process decreased slightly, whereas at 90 and 120 °C, superior results were achieved during digestion.

1. Introduction

The production of kitchen waste (KW) in China has risen sharply due to both rapid population growth and the increasing development of the restaurant industry, and numerous harmful effects to the environment may result if this waste cannot be effectively treated and disposed of efficiently. These effects may include surface water pollution, garbage accumulation and odour pollution due to the high organics and moisture content of KW. To follow EHS (Environmental, Health, and Safety) regulations and policies, the final disposal of KW requires thorough sterilisation and effective resource recycling [19].

Alternative processing technologies, such as anaerobic digestion (AD), offer some potential for the recovery of valuable resources and the reduction of organic compounds from organic wastes by producing biogas [9,36]. However, common problems that occur during the conventional AD of KW—problems related to the high oil content and the presence of macromolecular compounds in the waste—include the accumulation of lactic acid at an early stage of the digestion process resulting in a dramatic pH drop [38] and inhibitory levels of ammonia, sulphide and long-chain fatty acids [2,23]; these factors usually diminish and impede digestion stability, thus restricting the application of digestion. In order to relieve inhibition caused by these problems, numerous pretreatment methods, such as chemical and thermal pretreatment [3,4,12,22,28], and new process techniques, such as co-digestion with substrates containing high levels of ammonium nitrogen and alkalinity to compensate for their absence in KW [25,43], have been suggested to improve the properties of organic waste to promote biogas production and the solubilisation of particulate organics.

Two-phase AD may offer an attractive alternative to conventional one-phase anaerobic digestion because it has several advantages over traditional single-phase systems [13,41], such as a considerably shorter detention time [8,16], higher gas conversion efficiency [6,15,21] and higher methane concentration [37,6], either under mesophilic or thermophilic conditions [20]. This process has been researched in numerous fields, including those associated with waste water [24], fruits and vegetables [31], sewage sludge [7,35].), food waste [10], waste paper [40] and dairy manure [13].

Furthermore, recent research has demonstrated that thermal pretreatment prior to anaerobic stabilisation can positively affect the energy balance of the treatment process [4,32], for example, by allowing for a higher processing efficiency and distinct sterilisation

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http://dx.doi.org/10.1016/j.renene.2014.12.056
0960-1481/

effects [33,39], increased gas production [3,18] and reduced retention time [4,26].

However, two-phase AD has rarely been applied by researchers to treat pure KW prior to thermal pretreatment, and studies have mainly concentrated on direct anaerobic digestion and the combined digestion of KW with other biomass waste by adjusting the pH, mixing ratio, retention time and organic loading.

Moreover, in the interest of sustainable and green economic practices, various types of waste heat obtained from boiler steam and flue gas have been appropriated for secondary resource utilisation by the Chinese government in recent years and are already used widely for the drying of sewage sludge in most Chinese cities [17,27].

Therefore, taking into consideration the effects of both thermal pretreatment on the solubilisation characteristics of organic materials in KW in our previous research [5] and relating degradation characteristics at different retention time to evaluate the optimum operating conditions to upgrade the two-phase process, the objective of the current work was to evaluate the effect of thermal pretreatment at moderate temperatures (70, 80 and 90 °C) and high temperatures (120, 140 and 160 °C) on acidification characteristics in semi-continuous sequencing digesters operated at mesophilic temperature (35 °C)by monitoring the content of total solids (TS), volatile solids (VS), ammonia nitrogen (NH_4^+–N), crude protein, crude fat, volatile fatty acid (VFA)and production and composition of biogas under different retention times and organic loadings.

2. Materials and methods

2.1. KW characteristics

KW was collected on a weekly basis from a canteen in Tsinghua University; all materials were mixed using a kitchen blender to ensure uniform representation of the experimental materials and then stored at 4 °C in a refrigerator after being crushed into particles with an average size of 1–2 mm. The major components were carbohydrates derived from bread, cooked noodles and rice; proteins and fat from different types of meat and fish; and various vegetables and fruits. Table 1 shows the basic characteristics of the KW.

2.2. Thermal pretreatment

Thermal pretreatment was performed in a 20-L stainless steel hydrolysis reactor constructed as a pressure vessel with a heating shell. The effects of thermal pretreatment (55, 70, 90, 120, 140 and 160 °C) on anaerobic digestion performance were investigated. The temperature was kept constant by setting the temperature of the thermal fluid circulating through the outer heating shell of the reactor. During the pretreatment, approximately 16 kg kW was transferred into the vessel, which had been preheated to a predetermined temperature. After hydrolysation at this temperature over a preselected period, the heating process was stopped, and samples were then chilled in 10 °C water until the vessel cooled to room temperature; all oil in the supernatant was then removed. After pretreatment, the samples were stored at 4 °C in a refrigerator to minimise the volatilisation of organic compounds before analysis.

$$\text{Degree of solubilisation}(\%) = \frac{\text{Concentration before AD} - \text{Concentration after AD}}{\text{Concentration before AD}} \times 100$$

Table 1
Characteristics of the KW.

Sample	pH	TS (%)	VS (%TS)	C (%)	H (%)	N (%)	S (%)	O (%)
Average value	6.47	18.66	93.64	46.11	6.89	3.19	0.29	37.80
Standard deviation	0.21	0.37	0.46	1.69	0.17	0.34	1.61	0.01

2.3. Anaerobic digestion tests

The evolution of the net accumulated biogas production for KW without thermal pretreatment and for samples with thermal pretreatment at moderate temperature (55–90 °C) and high temperature (120–160 °C), respectively, for durations of 70 min and 50 min was carried out due to the analysis about solubilisation of organic compounds and their biodegradability analysis in Ref. [5]. Digestion experiments of acidification phase were conducted in 5.5-L airtight Plexiglas reactors at 35 °C to determine the acidification characteristics of the raw and thermally treated materials. The seed sludge was obtained from a steady-operation digester at a Gaobeidian waste water treatment plant with two days of gravity sedimentation prior to inoculation. Each digester was fed with a mixture of 14 kg seed sludge and 1 kg kW to enhance the effects of thermal pretreatment. The upper space of each reactor was flushed with nitrogen for at least 3 min to assure the anaerobic conditions and then sealed quickly. In each experimental run, three control digesters were operated. Two blank digesters which contained inoculums only were incubated at the same time to correct for the biogas yield from the inoculums. The digestion experiments were run for 21 days. When the acidification process with different retention time finished, 1 kg materials in the acidification phase was transferred into the methanogenic digester and 14 kg seed sludge was added and the rest procedure was the same as described about acidification of KW. The volume of biogas produced during anaerobic digestion was calculated by a wet type gas flowmeter and then collected in gas bags.

2.4. Analytical methods

Parameters including pH, TS, VS and NH_4^+–N were determined according to the standard methods of the American Public Health Association [1]. VFA was measured according to the procedures described in Ref. [11]. The concentrations of crude protein and crude fat were determined according to the Kjeldahl method and using a Soxhlet device, respectively [29]. The composition of biogas was analyzed by gas chromatography (Agilent 7890A).

3. Results and discussion

3.1. Effects of thermal treatment on KW solubilisation during anaerobic acidification

3.1.1. pH

pH can be described as an indicator of the stability of a digester medium, as it is dependent on the buffering capacity of the digester