Bioresource Technology 146 (2013) 619–627

Contents lists available at ScienceDirect

Bioresource Technology

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

Anaerobic digestion of municipal solid waste composed of food waste, wastepaper, and plastic in a single-stage system: Performance and microbial community structure characterization

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HIGHLIGHTS

- Anaerobic co-digestion food waste, wastepaper and plastic were examined.
- Stable anaerobic digestion of food waste, wastepaper and plastic was achieved.
- The accumulation of ammonium and free ammonia does not inhibit anaerobic process.
- Significant microbial shift was observed during the anaerobic process.
- Co-digestion food waste, wastepaper and plastic were feasible.

ARTICLE INFO

Article history:
Received 3 June 2013
Received in revised form 25 July 2013
Accepted 29 July 2013
Available online 6 August 2013

Keywords:
Anaerobic co-digestion
Municipal solid waste
Microbial diversity
DGGE

ABSTRACT

The performance of municipal organic solid waste anaerobic digestion was investigated using a single-stage bioreactor, and the microbial community structures were characterized during the digestion. The results showed that the biogas and methane production rates were 592.4 and 370.1 L/kg with volatile solid added at the ratio of 2:1:1 for food waste, wastepaper, and plastic based on dry weight. The methane volume concentration fluctuated between 44.3% and 75.4% at steady stage. Acetic acid, propionic acid, and butyric acid were the major volatile fatty acids produced during the digestion process. The anaerobic process was not inhibited by the accumulation of ammonia and free ammonia. The bacterial community was found to consist of at least 21 bands of bacteria and 12 bands of archaea at the steady state. All of the results indicated that the mixture of food waste, wastepaper, and plastic could be efficiently co-digested using the anaerobic digestion system.

1. Introduction

In China, 164.0 million tons of municipal solid waste (MSW) were collected and transported nationwide in 2011 (China, 2012). However, the MSW in China shows distinct compositional characteristics compared with that in developed countries: food waste, instead of paper, accounts for the largest fraction (50%) of MSW, and the moisture levels are significantly higher (typically around 50%, compared with 20–30% in the United States and European countries) (Cheng and Hu, 2010). Meanwhile, the organic fraction of municipal solid waste (OFMSW) is collected and treated along with other non-organic fractions of MSW through landfill and incineration, which account for 79% and 18% of treated MSW, respectively (Liu et al., 2012). Traditional landfill treatment can cause problems such as the generation of heavily polluted leachates (Renou et al., 2008) and the emission of volatile organic compounds and odors (Gonzáleza et al., 2013), which present a significant threat to public health and the environment. From the standpoint of energy recovery, the OFMSW is not composed of hazardous materials but of organic material for energy production. A promising alternative to landfill or incineration of the OFMSW is to apply an anaerobic digestion process for simultaneous waste treatment and renewable energy production.

A number of anaerobic biological systems, such as the single- and two-stage anaerobic bioreactors, have been adapted and developed for the treatment of OFMSW (Bouallagui et al., 2005). The single-stage systems have relatively simple designs and are easy to build and operate. Thus, 90% of full-scale plants in Europe relies on single-stage systems for the anaerobic digestion of organic waste (Forster-Carneiro et al., 2008). During the anaerobic digestion, organic substrates are decomposed in the absence of oxygen

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http://dx.doi.org/10.1016/j.biortech.2013.07.140

via enzymatic and bacterial activities, in which various microbial processes including hydrolysis, fermentation (or acidogenesis), acetogenesis, and methanogenesis occur simultaneously in a single digester (van Haandel and van der Lubbe, 2007).

Numerous environmental factors affect the performance of single-stage anaerobic digesters, such as low pH, ammonia inhibition, and the accumulation of volatile fatty acids (VFAs). The accumulation of ammonia, particularly, could inhibit the activity of microorganisms during the digestion of high-nitrogen organic waste, even at loading rate of 2.0 g volatile solid/L/day (Angelidaki and Ahring, 1993; Chen et al., 2008; El-Mashad et al., 2008). Previous study suggested that by adjusting parameters such as substrate concentration and initial solid loading rate, it could improve the performances of anaerobic digestion (Fernández et al., 2008). Mixing food waste with other organic solid waste such as dairy manure (Li et al., 2010) and green waste (Liu et al., 2009) also improved the digestion of organic wastes. However, no study has evaluated the biogas production potential of OFMSW composing of mixture of food waste, wastepaper, and plastic in a single-stage anaerobic reactor.

The objective of this study is to investigate the feasibility and performance of anaerobic co-digestion of food waste, wastepaper, and plastic in a small-scale and mid-scale single-stage semi-dry anaerobic digester, respectively. The variation of biogas production and composition, VFA concentration, pH values, free ammonia, and soluble organic matter concentration were evaluated in detail. The structure and diversity of the microbial community of the biogas residue slurry were investigated by polymerase chain reaction-denaturing gradient gel electrophoresis (PCR-DGGE) analysis.

2. Methods

2.1. Characterization of feed stocks

The food waste was obtained from a local canteen in Xiamen City, Fujian, China. The wastepaper and plastic garbage bags were provided by a waste recycling site, and were crushed to less than 50 mm. The sludge was employed as inoculums, and it was collected from a local wastewater treatment plant in Xiamen City, Fujian, China. The basic characterization of food waste, wastepaper, plastic, and sludge is shown in Table 1. Total solids (TS) content and volatile solids (VS) content were 18.9% and 90.1% for food waste, 91.0% and 90.7% for wastepaper, 99.3% and 69.7% for plastic, and 23.4% and 89.3% for sludge, respectively. All chemicals used were of analytical grade.

2.2. Co-digestion system

Two different scales experimental apparatus with single stage anaerobic digester system were employed, respectively. The small-scale anaerobic reactors system consisted in a 1.5 L serum bottle closed with a thick rubber cap and sealed with silicone glue. Three outlets were perforated on the cap: one outlet was connected to a water displacement system to measure biogas production. An erlenmeyer flask was connected between the serum bottle and water displacement system to prevent liquid exchange. The other two outlets were used for liquid samples collection. Reactors were kept at thermostatic bath at 37 °C. The horizontal mid-scale anaerobic reactor system consisted of a main reactor body, a temperature control unit, a gas–liquid separator, a gas purification unit, a wet biogas meter, and a biogas analyzer in situ. The main body of the digester was made of opaque rigid polypropylene with a total volume of 500 L. The waste treatment unit consisted of a stirrer to mix the feed stocks, a jacket to maintain the temperature constant, a discharge port, a feed inlet, a sample port, and two biogas exports. The temperature control unit kept the temperature of bioreactor constant by circulating the water between the water feed tank and the jacket. The biogas and condensing water vapor were separated through the gas–liquid separator, and then the biogas flowed to the purification union to remove the hydrogen sulfide produced. Moreover, a wet biogas meter and a biogas collector were connected in turn to the purification unit. The co-digester was operated under mesophilic conditions ($T = 38 \pm 1$ °C) by controlling the temperature of the feed tank.

Table 1
Basic characterization of feedstock.

Item	Type of raw materials			
	Food waste	Wastepaper	Plastic	Sludge
Total solid (wt%)	18.9	91.0	99.3	23.4
Volatile solid (wt%)	90.1	90.7	69.7	89.3
Carbon, C (%)	41.1	41.5	62.0	19.8
Nitrogen, N (%)	3.4	0.24	0.17	2.2
Sulfur, S (%)	0.92	0.18	0.23	2.24
C/N ratio	12.0	172.8	364.9	9.0

2.3. Experiment design

Small-scale experiments were employed to investigate the feasibility of the anaerobic co-digestion of food waste, wastepaper, and plastic at mixing ratio 2:1:1 (bench one) and 1:2:1 (bench two), respectively, in small-scale apparatus. The set-up was as follows: 50 g of food waste, 25 g of wastepaper, and 25 g of plastic for bench one; and 25 g of food waste, 50 g of wastepaper, and 25 g of plastic for bench two on dry basis were placed into the 1.5 L serum bottles as anaerobic reactors, respectively. Then, 300 mL anaerobic digester leachate as inoculum and 480 mL deionized water were transferred into the serum bottles to obtain final TS of 10%. The pH values were adjusted to approximately 7.0 by adding 1 M NaOH solution, and then calcium carbonate at 0.8% of the total weight was added as pH buffer. Triplicate preparations were performed for each serum bottle in the study.

The mid-scale experiment was conducted based on the results of the small-scale experiments. The mixture of 15 kg food waste, 7.5 kg wastepaper, and 7.5 kg plastic on dry basis were added to the anaerobic digester (TS: 10%). The activated sludge was selected as inoculum, and the amount was calculated as 3.5 kg on dry basis. After adding the required amounts of substrate and inoculum, the digester was further filled up to 300 kg with aeration dechlorination of tap water. The pH value was adjusted to about 7.0, and then calcium carbonate at 0.8% of total weight was added as pH buffer. Finally, the digester was started after closing the feed inlet and opening the valve of the exhaust pipe.

2.4. Analytical method

During the anaerobic co-digester run, the biogas yield, composition of biogas, COD, ammonia-N, short chain VFA, and pH values were measured daily. The biogas yield was determined by using a wet gas meter, and the biogas composition was analyzed with an infrared methane gas in situ analyzer (GASBOARD-3200L, Wuhan Sifang Instrument Factory, China). The VFA value was determined via ion chromatography (Model ICS-900, Dionex, USA). The TS, VS, COD, and ammonium-N of the digested samples were determined according to Standard Methods (APHA, 1998). The pH values were measured with a pH meter (PHB-4, Shanghai INESA Scientific Instrument Co., Ltd, China) for biogas slurry without any dilution.