Bioresource Technology 156 (2014) 307–313

Contents lists available at ScienceDirect

Bioresource Technology

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

Semi-continuous anaerobic co-digestion of dairy manure with three crop residues for biogas production

Jiang Li, Luoyu Wei, Qiwu Duan, Guoquan Hu, Guozhi Zhang *

Biogas Scientific Research Institute of the Ministry of Agriculture, Chengdu 610041, China

HIGHLIGHTS

- Semi-continuous co-digestion of wastes under five mass ratios can be operated stably.
- High biogas yields are achievable in mass ratio 5:5.
- Four periods were formed for the digestion.
- The N, P, S, Fe, Co and Ni improved gas production and kept the stability of AD.

ARTICLE INFO

Article history:
Received 19 November 2013
Received in revised form 13 January 2014
Accepted 15 January 2014
Available online 25 January 2014

Keywords:
Semi-continuous anaerobic co-digestion
Crop straw residue
Dairy manure
Mass mixing ratio
Biogas

ABSTRACT

The characteristics of anaerobic semi-continuous co-digestion of dairy manure (DM) with three crop straw residues (SRs), rice straw, corn stalks and wheat straw under five mass mixing ratios (SRs/DM) were investigated. During the anaerobic digestion (AD) process, four periods were identified: startup, first stage of stabilization, second stage of stabilization, and suppression. Following the four periods, the biogas production rate varied between 101 and 576 mL L^{-1} d^{-1}. A high CH_4 content and volatile solid reduction was maintained at the SRs/DM mass mixing ratio 1:9. The highest cumulative biogas production of more than 19 L was obtained at ratio 5:5. However, ratio 9:1 performed worst in the whole process. Systematic analysis of the elements revealed nitrogen, phosphorus, and trace elements contents were important for the AD. Overall, the semi-continuous AD is efficient within a wide range of SRs/DM mass mixing ratios.

1. Introduction

Anaerobic digestion (AD) is a biological process that produces biogas from bio-degradable wastes by microorganism under poor or no oxygen conditions. AD is gaining more attention, not only as a solution to environmental concerns, but also as a potential energy resource for today's energy-demanding life style. China is one of the largest agricultural countries, which produces over 600 million ton of crop straw residues (SRs) every year, ranking first in the world (MOA, 2011). Rice straw (RS), corn stalks (CS) and wheat straw (WS) are the top three crop straw wastes in China and account for 32.3%, 25.0% and 18.3% of the total crop straw output, respectively (MOA, 2011). Thus, making use of these wastes for biogas generation can be quite significant. However, crop wastes cannot be effectively degraded due to an imbalance in nutrients for microorganism and a lack of buffering capacity for the chemical reaction (Babaee et al., 2013). This can often be overcome by co-digestion with livestock manure. Annual yield of livestock manure in China is over 2.1 billion ton, including dairy manure (DM), swine manure, sheep manure and chicken manure (Zhang, 2010). The use of these wastes is a major component for producing renewable energy, and it is suitable for narrowing the gap between the energy requirement of the industrialized world and inability to replenish such needs from the limited sources of energy like fossil fuels.

Studies have been done to improve biogas production from co-digestion of livestock manure and other wastes by AD (Astals et al., 2013; Chen et al., 2013; Saidu et al., 2013). Compared with the digestion of single feedstock, co-digestion increases the biogas production rate because of the better nutrient balance and improvement of AD efficiency. Generally, livestock manure contains a high total nitrogen (TN), which decreases the carbon-to-nitrogen (C/N) ratios of single SRs substrates and is beneficial to co-digestion with SRs. Livestock manure is also helpful to achieve a suitable pH during anaerobic fermentation with the production

* Corresponding author. Address: Biogas Scientific Research Institute of the Ministry of Agriculture, No. 13, 4th Section, South Renmin Rd., Chengdu, Sichuan, China. Tel.: +86 28 85230701.

E-mail address: biomagongcheng2013@hotmail.com (G. Zhang).

http://dx.doi.org/10.1016/j.biortech.2014.01.064
0960-8524/

of ammonia (Ashekuzzaman and Poulsen, 2011). Hence, livestock manure is excellent raw material for anaerobic co-digestion with SRs. As one of the main livestock manure in China, DM has buffering capacity and excess nitrogen nutrients that can support additional carbon conversion of straws to methane gas. In fact, co-digestion, which utilizes various raw materials, such as agricultural waste, animal manure, sewage sludge and food waste, has been extensively applied as an effective waste management and energy production treatment (Ashekuzzaman and Poulsen, 2011; Curcio et al., 2010; De Vrieze et al., 2013; Larsen et al., 2013). However, these studies have mostly been carried out in batch fermentation, and the suitable mixing ratios of multi-component substrates such as SRs and DM are largely unknown. Most previous studies focused only on the effect of C/N ratio in the AD, omitting the analyses of the roles of other important elements, such as phosphorus (P), potassium (K), sulfur (S), iron (Fe), cobalt (Co), and nickel (Ni) in the degradation of substrates (De Vrieze et al., 2013; Podmirseg et al., 2013; Rajagopal et al., 2013; Wang et al., 2013). For example, methanogens need Fe, Co, and Ni to make the methane production feasible (Gustavsson et al., 2011; Uemura, 2010; Zhang and Jahng, 2012; Zitomer et al., 2008).

This study investigated how the different SRs and DM mass mixing ratios affected the biogas-producing efficiency of anaerobic co-digestion in a semi-continuous style. The main strategy was to determine the optimal ratio of SRs and DM, characterize the semi-continuous co-digestion of them, and evaluate the effect of the eight elements (C, N, P, K, S, Fe, Co and Ni) of the substrate on the biogas production.

2. Methods

2.1. Collection and preparation of substrates

SRs and DM were obtained from a local farm in Shuangliu County, Chengdu, Sichuan, China. DM had a total solid (TS) of 18.4%, and was stored at 4 °C. RS, CS and WS were prepared by cutting the residues into sections of 2–3 cm by using a grinder, with a TS of 90.2%, 89.6% and 90.0%, respectively. Inoculum was the anaerobic sludge, was obtained from an anaerobic digester of a sewage plant in Chengdu City, and had a TS of 11.2%, and was also stored at 4 °C. For preservation of more than one week, DM and sludge were stored at −17 °C.

2.2. Experimental design and set-up

The experiment was conducted by using lab-scale anaerobic digesters fabricated from 1 L polycarbonate cups with whorl cover for discharging and feeding flexibly. The cup had nozzle on the cover sealed with rubber stopper, where glass tube were inserted for gas flowing to the collection bottle full of water, forcing the water to be pressed out. Gas volume was recorded by measuring the volume of the drain. In this work, semi-continuous fermentation was used to determine the co-digestion of DM mixed with the three types of SRs. The working volume of each digester was 800 mL, including 91.69 g inoculum and an appropriate mass ratio of SRs and DM. To obtain the best mixing ratio of the co-digestion of DM and the three SRs, five different mass mixing ratios at 1:9, 3:7, 5:5, 7:3 and 9:1 were tested under mesophilic conditions (35 °C) for 47 days. Tap water was added to digesters to maintain a TS content of 8.0%. After 7 days' startup, anaerobic co-digestion was then initiated in a semi-continuous style. All reactors were gently mixed manually for approximately 1 min prior to discharging and feeding, with a conservative organic loading rate (OLR) of 3.2 g L^{-1} every two days, as difficulties were experienced in achieving steady state performance at an OLR of 1.6 g L^{-1} every day. Each treatment was performed in triple replicate to investigate the effect of different mixing ratios on biogas production.

2.3. Analysis and statistics

The amount of biogas produced from each digester was recorded every day by using the water displacement method during the digestion period. Biogas composition (CH_4 and CO_2 contents) was measured using biogas 5000 (Geotech Inc., China). pH was measured using an acidimeter (PHS-3C, DAPU, China). Chemical analysis tests were performed on the substrate of each reactor after the experiment was completed (the same batch of DM, SRs and sludge was used throughout testing). The TS, volatile solid (VS) were analyzed by Hach Method 8271 and 8276. Total carbon (TC), TN, total phosphorus (TP), and total potassium (TK) were determined in accordance with the standard methods for the examination of organic fertilizer of the Chinese agriculture industry standard (MOA, 2012). Total iron (Tfe) was determined according to the microwave digestion – atomic absorption spectrometry method (Xiao, 2006). Total sulfur (Tsu), total cobalt (Tco), total nickel (Tni) content of the samples were determined according to the microwave digestion – ICP-MS method (Wang et al., 2008). In the next step, principal component analysis (PCA) was utilized for the determination of the effect of the eight elements. PCA was performed using the CANOCO for windows 4.5 software. Each semi-continuous experiment was deemed complete when a clearly stable trend in daily biogas volume produced was observed for at least 7 days. ANOVA was performed to determine the significant differences among each treatment by using SPSS version 17.0 (SPSS China Inc.).

3. Results and discussion

3.1. Biogas yields and production rates at different DM/SRs ratios

The daily biogas production by the co-digestion of SRs and DM during 47 days was recorded under five mass mixing ratios (Fig. 1). From Fig. 1, it can be seen that, for all the five mass mixing ratios, the semi-continuous co-digestion of SRs and DM could be divided into four periods: startup, first stage of stabilization, second stage of stabilization and suppression. During the startup period, the biogas production increased rapidly, reaching about 400 mL d^{-1} on day 7, except for ratios of 7:3 and 9:1,which was only about 100 mL d^{-1}. It was suggested that recalcitrant polymers within straws limited their degradation, and the lower amounts of soluble carbohydrates in straws resulted in slow hydrolysis and fermentation. Consequently, ratio 7:3 and 9:1 showed a low daily biogas production during the startup period.

After the feeding at OLR of 3.2 g L^{-1} every two days, the semi-continuous co-digestion of the five ratios went into the first stage of stabilization period, and the biogas production of ratio 1:9, 3:7, 5:5, and 7:3 remained stable around 600 mL d^{-1} for 7 days, which suggested the destruction of substrates. However, after day 22, the gas production of the four ratios decreased to about 400 mL d^{-1} in the second stage of stabilization. On day 32, further decrease was observed, with a gas production of about 200 mL d^{-1} for the four ratios, which indicated the suppression period came, and the experiment was stopped on day 47. In fact, for all the SRs/DM, the mixing ratio 9:1 performed worst, especially in the startup period, with a daily gas production of less than 100 mL d^{-1}. In the first stage of stabilization period, daily gas production of SRs/DM 9:1 increased gradually, but still no more than 200 mL d^{-1}. Interestingly, in the second stage of stabilization period, all the SRs/DM at ratio 9:1 produced gas as much as other ratios, sometimes even more, and it remained in this state until suppression period. This could be explained that the substrate which was not used in the