Energy Conversion and Management 88 (2014) 40–48

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Psychrophilic anaerobic co-digestion of highland barley straw with two animal manures at high altitude for enhancing biogas production

Suzhen Wei *, Hongfeng Zhang, Xiaobu Cai, Jin Xu, Jiangping Fang, Heman Liu

Agricultural and Animal Husbandry College of Tibet University, Tibet Linzhi 860000, PR China

ARTICLE INFO

Article history:
Received 25 April 2014
Accepted 10 August 2014
Available online 2 September 2014

Keywords:
Psychrophilic anaerobic digestion
Biogas
Manure
Highland barley straw
High altitude

ABSTRACT

Biogas production from the co-digestion of highland barley straw (BS) with Tibet pig manure (TPM) and cow manure (CM) was investigated at Tibet plateau under low temperature (15 °C) condition. The effect of inoculum to substrate (*I*/*S*) ratio and BS to manure ratio on the biogas production was studied using a series of batch digesters performed at substrate concentration of 20%, based on total solid (TS). The results showed that biogas production from BS was feasible at low temperature and low air pressure condition. High *I*/*S* ratio (>2/1) and BS to manure ratio of 1/1 could increase the biogas production. Long solid retention time (SRT) (>80 days) was needed for biogas production at low temperature and low air pressure condition. The highest cumulative biogas production obtained from the co-digestion of BS with TPM and CM was 233.4 ml/gVS and 192.0 ml/gVS, respectively. Removal efficiencies of substrate showed that biogas production was correlated with the removal efficiency of water-insoluble volatile solids (IVS) but not with the change rate of soluble chemical oxygen demand (SCOD).

1. Introduction

Anaerobic digestion (AD) is a well-known method for the treatment of organic wastes such as municipal solid waste, sewage sludge, animal manure and crop residues. Properly functioning AD system not only can achieve high biogas production to supply the increasing societal energy demands but also can transform organic waste into high quality fertilizer. AD has been increasingly applied around the world, including in high altitude regions. Until now, only a few studies have focused on the biogas production at high altitude [1–5]. Biogas production at high altitude is associated with some unique characteristics, such as pressure, temperature and feedstock, which need to be well understood [1].

The influence of pressure on biogas production has been investigated by several researchers and their results were not consistent with each other. Hayes et al. [6] reported that a higher pressure in a digester was beneficial for increasing methane content of biogas. Álvarez et al. [1] studied biogas production from manure at high plateau (3000–4000 m altitude) in Bolivia, and estimated that there was little difference between high and low altitudes. Jiang et al. [7] compared the performance of AD of municipal solid waste under 101 kPa and 65.8 kPa, their results showed there was no obvious difference in the methane content but the low pressure reactor had a stronger buffering capacity, lower gas production rate and could achieve a higher loading rate.

Temperature is one of the most important factors that strongly affect the performance of AD. In general, as the anaerobic digester temperature decreases, so do degradation rate and biogas production [8,9]. In literature, most biogas processes were operated at either mesophilic or thermophilic condition. However, the AD at psychrophilic temperature substantially decreases the energy input required for heating the bioreactor and thus greatly reduces the operating cost. Psychrophilic anaerobic digestion (PAD) is increasingly gaining momentum in many parts of the world, especially when PAD was successfully applied [10,11]. At present, the feedstock for PAD generally was organic waste water and some easily degradable solid waste, such as human excreta and animal manure [4,12]. Lignocellulosic waste, due to the resistance to microbial and enzymatic hydrolysis, was little used as feedstock for PAD. One recent study found that biogas production from pure and complex lignocellulosic substrates at psychrophilic conditions (20 °C) was feasible [13]. This information is encouraging and surely warrants further investigation on the biogas production from lignocellulosic biomass like crop waste, which is plentiful around the world.

Due to high carbon content for AD, crop residues are generally co-digested with nitrogen-rich material such as animal manure. Manure is rich in a wide variety of nutrients necessary for optimal bacterial growth. During the co-digestion, manures and crop resi-

* Corresponding author.
E-mail address: weiszh@126.com (S. Wei).

http://dx.doi.org/10.1016/j.enconman.2014.08.018
0196-8904/

Table 1
Characteristics of milled feedstocks and inoculum used in this study.

Particular	TPM	CM	BS	Inoculum
TS (% wet weight)	91.5 ± 2.1	92.8 ± 1.8	94.2 ± 0.9	15.3 ± 1.7
VS (%TS)	52.1 ± 1.3	77.5 ± 1.9	93.6 ± 2.1	61.4 ± 1.4
pH	7.6 ± 0.1*	7.1 ± 0.1*	6.7 ± 0*	7.7 ± 0
SCOD (g/kgTS)	102.3 ± 5.3	52.6 ± 4.9	56.5 ± 5.1	51.2 ± 6.1
TKN (g/kgTS)	23.4 ± 3.1	14.6 ± 2.9	11.9 ± 2.8	39.1 ± 3.1
TOC (%TS)	28.9 ± 1.9	43.1 ± 2.8	52.0 ± 3.1	34.1 ± 4.1
C/*N* ratio	12.4 ± 3.1	29.6 ± 3.7	43.6 ± 5.1	8.7 ± 1.9

* *Note:* Adding distilled water until TS 20%, then measured pH.

dues provide a more balanced *C*/*N* ratio, and thus enhance bacterial growth and decrease the risk of ammonia inhibition and acidification [14]. Besides, manure based household biogas-reactors could be affected due to the scarcity of feedstock. The co-digestion process can assist to solve manure scarcity and increase the biogas production.

There have been many studies on the co-digestion of crop residual and animal manure under mesophilic and thermophilic condition; however, there is little information available concerning co-digestion of these materials under psychrophilic condition, especially in the high altitude regions. The objective of this study was to investigate the viability of co-digesting highland barley straw (BS) in batch mode with Tibetan pig manure (TPM) and cattle manure (CM) as an external nitrogen source in biogas and methane production. In addition, the influence of BS to manure and inoculum to substrate (*I*/*S*) ratios on biogas production, methane content in biogas and net methane volume were evaluated. Finally, the best BS to manure and *I*/*S* ratio for the process were presented.

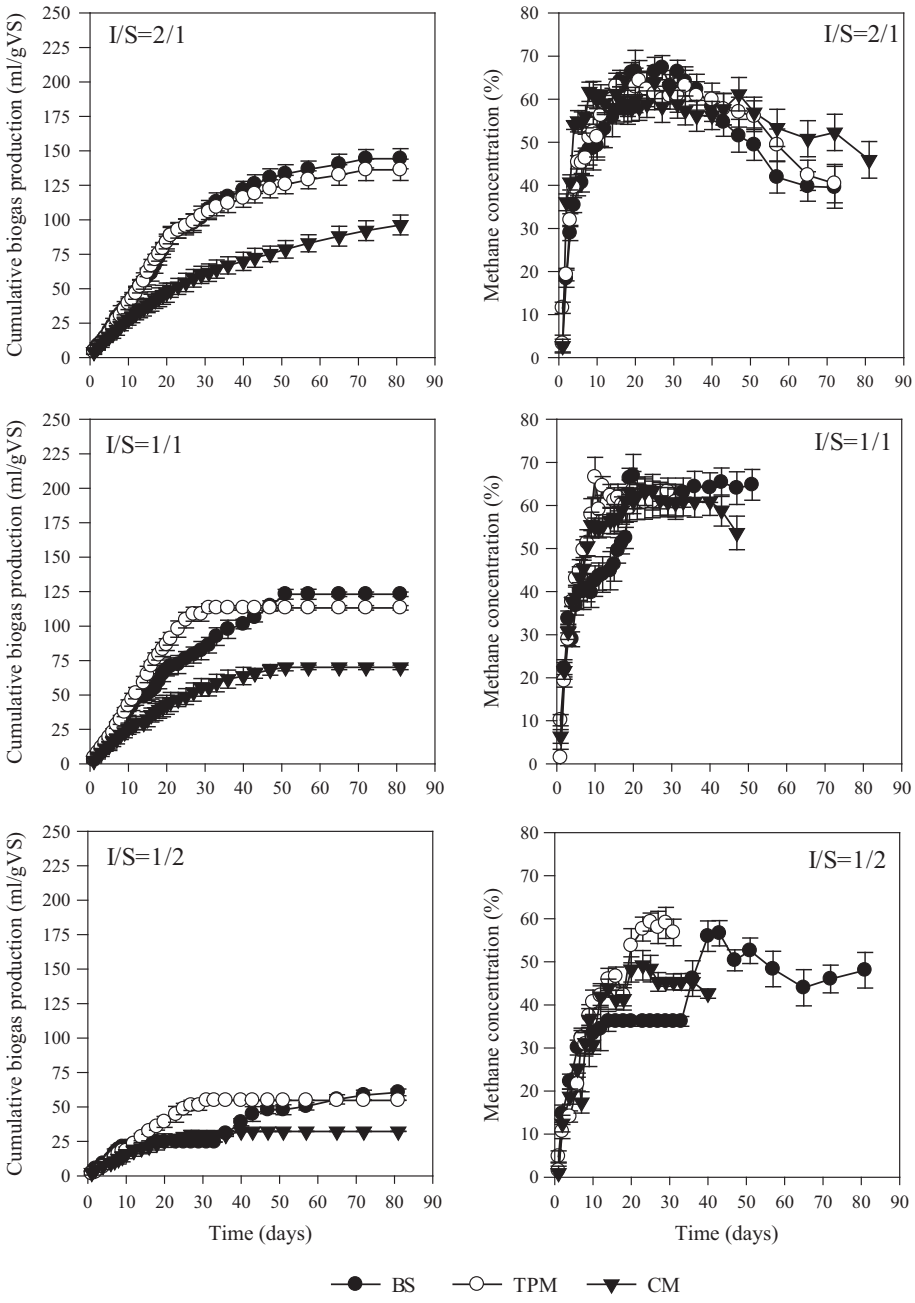

Fig. 1. Cumulative biogas production (left) and methane concentration (right) in the headspace of reactors during the anaerobic digestion of TPM, CM and BS alone at different *I*/*S* ratios.