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Optimizing feeding composition and carbon–nitrogen ratios for improved methane yield during anaerobic co-digestion of dairy, chicken manure and wheat straw

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HIGHLIGHTS

- ▶ Co-digestion of multi-substrates, dairy, chicken manure and wheat straw was conducted.
- ▶ Anaerobic co-digestion was optimized by feeding composition (DM/CM) and C/N ratio.
- ▶ Higher synergetic effect showed in mixed DM, CM and WS than single manure with WS.
- ▶ C/N ratios of 25:1 to 30:1 resulted in stable pH, low ammonium nitrogen and free NH_3.
- ▶ Maximize methane potential realized with DM/CM of 40.3:59.7 and C/N of 27.2:1.

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ABSTRACT

This study investigated the possibilities of improving methane yield from anaerobic digestion of multi-component substrates, using a mixture of dairy manure (DM), chicken manure (CM) and wheat straw (WS), based on optimized feeding composition and the C/N ratio. Co-digestion of DM, CM and WS performed better in methane potential than individual digestion. A larger synergetic effect in co-digestion of DM, CM and WS was found than in mixtures of single manures with WS. As the C/N ratio increased, methane potential initially increased and then declined. C/N ratios of 25:1 and 30:1 had better digestion performance with stable pH and low concentrations of total ammonium nitrogen and free NH_3. Maximum methane potential was achieved with DM/CM of 40.3:59.7 and a C/N ratio of 27.2:1 after optimization using response surface methodology. The results suggested that better performance of anaerobic co-digestion can be fulfilled by optimizing feeding composition and the C/N ratio.

1. Introduction

Anaerobic digestion converts plant biomass, crop residues, animal manures, and other organic wastes into methane-rich biogas, which is widely used as a source of renewable energy. As a result of global warming, increases in waste disposal and energy costs and the need for environmentally sustainable waste management, this technology has received great attention, especially in rural areas of developing countries. China produces about 600 million tons of crop straw (of which rice, corn and wheat straw account for 79.5%) and 3.9 billion tons of livestock and poultry manure every year (Zhang et al., 2009). Historically, rural households have used straw and manure as their prime sources of energy, animal feed and fertilizer (Hu et al., 2008). However, with gradual changes in the structure of rural energy consumption in China, commercial energy consumption is increasingly important (Pachauri and Jiang, 2008). The utilization of crop straw and manure as fuel has therefore decreased significantly, which has produced serious environmental pollution. Biogas production from anaerobic digestion of biomass is a technology that can produce sustainable energy and also reduce the environmental risks associated with manure and agricultural waste. By 2010, over 40 million household-scale small digesters and 30,000 large-scale digesters had been built in China.

Co-digestion of various biosolid wastes, which can use the nutrients and bacterial diversity in those wastes to optimize the digestion process, is an attractive approach for improving the efficiency of biotransformation (Wang et al., 2012). Many successful co-fermentation processes using different substrates have shown large increases in methane potential, compared with separate digestion of the substrates. Research by Xie et al. (2011) recommended applying pig manure to grass silage in a ratio of 1:1 in practice due to a high specific methane yield and a short lag phase. Umetsu et al. (2006) showed that the average yield of methane was

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Table 1
Chemical characterization of substrates used in the digestion experiments.

Material	pH	TS (%)	VS [a] (%)	Organic carbon [a] (g/kg VS)	TKN [a] (g/kg VS)	C/N	TAN (g/kg VS)
DM	7.12	14.4	78.6	65.3	2.96	22.1	5.71
CM	6.93	26.8	62.3	58.1	6.57	8.84	12.2
WS	ND [b]	86.1	90.6	456	5.62	81.1	ND [b]
Inoculum	7.91	4.75	66.2	ND [b]	ND [b]	ND [b]	ND [b]

[a] Dry basis.
[b] Not determined.

greater for a mixture of dairy manure and 40% beet tops, which produced 1.49 times more methane compared with 100% dairy manure mixture. The benefits of co-digestion lie in balancing the carbon–nitrogen (C/N) ratio in the co-substrate mixture, as well as macro and micronutrients, pH, inhibitors/toxic compounds and dry matter (Hartmann and Ahring, 2005). The C/N ratio is an important indicator for controlling biological treatment systems. Studies show that crop residues containing low levels of nitrogen (high C/N ratio) are characterized by a low pH substrate, poor buffering capacity, and the possibility of high volatile fatty acid (VFA) accumulation in the digestion process (Banks and Humphreys, 1998; Campos et al., 1999). Co-digestion of manure and other substrates overcomes those problems by maintaining a stable pH within the methanogenesis range due to their inherent high buffering capacity. In addition, manures that have low C/N ratios contain relatively high concentrations of ammonia, exceeding that necessary for microbial growth and probably inhibiting anaerobic digestion (Hansen et al., 1998; Procházka et al., 2012). This implies that added crop materials with high carbon contents could improve the C/N ratio of the feedstock, thereby decreasing the risk of ammonia inhibition of digestion (Hashimoto, 1983).

Although much research provides support for conducting co-digestion in rural areas with animal manures and agro-residues, little information is available about the digestion process of multi-component substrates containing various manures and agro-residues (Alvarez and Liden, 2008; Ashekuzzaman and Poulsen, 2011; Misi and Forster, 2001). Martinez et al. (2007) suggested that the possible technological, economic and ecological advantages of the anaerobic co-digestion include better handling of mixed wastes, the use of common access facilities, and the effect of economies of scale. In particular, the improved efficiency of anaerobic digestion by mixing manure and agro-residues provides an improved feasibility of energy production in rural areas. Co-digestion increases the volume of available feedstock for each household because of the limited amount of waste from a single source. Also, co-digestion is the most cost-effective and easiest way to improve digestion efficiency for farmers.

Therefore the purpose of this study was to investigate the possibility of improving methane yield from anaerobic digestion of multi-component substrates, mixture of dairy manure, and chicken manure and wheat straw, based on optimized feeding composition and C/N ratio.

2. Methods

2.1. Substrates and inoculum

Dairy manure (DM) and chicken manure (CM) were collected from a livestock farm located in Yang ling, China. Wheat straw (WS) was obtained from a local villager. Before being put into the reactor, the air-dried WS was cut into 2–3 cm pieces. The anaerobic sludge used as inoculum was collected from an anaerobic digester in a local village. The substrates and inoculum were individually homogenized and subsequently stored at 4 °C for further use. The chemical characterization of each substrate and the sludge tested in this study are given in Table 1. All samples were collected in triplicate, and the averages of the three measurements are presented.

2.2. Experimental design and set-up

Anaerobic batch digestion tests were carried out in triplicate at 35 °C for 30 days according to the method described by Wang et al. (2012). The initial volatile solid (VS) ratio of substrate to inoculum was kept at 1:2 for all the experimental setups. Each reactor had a 1 L capacity and contained 600 mL of total liquid, including 200 mL of inoculum and an appropriate amount of VS substrate. The compositions in the different batch set-ups were as follows. In set-up 1, based on dairy manure/chicken manure (DM/CM) ratios of 100:0 (M1), 0:100 (M2) and 50:50 (M3), multi-component substrates were prepared by adding wheat straw (WS) to the DM-CM mixtures to adjust the C/N ratio to 25:1. The DM/CM ratios were calculated from the VS contents in the substrates. Digestions of DM, CM and WS alone were also conducted (Table 2). The C/N ratio was calculated based on the chemical composition of the volatile solids (Shanmugam and Horan, 2009). In set-up 2, after determination of the optimum DM/CM ratio, the experiments were repeated at this ratio, but with adjusted C/N ratios of 15:1, 20:1, 25:1, 30:1 and 35:1(Table 2). In set-up 3, batch experiments were carried out based on a central composite design (CCD) described by Li et al. (2011) with two factors of the DM/CM and C/N ratios. The different levels in the experiment are shown in Table 3. In each treatment, WS was added to reach the given C/N ratios. Codified and real values for both factors are presented in Table 4. The selected response for analysis was methane potential based on methane

Table 2
Experimental design: different amount of substrates in co-digestion.

VS ratio (DM:CM:WS) Set-up 1 (C/N = 25:1)				VS ratio(DM:CM:WS) Set-up 2 (DM/CM = 50:50)			
DM/CM = 100:0(M1)	97.3	0	2.7	C/N = 15:1(R1)	48.7	48.7	2.6
DM/CM = 0:100(M2)	0	74.8	25.2	C/N = 20:1(R2)	45.5	45.5	9.0
DM/CM = 50:50(M3)	42.3	42.3	15.5	C/N = 25:1(R3)	42.3	42.3	15.4
				C/N = 30:1(R4)	39.0	39.0	22.0
				C/N = 35:1(R5)	35.6	35.6	28.8