



Anaerobic co-digestion of food waste and straw for biogas production



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ABSTRACT

The experimental biochemical methane potentials (BMP) of typical food waste (FW) and straw from northern China were individually measured in a 1 L enclosed reactor at 35 °C, and were 0.26 and 0.16 m³/kg-VS (volatile solids), respectively. Lab-scale mixtures of different FW and straw composition were conducted with a total organic load of 5 g VS/L. The optimum mixing ratio of FW to straw appears to be close to 5:1, and the methane production yield (MPY) reached 0.392 m³/kg-VS, i.e., increased by 39.5% and 149.7% compared with individual digestion results, respectively. Moreover, the gas production (GP) and methane content was reaching 0.58 m³/kg-VS and 67.62%, respectively. Further study about the optimal straw particle size was explored, and the recommended size range of straw was 0.3–1 mm for the economical and energy-saving consideration.

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1. Introduction

Municipal solid waste (MSW) mainly contains food waste, straws, leaves, fruit and vegetable wastes, among which the food waste accounts for the majority of the organic fraction of MSW. According to the reports of 2012, the MSW collected and disposed in China amounted to 1.3 billion tons [1]. As a result, the processing of MSW has become a big environmental problem. Currently, the main disposal method for food waste (FW) in China is landfill (90.5%), with a small percentage of FW being disposed off through incineration and composting. However, these disposal methods are problematic as the FW is putrescible. In landfill situation the organic fraction of FW will gradually produce methane, which has a global warming potential over a 100 year time, 23 times that of CO₂ [2]. Many EU countries have introduced high landfill levies, and have even banned dumping untreated MSW [2,3]. Anaerobic digestion has been suggested as an alternative method for high organic content waste to recovery a renewable energy-biogas in a controlled and efficient way [4–6], producing a potential energy source, e.g., power generation or fuel gas. Different research groups [7–9] have developed anaerobic digestion processes for different organic wastes such as FW, FVW (food and vegetable waste), and the organic fraction of MSW.

However, the efficiency and stability of individual FW fermentation were low due to the low C/N ratio and the labile organic fraction in FW which causes acidification [10]. For this reason, the co-digestion of FW with other organic wastes, such as animal manure and crop residual straw, were considered [11–13]. The co-digestion of FW with other wastes in a single digester became increasingly popular, with the advantage of adjusting the C/N ratio, increasing the methane production yield, and improving the utilization efficiency.

In China, straw resource is abundant with an annual production of six hundred million tons, accounting for about 30% of the world's total straw [14]. However, its utilization rate was below 33%. The main disposal method for straws in China is on-field incineration, and a small percentage of straws were utilized to produce paper, livestock feed, fertilizers [15], and rural energy [16]. In order to utilize straw materials more efficiently, its biochemical or thermochemical conversion has since been proposed. Biogas production from straws via anaerobic digestion is one of the promising options. Compared with conventional aerobic composting processes, anaerobic processes need a lower operating energy input and a lower initial investment cost [17]. They are widely applied in Europe. Still, anaerobic digestion of straws alone has some shortcomings, such as nitrogen deficiency due to its high C/N ratio and long digestion time due to the low cellulose conversion rate. There have reports about adjusting the C/N ratio of straws for higher biogas production, such as adding additional nitrogen source [18], aqueous ammonia treatment [14], and extrusion pretreatment [19].

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As two major sources of organic wastes in China, FW has lower C/N ratio and straw has higher cellulose content. A low C/N ratio may cause ammonia release, reduction of degradation and even inhibition of methanogenesis. However, co-digestion brought in a new opportunity for the process of FW and straw for nutrients balance. In this article, the anaerobic co-digestion of FW and straw for biogas production were investigated, including the effects of FW to straw ratios and optimal straw particle size.

2. Materials and methods

2.1. Food waste and straw

Raw FW was collected from a canteen of Beijing University of Chemical Technology (BUCT), Beijing, China, in different seasons of 2013, which mainly contained leftovers of cooked foods, such as meats, rice, breads, noodles and vegetables. The chopsticks, plastic bags and bones were removed before the food waste were dehydrated by a screw extruder, and then the food waste were crushed to a mean particle size of 1–2 mm by an electrical grinder.

Raw straw, were collected from the suburb of Beijing, China in 2013, mainly contained straw of maize, *sorgos* and wheat. After extracting most of the juice of straw by a juice extractor, the straw was dried in the sun before crushing to various particle sizes.

After being shredded to a small size and homogenized, the raw FW and the raw straw were stored separately at 4 °C.

2.2. Inoculum

Anaerobic granular sludge with good biodegradability and methanogenesis ability was used as inoculum to the digester, which was taken from a full-scale UASB reactor treating starch processing waste water at 35 °C in Beijing, China. The characteristics of anaerobic granular sludge were shown in Table 1.

2.3. Experimental biochemical methane potentials (BMP) test

The experimental biochemical methane potentials (BMP) tests were performed in a 1 L bottle at 35 °C and continuously shaken at 50 r/min. A total of nine such bottles were used and divided into three groups. The first group was added in 600 ml sludge only for blank experiment. The second group was added in 600 ml sludge and 12 g VS food waste for control experiment. The bottles of the third group were added in 600 ml sludge and 12 g straw for control experiment. Each group had three parallel experiments. All bottles were purged with nitrogen gas before sealing. No macro- or micro-nutrient solutions were added. Biogas produced from each bottle was collected, and measured by water displacement method, and then the volume was normalized to standard volume (0 °C, 1.013×10^5 Pa).

Biogas compositions were analyzed using a gas chromatograph (N2000, Beijing Beifenyiqichang, China) equipped with a thermal conductivity detector (TCD).

Table 1
Characteristics of inoculum used in this research.

	Density (kg/m ³)	Moisture content (%)	Total solids (%)	Volatile solids (%)	VS/TS (%)	C (%)	N (%)
Sludge	1.01	95.74	4.26	2.39	56.10	26.22	4.68

Table 2
Characteristics of BUCT canteen food waste.

Time	Total solids (%)	Volatile solids (%)	VS/TS (%)	Sugar (%)	Protein (%)	Fat (%)	Cellulose (%)
2013-3	20.61	19.86	96.36	33.38	15.14	25.24	7.58
2013-6	21.59	20.62	95.51	32.25	12.56	27.32	6.37
2013-9	19.79	19.08	96.41	34.65	14.29	23.78	7.42
2013-12	18.22	17.27	94.79	32.58	14.13	24.65	8.21
Average	20.05	19.21	95.81	33.22	14.03	25.25	7.40

2.4. Optimization experiment of the mixture ratio of FW to straw and of the straw particle size

Optimization experiments of the mixture ratio of the FW to straw were also performed in 1 L bottles at 35 °C and continuously shaken at 50 r/min. In this experiment, 10 control groups were designed, in which the ratios of FW to straw were 5:0, 0:5, 1:4, 1:1, 3:2, 4:1, 5:1, 6:1, 7:1 and 8:1. The total organic load of FW and straw in each group was 5 g VS/L. The project tested the stability of systems by measuring the pH, VFAs. By comparing methane-producing rate, this work ensured the optimum fermentation proportion of FW and straw.

Under the same conditions with the optimal ratio, optimization experiments for the straw particle size were also conducted. Five groups were designed with total organic load of 6 g VS/L, of which the straw sizes were 0.3 mm, 0.3–0.45 mm, 0.45–0.6 mm, 0.6–1 mm and >1 mm.

2.5. Analytical methods

The following parameters were analyzed: pH, VFAs, TS, VS, total C and total N. All samples were analyzed in triplicates. Samples were centrifuged at 15000 r/min for 20 min, then, the supernatant was filtered by the 0.45 µm cellulose acetate membrane. After that, the VFAs were measured according to standard methods (APHA, 2005). The cellulase activity was measured by filter paper enzyme activity (FPA) method [20].

3. Results & discussion

3.1. Characteristics and BMPs of food waste and straw

The characteristics of FW and the composition of straw were shown in Tables 2 and 3, respectively. The organic contents of FW included sugar, protein, fat and cellulose, and the organic fractions of straw were cellulose, hemicellulose and lignin. The C/N of FW and straw were 28.4 and 43.4 (Table 4), respectively, while the optimum C/N for sole straw fermentation was in the range of 25–30 [18]. It was found that the C/N of FW was lower than the optimum C/N of anaerobic fermentation, while the C/N of straw was higher than that, which meant that both of the nitrogen content of FW and the carbon content of straw were on the high side. Experimental results showed that the total methane production in BMP tests for FW and straw was 0.26 and 0.16 m³ CH₄/kg-VS, respectively, which indicated that the FW was easily biodegradable waste while the straws were difficultly biodegradable wastes.

Table 3
Composition of straw used in this research.

Material	Cellulose (%)	Hemicellulose (%)	Lignose (%)	Others (%)
Straw	31.57	22.38	19.17	26.88

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