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Experimental study of co-digestion of food waste and tall fescue for bio-gas production

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ABSTRACT

Chinese food waste (CFW) and Tall fescue (Tf) are obtainable at low cost, and the digestibility of the mixture is superior to mono-digestion. The major objective of this study was to determine optimal CFW/Tf ratio and organic loading rate (OLR) for biogas yields and organics removal rate in batch and hydraulic pressure semi continuous anaerobic treatment. Batch digestion of mixed substrates was carried out at CFW/Tf ratios of 8.89, 2.75, 1.52, 0.99 and 0.7 based on volatile solid (VS). For CFW/Tf ratio of 1.52, increasing OLR in hydraulic pressure semi continuous digester was evaluated. Results showed that positive synergistic effects of co-digestion took place at CFW/Tf ratios of 1.52 and 0.99. In semi continuous anaerobic digester, the reliability daily methane yield and effective organic matter removal was observed at OLR of 15.8 g VS/(L·d). This study showed that the co-digestion of CFW and Tf improved biogas yield and degradation efficiency. The improved characteristics indicated the co-digestion process had better stability.

1. Introduction

A large amount of food wastes have been produced by restaurants every year in China. Beijing, typically produces about 2000 tons of food waste per day, and may account for only around 3% of the total Chinese food wastes (CFW). The CFW are often different from food wastes in Europe or America. The food wastes in China contain a lot of fat, organic wastewater and semisolid residue. The Chinese food wastes which are high chemical oxygen demand (COD) and volatile solid (VS) have caused the increasing environmental and social problems recently. Improper food wastes disposal is causing air, soil and water contamination. For example, untreated food wastes are dumped on landfill or incinerated with household rubbish. The food wastes sometimes are also sold as new food resource and animal feed. Numerous scandals related to food waste have undermined people's confidence in restaurant food. Therefore, it is necessary to reinforce food wastes supervision and meanwhile develop the disposal technology.

Anaerobic digestion (AD) has been successfully used to decompose various food wastes, and then convert them to biogas [1,2]. Zhang et al. [3] found food waste from United States had average methane yields of 435 mL/g VS and VS removal of 81% using thermophilic anaerobic digestion at 50 ± 2 °C. Methane production potentials for cottage cheese of different pretreatments were thermal 357 mL/g VS, chemical 293 mL/g VS, and thermo-chemical 441 mL/g VS [4]. Anaerobic batch biodegradation of spent brewery grains and a monoazo dye was investigated in Portugal [5]. The highest value for the biogas yield was 516 mL/g CODremoved obtained under mesophilic conditions. Although differences exist in dietary habits, the biogas yield of anaerobic digestion of food wastes is often over 350 mL/g VS in most parts of the world [6,7].

Unfortunately, anaerobic treatment of food waste in China cannot be quite reliable because of many known or unknown factors. Most of anaerobic digestion settings had biogas production rate of less than 200 mL/g VS wastes. For example, Ningbo (a city in southern China) anaerobic treatment system, which is listed as demonstration project of food waste by government, is only

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102.5 mL/g VS. The reasons for the low efficiency of anaerobic projects may be due to lack of experience with operating the process, acid accumulation and also the lack of mineral elements, etc. [8,9]. Operators often dilute food waste to decrease the load and prevent the inhibition. However, dilution limits digesters productivity. Several research groups have tried to solve these problems. The effectiveness of some co-digestion and pretreatment had been tested [10–12]. Obviously, pretreatment is a convenient way to operate. However, co-digestion enjoys lower costs than pretreatment using thermochemical or enzyme process. Actually, compared with digesting a single substrate, mixed substrates can also offer more economic and ecological benefits [13–15]. Food waste and waste activated sludge were found to be complementary in the certain concentrations of carbohydrates, total Kjeldahl nitrogen, PO_4–P and some metal for biogas production. Food waste and yard waste (contained leaves and tree branches) had the potential to complement each other for SS-AD [16]. The study showed the increased methane yields and volumetric productivities as the percentage of food waste was increased to 10% and 20% of the substrate. A study by Chen et al. [17] also showed food waste/green waste ratio of 40:60 was determined as preferred ratio for optimal biogas production. Previous experiments demonstrated some advantages of co-digestion. However, sufficient substrates are difficult to obtain at times. Hence combining different types of substrates requires careful selection to enhance the reliability of anaerobic treatment. Moreover, ratio of the mixture is also one of the critical factors to improve the efficiency of digestion.

Green wastes incineration is one of the main causes of Smog in China. In most China' cities, lawn grass is the largest waste stream in green wastes. "In 2013 China land greening Status Bulletin" shows the lawn coverage rate of Chinese cities reached 35.72%, the annual amount of city lawn grasses garbage is about 27.18 million tons. At present, the largest quantity of lawn grass is turf-type tall fescue (Tf). Tf greens up early in spring and remains green well into fall, and can struggle in the hot humid weather.

Currently, there are no reported studies on anaerobic digestion of Chinese food wastes with Tall fescue in batch and hydraulic pressure semi continuous anaerobic digester. This study could provide baseline data for adopting the digestion of Chinese food waste and tall fescue that complement each other. Therefore, the major objective of this study was to determine biogas yields and organics removal rate for co-digestion of different Chinese food waste to tall fescue ratios in batch and hydraulic pressure semi continuous digester. The work presented the low efficiency of anaerobic fermentation under single Chinese food waste or tall fescue, and the effect of co-digestion on improving reliability. Function of CFW and Tf on improving digestion efficiency was commented synthetically.

2. Methods

2.1. Feedstock and inoculum

Tall fescue was obtained in August 2013 from Tianjin Bay Plaza greenbelt, and then dewater with a squeezer (LKM-ZZ01, Guangzhou, Shenzhen, China), and stored at 4 °C until used. The food wastes originated from three canteens which supply students with different regional Chinese foods in Nankai University, Tianjin, China. After sampling, food wastes was stored in plastic bottles at −20 °C until used. The food wastes was thawed overnight under ambient conditions, and ground up using a kitchen blender before usage.

Inoculum was processed anaerobic sludge. Sludge from an anaerobic digestion system fed with food waste and green waste. Prior to use, the sludge was isolated for one week at 37 °C to remove the easily degradable VS. Then, the sludge was centrifuged at 5000 rpm for 20 min. The supernatant was removed and the sediment was collected to be used as inoculum for this study.

2.2. Batch and semi continuous anaerobic treatment

Two sets of experiments were carried out in the AD system. First, the effect of CFW/Tf ratios (on dry VS) on the performance of batch anaerobic treatment was studied. Mono-digestions were run to compare with the biogas production and digestibility of the mixture. The feedstock and inoculum were loaded into the batch anaerobic system at a feedstock/inoculum volume ratio of 9:1. Based on the preferred CFW/Tf ratio, which was determined in batch AD, a wide range of organic loading rates (OLRs) of feedstock (g/L) was studied in hydraulic pressure semi continuous digester. These OLRs were applied between 3 and 5 times the hydraulic retention time to reach equilibrium. Digesters were operated in semi-continuous mode with daily feeding and sampling. The hydraulic pressure semi continuous digester was used for easily feeding and sampling. Fig. 1 is a schematic diagram showing how the work steps of hydraulic pressure semi continuous reactor. The CFW and Tf were mixed together. Then, the mixed substrates were loaded into the anaerobic digester. At the beginning of each anaerobic cycle, the feedstock of inlet, fermentator and outlet were in the same plane. The valve of exhaust pipe shown in Fig. 1 (a) was closed to prevent biogas emissions. Fig. 1 (b) shows that the fermentation liquid was squeezed to the inlet and outlet while the biogas of fermentator gradually increased. Fig. 1 (c) displayed that the biogas was discharged from the top of fermentator and fermentation liquid of inlet and outlet flowed back to fermentator when the valve of exhaust pipe was opened.

The feedstock was mixed by a hand-mixer for 5 min. Well-mixed materials were respectively loaded into 1 L batch anaerobic digesters and 2 L hydraulic pressure semi continuous reactors. And then, run at 37 ± 1 °C by the end of the experiments. Duplicate reactors were run for each condition. Inoculum without any feedstock addition was used as a control.

2.3. Analytical methods

The standard methods for the examination of waste and wastewater were used to analyze the TS, VS and ammonium contents of feedstock, inoculum, and material taken in the beginning and at the end of the AD process [18]. The pH was determined by a pH meter (SX620, SanXin, China). Samples were taken and prepared to determine total carbon, nitrogen and S contents by an elemental analyzer (Vario Micro cube, ELEMENTAR, Germany). Cellulose, hemicellulose, and lignin contents in the tall fescue were analyzed according to the procedure described by Van Soest et al. [19]. CODcr of substrates and effluent were quantified in accordance with the standard methods of the American Public Health Association [18]. Fat content in Chinese food wastes was measured using a Soxhlet extractor method [20].

Biogas generated was collected in 2 L or 10 L gas bags (Delin, China). The volume of biogas collected in a gas bag was measured with a water displacement method and the composition of biogas was analyzed using a GC (Agilent 7890A, USA) equipped with a Thermal Conductivity Detector. The column used was a packed column with Molsieve 5A 6 ft 1/8″*2 m. For qualitative and quantitative analysis of biogas, external standard method was adopted with standard gas provided by Tianjin Lianbo Chemical Co., Ltd. which is made of CH_4 (5.00 mol%), C_2H_4 (2.08 mol%), C_2H_6 (1.02 mol %), C_3H_6 (1.02 mol%), C_3H_8 (0.5 mol%), H_2 (1.92 mol%), CO (38.85 mol %), CO_2 (49.61 mol%). Chen et al. [21] described the analytical procedure. The composition and volume of biogas were measured