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Batch anaerobic co-digestion of pig manure with dewatered sewage sludge under mesophilic conditions

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HIGHLIGHTS

- Dewatered sewage sludge (DSS) was co-digested with pig manure (PM).
- Mixture of PM and DSS produced a higher methane yield than digesting DSS alone.
- Anaerobic co-digestion of PM with DSS exhibited a shorter hydraulic retention time.
- Digestates from mixture of PM and DSS showed high pH and low VFA/TIC ratio.
- Modified Gompertz model shows better fit to the results than the first order model.

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ABSTRACT

The objective of this study was to investigate the characteristic of anaerobic co-digestion of pig manure (PM) with dewatered sewage sludge (DSS). The batch experiment was conducted under mesophilic (37 ± 1 °C) conditions at five different PM/DSS volatile solid (VS) ratios of 1:0, 2:1, 1:1, 1:2, and 0:1. The batch test evaluated the methane potential, methane production rate of the PM co-digestion with DSS at different mixing ratios. The first-order kinetic model and modified Gompertz model were also introduced to predict the methane yield and evaluate the kinetic parameters. The optimum mixing ratio of PM with DSS was 2:1 and the cumulative methane yield (CMY) was 315.8 mL/g VS_{added}, which is greater by 82.4% than that of digesting DSS alone. This result might be due to the positive synergy of PM with DSS, which resulted in an active microbial activity and a higher hydrolytic capacity of DSS. The systems with co-digestion of PM and DSS was demonstrated to be more stable. The modified Gompertz model (R^2: 0.976–0.999) showed a better fit to the experimental results and the calculated parameters indicated that the co-digestion of PM with DSS markedly improved the methane production rate and shortened the effective methane production time.

1. Introduction

The rapid economic growth has led to rapidly increasing energy consumption in China. Crude oil consumption of China reached 388 million t in 2009, of which over 50% was imported. As reported that China's primary energy consumption reached more than 3 billion t of standard coal equivalent (tce), with non-fossil fuels, including renewable accounting for only 9.9% (National Bureau of Statistics of China, 2010) [1]. Reducing the dependency on fossil fuels through the development of sustainable energy sources is therefore a prerequisite for the sustainable economic development of China. Basis on renewable energy production and reduction of the greenhouse gas emissions and energy dependency associated with fossil fuels has made anaerobic digestion of agricultural biomass an attractive option [2,3]. Biogas, a methane rich biofuel, produced from renewable biomass by means of anaerobic digestion has received intense attention [4].

Activated sludge processes are the main alternative to wastewater treatment because of their high efficiency of organic matter removal [5,6]. With the rapid development of population and urbanization of China, wastewater generation has increased, which resulted in the increased amount of sewage sludge caused by an

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elevated amount of wastewater being treated in the country. As reported, the annual amount of dewatered sewage sludge (80% moisture content) has reached up to about 3000 tons in 2010, and 80% of it has not reached necessary stabilization [7]. Therefore, developing strategies for treating the generated sewage sludge is necessary.

At present, many conventional ways have been attempted to treat the sewage sludge, including landfill, combustion, and composting for farmland use [8]. Considering the waste stabilization and energy recovery, interest has gradually focused on anaerobic digestion (AD), which is considered as one of the sustainable options for the management of sewage sludge [7,9].

The hydrolysis of these organic matters in the AD process is generally limited because of the organics in sewage sludge that are mainly hard biodegradable cells and extracellular biopolymers. A biogas generation potential of 120–150 mL/g VS_{added} from sewage sludge at a mesophilic temperature was reported [5]. This low biogas output makes the use of anaerobic digesters for sewage sludge treatment not always economically feasible [10]. For example, leading up to 2010, a total of 50 WWTPs (wastewater treatment plants) were designed with anaerobic digestion systems in China, but around 80% of them were poorly operated with low volumetric biogas production rates [7]. Moreover, the existing anaerobic digesters operated at wastewater treatment plants are also oversized and underloaded [10,11].

Co-digestion with other organic wastes could be a potential, effective method to improve the biogas production from sewage sludge and the utilization efficiency of existing digesters at WWTPs [10,12,13]. The co-digestion of sewage sludge with a grease trap sludge from food industrials [14,15], organic fraction of municipal solid wastes (OFMSW) [16–18], agro-industrial waste [19], vegetable processing wastes [20], and poultry manure [21] has been examined. The biogas production from the co-digestion of OFMSW and sewage sludge reached up to 500 mL biogas/g VS_{added}, which was significantly higher than the digestion of sewage sludge alone (120–150 mL biogas/g VS_{added}) [5,16]. Similarly, the biogas yield was increased by 5–63% when sewage sludge was supplemented with 40% of grease trap sludge [14]. Likewise, the investigation of sewage sludge co-digested with poultry manure conducted by Borowski and Weatherley [21] indicated that the addition of 30% poultry manure to sewage sludge increased the biogas yield by 50%, with no inhibiting effect of ammonia on methanogenesis. Sosnowski et al. [17] reported that the addition of around 25% of OFMSW to the sludge considerably increased the biogas yield and Zupančič et al. [16] investigated the anaerobic co-digestion of OFMSW and sewage sludge in a full-scale digester. A volumetric biogas production of 0.7 m^3/m^3 d with an organic loading rate (OLR) of 1.4 kg VS/m^3 d was obtained.

Although the co-digestion of sewage sludge with OFMSW could improve biogas production, the distribution of OFMSW in China is quite dispersed. However, the pig farms in China are becoming more intensive and specialized production units, thereby making the collection of pig manure (PM) more cost-effective [1]. The co-digestion of sewage sludge with PM could be a prospective method for treating both these solid wastes.

Based on the knowledge obtained from previous investigations, the co-digestion of PM with sewage sludge could enhance the buffering capacity of the AD process, improve nutrient balance, and increase the positive synergisms established in the digesters. Moreover, this co-digestion would improve the utilization efficiency of existing digesters at WWTPs and reduce the collection and transport cost of other decentralized organic matter [1,21]. However, little information is available regarding the co-digestion of sewage sludge with PM.

Therefore, the anaerobic co-digestion characteristics of PM with dewatered sewage sludge (DSS) were investigated in batch experiments at various PM to DSS ratios in mesophilic conditions. First, the biogas production rate and specific methane yield of single and mixing samples were determined, and the difference between actual methane yield and simulated and calculated methane yields from the co-digestion of PM with DSS was then compared. Secondly, based on the pH, VFA (volatile fatty acids)/TIC (total inorganic carbon) ratio, TAN (total ammonia nitrogen) concentration, and VS removal rate, the performance of batch digesters was evaluated. Lastly, the kinetic model parameters of the batch experiment were analyzed.

2. Material and methods

2.1. Substrates and inoculum

The PM and DSS samples used in this investigation were obtained from a large-scale pig farm and a wastewater treatment plant located in Hebei Province, China (38.14°N, 115.19°E). The sludge was obtained by collecting primary and excess sludge and dewatered with the aid of a high-molecular flocculant based on polyacrylamide (PAM). The inoculum (seed sludge) was collected from another municipal wastewater treatment plant (Xiaohongmen WWTP, located in southern Beijing), where the sewage sludge was treated by AD. After the samples were delivered to the laboratory, the PM samples were sieved through 2 mm sieves to remove coarse materials. The PM and DSS samples were frozen at −20 °C to prevent biological decomposition. Prior to launching this experiment, the frozen substrates were transferred to a refrigerator at 4 °C for 1 day. The characteristics of PM, DSS, and inoculum used for the experiment are shown in Table 1.

2.2. Experimental design

The batch anaerobic co-digestion of PM and DSS was carried out in five PM/DSS VS ratios: 1:0, 0:1, 2:1, 1:1, and 1:2. The co-digestion was performed in 250 mL serum bottles capped with natural rubber sleeve stoppers, and the working volume of the bottle is 150 mL. In comparison to German biogas plants with 8–12% TS, the fermentation concentration in Chinese biogas plants is relative lower (3–8% TS) [22]. According to the fermentation concentrations of Chinese biogas plants, the initial fermentation concentration of 4.0%VS (40 g VS/L) was adopted in this test. So, the initial substrate concentration and the inoculum amount of each bottle were 40 g VS/L and 100 mL, respectively (Fig. 1). The feed to inoc-

Table 1
Characteristics of pig manure (PM), dewatered sewage sludge (DSS), and inoculums.

Characteristics	PM	DSS	Inoculum
TS (% FM)	29.96(0.26)	17.69(0.16)	4.73(0.27)
VS (% FM)	20.89(0.23)	11.86(0.06)	3.86(0.14)
VS/TS (%)	69.73(0.33)	67.04(0.21)	81.61(6.31)
pH	8.41(0.02)	7.46(0.03)	7.36(0.06)
TAN (mg/kg FM)	1741.7(128.0)	342.4(36.2)	526.3(22.9)
SCOD (mg/kg FM)	54691(3887)	20769(316)	1047(75)
Cellulose (% TS)	18.42(0.02)	ND	ND
Hemi-cellulose (% TS)	25.33(0.63)	ND	ND
Lignin (% TS)	1.16(0.13)	ND	ND
C (% TS)	39.40(2.1)	35.16(1.4)	ND
N (% TS)	3.04(0.23)	5.20(0.15)	ND
H (% TS)	5.56(0.13)	5.32(0.07)	ND
S (% TS)	0.56(0.06)	0.48(0.02)	ND
O (% TS)[a]	21.73(1.0)	20.88(1.2)	ND
C/N	12.96	6.76	ND

Values are expressed as mean and figures in parentheses are standard deviations ($n = 3$).

[a] Calculated by difference (O% = 1-C%-N%-H%-S%-ash%); FM: fresh matter, TAN: total ammonia nitrogen; ND = Not determined.