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Technical Note

Effects of thermal pre-treatment on anaerobic co-digestion of municipal biowastes at high organic loading rate

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HIGHLIGHTS

- Co-digestion of FW, FVR with DAS can enhance the stability of biogas process.
- The threshold weight ratio of DAS is 30% when the digester run at high OLR.
- Thermal pretreatment decreases the biodegradability of FW and FVR.
- Co-digestion of FW, FVR with thermal treated DAS is suggested.

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ABSTRACT

Anaerobic co-digestion of thermal pre-treated municipal biowaste (MBW) is a field of research that has had limited contributions to date. In this study, laboratory-scale semi-continuously fed anaerobic digesters treating thermally treated and non-treated MBW were operated at high organic loading rates (OLR). The results show that the methanogenesis process was inhibited by the accumulated volatile fatty acids when 30% (w/w) of dewatered activated sludge (DAS) was co-digested with food waste (FW) and fruit/vegetable residue (FVR) at high OLR ⩾ 10 kg volatile solid m^{-3} d^{-1}. Co-digestion with thermal hydrolysed DAS can significantly improve digester performance. In contrast to DAS, some adverse effects of thermal pretreatment on the biodegradability of FW and FVR were observed. Therefore, co-digestion of FW, FVR with thermally treated DAS is suggested as an alternative to promote high methane production and process stability.

1. Introduction

With the economic development and urbanisation of China, the production of municipal solid waste (MSW) has increased rapidly in recent years. In 2010, 158 Mt of MSW were collected and transported (National Bureau of Statistics of China, 2011). Of these, more than 60% is organic, that is, characteristically had a high water content and is biodegradable, for example, food waste (FW) and fruit/vegetable residue (FVR). In China, the annual production of dewatered activated sludge (DAS, 80% moisture content) from wastewater treatment plants has reached almost 30 Mt, and 80% of it has not obtained necessary stabilisation (Duan et al., 2012).

Anaerobic digestion of the above municipal biowastes (MBWs) is an effective way to convert organic matter into renewable energy. Co-digestion of MSW with sewage sludge can offer a number of advantages: dilution of potential toxic compounds; improved balance of nutrients; synergistic effect of microorganisms; increased load of biodegradable organic matter and better biogas yields (Sosnowski et al., 2002).

The hydrolysis stage is considered as a rate-limited step in the anaerobic digestion of solid wastes. Consequently, physico-chemical treatments are often used to promote solubilisation of organic matter. Thermal pretreatment has proved as a useful pretreatment method and it is thought that it can break cell structure to release organic matter inside the cells and consequently improve digestion performance. Therefore, most of the previous studies aimed to improve anaerobic degradability of activated sludge (Li and Noike, 1992; Bougrier et al., 2008; Christopher and John, 2009) or activated sludge dewaterability (Neyens and Baeyens, 2003; Qiao et al., 2010) via thermal pretreatment. Fewer studies have been undertaken on the effect of thermal pretreatment on mixed MBW. Qiao et al. (2012) found that the choice of feeding material (household sewage, sewage from mixture of domestic and industrial wastewater, and industrial and oil wastewater treatment plants) affects the performance of thermal pretreatment. Liu et al. (2012a) has studied the effect of thermal pretreatment on the physical and chemical properties of MBW and a batch test of each substrate was conducted to determine the biodegradability

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of the raw and thermally treated materials. The results showed that methane potential of thermally treated DAS increased by 35%. On the other hand, methane potential of thermally treated FW and FVR decreased by 8% and 12%, respectively. However, they had not considered that biogas production could possibly be stimulated by co-digested substrates in a semi-continuous system. Some conflicting results have been reported by Zhou et al. (2013) who has compared the performance of the semi-continuously fed digester processing thermally treated and non-treated MBW at a relatively low organic loading rate (OLR) of 1.5 and 3.0 kg VS m^{-3} d^{-1}. They found that the hydrolysis rate increased after thermal pretreatment. However, they did not find any obvious differences in volatile solids (VS) removal rate.

The objective of this study is to evaluate the effect of thermal pretreatment and different mixing ratios on the anaerobic co-digestion of FW, FVR and DAS at high OLR ($\geqslant$10 kg VS m^{-3} d^{-1}) via the stable operation of a semi-continuously fed digester.

2. Materials and methods

2.1. Municipal biowaste

FW used in this study was collected from a student canteen at Tsinghua University, FVR was collected from a wholesale market and DAS came from a municipal wastewater treatment plant in Beijing. Their differing characteristics are shown in Table 1. The inert materials in FW and FVR were manually separated (e.g., plastics, bone, wood and others). FW and FVR were shredded separately by a pulverizer to less than 3.0 mm. The mixed feedstock was kept at 4 °C. The properties of the mixed substrates are shown in Table 2.

2.2. Thermal pre-treatment

Thermal pre-treatment was applied at a temperature of 170–175 °C for 60 min. Steam was used as a heat source at a pressure of 0.5 MPa. A detailed description of the thermal pre-treatment process has been reported by Zhou et al. (2013). In the thermal pre-treatment process, MBW was inevitably diluted by the steam and some additional water, which resulted in around 1-fold dilution (Table 2).

2.3. Digester

Six completely stirred anaerobic reactors (30 L) with an effective volume of 20 L were used. Each digester was sealed by a dull polished glass cap with a stirrer in the middle of the cap. Stirring was conducted automatically for 10 min h^{-1} at a speed of 120 rpm throughout the entire experimental period. Two ports were fitted at the top and bottom of the digester walls for feeding and withdrawing liquid samples, respectively. The temperature was controlled at 38 ± 1 °C by water jackets surrounding the digesters.

Table 1
Characteristics of raw materials used in this study (Liu et al., 2012a).

	FW	FVR	DAS
Water content (%)	80.0	89.3	84.3
TS (g kg^{-1})	200	107	157
VS (g kg^{-1})	180	100	114
Carbohydrates (g kg^{-1})	107	84	59
Crude protein (g kg^{-1})	30	13	69
Crude fat (g kg^{-1})	44	3	21
C/N	17	22	7

Table 2
Properties of bio-waste with different mixing ratios used in this study.

Treatment	Substrates	Ratio (w/w/w)	TS (g kg^{-1})	VS (g kg^{-1})
1	FW, FVR, thDAS[a]	2:1:1	121 ± 3	103 ± 3
2	FW, FVR, dDAS[b]	2:1:1	126 ± 7	107 ± 6
3	FW, FVR, thDAS	2:2:1	108 ± 3	91 ± 4
4	FW, FVR, dDAS	2:2:1	112 ± 4	93 ± 3
5	FW, FVR, DAS	1:1:1	122 ± 11	102 ± 11
6	thFW, thFVR, thDAS	1:1:1	62 ± 5	49 ± 4

[a] Prefix th means thermal hydrolysed.
[b] In the consideration of dilution effect in the thermal treatment process, dDAS used in the experiment is the DAS diluted with water at a ratio of 1:1.

2.4. Digester start-up and operation

Each digester was inoculated with 20 L inoculum (total solids (TS): 3.9%; VS: 1.9%). The inoculum came from a pilot scale biogas plant (200 L) treating biowastes, which had run stably for more than 2 yr.

The OLR was increased aggressively until it reached 10 kg VS m^{-3} d^{-1}. Two high OLR levels (Table 3) were focused on in each treatment. The two OLRs were operated for at least 2–3 hydraulic retention time (HRTs). The nominal HRT is shown in Table 3. In treatment 6, the OLR cannot reach a nominal OLR of 10 kg VS m^{-3} d^{-1} at fixed HRT because of the dilution effect of the thermal pretreatment process. The steady-state values of daily gas production and VS of the effluent were taken as the average of these consecutive measurements when the deviations between the observed values were less than 5% in all cases.

2.5. Monitoring

The TS and VS were analysed according to APHA (1995). Biogas production was monitored by using a drum type gas meter (LML-1, China). The quality of biogas was analysed with an infra-red sensor (OMBION 1.42 Biogas Check, Geotechnical Instruments (UK) Limited). The pH was measured during the experiments (FE20, Mettler-Toledo, Switzerland). pH is commonly used as a process indicator, but its effectiveness as a control parameter strongly depends on the alkalinity, i.e. the buffering capacity of the process. The most important buffer within the optimal pH for methanogenic organisms is bicarbonate. The ratio of volatile fatty acid (VFA) and total inorganic carbon (TIC) gives a good indication of the process stability of anaerobic digestion. Therefore, TIC and VFA content were analysed in this study using a titration method (Rieger and Weiland, 2006).

2.6. Statistical analysis

At nominal OLR of 10 kg VS m^{-3} d^{-1}, independent-samples *t*-tests at the 0.05 significance level were conducted to determine whether the observed differences between thermally treated and non-treated treatments were significantly different.

3. Results

This section focuses the discussion (Section 4) on the effects of MBW thermal pretreatment and DAS content on digester performance. The discussions will be based on the experimental results below.

3.1. pH, methane content and process stability

In treatments 1–4, a stable pH range of 7.6–7.8 was observed throughout the experiment. However, pH sharply decreased to