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Synergism of co-digestion of food wastes with municipal wastewater treatment biosolids

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ABSTRACT

Five semi-continuous flow anaerobic digesters treating a mixture of food waste (FW) and municipal biosolids (primary sludge and thickened wasted activated sludge) at an solids retention time (SRT) of 20 days and different blend ratios i.e. 0, 10%, 20%, 40% by volume with the fifth digester treating only biosolids at the same COD/N ratio as the 40% FW digester were operated to investigate co-digestion performance. Sixty days of steady-state operation at organic loading rates (OLR) of 2.2–3.85 kgCOD/m^3/d showed that COD removals were higher for the three co-digesters than for the two municipal biosolids digesters i.e. 61–69% versus 47–52%. Specific methane production per influent CODs were 1.3–1.8 folds higher in co-digestion than mono-digestion. The first-order COD degradation kinetic constants for co-digestion were more than double the mono-digestion. Additional methane production through synergism accounted for a minimum of 18–20% of the overall methane production. The estimated non-biodegradable fraction of the FW particulate COD was 7.3%. However, the co-digesters discharged 1.23–1.64 times higher soluble nitrogen than the control.

1. Introduction

Anaerobic digestion is the most widely used technology to produce biogas such as methane and hydrogen from the decomposition of organic compounds. The effectiveness of the process depends on the stability of the consecutive reactions i.e. hydrolysis, acidification, acetogenesis, and methanogenesis. The process is widely used in municipal wastewater biosolids treatment for stabilization and production of methane gas. Due to the increasing demand on renewable energy as well as the energy-efficiency of anaerobic digestion, anaerobic digestion has also been used for treating biodegradable wastes; for instance, the organic fraction of municipal solids wastes, wastewater treatment biosolids, and various food and beverage wastes (Iacovidou et al., 2012). Particularly, anaerobic digestion of food wastes (FW) is also considered as one of the effective methods of waste management (Iacovidou et al., 2012). Annual food waste generation in USA is 34.2 million tons (Curry and Pillay, 2012). Assuming that potential biogas generation is 367 m^3 per FW (dry tonne) with an energy content of 6.25 kW h/m^3, the annual food waste in the US of 34.2 million tons can generate 3.76×10^9 m^3 of biogas with an energy value of 23.5×10^6 MW h, corresponding to 0.12% of the total global electrical energy consumption of 20,181 TW h (Curry and Pillay, 2012). However, despite the potential benefit, digestion stability can be hampered when FW is used as single substrate because of potential nutrients imbalance such as insufficient trace metals (Zn, Fe, Mo, etc.) and excessive macronutrient (Na, K), high C/N ratio, and lipid content (5 g/L) as well as due to the high variability of its composition depending on its source (Iacovidou et al., 2012; Zhang et al., 2014). Thus, the use of FW as co-substrate for municipal sludge digestion has emerged to enhance sludge digestibility, and increase energy generation to facilitate the achievability of energy-neutral wastewater treatment.

The beneficial effects of FW as co-substrate for sludge anaerobic digestion include improvement of methane yield and acceleration of methane production rates (Iacovidou et al., 2012; Koch et al., 2016). Various studies on the positive impact of co-digestion in lab-scale and full-scale continuous-flow systems fed with various co-substrates such as FW and organic fraction municipal solid waste (OFMSW) are summarized in Table 1. A study by Dai et al. (2013) reported the performance of different FW digesters ranging from 0% to 100% (by w/w VS). VS destruction and methane yield increased from 38% to 86% and 0.24 LCH_4/gVS$_{added}$ to 0.62 LCH_4/gVS$_{added}$, respectively at an SRT of 30 days with similar trends

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Table 1
Continuous-flow FW and wastewater treatment biosolids co-digestion studies.

References	System type	Co-substrate source[a]	Temp[b]	SRT	C/N ratio[c]	Biosolids and co-substrate mixing ratio[d]	OLR (kg VS m^3/d)	VS removal (%) [e]	Methane yield (LCH_4/gVS_{added})[f]	SMP (L CH_4/gVS $_{removed}$) [g]
Dai et al. (2013)	Lab scale (CSTR)	FW	35	8–30	6.7–7.8	100:0	4–13.4	26.8–38.2	0.16–0.24	0.59–0.62
			35	8–30	8.5–9.0	71:29	4.6–15	39.7–51	0.22–0.30	0.54–0.59
			35	8–30	9.6–10.7	47:53	5.1–17.8	52.2–62.2	0.29–0.35	0.54–0.56
			35	8–30	10.2–12.5	29:71	6–18.5	59.2–70	0.3–0.4	0.51–0.57
			35	8–30	11.2–14.8	0:100	6.4–21.8	74.1–86.1	0.38–0.47	0.51–0.54
Sosnowski et al. (2003)	40 m^3 Semi-UASB	KW	56	35	9.3	100:0	0.39	N/A	N/A	N/A
			56	38	14.2	75:25	1.5	N/A	N/A	N/A
	9 m^3 CSTR + 14 m^3 Semi-UASB		56 + 36	30	24.5	0:100	2.76	N/A	N/A	N/A
			56 + 36	62	8.16	100:0	0.67	N/A	0.22	N/A
			56 + 36	28	14.2	75:25	3.1	N/A	0.18	N/A
Sosnowski et al. (2008)	40 m^3 bioreactor	KW	35	N/A	N/A	0:100	N/A	N/A	N/A	0.23
			35	N/A	N/A	100:0	N/A	N/A	N/A	0.32
			35	N/A	N/A	75:25	N/A	N/A	N/A	0.44
Aichinger et al. (2015)	Full scale1	OFMSW	35	N/A	N/A	100:0	1.17	N/A	N/A	N/A
			35	28.7	N/A	54:46	2.18	N/A	N/A	N/A
	Full scale2		35	N/A	N/A	100:0	1.69	N/A	N/A	N/A
			35	27.7	N/A	85:15	1.98	N/A	N/A	N/A
	Lab scale (CSTR)		35	N/A	N/A	100:0	5.33	53 (52)	N/A	N/A
			35	N/A	N/A	80:20	6.66	55 (57)	N/A	N/A
Gou et al. (2014)	Lab scale (CSTR)	FW	35	4.2–33.3	13	67:23	1–8	48–62	0.23–0.26	N/A
			45	4.2–33.3	13	67:23	1–8	46–68	0.23–0.3	N/A
			55	4.2–33.3	13	67:23	1–8	44–75	0.23–0.4	N/A
Koch et al. (2016)	Full scale	FW	33	40	8.8	54:46:0	N/A	N/A	0.31	N/A
			33	40	17.7	55:35:10	N/A	N/A	0.39	N/A
Kim et al. (2011)	Lab (SBR)	FW	35 + 35	8	N/A	60:40	3.5	42	0.18	N/A
			55 + 35	7	N/A	60:40	6.1	45	0.2	N/A
Liu et al. (2012)	Lab scale (CSTR)	FW	35	50	12.9	25:75	2.40	65.6	0.41	0.67
			35	33	12.9	25:75	3.60	62.6	0.38	0.61
			35	25	12.9	25:75	4.8	64.5	0.43	0.67
			35	20	12.9	25:75	6	64.9	0.39	0.62
Cavinato et al. (2013)	Pilot scale	OFMSW	37	22	13	100:0	1.22	N/A	0.09	N/A
			37	24	28	50:50	1.6	N/A	0.21	N/A
			55	22	28	50:50	1.66	N/A	0.30	N/A
Schmit and Ellis (2001)	Lab scale (CSTR)	Synthetic OFMSW	55 + 35	15	N/A	100:0/80:20/60:40/40:60/20:80	1.5–3.5	47.5–71.6	0.30–0.42	N/A
			55 + 35	15	N/A	100:0/80:20/60:40/40:60/20:80	1.5–3.8	39.6–69.3	0.28–0.33	N/A
Fitamo et al. (2016)	Lab scale (CSTR)	OFMSW	55	30	N/A	100:0:0	0.62–0.65	N/A	0.29	N/A
			55	10, 15, 20, 30	N/A	10:67.5:15.7:6.75	2.55, 3.91, 5.04, 7.79	N/A	0.42–0.43	N/A
			55	10, 15, 20, 30	N/A	10:45:31.5:13.5	2.25, 3.74, 4.99, 7.57	N/A	0.32–0.39	N/A

[a] Dai et al. (2013) - cafeteria (rice, vegetables, oil and meat)/Sosnowski et al. (2003, 2008) – KW (kitchen waste, potato 55%, fruit and vegetables 28%, bread 5%, paper 2%, rice and pasta 10% wt)/Gou et al. (2014) - university cafeteria/Kim et al. (2011) – cafeteria of academic institute/Liu et al. (2012) - student canteen/Cavinato et al. (2013) - a mixture of food waste from large communities (supermarkets, canteens, restaurants, etc.) and separately collected household biowaste/Schmit and Ellis (2001) - 60% paper products + 14% FW + 26% Yard waste (dry weight)/Fitamo et al. (2016) - FW (university canteen) + grass and garden waste (garden and recycling centre).

[b] Two stages systems for Kim et al. (2011), Sosnowski et al. (2003) and Schmit and Ellis (2001).

[c] COD/N for Cavinato et al. (2013).

[d] Dai et al. (2013) - dewatered sludge: FW w/w, based on VS. Sosnowski et al. (2003, 2008) - mixed sludge (PS + TWAS): OFMSW, based on volume. Aichinger et al. (2015) - mixture ratio for two full scale tests was estimated using VS loading increase before and after using organic wastes. Gou et al. (2014) – TWAS: FW (TS basis). Koch et al. (2016) – PS: TWAS: FW (TS basis). Kim et al. (2011) - sludge: FW (VS basis). Liu et al. (2012) - sludge: FW + fruit vegetable waste (TS basis). Cavinato et al. (2013) – WAS: OFMSW (uncertain basis of mixture). Schmit and Ellis (2001) – PS: OFMSW (TS w/w basis). Fitamo et al. (2016) – sludge: FW: Grass clipping: Garden waste (VS basis).

[e] COD removals are indicated within brackets for Aichinger et al. (2015).

[f] L CH_4/$gVSS_{added}$ for Sosnowski et al. (2008). Two full scale tests by Aichinger et al. (2015) show that co-digestion increased specific methane yield maximum 1.59–2.87 times compared to sludge mono-digestion.

[g] LCH_4/gVSS/day for Sosnowski et al. (2008).

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