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Research paper

Co-digestion of food waste and chemically enhanced primary treated sludge in a continuous stirred tank reactor

Debkumar Chakraborty, Obulisamy Parthiba Karthikeyan, Ammaiyappan Selvam, Jonathan W.C. Wong*

Sino-Forest Applied Research Centre for Pearl River Delta Environment, Department of Biology, Hong Kong Baptist University, Hong Kong SAR, P.R. China

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ABSTRACT

Anaerobic digestion of food waste (FW) requires external addition of buffer and/or trace metals, while co-digestion with complementary organic substrates such as sewage sludge is an alternative approach to overcome with the operational failures. In this batch study, co-digestion of chemically enhanced primary treated (CEPT) sludge mixed (mass to mass ratio) with FW in continuous stirred tank reactors (CSTR) was investigated. The total solid (TS) contents of the CSTR varied between 60 and 100 kg dm^{-3} were prepared by mixing FW:CEPT sludge (on wet weight basis) at ratios of 1:3, 1:5 and 1:7. In addition, ~200 kg dm^{-3} inoculum was added to make up the total working volume in the CSTRs while contents were continuously mixed at 6.7 Hz and incubated at 35 °C for 20 days. Samples were collected intermittently from the CSTRs for the physiochemical analysis. The total biogas and methane (CH_4) productions are reduced in all CSTRs within 7–10 days due to the accumulation of VFAs to inhibitory concentrations. The maximum CH_4 production of 0.276 ± 0.02 dm^3 kg^{-1} VS added was recorded for treatment with 1:7 mixing ratio with an acetic acid accumulation of 0.35 g g^{-1} (~90% of total VFAs). The results suggested that the addition of FW in a sewage sludge digester will be beneficial to improve the CH_4 recovery and provide an alternative mean for treating FW locally. However, the inoculum size and buffering requirements need to be critically analyzed during the continuous operations to avoid any process inhibition.

1. Introduction

Hong Kong is a densely populated city with per-capita municipal solid waste (MSW) generation of 1.27 [1]. Every year, around 3.48 tonne of MSW are disposed-off in the 3 major landfill facilities in Hong Kong and all their full capacities by 2019. Therefore, the specific target of Hong Kong Environmental Protection Department (HKEPD) is to increase the number of waste to energy recovery facilities on or before 2022 to minimize/eliminate the usage of landfill facilities for MSW management (Hong Kong Blue Print 2013–2022 [1]). One major target is to treat the food waste (FW; ~3360 tonne per day) through biological anaerobic digestion process for the recovery of methane (CH_4). FW is highly biodegradable component of MSW that uphold high organic mass fractions i.e., 20–45% carbon; 80–90% volatile solids, 10–40% lipids, 5–10% protein and energy potential of ~0.25 kWh kg^{-1} [2–4]. Quick acidification, long solid retentions, high oil fractions (up to 100 kg t^{-1}), and toxic inhibitors affect the overall CH_4 recovery [3,5]. This will subsequently alter the reactor performance and cause frequent reactor failures [6,7]. Therefore, addition of essential nutrients or trace metals [8] or co-substrates are vital. However, the former will not be economically feasible while the latter required optimization to utilize locally available co-substrates. Co-substrates like fish waste, abattoir wastewater and waste activated sludge with high nitrogen content was used before [9] to provide buffering capacity against high organic loading of FW.

Compare to external addition of nutrients, co-digestion of two or more substrates with complementary characteristics is expected to provide a better nutrient balance, digester performance and biogas yields. However, the choice of suitable substrate is very important for co-digestion due fact that it should: (a) offer positive interactions that can provide nutrient, moisture balance and microbial synergisms; (b) avoid/causing any inhibitory effects (e.g., ammonia); and (c) support high-rate CH_4 production and reduce the digestion time [10]. A number of research studies have reported the benefits of FW co-digestion with different organic substrates

* Corresponding author. Department of Biology, Hong Kong Baptist University, Kowloon Tong, Kowloon, Hong Kong SAR, P.R.China.
E-mail address: jwcwong@hkbu.edu.hk (J.W.C. Wong).

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(Table 1 [11–18]). Nowadays, anaerobic co-digestion has gained more momentum to treat various organic resources with FW [7,19]. Xu and Li [20] showed that the FW to effluent mixing ratio of 2 was better than 4 and 6 to improve the cumulative CH_4 yield. El-Mashad and Zhang [21] found that the addition of FW with dairy manure resulted in higher biogas yields as compared to dairy manure alone. Thus, FW is more desirable organic resource available from any urban centres that can co-digest with sludge, manure or lingo-cellulosic to maximize the CH_4 yield [21–29]. However, the total solid (TS) contents plays a crucial role in overall digestion process, the digester efficiency, and the final digested product quality [28]. Digesters with total solids contents between 50 and 150 kg m^{-3} (i.e., semi-solid digestion) frequently encounter signs of toxicity and inhibitions [30], and hence most of the commercialized digesters work under solid content of <50 kg m^{-3} (wet-digestion) or > 200 kg m^{-3} (dry-digestion). Also, based on the availability of specific substrate the co-digestion should be substantiated. In urban centres, sewage sludge is readily digested in anaerobic digesters to remove the pathogens and harvest the bioenergy. But, digesters are either underperformed or poorly utilized to design capacities. Therefore, optimization of FW mixing ratio with sewage sludge digesters for co-digestion or vice versa will be highly feasible.

Although, co-digestion of FW and sewage sludge in wastewater treatment plants (WWTPs) are widely demonstrated in Italy, Germany, Denmark and Switzerland, it is still not recognized in developing countries [5]. In Hong Kong, every day ~2.2 hm^3 of sewage is treated through chemically enhanced primary treatment (CEPT) process generating tremendous volumes of iron rich polymeric sludge i.e., ~1200–1400 tonne, which are treated by incinerator process. The CEPT sludge contains iron (III) chloride, cationic and anionic polymers as flocculating materials [31]. It may support self-granulation during co-digestion with FW, which is the most desirable factor for methanogenic archaea and supports high-rate CH_4 production through improved interspecies electron transfers. The extracellular polymers secreted by methanogens help to form a bridge between two neighboring bacterial cells physically as well as binding them to other inert particulate matter, and settle out as floc aggregates [32–34]. In addition, the CEPT sludge as a co-substrate (i) introduces fermentative type of inoculums; (ii) buffer the system and regulate the pH; (iii) enhance the rate of hydrolysis and acidogenesis; (iv) provide iron which is essential trace metal for many enzymatic reactions during anaerobic digestion; (v) improve the oil degradation; and (vii) reduce the hydrogen sulfide contents in biogas [4,7,35–38]. There are few study reports available on co-digestion of iron-rich activated sludge with kitchen waste or FW [5,16]. However, these studies have not clearly reported the effects of volatile fatty acids (VFAs) accumulation on CH_4 production under co-digestion conditions.

Therefore, the major objective of this study is (i) to monitor the VFA accumulation under different mixing ratios of FW:CEPT sludge and (ii) to explain the early process inhibition and low CH_4 recovery from co-digestion conditions. The present study tested the three FW:CEPT sludge mixing ratios on wet weight basis i.e., 1:7 (~60 kg m^{-3}); 1:5 (~80 kg m^{-3}) or 1:3 (100 kg m^{-3}) for co-digestion. The results are compared with the control treatment with CEPT sludge only. Experiments are conducted using bench-scale continuous stirred reactors (CSTRs) under controlled test conditions. A first-order kinetic model calculation is used to compare the results and discuss the variations between treatments.

2. Material and methods

2.1. Substrates and inoculums

Artificial FW was prepared using 35% bread, 25% boiled rice, 25% cabbage and 15% boiled pork on wet weight basis and size reduced to ~ 4–6 mm [39]. The CEPT sludge was collected from Stonecutter Island wastewater treatment plant, Hong Kong (22°18′ N and 114°10′ E) and the sludge characteristics were reported earlier [31]. Anaerobically digested (AD; TS ~ 15 kg m^{-3}) sludge and up flow anaerobic sludge blanket reactor (UASB; TS ~ 16 kg m^{-3}) sludge were mixed at 1:1 ratio (at mass by mass) and used as source of inoculum for co-digestion process. The AD sludge was collected from Shatin wastewater treatment plant, Hong Kong (22°18′ N and 114°10′ E). The UASB effluent was collected from an in-house facility that was treating FW leachate over a year [40]. The inoculums, substrates and sludge samples were characterized prior to use in experiments.

2.2. Co-digestion of FW and CEPT sludge in continuous stirred tank reactors

Co-digestion of FW with CEPT sludge was carried out in a 2-L CSTR. The total and working volumes of CSTRs were 2.5 and 1-L, respectively. Three different mixing ratios of FW and CEPT sludge

Table 1
Methane production from co-digestion studies reported in literature.

Co-digestion strategy	VS removal efficiency (%)	Methane production (m^3 kg^{-1}) VS added	Reference
Sewage sludge (50% VS) + Food waste (50% VS)	–	0.22	[44]
Sewage sludge (75% DS) + Food waste (25% DS)	–	0.44	[72]
Sewage sludge (80% VS) + Food waste (20% VS)	–	0.40	[73]
WAS (10% VS) + Food waste (90% VS)	–	0.35	[74]
Sewage sludge + food waste	61.3	0.41*	[12]
kitchen biowaste + sewage sludge	63.6	0.36	[17]
32% Food waste + 68% Manure 48% Food waste + 52% Manure	60 and 68	0.25–0.29	[21]
Biowaste + food waste	50.5	3.4*	[13]
Co-digestion of a mixture of 70% manure + 20% food waste and 10% sewage sludge	–	0.60	[14]
Co-digestion of food waste + piggery wastewater	75.6	0.40	[75]
Food waste + Cattle manure (4.0, 2.7 and 2.0 gVS L^{-1})	–	0.40	[15]
15% KW and 85% Fe-sludge (mesophilic and thermophilic)	–	1.15 and 1.12@(respectively)	[16]
Sludge + food waste + grass clippings + garden, VS% (10:67.5:15.75:6.75) and (10:45:31.5:13.5)	–	0.39–0.43	[18]
Cattle manure + fruit and vegetable wastes in CSTR	–	0.45	[11]
FW + CEPT (6.32, 8.23 and 10.08% TS)	40.68, 37.84 and 40.26	0.27, 0.49 and 0.34 (respectively)	This study

Note: *LCH_4 L^{-1} day^{-1}; @ LCH_4 day^{-1}; VS - volatile solids; DS - dry solids; WAS - waste activated sludge; KW - kitchen waste; TS - total solids; CSTR - continuous stirred tank reactor; FW - food waste; CEPT - chemically enhanced primary treated sludge.

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