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Inhibition of volatile fatty acids on methane production kinetics during dry co-digestion of food waste and pig manure

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ABSTRACT

Compared with wet digestion, dry digestion of organic wastes reduces reactor volume and requires less energy for heating, but it is easily inhibited by high volatile fatty acid (VFA) or ammonia concentration. The inhibition on methane production kinetics during dry co-digestion of food waste and pig manure is rarely reported. The aim of this study was to explore the inhibition mechanisms and the microbial interactions in food waste and pig manure dry co-digestion systems at different inoculum rates (25% and 50% based on volatile solids) and food waste/pig manure ratios (0:100, 25:75, 50:50, 75:25 and 100:0 based on volatile solids). The results showed that the preferable operation conditions were obtained at the inoculum rate of 50% and food waste/pig manure ratio of 50:50, with a specific methane yield of 263 mL/g VS_{added}. High VFA concentration was the main inhibition factor on methane production, and the threshold VFA inhibition concentrations ranged 16.5–18.0 g/L. Syntrophic oxidation with hydrogenotrophic methanogenesis might be the main methane production pathway in dry co-digestion systems due to the dominance of hydrogenotrophic methanogens in the archaeal community. In conclusion, dry co-digestion of food waste and pig manure is feasible for methane production without pH adjustment and can be operated stably by choosing proper operation conditions.

1. Introduction

In Ireland, about 621 kilotonnes biodegradable municipal waste (BMW) was produced in 2016, comprising mainly food waste (FW) (EPA, 2018a; EPA, 2018b). Landfilling, composting and anaerobic digestion were main treatment methods for BMW, accounting for 62.8%, 29.4% and 7.8% of the total amount, respectively. Animal manure is largely produced in the livestock industry. The annual production of pig slurry is estimated at 3.19 million tonnes in Ireland (Jiang et al, 2018), and land farming is the main PM management method. The high volatile solids (VS) to total solids (TS) ratios of FW (80–98%) and PM (71–82%) make renewable biomethane production through anaerobic digestion a preferable management method for both wastes (Dennehy et al., 2017a, 2017b). However, the mono digestion of FW is prone to inhibition caused by high volatile fatty acid (VFA) concentrations and mono-digestion of PM can be negatively affected by the high ammonia concentration (Zhang et al., 2011). Co-digestion of FW and PM provides a promising solution to address these issues due to the buffering effect between VFAs and ammonia; significant synergistic effects during wet co-digestion of FW and PM have been reported (Dennehy et al., 2016; Zhang et al. 2011, Ebner et al, 2016).

Depending on the TS content of the substrate, anaerobic digestion can be classified as wet digestion (TS < 15%) or dry digestion (TS ≥ 15%) (Kothari et al., 2014; Li et al., 2011). Asam et al. (2011) reported wet digestion of PM was not economically feasible because of the low specific methanogenic capacities, high capital cost for large reactors and high transport cost. Nolan et al. (2012) also indicated that wet co-digestion of PM and grass silage was not cost effective due to the large reactor volume, high heating energy consumption, and high cost for post treatment of liquid digestate. Compared with wet digestion, dry digestion can (1) reduce the reactor volume significantly, (2) decrease the energy consumption for heating, (3) improve volumetric methane yield,

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Nomenclature

BMW	biodegradable municipal waste
C/N	carbon to nitrogen ratio
C_V	the VFA concentrations (mg/L)
$C_{V\theta}$	the threshold inhibition concentration of VFA (mg/L)
C_{VC}	the maximal inhibition concentration of VFA (mg/L)
D	the specific daily methane yield (mL/(g VS_{added}·d))
D_{max}	the maximum specific daily methane yield (mL/(g VS_{added}·d))
DNS	3, 5-Dinitrosalicylic acid
e	exp(1) = 2.7183
FW	food waste
i	the constant associated with VFA inhibition
K	the Monod saturation constant for VFAs (mg/L)
M	the cumulative methane production (mL/g VS_{added}) at time t (day)
MC	moisture content
MSW	municipal solid waste
n	the constant associated with VFA inhibition
OFMSW	organic fraction of municipal solid waste
P	the methane production potential (mL/g VS_{added})
PM	pig manure
R_{max}	the maximum methane production rate [mL/(g VS_{added}·d)]
SCOD	soluble chemical oxygen demand
SMY	specific methane yields
TAN	total ammonia nitrogen
TS	total solids
VFA	volatile fatty acid
VS	volatile solids
λ	the lag phase duration (day)

and (4) cut transport cost due to the greatly reduced digested waste volume. Therefore, dry co-digestion of FW and PM is expected to provide an economically feasible and environmentally sustainable treatment method for both wastes (Dennehy et al., 2017c).

However, accumulation of VFA and ammonia nitrogen often occurs in dry digestion systems, leading to inhibition and even failure of the digesters (Capson-Tojo et al., 2017; Jiang et al., 2018). Nowadays, studies on dry co-digestion mainly focus on feasibility of digesting different substrates and their combinations (Capson-Tojo et al., 2017; Maragkaki et al., 2018), optimization of parameters, e.g. initial pH and TS content (Abbassi-Guendouz et al., 2012; Zhang et al., 2015), and enhancement of methane production (Feng et al., 2015; Yang et al., 2015). The inhibition of VFA or ammonia on methane production kinetics in dry co-digestion systems is rarely reported. In addition, the microbial community structure under extremely high VFA or ammonia concentration in dry co-digestion systems is seldom reported, and the microbial roles and interactions are not clear.

Therefore, in this study, dry co-digestion of FW and PM was conducted to investigate (i) the inhibition factor on methane production at different inoculum rates and FW/PM ratios; and (ii) the microbial community structure and their interactions in dry co-digestion systems.

2. Materials and methods

2.1. Experimental design and parameter analysis

The inoculum was dewatered sludge collected from a local wastewater treatment plant in Galway City, Ireland, and was stored at 11 °C for about one month to release biogas. Pig manure was previously collected from the finishing unit of a local pig farm in Galway County, Ireland, and was stored at −4 °C in the lab. Prior to use, the PM was melt overnight and centrifuged at 1500 × g for 5 min (MSE super minor centrifuge, London, UK) to remain the solid fraction. Food waste was collected from 6 local residences in Galway City, and the non-degradable parts were removed before being ground by a food processor (Kenwood FPP210 Multipro Food Processor, Havant, UK) to less than 2 mm (Jiang et al., 2018). The initial characteristics of the FW, PM and inoculum are listed in Table 1.

Batch experiment was conducted in 1 L glass digesters. The inoculum rates were set at 25% and 50% based on VS, and the FW/PM ratios were 0:100, 25:75, 50:50, 75:25 and 100:0 on a VS basis. The co-digestion digesters were operated in duplicate (FW/PM = 25:75, 50:50 and 75:25) and the mono-digestion of PM or FW (FW/PM = 0:100 or 100:0) was operated separately as control. The detailed qualities of FW, PM and inoculum added to each digester are shown in Table 2. Tap water was added to adjust the TS content in each digester to 20%. After adding the inoculum and substrates, all of the reactors were flushed with nitrogen gas for 5 min to remove oxygen, and then placed in an incubator at 37 °C. The digesters were shaken by hand every day.

Biogas from each digester was collected with a Tedlar bag (Restek Corporation, Bellefonte, PA, USA) twice a week. The biogas volume was measured by a flow meter (FMA-1620A-TOT, Omega, Deckenpfronn, Germany) and converted to standard temperature and pressure, the methane content was measured by gas chromatography (GC 7890 A, Agilent Technology, Santa Clara, CA, USA). About 2 g samples were taken weekly from the bottom of the digesters for analysis of pH, TS, VS, soluble chemical oxygen demand (SCOD), VFAs and total ammonia nitrogen (TAN). The analysis methods were detailed by Jiang et al. (2018). Briefly, the TS and VS contents were analyzed by standard method (APHA, 1995). A 20-fold dilution was obtained by adding 19 parts of deionized water (w/w) to 1 part of sample. After mixing well, pH was analyzed by a pH meter (pH 3210, WTW, Weilheim, Germany). Then the mixture was centrifuged at 18,000 × g for 10 min, and the liquid part was filtered by 0.45 μm filter paper. SCOD of the filtrate was measured by standard method (APHA, 1995). The VFA was analyzed by high performance liquid chromatography (HPLC, Agilent 1200, Agilent Technology, Richardson, TX, USA), and TAN was analyzed by a nutrient analyzer (Thermo Clinical Labsystems, Vantaa, Finland). The VS amount of samples taken from the digesters was recorded and subtracted from the total VS

Table 1
Characteristics of the food waste, pig manure and inoculum added to the digesters.

Characteristics	Food waste	Pig manure	Inoculum
pH	4.5	8.4	8.4
Moisture content (MC, %)	70.6	74.4	81.2
Total solids (TS, g/kg)	293.8	256.2	188.0
Volatile solids (VS, g/kg)	283.7	211.4	128.3
VS/TS (%)	96.6	82.5	68.2
Soluble chemical oxygen demand (SCOD, g/L)	92.6	35.0	16.4
Volatile fatty acids (VFA, mg/L)	3007	9821	0
Total ammonia nitrogen (TAN, mg/L)	386	3666	990
Carbohydrate (g/g TS)	0.45	0.18	0.16
Protein (g/g TS)	0.18	0.17	0.34
Fat (g/g TS)	0.10	0.05	0.06