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Influence of feed/inoculum ratios and waste cooking oil content on the mesophilic anaerobic digestion of food waste

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A B S T R A C T

Information on the anaerobic digestion (AD) of food waste (FW) with different waste cooking oil contents is limited in terms of the effect of the initial substrate concentrations. In this work, batch tests were performed to evaluate the combined effects of waste cooking oil content (33–53%) and feed/inoculum (F/I) ratios (0.5–1.2) on biogas/methane yield, process stability parameters and organics reduction during the FW AD. Both waste cooking oil and the inoculation ratios were found to affect digestion parameters during the AD process start-up and the F/I ratio was the predominant factor affecting AD after the start-up phase. The possible inhibition due to acidification caused by volatile fatty acids accumulation, low pH values and long-chain fatty acids was reversible. The characteristics of the final digestate indicated a stable anaerobic system, whereas samples with F/I ratios ranging from 0.8 to 1.2 display higher propionic and valeric acid contents and high amounts of total ammonia nitrogen and free ammonia nitrogen. Overall, F/I ratios higher than 0.70 caused inhibition and resulted in low biogas/methane yields from the FW.

1. Introduction

Anaerobic digestion (AD) has been widely applied to reduce the volume of food waste (FW) and to recover energy (e.g., methane) from FW. The content of waste cooking oil in FW may vary from 1% to 5% (wet basis) (Li et al., 2016a,b; Nie et al., 2013) due to different eating habits, cooking methods and local cultures (Koch et al., 2015). In addition, waste cooking oil often results in a higher biochemical methane production than carbohydrates and protein (Angelidaki and Sanders, 2004). However, the FW biodegradation processes can be hampered by long-chain fatty acids (LCFAs), which are produced from waste cooking oil and can cause toxicity to microorganisms and biomass adsorption (Chen et al., 2014).

Previous studies have reported various inhibitory concentrations of lipids, including 31–47% for chemical oxygen demand basis (Cirne et al., 2007) and 65% for volatile solid (VS) basis (Sun et al., 2014). FW with lipid contents higher than 35% have been shown to result in AD processes with longer lag phases and lower first-order degradation constants (Zhang et al., 2017). Studies have also shown that the inhibition caused by LCFAs varies depending on the type of feedstock and is more correlated with the physical characteristics (e.g., specific surface area and size distribution) than the biological characteristics (e.g., inoculum origin, specific acetoclastic methanogenic activity and inoculum adaptation to lipids) of the process (Chen et al., 2008; Hwu et al., 1996). However, these studies were often carried out using either model lipid-rich waste (Cirne et al., 2007) or edible oil (Sun et al., 2014), which have significantly different characteristics from those of waste cooking oil in FW. The waste cooking oil existed in FW is of low hygiene quality (Ren et al., 2013; Zhang et al., 2003) and has higher triacylglycerol content (e.g., C14:0, C16:1, C16:0 and C17:0), oleic acid (C18:1) and linoleic acid (C18:2) contents (Zhuang et al., 2013) that are present in the intermediates generated during AD and are considered to be the main inhibitory factors of LCFAs (Alves et al., 2009). Therefore, investigating the influence of the waste cooking oil ratio on FW digestion performance is necessary.

An excessive amount of biomass substrate may lead to the accumulation of total ammonia-nitrogen (TAN) and volatile fatty acids (VFA), resulting in an inhibitory effect on the biogas yield

Abbreviations: FW, Food Waste; AD, Anaerobic Digestion; F/I, Feed/Inoculum; EE, Ether Extract; VFA, Volatile Fatty Acids; LCFA, Long Chain Fatty Acids; SFA, Saturated Fatty Acids; MUFA, Monounsaturated Fatty Acids; PUFA, Polyunsaturated Fatty Acids; RT, Retention Time; TS, Total Solid; VS, Volatile Solid; AMPTS, Automatic Methane Potential Test System; TAN, Total Ammonia Nitrogen; FAN, Free Ammonia Nitrogen.

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(Fernández et al., 2008; Zhao et al., 2017). Studies have shown that the inhibition caused by LCFAs can be alleviated by increasing the biomass/LCFA ratio using inoculums (Palatsi et al., 2009), and that methane production can decrease or even stop without proper F/I ratios. Additionally, F/I ratios have been reported to affect methane yield mainly with substrates derived from durian shells (Zhao et al., 2017), food and green wastes (Liu et al., 2009), swine slurries (González-Fernández and García-Encina, 2009), wheat straws, whole crop maize, cattle manure, grass, cellulose (Moset et al., 2015) and other organic wastes (Boulanger et al., 2012; Dechrugsa et al., 2013; Fagbohungbe et al., 2015; Haider et al., 2015; Pellera and Gidarakos, 2016). However, considering the potential VFA production and the buffering capacity of the medium using ammonium, each substrate has its own optimum feed/inoculum (F/I) ratio (Lesteur et al., 2010). Moreover, studies examining the combined influence of waste cooking oil and F/I ratios on process stability and biogas/methane productivity in the AD of FW are still lacking. A literature review of ether extract (EE) content in FW showed that EE accounts for approximately 6–45% of the total FW in China (VS basis) (Li et al., 2016a,b; Nie et al., 2013). Since lipid-rich waste is more likely to result in operational problems (Chen et al., 2008; Cirne et al., 2007; Long et al., 2012), the influence of higher waste cooking oil ratios, specifically EE/VS feedstock ratios ranging from 33% to 53%, were investigated in the present study (Table 1).

This paper aims to investigate the AD characteristics of FW containing different waste cooking oil and F/I ratios. The modified Gompertz model was applied to describe biogas production process and to determine the digestion efficiency, which were then further evaluated to determine how and over which ranges the two ratios affect digestion performance, process kinetics and biodegradability. From this analysis, possible inhibitory effects were discussed, and the optimal waste cooking oil and F/I ratios that increased methane yields were presented.

2. Materials and methods

2.1. Substrates and inoculum

2.1.1. FW

FW was collected from a school canteen in Beijing, China. Impurities in the collected FW (e.g., big bones, plastics and metals) were manually removed before the FW was macerated into 1–2 mm particles. The main characteristics of the FW used in the experiments were (average values of three determinations with standard deviations) shown in Table 1.

Some samples were used to extract waste cooking oil with petroleum ether (analytically pure, boiling point: 30–60 °C) using a rotary evaporator at 60 rpm. Then the extracted oil was used for adjusting the waste cooking oil ratio in FW, and the ratio was characterized by the concentration of the EE in the VS of the FW (EE/VS):

$$EE/VS = \frac{m_{FW} \times EE_{FW}\% + m_{oil-extracted}}{m_{FW} \times VS\% + m_{oil-extracted}} \times 100\% \quad (1)$$

where m_{FW} is the mass of the initial FW, $EE_{FW}\%$ is the percent of EE in the initial FW sample, $m_{oil-extracted}$ is the mass of waste oil added in the FW, which was extracted from FW, and $VS\%$ is the VS content of the initial FW. Table 2 presents the LCFA composition of the waste cooking oil in the FW.

2.1.2. Inoculum

Seed sludge was obtained as an inoculum from a steady-operation digester (37 °C) at a wastewater treatment plant in Beijing, China. After a two-day gravity sedimentation period, the supernatant was discarded, and the remainder was passed through a 2-mm sieve to remove large particles/grit. The characteristics of the inoculum are shown in Table 3.

2.2. AD experimental setup

2.2.1. Determination of the inoculum ratios

To identify the synergistic impacts of the F/I and EE/VS ratios on FW digestion, we focused on their interactions with inoculum ratios in digestion experiments on a VS basis (Table. 1). All the F/I ratios as shown in Table 1 were based on a mass of VS basis.

2.2.2. Batch digestion tests

Batch tests were conducted in 15 parallel 500-mL glass bottles at 37 °C with an automatic methane potential test system II (AMPTS II) that was supplied by Bioprocess Control (Lund, Sweden). AMPTS II features automatic sample stirring, an acid gas (such as CO_2 or H_2S) removal system and a biomethane yield recording system. The system performs fast and accurate on-line measurements of ultra-low biogas and biomethane flow to determine the biogas potential. All the reactors were started simultaneously and used synchronous agitation at the same speeds (160 r/min) and intervals (60 s on/off).

The substrates and inoculums were placed into bottles with different F/I ratios. The upper area of each reactor was flushed with nitrogen for at least 1 min to ensure anaerobic conditions and was then quickly sealed. All of the reactors were placed in a water bath to maintain the digestion system at a mesophilic temperature (37 °C) for AD. For each test, three samples were examined, and two digesters containing only inocula were incubated to correct for the biogas yield from the inoculum. The biogas yield was calculated by the VS of substrate in the bottle, including FW and waste cooking oil added. The digestion assays were stopped when the daily biogas (or methane) production was less than the 1% of the total accumulated biogas (or methane).

Table 1
Characteristics of the FW and the F/I ratios.

Items	Waste cooking oil ratios (EE/VS)						
	33%	36%	40%	43%	46%	50%	53%
pH	4.47 ± 0.21	4.46 ± 0.32	4.46 ± 0.28	4.46 ± 0.41	4.45 ± 0.32	4.45 ± 0.29	4.44 ± 0.44
TS[a,b] (%)	15.01 ± 0.98	15.47 ± 0.71	16.41 ± 0.63	17.02 ± 0.42	17.76 ± 0.45	18.71 ± 0.29	19.93 ± 0.35
VS[a,c] (%)	14.18 ± 0.52	15.52 ± 0.82	18.06 ± 0.91	19.71 ± 0.71	21.63 ± 0.50	23.98 ± 0.46	26.90 ± 0.49
Protein[a] (%)	3.58 ± 0.15	3.56 ± 0.22	3.53 ± 0.06	2.17 ± 0.06	2.15 ± 0.33	2.12 ± 0.17	2.09 ± 0.28
F/I[d]	1.20	1.00	0.80	0.70	0.60	0.56	0.50

[a] Wet basis.
[b] Total solid.
[c] Volatile solid.
[d] Feed to inoculum ratio.