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Real-time recovery strategies for volatile fatty acid-inhibited anaerobic digestion of food waste for methane production

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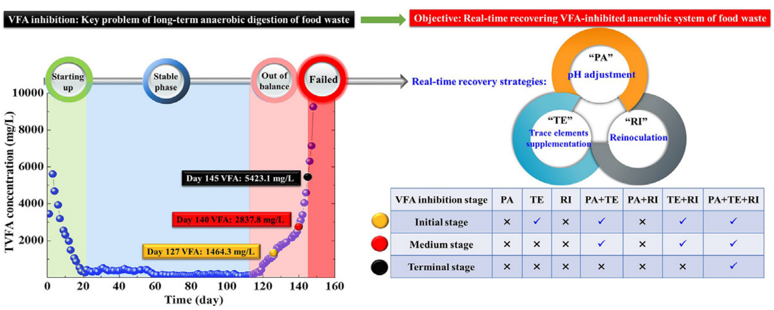
GRAPHICAL ABSTRACT



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ABSTRACT

This study investigated effects of real-time recovery strategies on VFA (volatile fatty acid)-inhibited anaerobic system of FW (food waste) and identified key driver of process recovery. The long-term anaerobic system of FW encountered serious VFA (mainly propionate) inhibition. The pH adjustment (PA) strategy could not reverse process imbalance but only delayed the process failure. The short-term effect of reinoculation (RI) strategy was greatly effective, but its long-term effect was non-sustainable. Trace elements were key drivers of process recovery owing to their indispensable roles in activating methanogenesis and therefore stimulating propionate conversion. From the viewpoint of economic feasibility, the single strategy of trace elements supplementation (TE) and the combinational strategy of PA + TE were respectively recommended in the initial and medium VFA-inhibition stages. The three-in-one strategy of PA + TE + RI was always effective but was costly. This study provided practical guidance on real-time recovery of VFA-inhibited anaerobic system of FW.

1. Introduction

Nowadays, the development of society overly depends on the fossil fuels. According to BP Statistical Review of World Energy, 2017, fossil fuels (coal, petroleum and natural gas) reached 85.5% of global primary energy consumption in 2016, but the percentage of renewable energy was only 3.16%. The extensive utilization and great consumption of coal and petroleum have raised a lot of environmental, social and economic concerns due to the aggravating air pollution and global warming and the non-renewability and non-sustainability of fossil fuels, which have led to a move towards alternative, renewable, sustainable, efficient and cost-effective energy sources with lesser emissions (Chu and Majumdar, 2012; Nigam and Singh, 2011). In this context, biofuels produced from renewable biomass sources were considered as an

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answer to sustainable fuel (Nigam and Singh, 2011; Rodionova et al., 2017). Especially, methane production from FW via anaerobic digestion has attracted worldwide attention owing to the "three-in-one" advantage of waste disposal, energy recycling and benign ecological cycle (Braguglia et al., 2018; Capson-Tojo et al., 2016; Jeison, 2015; Zhang et al., 2016).

FW was regarded as an ideal substrate of anaerobic digestion for its suitable physical and chemical properties, good biodegradability, high methane production potential and nutrient-rich digestate (Capson-Tojo et al., 2016; Xu et al., 2018; Zhang et al., 2015b,c,d). Many investigations focusing on the topic of anaerobic digestion of FW were carried out in recent years (Braguglia et al., 2018; Capson-Tojo et al., 2016; Komilis et al., 2017; Leung and Wang, 2016; Sen et al., 2016; Uçkun Kiran et al., 2014; Zhang et al., 2014). However, in practice, long term operated anaerobic system of FW was confronted with several challenges including VFA (volatile fatty acid) inhibition, ammonia inhibition, high salinity inhibition and long chain fatty acid inhibition, etc., which might result in poor performance and instability even the failure of anaerobic process (Li et al., 2018; Wang et al., 2018). VFA inhibition was often reported as the first and foremost factor affecting process stability of anaerobic digestion of FW, which manifested as great accumulation of VFA, sharp drop of pH and the subsequent decrease of methane production. Zhang and Jahng (2012) observed the serious acidification in semi-continuous anaerobic system of FW from Day 75. Finally, VFA concentration reached above 18,000 mg/L and no more methane was produced from Day 85. Banks et al. (2012) used FW as the substrate of anaerobic digester operated at a low organic loading rate (OLR) of 3 g VS/L·day, a long hydraulic retention time (HRT) of 63 days and elevated ammonia concentration. They detected the obvious accumulation of propionate, which was proved to be the main inhibitor of anaerobic system. Wei et al. (2014) and Zhang et al. (2015a) verified the instability of long-term anaerobic digestion of FW as noted by the strong inhibition of VFA (reached about 35,000 mg/L) to methane production. Li et al. (2015) found that VFA concentration in anaerobic system of FW rose to 9000 mg/L after the stepwise increase of OLR from 3 to 6 g VS/L·day and the corresponding methane yield dropped sharply. Voelklein et al. (2017) suggested that both single-stage and two-stage anaerobic systems of FW suffered from VFA inhibition even when the OLR was as low as 2.5 g VS/L·day. VFA inhibition seemed to be a common problem of long-term anaerobic digestion of FW, which greatly limited the development and application of this technology and should therefore be solved completely.

In recent years, researchers concentrated on developing high-efficiency and stable anaerobic digestion technology of FW and have accumulated rich experience on how to avoid the occurrence of VFA inhibition. Substrate pretreatment (Carrere et al., 2016; Leung and Wang, 2016), multiple additives (Romero-Güiza et al., 2016), co-digestion (Chiu and Lo, 2016; Sen et al., 2016), optimizing operating parameters and reactor configuration (Zhang et al., 2016) and other technologies related to microbial ecology (Amani et al., 2010; Mata-Alvarez et al., 2014) were proved to be effective. However, if VFA inhibition already occurred, which strategy should be applied to reverse it? This point seemed to be neglected. In practice, the feeding to the digester should be stopped to restore the ecological function of anaerobic system via self-recovery of microorganism. However, this method requires a long time and is not economically feasible. Wei et al. (2014), Zhang et al. (2015a) and Voelklein et al. (2017) tried the strategy of stoppage of feeding coupled with trace elements supplementation to recover the VFA-inhibited anaerobic system of FW and suggested that Co, Fe, Mo, Ni and Se elements could accelerate process recovery, but a long feeding-stop period more than 20 or 30 days proposed by them was still unacceptable in real-scale applications as it meant great economic loss and retardation of waste disposal. How to eliminate VFA inhibition and real-time recover the process stability of anaerobic system of FW without stoppage of feeding is still a great challenge. The strategy of adjusting pH to a near-neutral value was often applied to enhance the buffering capacity of anaerobic system against to VFA disturbance (Li et al., 2009). The additives of trace elements could offer essential micronutrients to anaerobic microorganism and facilitate maintaining high metabolic activity of anaerobic system, especially in the case when the basic substrate had low concentrations of trace elements (typical for FW) (Banks et al., 2012; Zhang and Jahng, 2012; Zhang et al., 2011, 2015c). In the previous study (Zhang et al., 2015b), the exciting real-time recovery effects of trace elements (Fe, Co, Mo, Ni) supplementation on unstable anaerobic system of FW in the initial VFA-inhibition stage were verified. This early exploration provided valuable guidance on real-time recovery of VFA-inhibited anaerobic system of FW. In practice, the strategy of reinoculation (Wu et al., 2015) or bioaugmentation (Li et al., 2017) was usually used to restart the anaerobic system which was out of order via supplementing high-activity anaerobic microorganism directly. These three strategies were proved to be effective methods to improve the performance of anaerobic process and had the potential of real-time recovering the VF-inhibited anaerobic system of FW theoretically. However, so far, there is no report that provides the systematic and comprehensive evaluation about this subject. This was the reason to initiate this study, where the restorative effects of pH adjustment, trace elements supplementation, reinoculation and their different combinations on process performance and stability of anaerobic system of FW in varying VFA-inhibition stages were investigated and the key driver of methanogenic activity recovery and process rebalance was also explored.

2. Materials and methods

2.1. Materials and sample preparation procedures

The FW used as the substrate of anaerobic digestion was collected from a student restaurant of Dalian University of Technology in China. The impurities in the FW, such as bones, napkins, plastic bags, one-off chopsticks, etc., were sorted out by hand. The rest was minced and homogenized using a blender and then screened through a 14-meshes screen (1.40 mm). The FW sample was stored at −20 °C and was thawed for 12 h at 5 °C before use. The characteristics of FW sample are shown in Table 1. The anaerobic sludge used as the inoculum was obtained from a digester fed by sewage sludge in a municipal sludge

Table 1
Characteristics of FW used in this study.

Parameter	Unit	Value	Parameter	Unit	Value
Moisture	%	76.8 ± 0.6	C/N ratio	–	20.6
pH	–	4.4 ± 0.1	TKN[h]	mg/L	4900 ± 200
TS[a]	wt%	23.2 ± 0.2	Ammonia	mg/L	230 ± 10
VS[b]	wt%	21.7 ± 0.2	TMP[i]	mL/g VS	558.8
VS/TS	%	93.5	Na	g/kg TS	8.081
TCOD[c]	wt%	30.4 ± 0.3	K	g/kg TS	2.933
SCOD[d]	%TCOD	51.0 ± 0.4	Mg	g/kg TS	0.821
Lipid	%VS	29.9 ± 0.4	Fe	mg/kg TS	167.7
Protein[e]	%VS	13.5 ± 1.0	Zn	mg/kg TS	56.2
Carbohydrate[f]	%VS	56.6 ± 0.7	Ni	mg/kg TS	15.3
C	%TS	49.5 ± 0.2	Mn	mg/kg TS	13.7
H	%TS	7.0 ± 0.1	Cu	mg/kg TS	8.0
N	%TS	2.4 ± 0.1	Mo	mg/kg TS	1.6
O[g]	%TS	34.6 ± 0.2	Co	mg/kg TS	0.2
Ash	%TS	6.5 ± 0.1			

[a] Total solid.
[b] Volatile solid.
[c] Total chemical oxygen demand.
[d] Soluble chemical oxygen demand.
[e] Protein = (TKN − ammonia) × 6.25.
[f] Carbohydrate = VS − Lipid − Protein.
[g] O% = 100% − (C + H + N + Ash)%.
[h] Total Kjeldahl nitrogen.
[i] Theoretical methane potential.