Bioresource Technology 193 (2015) 234–242

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Evaluation and characterization during the anaerobic digestion of high-strength kitchen waste slurry via a pilot-scale anaerobic membrane bioreactor

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HIGHLIGHTS

- The high-strength kitchen waste slurry was reliably treated via an AnMBR.
- The precipitation and agglomeration of LCFAs and Ca^{2+} influenced the treatment.
- SRT control was significant to methane recovery enhancement in the digestion.
- SRT control was significant to membrane fouling mitigation in the digestion.

ARTICLE INFO

Article history:
Received 18 April 2015
Received in revised form 11 June 2015
Accepted 13 June 2015
Available online 18 June 2015

Keywords:
Anaerobic membrane bioreactor (AnMBR)
Kitchen waste slurry
Anaerobic digestion
Long chain fatty acids (LCFAs)
Membrane fouling

ABSTRACT

The anaerobic digestion of high-strength kitchen waste slurry via a pilot-scale anaerobic membrane bioreactor (AnMBR) was investigated at two different operational modes, including no sludge discharge and daily sludge discharge of 20 L. The AnMBR provided excellent and reliable permeate quality with high COD removal efficiencies over 99%. The obvious accumulations of long chain fatty acids (LCFAs) and Ca^{2+} were found in the anaerobic digester by precipitation and agglomeration. Though the physico-chemical process contributed to attenuating the free LCFAs toxicity on anaerobic digestion, the digestion efficiency was partly influenced for the low bioavailability of those precipitates. Moreover, higher organic loading rate (OLR) of 5.8 kg COD/(m^3 d) and digestion efficiency of 78% were achieved as the AnMBR was stably operated with sludge discharge, where the membrane fouling propensity was also alleviated, indicating the crucial significance of SRT control on the treatment of high-strength kitchen waste slurry via AnMBRs.

1. Introduction

Energy crisis and environment pollution have received much more public and professional attentions in recent years. The resource recovery from various wastes is a significant way to relieve the two problems, which is also a core strategy for sustainable social & economic development. With approximately 110 million tons of annual emissions, kitchen waste has become an important part of organic contaminants in China (Yin et al., 2013). Meanwhile, as shown in Fig. S1, a combined process, successively including raw material pretreatment, biodiesel refining, anaerobic digestion and wastewater further treatment, is now promisingly adopted for the numerous waste disposal (Gao et al., 2015). The integrated system can not only solve the related environmental problems, but can also realize an industrialized energy production in a large scale. However, the kitchen waste slurry generated from the process contains various kinds of organic compounds, which is typically characterized by high organic concentration, high suspended solids content and high salinity. Hence, a forceful anaerobic digestion technology is very necessary for efficient energy recovery from the high-strength organic slurry. Moreover, it is also a crucial step to guarantee continuous and stable operation of the whole combined process.

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http://dx.doi.org/10.1016/j.biortech.2015.06.065
0960-8524/

In the authors' previous experiments, some conventional anaerobic bioreactors including Upflow Anaerobic Sludge Blanket (UASB), Continuous Stirred Tank Reactor (CSTR) and Expanded Granular Sludge Bed (EGSB) had been used to treat the high-strength kitchen waste slurry. However, though there were many biodegradable substrates for high rate anaerobic digestion, the efficiencies of COD (Chemical Oxygen Demand, COD) removal and energy recovery were still not satisfactory. And it was even very difficult to establish a stable fermentation process under certain operational conditions. The obstacles involved in those bioreactors mainly included VFAs (Volatile Fatty Acids, VFAs) accumulation, low VSS (Volatile Suspended Solids, VSS) degradation efficiency, poor sludge granulation, serious sludge flotation and washout, and even reactor plugging. Thus, the characteristic of the kitchen waste slurry makes it a challenging substrate for efficient anaerobic digestion.

Anaerobic membrane bioreactors (AnMBRs) have currently drawn an increasing professional interest (Dereli et al., 2014a; Giménez et al., 2012). With the aid of membranes, all the particulate matters including biomass are retained in the anaerobic reactors. In this respect, AnMBRs enable reactor operation at high biomass concentration, better control of sludge retention time (SRT), and therefore high organic loading rates (Smith et al., 2012). Moreover, since many wastewaters have characteristics that may limit the stable formation of microbial aggregates, AnMBRs also have great potential for the treatment of extreme organic wastewaters or slurries where the conventional granular sludge bed systems fail to retain highly active anaerobic biomass in the reactors (Van Lier et al., 2001). Recently, AnMBRs have been utilized to treat real industrial wastewaters in some researches, and the investigations about their dynamics, performance, stability and membrane fouling show that the anaerobic biotechnology has a good application prospect (Shin et al., 2014; Gouveia et al., 2015; Wang et al., 2013). Nevertheless, since the complexity, interaction and impact of various organic and inorganic compounds present in different real wastewaters, the availability and performance of AnMBRs still requires further investigation. Therefore, given the challenge for efficient biodegradation and energy recovery, the anaerobic digestibility of high-strength kitchen waste slurry via a pilot-scale AnMBR was evaluated in this study, where the operational characteristics and optimization suggestions were also discussed.

2. Methods

2.1. Kitchen waste slurry characterization

The feed slurry used in this study was daily collected from a full scale kitchen waste treatment plant (Suzhou City, China) and then was prepared by a grid filtration (1 mm). The slurry characterization was given in Table 1. The main organic compounds were carbohydrate (16.4–19.7 g/L), protein (10.3–12.4 g/L) and lipids (4.4–6.3 g/L). The concentrations of total chemical oxygen demand (TCOD) and suspend solid (SS) were 78.0–100.0 g/L and 15.5–21.4 g/L, respectively. The feed pH was varied from 3.59 to 4.12. Furthermore, the feed slurry had a high level of salinity with conductivities ranging from 9.0 to 12.4 ms/cm, where the Ca^{2+} concentration reached 1100–1200 mg/L.

2.2. AnMBR configuration and operation

As shown in Fig. 1, the pilot-scale AnMBR system consisted of a continuously mixed feed vessel, a 1.2 m^3 anaerobic digester and an external ultrafiltration membrane (UF) system. The tubular membrane modules (Berghof, Germany) used in this study were made of PVDF with a molecular weight cut-off of 100,000 Daltons, and each of them had a surface area of 0.1 m^2. The AnMBR was operated at a cross flow velocity of about 2.2 m/s, which produced a 2.0 m/h up-flow velocity and could ensure a good mixing of substrates and anaerobes without additional mechanical stirring. The average membrane operation pressure was 0.23 MPa, and the concentrate was continuously returned to the digester with a recirculation rate of 1.6 m^3/h throughout the whole study. The biogas production and pH were determined and recorded on-line.

The AnMBR system was inoculated with 1 m^3 anaerobic sludge containing 7.8 g/L VSS from a full-scale CSTR reactor treating kitchen waste slurry in the plant, and it was then operated for 220 d under mesophilic condition (39 ± 1 °C) in this study. The reactor was fed continuously, where anaerobic digestion performance was evaluated at two different operational modes, including no sludge discharge in the first 140 d and daily sludge discharge of 20 L from anaerobic digester in the following 80 d. The permeate flow rates were checked daily, which varied with the change of membrane flux. The feed rate was daily adjusted to maintain a balance between inflow and outflow in the anaerobic digester with a fixed working volume of 1 m^3. The membrane was periodically cleaned by chemical method, successively with tap water flushing, 0.2% sodium hypochlorite (10 L), pH 2 hydrochloric acid solution (10 L) and 1% ethylene diamine tetraacetic acid (EDTA) (10 L).

2.3. Analytical methods

The feed, permeate and fermentation broth were frequently analyzed during the AnMBR operation. Chemical oxygen demand (COD), mix liquid suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), total phosphorus (TP), and alkalinity were measured according to Standard Methods (APHA, 2005). The volatile fatty acids (VFAs) were determined using a gas chromatography (GC-2010, Shimadzu, Japan) equipped with a flame ionization detector (FID) and a 30 m × 0.25 mm × 0.25 μm capillary column (Rtx-5, Restek, USA) (Huang et al., 2012). The methane content was analyzed using a gas chromatography (GC-2010, Shimadzu, Japan) equipped with a thermal conductivity detector (TCD) and a 1.8 m × 3.2 mm stainless-steel column packed with porapak Q (80/100 mesh) (Xu et al., 2014). The feed conductivity was measured by a conductivity meter (DDS-307, Shanghai, China). Calcium (Ca^{2+}) and magnesium (Mg^{2+}) were analyzed by

Table 1
Kitchen waste slurry characterization.

Parameters	Unit	Value	Parameters	Unit	Value
TCOD	(g/L)	78.0–100.0	Calcium	(mg/L)	1100–1200
MLSS	(g/L)	15.5–21.4	Magnesium	(mg/L)	95–110
MLVSS	(g/L)	13.8–19.6	NH_4^+	(mg/L)	180–480
pH	–	3.59–4.12	TKN	(mg/L)	1600–2100
Total carbohydrate	(g/L)	16.4–19.7	TP	(mg/L)	76.5–89.3
Protein	(g/L)	10.3–12.4	Conductivity	(ms/cm)	9.0–12.4
Lipids	(g/L)	4.4–6.3	Temperature	(°C)	50–55