Bioresource Technology 102 (2011) 5048–5059

Contents lists available at ScienceDirect

Bioresource Technology

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

Anaerobic co-digestion of food waste and piggery wastewater: Focusing on the role of trace elements

Lei Zhang [a], Yong-Woo Lee [b], Deokjin Jahng [a,*]

[a] Department of Environmental Engineering and Biotechnology, Myongji University, San 38-2, Namdong, Cheoin-Gu, Yongin, Gyeonggi-Do 449-728, Republic of Korea
[b] Major in Chemistry & Applied Chemistry, College of Science and Technology, Hanyang University, 1271 Sa-3 Dong, Sangnok-Gu, Ansan, Gyeonggi-Do 426-791, Republic of Korea

ARTICLE INFO

Article history:
Received 19 October 2010
Received in revised form 26 January 2011
Accepted 28 January 2011
Available online 23 February 2011

Keywords:
Anaerobic digestion
Co-digestion
Food waste
Piggery wastewater
Trace elements

ABSTRACT

The objective of this study was to evaluate the feasibility of anaerobic co-digestion of food waste and piggery wastewater, and to identify the key factors governing the co-digestion performance. The analytical results indicated that the food waste contained higher energy potential and lower concentrations of trace elements than the piggery wastewater. Anaerobic co-digestion showed a significantly improved biogas productivity and process stability. The results of co-digestion of the food waste with the different fractions of the piggery wastewater suggested that trace element might be the reason for enhancing the co-digestion performance. By supplementing the trace elements, a long-term anaerobic digestion of the food waste only resulted in a high methane yield of 0.396 $m^3/kg\ VS_{added}$ and 75.6% of VS destruction with no significant volatile fatty acid accumulation. These results suggested that the typical Korean food waste was deficient with some trace elements required for anaerobic digestion.

1. Introduction

Generation of municipal solid waste (MSW) has been increasing over the years worldwide, a considerable fraction of which is food waste (Banks et al., 2011; Zhang et al., 2007). In Korea, the food waste reached about 14,452 tons per day in 2007, which accounted for 28.7% of the MSW (MOE, 2010). The untreated food waste is known to cause many environmental problems, such as contaminations of soil, water, and air during collection, transportation and storage due to its rapid decomposition (Han and Shin, 2004). Currently, various methods for reutilization and disposal of the food waste are available, which include landfill, incineration, use of animal feed, aerobic composting and anaerobic digestion. Due to newly issued environmental regulations, some disposal methods are going to be prohibited and becoming less desirable (Kelley and Walker, 2000; Oh et al., 2008).

Nonetheless, food waste is a highly desirable substrate for anaerobic digestion because its biodegradability and nutrient contents are high. The typical food waste contains 7–31 wt.% of total solid (TS), and the biochemical methane potential (BMP) of the food waste is estimated to be about 0.44–0.48 $m^3\ CH_4/kg$ of the added volatile solid (VS_{added}) (Han and Shin, 2004; Heo et al., 2003; Zhang et al., 2007). Nowadays, anaerobic digestion of the food waste is attracting strong interest, and many novel anaerobic digestion systems have been developed and applied to treat the food waste. Two-stage anaerobic digestion system and HASL (hybrid anaerobic solid–liquid) system are well known examples (Lee et al., 1999; Wang et al., 2005). In practical application, however, about 90% of the full scale plants currently in use in Europe rely on continuous one-stage systems (De Baere, 2000). Even so, there are rare reports on the successfully operating single-stage anaerobic digestion of the food waste. These results indicated that anaerobic digestion of the food waste still remains as a challenge.

Piggery wastewater is another major organic waste. Anaerobic digestion has long been employed to treat piggery wastewater because through which waste treatment and energy production could be achieved simultaneously. The methane yields of animal manures are generally in the range of 12.0–13.9 $m^3\ CH_4/m^3$ waste (wet basis). According to the economic analysis of the existing biogas plants, however, the methane yield should be higher than 20 $m^3\ CH_4/m^3$ substrate to meet the economic balance (Angelidaki and Ellegaard, 2003). In addition, ammonia inhibition was often observed in the anaerobic digestion of the pure manure, which resulted in a low methane production and a high VFA level in the effluent (Hansen et al., 1998).

Nowadays, anaerobic co-digestion has attracted more attentions (Angelidaki and Ellegaard, 2003; Creamer et al., 2010; Heo et al., 2003). Generally, animal manures like piggery wastewater are considered to be excellent co-substrates because of its high buffering capacity, high nitrogen content and the wide range of nutrients needed by the methanogens (Moral et al., 2008; Weiland, 2000). The co-digestion of animal manure with other substrate can be successful because C/N ratio, concentrations of the macro and micronutrients, and buffering capacity are adjusted by mixing

* Corresponding author. Tel.: +82 31 330 6690; fax: +82 31 336 6336.
E-mail addresses: wxzyfx@yahoo.com (L. Zhang), djahng@mju.ac.kr (D. Jahng).

0960-8524/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biortech.2011.01.082

the substrates. Co-digestion of animal manure with a biodegradable waste appears as a robust process technology that can increase the biogas production by 80–400% in biogas plants (Braun et al., 2003; Weiland, 2000). Moreover, many studies showed that the sensitivity of the anaerobic digestion process to the environmental changes may be improved by combining several waste streams (Creamer et al., 2010; Heo et al., 2003; Kayhanian and Rich, 1995; Romano and Zhang, 2008; Wu et al., 2010). These practices suggest that anaerobic co-digestion of the food waste and the piggery wastewater could solve the operational problems and low economical feasibility found in anaerobic digestion of food waste or piggery wastewater alone.

The aim of this study was to evaluate the technical feasibility of anaerobic co-digestion of the food waste and the piggery wastewater in a mesophilic single stage reactor and to identify the key factors governing the process performance. In order to more clearly explain the co-digestion results, the food waste and piggery wastewater were characterized. Special focus was put on trace elements, since many previous reports showed that the trace element supplementation enhanced anaerobic digestion of different substrates (Agler et al., 2008; Jarvis et al., 1997; Wilkie et al., 1986). In addition, the literatures reported that piggery wastewaters were rich in trace elements (Creamer et al., 2010; Moral et al., 2008), and the food wastes contained less trace elements or analytical data were unavailable (Zhang et al., 2007; Zhu et al., 2008).

2. Methods

2.1. Feedstocks and inoculum

The food waste used in this study was collected from a Korean food waste restaurant on the campus of the Myongji University, Yongin, Korea. The obtained food waste was crushed using an electrical kitchen blender (HMF-347, Hanil, Korea) and the resulting slurry food waste was sieved (No. 10) to remove coarse particles larger than 2 mm and kept at −18 °C until use.

The piggery wastewater used in this study was obtained from storage tanks on a swine farm located in Yongin, which contained the mixture of feces, urine and tap water. After arriving at the laboratory, the wastewater was filtered through a 2 mm mesh to remove coarse particles, and then stored at 4 °C until use.

In order to analyze the distribution of trace elements, the piggery wastewater was centrifuged at 14,000*g* for 30 min (SUPRA 21 K, Hanil, Korea). The solid part was resuspended in the same volume of distilled water (DW) as that of the liquid fraction. The concentrations of trace elements in the liquid fraction and the solid suspension were separately analyzed. The liquid fraction and the solid suspension were stored at 4 °C until use as substrates for co-digestion experiments.

The seed sludge used in this study was taken from a 20-L bench scale anaerobic reactor treating the piggery wastewater for more than 2 years. The operating conditions were hydraulic retention time (HRT) of 20–30 days and OLR of 1.0–2.3 g VS/L day. The volatile suspended solids (VSS) concentration of the seed culture was approximately 15 g/L.

2.2. Anaerobic digestion in semi-continuous mode

Semi-continuous anaerobic digestion was carried out in a 500-mL Schott Duran bottle with a 200-mL working volume. Initially, the bottle was filled with 190 mL seed sludge and 10 mL substrate. After sparged with nitrogen gas, the digester was capped with a rubber septum, and then inversely incubated in a shaking incubator at 37 °C and 140 rpm, which provided the constant agitation and temperature. Incubation was proceeded in a semi-continuous mode with daily or every other day withdrawing and feeding of the same of amount, and the HRT was kept at 20–40 days. All the operations were made under nitrogen atmosphere to avoid contacting oxygen.

Three series of semi-continuous experiments were conducted to evaluate the feasibility of anaerobic co-digestion of the food waste and the piggery wastewater and to identify the key factors responsible for enhancing co-digestion performance. Table 1 summarizes the experimental design and operating conditions. In Experiment 1, four digesters were operated by feeding different mixtures of the piggery wastewater and the food waste. In Experiment 2, in order to figure out the location of the effective

Table 1
Summary of reactor operating conditions.

Experiment	Digester	HRT (day)	OLR (g COD/L day)	Composition of feedstock (on COD basis)	Objective
Experiment 1	EX1-1	20	4.71	100% whole PW (piggery wastewater)	Examine the possibility of anaerobic co-digestion of the food waste and the piggery wastewater
	EX1-2	20	6.35	100% FW (food waste)	
	EX1-3	20	6.35	7% whole PW/93% FW[a]	
	EX1-4	20	6.35	17% whole PW/83% FW	
Experiment 2	EX2-1	20	6.35	100% FW	Identify the stimulatory substances in piggery wastewater for co-digestion, including the C/N ratio, buffering capacity and concentrations of trace elements
	EX2-2	20	6.35	83% FW/17% whole PW	
	EX2-3	20	6.35	83% FW/17% PW liquid fraction	
	EX2-4	20	6.35	83%FW/17% PW solid fraction	
Experiment 3	Period 1 (Day 0–92)	20	6.35	Continued operation of EX2-2 and EX2-4 83% FW/17% whole PW (Run 1) 83% FW/17% PW solid fraction (Run 2)	
	Period 2 (Day 93–155)	40	3.2	83% FW/17% whole PW (identical for Run 1 and Run 2)	
	Period 3 (Day 156–161)	30	5.1	83% FW/17% whole PW (identical for Run 1 and Run 2)	
	Period 4 (Day 162–179)	30	4.3	100% FW (identical for Run 1 and Run 2)	
	Period 5 (Day 180–253)[b]	30	4.3	100% FW (Run 1) 100% FW + Trace elements (Run 2)	Examine the process stability in a long-term operation, and confirm the role of trace elements on anaerobic digestion of the food waste by supplying synthetic trace elements instead of the piggery wastewater
	Period 6 (Day 254–367)[b]	20	6.35	100% FW (Run 1) 100% FW + Trace elements (Run 2)	

[a] 7% PW/93% FW represents that 7% of OLR was contributed by the piggery wastewater and 93% by the food waste on COD basis.
[b] During this period, Run 1 served as the control, whereas synthetic trace elements were added in Run 2 (see Fig. 5).