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A prototype single-stage anaerobic digester for co-digestion of food waste and sewage sludge from high-rise building for on-site biogas production

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ABSTRACT

At present, there has been less results from pilot-scale experiments on anaerobic co-digestion system, especially as an on-site system for high-rise building application. The objective of this study was to develop a prototype single-stage anaerobic digester for the co-digestion of food waste (FW) and sewage sludge (SWS) from high-rise building for on-site biogas production. Here, the prototype system was operated at different hydraulic retention times (HRTs) of 27, 22 and 19 days, corresponding to organic loading rates of 7.9, 10.8 and 14.0 kgCOD/m^3 d. The feed mixed waste ratio (FW/SWS) of 10:1 by weight was selected from the previous laboratory-scale experiment. The results of this study indicate that higher gas production rate was obtained at shorter hydraulic retention time (HRT) of 19 days; however, higher methane content of the biogas was obtained at longer HRT of 27 days. Therefore, enhancement of methane production from the co-digestion could be achieved with sufficient operating HRT. Moreover, the proposed prototype system could reduce total volatile solid up to 70 percent at HRT of 27 days. Up to now, the biogas from on-site production has been utilized for cooking at Chulalongkorn University as a model case study for high-rise building application.

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1. Introduction

Recently, anaerobic digestion of organic solid wastes has been promoted greatly in Thailand to produce alternative renewable energy source from biogas production. The amount of solid waste generation is reported approximately 67,577 tons/day of MSW (municipal solid waste) (Pollution Control Department, 2012). Food waste is one of the largest waste stream and accounts for 39.25% of total MSW. Due to the characteristics of food waste with 70–90% moisture content and high organic content of volatile solid (VS) (Tchobanoglous et al., 1993; Zhang et al., 2007), improper waste treatment would cause serious environmental problems, such as odor, leachate production and groundwater contamination (Slack et al., 2005). Anaerobic digestion has been recognized as an environmentally friendly technology to convert organic solid waste such as animal manure, food waste, and organic fraction of MSW into renewable energy in biogas form (Mata-Alvarez et al., 2000; Digman and Kim, 2008). Anyhow, digestion process tends to fail, when one readily degradable organic matter is used as sole substrate without external nutrients and buffering agent (Demirel and Scherer, 2007).

Chulalongkorn University has started the government project on "Development of energy recovery system from solid organic wastes for high-rise building application" under Ministry of Natural Resource and Environment (MONRE), Thailand with the financial support from JICA-Water Intro Project, Japan. The main objective of this research work is to develop a prototype anaerobic co-digestion system of food waste and sewage sludge for on-site biogas production and energy recovery together with organic waste reduction. Here, the single-stage anaerobic digester has been designed and constructed as a compact prototype system with fibreglass structure, having total volume of 2500 L to receive food waste that is source separated from a canteen in Julajakrapong Building, which is located inside Chulalongkorn University and sewage sludge from a conventional wastewater treatment plant, located at the same building. Average food waste amount that generated from this canteen was found to be 80 kg per day. Before starting our anaerobic digestion project, food waste was considered as a waste material to be disposed of to landfill. Indeed, food waste from this

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canteen has high moisture content in the range of 80–85%. This could result in significant greenhouse gas emission from waste degradation in landfill. Thus, food waste is our main concern for organic solid waste from this high-rise building. Also, sewage sludge from building's wastewater treatment plant can be considered as a potential biowaste for co-digestion with food waste for on-site biogas production. Nowadays, sewage sludge from high-rise building in Thailand is usually dewatered before disposal as domestic solid waste to landfill. Anaerobic co-digestion can minimize the problem of bad practice in sewage sludge management.

The benefits of anaerobic co-digestion process can include: dilution of potential toxic compounds, improved balance of nutrients, synergistic effects of microorganisms, increased load of biodegradable organic matter and better biogas yield due to synergisms (Sosnowski et al., 2003;; Alvarez and Liden, 2008). Some previous studies (Murto et al., 2004; Serrano et al., 2014; Estevez et al., 2014) have suggested that anaerobic co-digestion process is also expected to provide more balanced nutrients for efficient digestion and high biogas production; thus, it could be used to help achieve higher digestion efficiency.

At present, there has been less results from pilot-scale experiments on anaerobic co-digestion system, especially as an on-site system for high-rise building application. From available literature, the previous studies on co-digestion of sewage sludge and diverse array of biowastes (eg.municipal solid waste, microalgae, food waste, cattle manure, corn straw) were performed mostly at laboratory scale (Sosnowski et al., 2003; Costa et al., 2012; Garcia and Perez, 2013; Zhou et al., 2013). Thus, the research work on development of economically self-sustainable pilot-scale system for anaerobic co-digestion process is still needed. In this study, reactor design and tank configuration of the pilot-scale system is also different from a previously published pilot-scale study, conducted by Kim et al. (2011) since our reactor design is a horizontal-shaft paddle digester with fiberglass fabricated structure as an on-site prototype system. The advantage of an on-site prototype system is that organic wastes can be separated at source, and then fed directly to the anaerobic digester. Furthermore, this proposed tank configuration has plug flow character that can reduce short-circuit flow through the system. Here, effects of hydraulic retention time (HRT) and mixed waste ratio (Food waste: sewage sludge) on biogas production using the single-stage anaerobic co-digestion of food waste and sewage sludge were investigated. Up to now, the prototype system has produced biogas on-site that can be utilized for cooking at Chulalongkorn University as a prototype model for high-rise building application.

2. Material and methods

2.1. The characteristics of feeding substrates

Here, food waste was collected from a canteen in Julajakrapong Building, Chulalongkorn University, which was composed of food residues, grain, fruits, vegetables, starch, and grease, etc. The food waste was shredded into 5–10 mm size pieces by food grinder. Sewage sludge was collected from an on-site wastewater treatment plant, located at the same building, which is a conventional activated sludge process, having a maximum treatment capacity of 80 m^3/day. In the previous laboratory-scale experiment, by varying the mixing ratios of the feeding substrates (FW/SWS) to 1:1, 6:1 and 10:1 by weight, we observed that the highest amount of biogas could be obtained at the mixing ratio of 10:1 (data not shown). Also, the enhancement of methane production could be achieved by this substrate mixing ratio. Thus, the mixing ratio of 10:1 for feeding substrates was selected for further operating the prototype single-stage anaerobic digester. Here, the characteristics of FW, SWS and the mixed waste (FW/SWS) used in this study, in terms of total solids (TS), SS, TVS, chemical oxygen demand (COD), VFA, pH, total phosphorus (TP), and total Kjehldahl nitrogen (TKN) are presented in Table 1.

2.2. Development of a prototype single-stage anaerobic digester for co-digestion system

A prototype single-stage anaerobic digester for co-digestion of food waste and sewage sludge was newly designed and constructed for tropical application at Julajakrapong Building, a high-rise building inside Chulalongkorn University campus. The schematic diagram of a prototype single stage anaerobic digester used in this study is illustrated in Fig. 1. The volume of the reactor was 2500 L with a working volume of 1975 L. The digestion system was thus performed in semi-continuous mode of feeding and operated at mesophilic temperature (35 ± 2 °C). The reactor was operated at hydraulic retention time (HRT) of 27, 22 and 19 days, corresponding to organic loading rates of 7.9, 10.8 and 14.0 kgCOD/m^3 d. The feeding substrate was initially prepared by mixing food waste with sewage sludge at the selected mixing ratio by the mixing apparatus. Then, the screw conveyor was utilized to move the mixed waste into the single-stage anaerobic digester. A paddle-type mixer was provided for slow mixing at short period after waste feeding to the digester tank. The biogas generated from the anaerobic activity was kept in the biogas holding tank and sent through the gas pipeline for further utilized in canteen for cooking purpose. In this study, effect of hydraulic retention time (HRT) at 19,22 and 27 days on system performance and biogas production using the prototype single-stage anaerobic co-digestion system was investigated for high-rise building application.

2.3. Analytical methods

The anaerobic digestion process was evaluated by measuring the following parameters: total solids, total suspended solids, volatile solids, COD, VFA, pH, Alkalinity, total phosphorus (TP), total Kjehldahl nitrogen (TKN), and daily biogas production. TS, SS, TVS, VFA, pH, alkalinity, TP and TKN were determined in accordance with standard methods (APHA, AWWA, WPCF, 2005). The dichromate Chemical Oxygen Demand (COD) was analyzed by COD analyzer (HACH, DR 2500, USA). The biogas was collected and analyzed for gas composition. CH_4 and CO_2 compositions were determined through a TRACE GC (Thermo Finnigan) equipped with a thermal conductivity detector.

3. Results

3.1. pH, VFA and alkalinity variation during the anaerobic co-digestion

It has been recognized that anaerobic digestion includes normally three steps; hydrolysis, acidogenesis and methanogenesis.

Table 1
Characteristics of food waste (FW) and sewage sludge (SWS) used in this study.

Parameters	Food waste (FW)	Sewage sludge (SWS)	Mixed waste (FW/SWS)
TS, mg/L	80,676	39,100	76,897
SS, mg/L	72,410	38,968	69,371
TVS, mg/L	78,823	32,400	74,603
COD, mg/L	232,795	17,208	213,196
VFA, mg/L	2957.8	504.3	2734.8
pH	4.7	6.7	4.5
TP, mg/L	926	281	867
TKN, mg/L	6275	1254	5818.5

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