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

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ABSTRACT

Up to now, there has been less results from on-site pilot-scale anaerobic co-digestion system, especially for high-rise building application. The objective of this study was to develop an on-site prototype two-stage anaerobic digester for co-digestion of food waste and sewage sludge from high-rise building for biogas production. The optimal mixing ratio of food waste to sewage sludge, obtained from laboratory-scale, was found to be 7:1. Then, the prototype two-stage anaerobic digester was further designed and constructed. The results showed that COD and total volatile solid (TVS) reduction could be achieved up to 89 and 74%, respectively with the applied hydraulic retention time (HRT) of 24 days. The methane content of biogas was 64 percent. 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.

Introduction

During recent years, renewable energy obtained from organic waste has been receiving attention greatly in Thailand as an alternative energy source. At present, Thailand has faced large quantity of municipal solid waste generation. Approximately 67,577 tons of municipal solid waste is generated every day (Pollution Control Department, 2012). Food waste is the largest waste stream and accounts for 39.25% of total municipal solid waste. Due to the characteristics of food waste with 70–90% moisture content and high organic content of volatile solid (VS) (Tchobanoglous et al., 1993), improper treatment would cause serious environmental problems, such as odor and leachate production. Landfill is recognized as one of typical approaches for food waste disposal; however, it would be limited in the near future, due to the concerns of greenhouse gas emission or other negative impacts on the environment.

Food wastes that cannot be avoided should be reused or recycled to some value added products e.g. renewable energy, compost as far as possible. Moreover, the global trend for new regulations have been set to strictly limit the disposal of organic waste by landfill and the landfill disposal fee has been raised as well (European Council, 2002). Anaerobic digestion has been considered as an attractive technology which is used to convert organic solid wastes such as food waste, animal manure and organic fraction of MSW into renewable energy in biogas form (Mata-Alvarez et al., 2000; Digman and Kim, 2008). Anyhow, anaerobic 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, 2008).

Chulalongkorn University has participated in the program of in-situ building energy recovery from waste utilization under Ministry of Natural Resource and Environment (MONRE) with the support from JICA-Water Intro Project, Japan. Here, our research projects have focused attention on the anaerobic co-digestion system development and the design of proper digester configuration to handle organic wastes, especially food waste. In the previous research work, we developed the prototype single-stage anaerobic digester for co-digestion of food waste and sewage sludge for

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biogas recovery from high-rise building (Ratanatamskul et al., 2014). The developed digester can give a good practice for the on-site operation. Nevertheless, another system configuration of the prototype two-stage anaerobic digester also has been proposed here as an alternative system. Therefore, a prototype two-stage anaerobic digester for co-digestion of food waste and sewage sludge has been newly designed and built to compare with the performance of the previous single-stage anaerobic digester. The performance of this newly designed prototype system for anaerobic co-digestion of food waste and sewage sludge for biogas recovery together with organic waste reduction in field-scale on-site operation has been investigated. The benefits of anaerobic co-digestion include: dilution of potential toxic compounds, improved balance of nutrients, synergistic effects of microorganisms, increased load of biodegradable organic matter and better biogas yield (Sosnowski et al., 2003). 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 solve the problem or help achieve higher digestion efficiency.

To circumvent this problem, some authors have proposed co-digestion of the organic fraction of MSW, either with sludge from wastewater treatment plants (WWTPs) or residues from livestock farms (Callaghan et al., 2000; Stroot et al., 2001; Bujoczek et al., 2002). Besides feedstock used for co-digestion, digestion system is another important factor. For the highly biodegradable waste, two-stage digestion system was believed to be more advisable (Mata-Alvarez et al., 2000). A number of studies presented the advantages of two-stage system in the anaerobic digestion of organic wastes (Dinsdale et al., 2000; Mata-Alvarez et al., 2000; Bouallagui et al., 2004). Bouallagui et al. (2004) reported that two-stage anaerobic digestion of fruit and vegetable wastes using two coupled anaerobic sequential batch reactors resulted in high process stability, significant biogas productivity, and better effluent quality. Co-digestion with other wastes could provide more suitable physicochemical property of feedstock and more balanced nutrients for efficient digestion and high biogas production; thus, it could be used to solve the problem or help achieve higher digestion efficiency. An additional advantage of the process is the obtaining of a valuable sludge which can eventually be used as a soil amendment after minor treatments (Converti et al., 1999; Poggi-Varaldo et al., 1999).

Materials and methods

The characteristics of feeding substrates

Food waste (FW) was collected from a university canteen at Mahitalatibesr Building, Chulalongkorn University, which was composed of food residues, grain, fruits, vegetables, starch, and grease, etc. The FW was shredded into 5–10 mm size pieces by food grinder. Sewage sludge (WS), obtaineded from building's wastewater treatment plant (maximum capacity of 200 m^3/day), was composed of secondary activated sludge. Here, the characteristics of FW and WS used in this study, in terms of total solids (TS), SS, TVS, chemical oxygen demand (COD), VFA, pH, Alkalinity, total phosphorus (TP), and total Kjehldahl nitrogen (TKN) are presented in Table 1.

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

Parameters	Food waste	Sewage sludge
TS, mg/l	74,520	49,100
SS, mg/l	39,441	38,968
TVS, mg/l	69,688	42,460
COD, mg/l	201,083	17,116
VFA, mg/l	694.3	594.3
pH	4.5	6.7
Alkalinity, mg/l	189.3	115.8
TP, mg/l	926	281
TKN, mg/l	6275	1254

Laboratory experiment

Effect of mixing ratios of FW/WS on performance of two-stage anaerobic digester was preliminary investigated using laboratory-scale experiment. Here, two stirred-tank reactors, made of acrylic, were used as the acidific and methanogenic reactors. The volume of the first reactor for acidification was 4 l with a working volume of 3 l, while the volume of second reactor for methanogenesis was 10 l with a working volume of 7.5 l. At the start-up period, the anaerobic digester was seeded with the inoculum sludge, obtained from an anaerobic sludge digestion plant. The system was operated at total hydraulic retention time (HRT) of 33 days, corresponding to organic loading rate of 7.0 kg COD/m^3 d. In this study, the mixing ratios of FW/WS were varied to 1:1, 3:1, 5:1, 7:1 and sole FW digestion by maintaining the same total solid concentration of approximately 7 percent. The characteristics of the feeding wastes with different mixing ratios of FW and WS are illustrated in Table 2.

Prototype two-stage anaerobic digester experiment

A prototype two-stage anaerobic digester for co-digestion of food waste and sewage sludge from high-rise building at maximum capacity of 100 kg per day was newly designed and built. At present, no research works have focused attention on development and operation of the on-site prototype system for high-rise building application. The obtained results from the previous laboratory experiment provide the input parameters to scale-up the on-site prototype system. Two completely mixed reactors, made of fiberglass, were used as the acidific and methanogenic reactors. The schematic diagram of the prototype two-stage anaerobic digester is illustrated in Fig. 1. The volume of the first reactor for acidification was 1000 l with a working volume of 750 l, while the volume of second reactor for methanogenesis was 2500 l with a working volume of 1875 l. The digestion system was thus performed in semi-continuous mode (fed twice a day at 13:00 p.m. and 17:00 p.m.) and operated at mesophilic temperature. The reactor was operated at three different hydraulic retention times (HRT) of 24, 19 and 16 days, corresponding to organic loading rate of 8.66, 12.56 and 16.04 kg COD/m^3 d. The mixture FW/WS ratio of 7:1, obtained from the previous laboratory experiment was selected as the most suitable substrate to feed the digester in long run operation. To start up the process, the digester was filled with the inoculums sludge from an anaerobic sludge digestion plant. The acclimation time needed to reach stationary conditions was 2 weeks. After reaching stationary condition, the system operation was continued for the three different hydraulic retention times.

Table 2
Characteristics of substrate made by mixing food waste with sewage sludge at different mixing ratios.

Parameters	Mixing ratio of FW/WS			
	1:1	3:1	5:1	7:1
TS, mg/l	62,852	70,590	71,010	73,040
SS, mg/l	38,230	38,800	39,841	41,383
TVS, mg/l	56,788	61,150	63,782	66,900
COD, mg/l	115,356	189,500	199,380	215,030