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Volumetric scale-up of a three stage fermentation system for food waste treatment

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Abstract

In this study, a volumetric scale-up of this system was designed and built on a field pilot-scale (total digester volume 10 m^3), with the results from the field pilot-scale experiments compared with those from the bench-scale (total digester volume 0.4 m^3) process prior to scale-up. The reduction rate of total chemical oxygen demand (tCOD) and the maximum methane content produced in the biogas from the bench-scale system were 90.6% and 72%; whereas those from the field pilot-scale system were 90.1% and 68%, respectively. The estimated methane yields were 282 and 254 l CH_4/kg $tCOD_{degraded}$ in bench and field pilot-scale fermentation systems, respectively. These results indicate that the three stage fermentation system developed in this study can be applied as a commercial process for the disposal of food waste in view of process stability.

Keywords: Three stage fermentation system; Anaerobic digestion; Methane; Food waste; Bioenergy

1. Introduction

In Korea, approximately 82 million tons of organic wastes, such as food waste, livestock manure, vegetable waste and wastewater sludge, are produced every year. In particular, the disposal of food waste has become a major concern, the burden of which has been growing since 2005, as environmental law has prohibited the sanitary landfill of such wastes. Therefore, several techniques, such as animal feed use (Kelley and Walker, 1999), composting (Manios, 2004) and anaerobic digestion (Linke, 2006), have been suggested and developed. In particular, anaerobic digestion, as an alternative method for the digestion of organic wastes, concomitantly produces methane that can be used as a renewable energy source.

Anaerobic digestion is a multiple biochemical process, where several organic materials are converted to biogas through a series of reactions mediated by several groups of microorganisms, with these gases mainly consisting of methane and carbon dioxide (Pullammanappallil et al., 2001). Several research groups have developed anaerobic digestion processes using different substrates (Choi et al., 2003; Gallert et al., 2003; Nakamura and Mtui, 2003; Neves et al., 2006; Tada and Sawayama, 2004). The advantages of such processes are the low energy consumption for operation, low initial investment cost and reduced sludge production. In addition, the anaerobic digestion process is an energy production technology. During the anaerobic treatment, the biogas produced, which contains 50–70% methane, can be used as a clean renewable energy source (Bouallagui et al., 2003; Milan et al., 2001; Uemura and

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Harada, 2000). Considering the dual benefits of the control of environmental pollution and production of an alternative energy source, the potential of methane generation from food waste is attractive.

A modified three stage methane fermentation system, able to produce methane from biodegradable food waste, was previously developed in our laboratory (Kim et al., 2000, 2002). This system used a process composed of three stages: semi-anaerobic hydrolysis/acidogenesis, strictly anaerobic acidogenesis and strictly anaerobic methanogenesis. This separate-reactor system efficiently decreased the hydraulic retention time (HRT) by increasing the rates of hydrolysis, acidogenesis and methanogenesis without affecting the pH.

In this paper, a volumetric scale-up of this system to a 10 m^3 field pilot-scale system was developed, with the experimental results compared with those of the bench-scale fermentation system.

2. Methods

2.1. Feedstock and microorganisms

Food waste was collected from a cafeteria at this University, which was crushed into small particles (average size of 3–5 mm) using a crusher developed in our lab. Table 1 shows the characteristics of the Korean food waste used in this study. The characteristics of some food wastes have been reported in the literature: moisture content of 80–93%; volatile solids to total solids ratio (VS/TS) of 89–96%; and carbon to nitrogen ratio (C/N) of 14.7–36.4 (Han and Shin, 2004; Kim et al., 2004; Kwon and Lee, 2004; Rao and Singh, 2004; Shin et al., 2004). These characteristics were very similar to those of the food wastes used in this study, and indicate that food wastes are a good source for methane fermentation. Zhang et al. (2007) also reported that biological treatments, such as anaerobic digestion, were more suitable than thermochemical treatments, such as combustion and gasification, due to the relatively high moisture content of food waste.

Table 1
Characteristics of the food wastes collected for the bench and field pilot-scale three stage fermentation systems

Parameter	Bench-scale	Field pilot-scale
pH	5.14	5.22
TS (%)	12.38	12.86
VS/TS (%)	89.3	89.5
tCOD (g/l)	79.0	63.2
T-N (g/l)	5.2	4.9
NH_3-N (g/l)	0.031	0.025
Elemental composition (%)		
C		47.8
H		6.1
O		40.9
N		5.2

In the primary semi-anaerobic hydrolysis/acidogenic process, a mixture of moderately thermophilic bacteria including *Bacillus subtilis*, *Bacillus amyloliquefaciens*, *Bacillus alcalophilus*, *Bacillus polymyxa*, *Bacillus licheniformis*, *Cellulomonas cellulans*, *Flavobacterium breve*, *Rhodopseudomonas* spp., *Pseudomonas* spp., *Nitrobacter* spp., *Lactobacillus* spp., *Trichoderma viride*, *Actinomycetes* spp., and yeast, collected from commercial microbial agents (GT1000-WT, MPTECH Technology, Seoul, Korea; GT1000-GT, Bio-Genesis Technology Inc., Arizona, USA), were inoculated. These bacteria can rapidly hydrolyze carbohydrates, proteins, fats, chitins and pectins. *Clostridium beijerinckii* (KCTC1785) and *Clostridium acetobutylicum* (KCTC1788) were inoculated into the secondary acidogenic reactor for the mass production of volatile fatty acids (VFAs), especially acetic and butyric acids. To support the methanogenic process, several sources of cow manure, methane-generating landfill soil and a methanogenic fluid eluted from the methanogenic digester, which had been operated for more than three years, were supplied to the digester.

2.2. Design and operation conditions of three stage fermentation system

A three stage fermentation system was designed on both bench and field pilot-scales based on our previous work (Kim et al., 2000, 2002) from the two phase digestion system. Each of these systems consisted of a semi-anaerobic hydrolysis/acidogenic process (the total volumes of the bench and field pilot-scale digesters were 0.05 and 2 m^3, respectively), an anaerobic acidogenic process (the total volumes of the bench and field pilot-scale digesters were 0.05 and 2 m^3, respectively), and a strictly anaerobic methanogenic process (the total volume of the bench and field pilot-scale digesters were 0.3 and 6 m^3, respectively). The system also composed of additional facilities such as food waste reservoir, crusher, biogas storage tank and gas boiler. All facilities were made of stainless steel. Reservoir (i.d. 1700 × 2200 mm), crusher (710 × 1050 × 1500 mm) and biogas tank (i.d. 1060 × 2420 mm) were built by our own lab. Biogas tank was connected to a gas boiler (2035 GPG, KDNaVIeN, Seoul, Korea) and the hot water generated from a gas boiler was used for controlling the temperature of each digester.

The primary semi-anaerobic digester was a continuously stirred-tank reactor (CSTR), designed for the rapid hydrolysis and acidogenesis of food waste. The working volumes of the bench and field pilot-scale reactors were 40 and 800 l, respectively. Food waste was mixed with water at a ratio of 1:1 (v/v) due to a high total solid (TS) content of 12–13%, and crushed into small particles (3–5 mm) and fed into the digester by motor pump. The fluid was stirred at 150 rpm by impeller fixed in the center of the digester, with 0.06 vvm air supplied to the bottom of the digester by air compressor (AC-B10PA1, Kyungwon compressor, Incheon, Korea). Food waste was semi-anaerobically