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Enhancement in characteristics of sewage sludge and anaerobic treatability by electron beam pre-treatment

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ABSTRACT

Electron beam was studied to enhance the biodegradability of sewage sludge. Changes in physicochemical characteristics of the sludge were examined with various irradiation doses, sludge thicknesses and exposure times. Irradiation thickness was suggested as the key factor affecting the efficiency of solublization of solid organic matter, whereas exposure time would be the most critical parameter in inducing cell lysis in sewage sludge. In addition, biogas production was improved as much as 22% when the sludge thickness was 0.5 cm with a dose of 7 kGy.

1. Introduction

Anaerobic digestion technology has been considered as a promising process for the biological treatment of wastewaters and solid wastes containing a large amount of organics and even for the production of valuable gases such as methane and hydrogen (Hwang et al., 2004; Hyun et al., 1998; Park et al., 2005). It is typically conducted in three steps: hydrolysis, acidogenesis and methanogenesis. Among the three steps, hydrolysis is the rate-limiting step resulting in a long time period for the treatment of wastewaters containing a high concentration of solids.

Recently, organic solid wastes such as sewage sludge and food waste have emerged as a global environmental problem as ocean dumping is not allowed any longer. In the field of biotechnology, a large amount of research fund is being invested to develop sustainable technologies. Various methods have been applied to enhance the treatability of wastewaters containing solids and recalcitrant pollutants. Tomei et al. (2008) used sonication to treat sewage sludge and Kim et al. (2007) applied electron beam for the treatment of textile wastewater. Both studies were aimed at enhancing degradability prior to biological treatment. Alkaline (Li et al., 2008) and thermal treatments (Bougrier et al., 2008) are trials for the same purpose.

Electron beam is a powerful source for solid treatment and thus could be utilized as a method for the pre-treatment of solid components prior to anaerobic digestion. This method is advantageous as no additional chemical is required, no residual material is produced and toxic and recalcitrant materials can be degraded by the OH radical produced by irradiation (Kim et al., 2007). When pure water is irradiated by an electron beam, the following chemical species are formed in 10^{-7} s (Lubicki et al., 1998):

$$H_2O \xrightarrow[\wedge/\vee(100\ eV)]{} [2.6]e_{aq}^- + [0.6]H\cdot + [2.7]OH\cdot + [0.45]H_2 + [0.7]H_2O_2 + [2.6]H_3O^+ \quad (1)$$

The reaction will be expected when sewage sludge is irradiated because of its high water content. The numbers are the number of products formed per 100 eV absorbed dose.

In this study, electron beam irradiation was examined to improve the biodegradability of sewage sludge for further anaerobic fermentation. It was expected that the strong oxidants would be produced by irradiation, which play a critical role in destructing and/or enfeebling solid materials. Then anaerobic fermentation of the sludge would be enhanced, resulting in increased yields of methane.

2. Experimental

2.1. Master culture reactor (MCR) operation

A raw-master culture reactor (R-MCR) and an electron beam pre-treated-MCR (E-MCR) were used to provide cultures exhibiting

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identifiable and repeatable characteristics so that measurements conducted at different times and by different sets of tests would have a common microbial and biochemical basis (Young and Tabak, 1993; Kim et al., 1994; Hyun et al., 1998). For the R-MCR, primary and secondary anaerobic digested sludge were mixed in the ratio of 1:1, and fed with thickened sludge from a municipal sewage treatment plant in G city in South Korea. The reactor was operated at 35 ± 1 °C during the experimental period with a solid retention time (SRT) of 30 days. On the other hand, the E-MCR was fed with electron beam pre-treated sludge under the same operational conditions. Consequently, the irradiation of the electron beam could be considered as the only factor affecting the efficiency of anaerobic treatment of sludge.

2.2. Evaluation of the changes in sludge characteristics after electron beam irradiation

The thickened sludge used in the study contained $24{,}000\pm1000$ mg/L of total chemical oxygen demand (TCOD), 1600 ± 200 mg/L of soluble chemical oxygen demand (SCOD), 900 ± 40 mg/L of volatile fatty acids (VFAs) and 160 ± 20 mg/L of protein. Total solid (TS) and volatile solid (VS) were $25{,}000\pm2000$ and $15{,}000\pm1500$ mg/L, respectively, and the initial pH and alkalinity were measured as 6.0 ± 0.2 and 500 ± 80 mg/L as $CaCO_3$. The analytical methods and experimental conditions are shown in Tables 1 and 2. The first sets of experiments were conducted with various irradiation doses and exposure thicknesses. Then, the effect of exposure time for the various exposure thicknesses was studied. Sewage sludge was irradiated in a pyrex-glass tray ($15\times10\times2$ in) by an electron accelerator (1 MeV, 40 kW, ELV-4 Model, EB-TECH Co.). The absorbed dose was measured with dichromate solution following the method suggested by Han et al. (2002). In addition to the chemical properties, the sludge was characterized physically with a scanning electron microscope (SEM).

2.3. Anaerobic fermentation experiment (semi-continuous)

Subsequent anaerobic fermentation experiments were conducted based on the method suggested by Johnson and Young (1983) to determine the treatability of sludge before and after electron beam irradiation. Cultures transferred from the two MCRs were used for batch biogas test and a respirometer (AER-200, Challenge Environmental Systems, Inc., Fayetteville, Arkansas, USA) was used for on-line monitoring of the biogas production from a 250 mL medium bottle reactor. The working volume was 210 mL and the reactor was mixed continuously on a magnetic stirrer. SRT and organic loading rate (OLR) were fixed to 30 days and 0.83 g TS/L/day, respectively. In case of liquid analysis, 500 mL medium bottles were also used with 450 mL of working volume and 30 days of SRT.

Table 1
The methods for analysis of raw and pre-treated sludge

Items	Analytical methods
TCOD, SCOD, TS, VS	TCOD, SCOD, TS, VS: Wet analysis standard method
Protein	Protein: BCA method
SEM	SEM: Instrumental analysis, JSM-5800
Alkalinity	Alkalinity: Standard method
VFAs	VFAs: HP5890 series II
pH	pH: pH meter Orion 230A

Table 2
Experimental conditions for irradiation of sludge

Parameter	Conditions
Irradiation dose (kGy)	1, 3, 5, 7, 10 and 20
Exposure time (s)	0.3, 0.6 and 1.2
Thickness of sludge (cm)	0.25, 0.5, 0.75 and 1.0

3. Results and discussion

3.1. MCR operation

The average pH was 7.2 during the operation of the R-MCR, which was stabilized after the operational period of 120 days. The volume of biogas produced under these conditions was 305 mL/g TS in average and the final TS was 2.1% (VS: 52% of TS). In case of E-MCR, stabilization was achieved slightly earlier, showing 7.4 of average pH. Biogas production and the final TS was 335 mL/g TS and 2.1% (VS: 57% of TS), respectively. The VS content of E-MCR was higher than that of R-MCR, showing that the electron beam irradiation would be positive in enhancing biodegradability.

3.2. Characterization of sludge after irradiation

Changes in pH and alkalinity were investigated according to experimental parameters such as irradiation dose and sludge thickness at a fixed exposure time of 0.6 s (Fig. 1). As the irradiation dose increased, the alkalinity decreased while the pH remained constant. It could be suggested that OH radicals generated by irradiation contributed to HCO_3^- consumption (Borrely et al., 1998).

TCOD changed slightly whereas SCOD increased tremendously according to irradiation dose and sludge thickness (Fig. 2(a)). SCOD increased to 49%, 54%, 97% and 147% when sludge thickness for irradiation was changed to 1.0, 0.75, 0.5 and 0.25 cm, respectively, at 20 kGy of irradiation dose. It was concluded that a portion of the organics contained in solid were solubilized by irradiation. The effect of the exposure time was investigated at a fixed thickness and dose. As the exposure time was increased from 0.3 to 1.2 s, the changes in the SCOD were insignificant (Fig. 2(b)) compared to Fig. 2(a). On the other hand, the protein concentration increased up to 5 folds (Fig. 3(a)), which was probably the

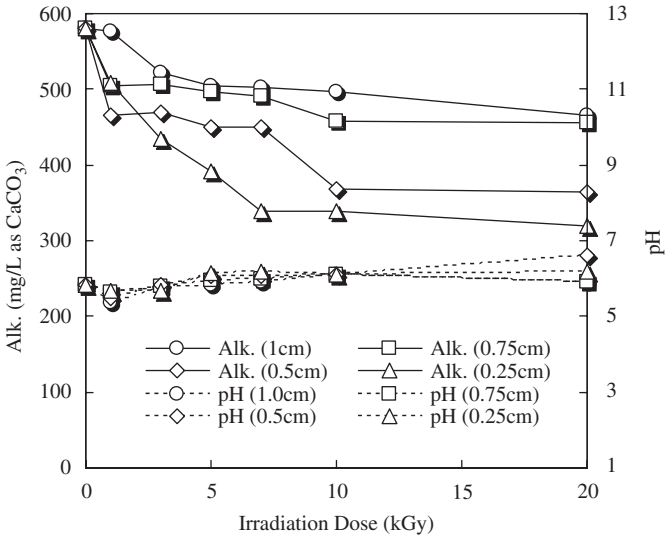

Fig. 1. Changes in pH and alkalinity for different irradiation doses and sludge thickness at fixed exposure time (0.6 s).