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Enhanced anaerobic gas production of waste activated sludge pretreated by pulse power technique

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Abstract

An electric pulse-power reactor consisting of one coaxial electrode and multiple ring electrodes was developed to solubilize waste activated sludge (WAS) prior to anaerobic digestion. By pretreatment of WAS, the soluble chemical oxygen demand (SCOD)/total chemical oxygen demand (TCOD) ratio and exocelluar polymers (ECP) content of WAS increased 4.5 times and 6.5 times, respectively. SEM images clearly showed that pulse-power pretreatment of WAS was found to result in destruction of sludge cells. Batch-anaerobic digestion of pulse-power treated sludge showed 2.5 times higher gas production than that of untreated sludge. Solubilized sludge cells by pulse-power pretreatment would be readily utilized for anaerobic microorganisms to produce anaerobically-digested gas. Slow or lagged gas production in the initial anaerobic digestion stage of pulse-power pretreated sludge implied that the methane-forming stage of anaerobic digestion would be the rate-limiting step for anaerobic digestion of pulse-power pretreated sludge.

Keywords: Waste activated sludge; Anaerobic digestion; Pretreatment; Solubilization; Gas production; Pulse-power; Shockwave

1. Introduction

Waste activated sludge (WAS) is generated by operation of the conventional wastewater treatment system. The disposal of excess sludge poses a significant challenge to wastewater treatment because the London agreement on the prevention of marine pollution by dumping of wastes prohibits sludge disposal into the sea (AGPS, 1996). Although anaerobic digestion has been chosen as economical volume reduction and stabilization methods for WAS, it presents some challenges for enhancing digestibility of sludge and reducing the final volume.

The three stages of anaerobic digestion process include hydrolysis, acetogenesis and methanogenesis. Among the three stages, hydrolysis is known as the rate limiting stage for the anaerobic digestion process and plays an important role to determine anaerobic digestibility (Eastman and Ferguson, 1981). Many attempts involving thermal and physical pretreatments have been made to increase substrate solubilization prior to anaerobic digestion. The primary objective of the attempts was to disrupt sludge floc structure. Vlyssides and Karlis (2004) achieved 46% reduction of the initial VSS and 0.281 l methane production per kg of the initial VSS by thermal-alkaline pretreatment. Weemaes et al. (2000) used ozone oxidation for pretreatment of WAS to obtain an increased methane production by a factor of 1.8. Kim et al. (2003) evaluated four pretreatment methods (thermal, chemical, ultrasonic, and thermo-chemical methods) on COD solubilization and gas production.

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They showed that a thermo-chemical method involving alkaline (7 g NaOH/l of WAS) addition and thermal condition at 121 °C for 30 min gave the highest solubilization and gas production.

This study employed an electric pulse-power technology to disrupt sludge floc structure and to enhance digestibility of WAS. Although the pulse-power technology is known to be effective in destructing living cells and is widely utilized for the food industry (Mizuno and Hori, 1988; Devlieghere et al., 2004), no studies have been done to confirm that it may disrupt sludge floc structure and contribute anaerobic digestion of WAS. The electric pulse-power technology generates a pulsed high voltage discharge in water, which induces arc discharge. Electric power of the arc discharge in water would be spent to generate shockwave, intense ultraviolet radiation, strong electric field, and various radicals (Sunka, 2001). This study intended to use these generated impacts to destruct the cell wall of sludge. The objectives of this study were to utilize the electric pulse power technology for pretreatment of WAS by developing a pulse-power reactor, and to evaluate anaerobic digestibility of the pretreated WAS.

2. Methods

2.1. Pretreatment

An electric pulse-power reactor was developed for pretreatment of WAS. Pulse power of the reactor was generated by a system consisting of a high voltage DC power supply (20 kV), a capacitor (25 kV–100 nF), a thyratron switch (35 kV–15 kA), and a pulse transformer. The system provided a pulsed power of 1.2 kW under a capacitance of 30 nF. Details of the pulse-power generation system were shown in Lee et al. (2003). This study developed a new ring-type pulse-power reactor. The reactor and electrodes were made of stainless steel and the void volume of the reactor was about 20 ml. The reactor produced an arc discharge by the electric gap between a coaxial electrode and ring electrodes. The gap between the coaxial electrode and ring electrodes was about 3 mm. The length of the coaxial electrode exposed to the liquid was 11 cm. Fig. 1 shows a diagram of the pulse-power reactor consisting of a coaxial electrode and multiple ring electrodes. An arc discharge under a pulse power field was verified by waveform measurement and was also visualized by light generation. Fig. 2 shows experimental waveforms of natural and arc discharges.

This study used two kinds of WAS. Feed sludges were collected from the thickeners of WAS at two wastewater treatment plants (Tanchun and Anyang, Korea) and then chilled to 4 °C for experiments. Each sludge of two plants was separately prepared. Tanchun sludge was used for evaluation of WAS solubilization by pulse-power treatment. The sludge was introduced into the pulse-power reactor by using a peristaltic pump at a rate of 800 ml/min. The hydraulic retention time of sludge in the pretreatment reactor was approximately 1.5 s. To pretreat WAS, 7 rings of the outer electrode were used with one coaxial electrode, and pulse-power at the conditions of a voltage of 19 kV and a frequency of 110 Hz was applied to the reactor.

Anyang sludge was used for evaluation of digestibility of pretreated sludge. The sludge was treated by pulse-power technology prior to anaerobic digestion. The sludge was introduced into the pulse-power reactor by using a peristaltic pump at a rate of 600 ml/min. To pretreat WAS, 7 rings of the outer electrode were used with one coaxial electrode, and pulse-power at the condition of a voltage of 17 kV and a frequency of 150 Hz was applied to the reactor. The pretreated sludge was stored in a 20-l tank and then utilized for anaerobic digestion experiments.

2.2. Anaerobic digestion

A laboratory-scale anaerobic batch digester was used for anaerobic digestion of solubilized sludge. It consists of a 1 l bottle, a 50 ml-glass syringe, and a three-way glass valve. The produced gas was collected in the syringe and then vented by three-way valve after the amount of gas was recorded. The reactor was seeded with digester sludge taken from the waster water treatment plant of Tanchun, Korea. The seed sludge and the pretreated sludge were poured into the digester with a ratio of 1:1 to 1:2, depending on the organic load rate (OLR) to be evaluated. The total sludge volume of the

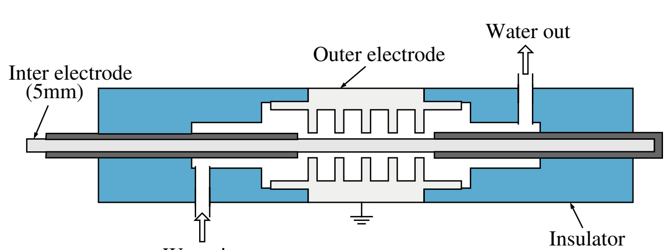

Fig. 1. Pulse-power reactor consisting one coaxial electrode and 5-ring outer electrode.