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Enhancement of waste activated sludge aerobic digestion by electrochemical pre-treatment

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ABSTRACT

Electrochemical technology with a pair of RuO_2/Ti mesh plate electrode is first applied to pre-treat Waste Activated Sludge (WAS) prior to aerobic digestion in this study. The effects of various operating conditions were investigated including electrolysis time, electric power, current density, initial pH of sludge and sludge concentration. The study showed that the sludge reduction increased with the electrolysis time, electric power or current density, while decreased with the sludge concentration. Additionally, higher or lower pH than 7.0 was propitious to remove organic matters. The electrochemical pre-treatment removed volatile solids (VS) and volatile suspended solids (VSS) by 2.75% and 7.87%, respectively, with a WAS concentration of 12.9 g/L, electrolysis time of 30 min, electric power of 5 W and initial sludge pH of 10. In the subsequent aerobic digestion, the sludge reductions for VS and VSS after solids retention time (SRT) of 17.5 days were 34.25% and 39.59%, respectively. However, a SRT of 23.5 days was necessary to achieve equivalent reductions without electrochemical pre-treatment. Sludge analysis by Scanning Electron Microscope (SEM) images and infrared (IR) spectra indicated that electrochemical pre-treatment can rupture sludge cells, remove and solubilize intracellular substances, especially protein and polysaccharide, and consequently enhance the aerobic digestion.

1. Introduction

Waste Activated Sludge (WAS) generated during wastewater treatment should be stabilized sufficiently to reduce its organic content, pathogen contamination and odor problems prior to ultimate disposal (Vlyssides and Karlis, 2004; Fytili and Zabaniotou, 2009; Li et al., 2009). The most common methods of sludge stabilization are biological processes of anaerobic digestion and aerobic digestion. Compared with anaerobic digestion, simplicity of process and lower capital costs are the advantages of aerobic process. Aerobic digestion has been a popular option for small or medium-sized wastewater treatment plants because of these merits (Barbusinski and Koscielniak, 1997; Bernard and Gray, 2000). However, conventional aerobic digestion still requires large digestion tanks due to its relatively long retention time (15–30 days) (Jin et al., 2009).

During sludge digestion, the hydrolysis of large organic molecules associated with microbial cells has been proven as the rate-limiting step (Eastman and Ferguson, 1981; Shimizu et al., 1993; Tiehm et al., 2001; Gronroos et al., 2005; Park and Novak, 2007; Appels et al., 2008). Therefore, the pre-treatment which disintegrates sludge flocs and disrupt microbial cell walls of sludge was developed to improve subsequent biological digestion. Several successful sludge disintegration technologies include alkaline treatment (Lin et al., 1997, 1998;

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Li et al., 2008), thermal treatment (Kim et al., 2003; Bougrier et al., 2006; Salsabil et al., 2010), alkaline combined with thermal hydrolysis (Neyens et al., 2003a; Vlyssides and Karlis, 2004), ultrasonic treatment (Wang et al., 1999; Neis et al., 2000; Tiehm et al., 2001; Sangave et al., 2007; Yu et al., 2008; Jin et al., 2009), ozone oxidation(Arodi et al., 2007; Dytczak and Oleszkiewicz, 2008), hydrogen peroxide (Neyens et al., 2003b) and biological hydrolysis with enzymes (Ucisik and Henze, 2008).

As a result of the more stringent environmental regulations on the discharge of industrial and municipal wastewater, electrochemical technology is considered a powerful means of pollution control and has been widely used. It has shown great versatility, high removal efficiency, lower temperature requirement and environmental compatibility. The main regent, the electron, is clean (Rajeshwar et al., 1994). In some situations, the technology may be the indispensable step for the treatment of industrial effluents which contain bio-refractory organic pollutants, such as landfill leachate (Deng and Englehardt, 2007), phenol (Yavuz and Koparal, 2006), cyanides (Arellano and Martínez, 2007), cigarette industry wastewater (Bejankiwar, 2002), textile (dye) wastewater (Vlyssides et al., 2000; Körbahti, 2007), tannery wastewater (Costa et al., 2008), etc.

Complete mineralization or partial degradation of organic pollutants depends on the anode materials. It was reported that the use of Ti/RuO_2 anode produced a series of electrochemical steps which converted high biopolymer substances to low-molecular-weight products. The low-molecular-weight products then can be easily removed by the subsequent biological treatment (Torresa et al., 2003). It was indicated that the combination of electrochemical and biological technology might be a promising choice for the industrial wastewaters that contain recalcitrant compounds.

Although the literature on electrochemical treatment of activated sludge is rare, the capability of electrochemical technique to decompose organic macromolecules to small molecules observed from above studies may justify its application in WAS treatment. In this study, electrochemical method is first applied to pre-treat WAS, aiming to enhance subsequent aerobic digestion. Firstly, the effects of electrochemical treatment on sludge reduction and solubilization were evaluated and optimized under different electrochemical conditions. Secondly, the performances of aerobic digestion of treated sludge and untreated sludge were compared and assessed in terms of sludge reduction. The feasibility of electrochemical pre-treatment on the enhancement of WAS aerobic digestibility was finally discussed.

2. Materials and methods

2.1. Sludge samples

In this study, WAS was obtained from the sludge return well of the secondary clarifier of a municipal wastewater treatment plant in Shanghai, China. The plant treats 50,000 m^3d^{-1} of wastewater with the anaerobic-anoxic-aerobic process. The sludge samples were thickened to required solid concentrations and stored at 4 ± 1 °C prior to use. Maximum sludge storage period was one week. Table 1 shows the characteristics of sludge samples.

2.2. Electrochemical pre-treatment

All electrochemical experiments of waste activated sludge were carried out in a 500 mL single-compartment glass cell. Both the anode and the cathode were a pair of Ti/RuO_2 mesh plate electrodes of 7.0 × 10.0 cm^2 size. The current was supplied by a highly stable power unit (WYJ. 5 A 60V DC. REGUL. ATED. POWER SUPPLY, Shanghai, China). Copper wires were used for electrical circuit. During the experiments, air was bubbled with an air pump (AIR PUMP, X-6500) to avoid sludge settling and alleviate anode passivation.

Experiments were carried out at ambient temperature. All samples were performed in triplicate and average, standard deviation were calculated for each sample.

2.3. Aerobic digestion reactor

Aerobic digestion experiments were carried out in two plexiglass cylinders with an effective volume of 5 L each (Fig. 1). One reactor was filled with control sample, and the other one was filled with electrochemical pretreated sludge. After adjusting the sludge pH to 7.0 approximately, inoculations were performed with microbial consortia of 2% (V/V) of fresh activated wastewater sludge at a solids concentration of 25 gL^{-1}. The digesters were aerated by an air compressor (AIR PUMP, X-6500) to maintain an uniform oxygen concentration of 2 mgO_2L^{-1} and good mixing between the electrochemically treated sludge and the biomass. The digesters were operated at room temperature (20–28 °C) for 28 days. Oxygen concentration was monitored by an O_2 probe at the top of the column. Periodic samples (150 mL each) were taken from the biological reactor, filtered and analyzed for total solids (TS), volatile solids (VS), suspended solids (SS) and volatile suspended solid (VSS). During the period of incubation, the volume loss due to evaporation was readjusted with distilled water.

2.4. Analytical methods

All analyses were evaluated using chemicals of analytical grade. pH, TS, VS, SS, VSS, and SCOD were determined by the Standard Methods (APHA et al., 1998). TP was determined with the ammonium molybdate spectrophotometric method. TN

Table 1 – Characteristics of sludge samples.

Parameter	Value
pH	6.69–7.07
Moisture content (%)	99.2–98.2
Conductivity (μScm^{-1})	794–1148
Chemical oxygen demand (COD) (mgL^{-1})	17,462–18,990
Soluble chemical oxygen demand (SCOD) (mgL^{-1})	36–52
Total solid (TS) (gL^{-1})	8.0–18.2
Volatile solid (VS) (gL^{-1})	5.5–12.7
Suspended solid (SS) (gL^{-1})	7.6–17.0
Volatile suspended solid (VSS) (gL^{-1})	5.4–12.6
Organic content (VSS/SS) (%)	0.68–0.74