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Pilot-scale study of enhanced anaerobic digestion of waste activated sludge by electrochemical and sodium hypochlorite combination pretreatment

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ABSTRACT

A pilot-scale study was carried out to evaluate the sludge anaerobic digestion in Qingpu wastewater treatment plant in Shanghai, China. This performance of sludge anaerobic digestion with electrochemical and sodium hypochlorite combination pretreatment was assessed by VS removal and biogas production. The results showed that the system with the pretreatment of electrochemical and sodium hypochlorite combination method performed better than the control. Electrochemical and sodium hypochlorite combination pretreatment significantly enhanced the biogas yields from sludge anaerobic digestion and shortened the stabilization period. The changes of the sludge composition resulted in an increase in both biogas and methane production by 1.83 times and 1.89 times, respectively. Up to 48.97% of VS reduction could be obtained with the electrochemical and sodium hypochlorite combination pretreatment compared to the control of 42.64%. Furthermore, sludge anaerobic digestion with the electrochemical and sodium hypochlorite combination pretreatment could reach stabilization 9 days earlier than that without pretreatment. Processes showed that the electrochemical and sodium hypochlorite combination pretreatment was feasible and had the potential to provide environmental and economic benefits for wastewater treatment plants in China.

1. Introduction

Waste activated sludge is the main by-production generated in the urban wastewater treatment process which is increasing significantly year by year, and almost 80% of which has not been properly disposed (Yang et al., 2015). The treatment of WAS has become a big challenge due to its easily decomposable organic matters, hazardous heavy metals, pathogens, and toxic chemicals which are leading to the secondary environment pollution risk (Yu et al., 2013; Ren et al., 2015). As a result, the reduction of waste activated sludge production has been increasingly concerned worldwide.

Waste activated sludge handling is one of the most growing importance problems since it accounts for up to 65% of the total wastewater treatment plants operating costs (Wilson and Novak, 2009; Wu et al., 2015). Nowadays, the reduction of sludge volume and mass in large urban wastewater treatment plant as well as methane production is commonly designed around the anaerobic digestion process (Abelleira et al., 2012; Kim et al., 2015). Anaerobic digestion is considered to be a favored stabilization method for energy recovery from waste sludge, especially in large-sized wastewater treatment plant (Tyagi and Lo, 2013). Three stages are involved in the anaerobic digestion process of sludge including: hydrolytic acidification, acetogenisis, and methanogenesis (Lv et al., 2010). The cell walls and extracellular polymeric substances (EPS) of the microorganisms in sludge require a long retention time and leading to a low biodegradability (Cho et al., 2012; Zhao et al., 2016). Hydrolysis is recognized as rate-limiting step during the degradation of complex organic matters and consequent generation of biogas (mainly CH_4 and CO_2) (Li et al., 2011). Pretreatment of wastewater sludge can speed up the hydrolysis step result from the reduction of the sludge particle size and accelerating the solubilization (hydrolysis).

The non-availability of the easily biodegradable matter in sludge

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reduces biogas production and increases the digestion time during the anaerobic digestion process. Therefore, different pretreatments of sludge stabilization were studied to enhance the hydrolysis by disintegration process leading to the formation of bioavailable organic matter to the microorganisms (Carrere et al., 2010). Various pretreatment methods included mechanical, physical, chemical, and biological pretreatments (Kim et al., 2015), such as alkaline-mechanical pretreatment (Cho et al., 2014), endogenous hydrolytic enzymes pretreatment (Yu et al., 2013), addition of ZVI (Feng et al., 2014), thermal treatment (Imbierowicz and Chacuk, 2012), low-temperature thermal method (Liao et al., 2016), advanced thermal hydrolysis (Abelleira et al., 2012), ultrasonic (Aldin et al., 2010), ozonation (Liu et al., 2001), microwave irradiation (Coelho et al., 2011), surfactants treatment (Zhao et al., 2015), sulfate radical oxidation (Ren et al., 2015) and Fenton' peroxidation (Erden and Filibeli, 2010). All these pretreatments could cause lysis or disintegration of sludge in order to improve solubilization efficiency and subsequent methane production rates based on different mechanisms (Carrere et al., 2010).

However, the operating cost of the pretreatment methods mentioned above is generally high. Moreover, these pretreatment methods are often difficult to be accepted for application due to their environmental risk. The application of a single pretreatment for sludge anaerobic digestion is not very effective due to the intensive energy requirements, high chemical costs, high maintenance costs, deterioration of sludge characteristics and limitations in being scaled up for field application (Kim et al., 2013; Lee and Han, 2013). The combinations of the pretreatments have been widely studied in the recent years. Each pretreatment with different mechanisms might lead to higher solubilization efficiency of sludge result from a synergistic effect with lower energy consumption (Kim et al., 2010).

The electrochemical method has been applied widely in the wastewater treatment field for its effective degradation and clean, flexible, environment-friendly (Chen, 2004). During the treatment of the wastewater, the electrochemical method could degrade the pollutants effectively with no production of toxic intermediate by the strong oxidizing substances. Physically adsorbed "active oxygen" (·OH) or chemisorbed "active oxygen" could be generated by electro-oxidation taking place directly on anodes, and indirect oxidation. These active chlorine species (Cl_2, HClO, and ClO·) could be generated by electrolysis of chloride as energy rich intermediate products (Yu et al., 2014). These powerful oxidants could efficiently convert high biopolymer substances to low-molecular weight products in the region close to the anode surface or in the bulk of the electrolyte (Costa and Olivi, 2009). Therefore, the electrochemical treatment could be used for an effective biodegradation, and disintegrated sludge would be obtained using the technique through hydrolysis/acidogenesis. Practically, in our previous study, the electrochemical method was combined with sodium hypochlorite treatment to disintegrate waste activated sludge. A degree of disintegration (DD) of 22% was achieved (Xu et al., 2014). Furthermore, a bench-scale sludge anaerobic digestion system integrated the combined electrochemical and sodium hypochlorite pretreatment was operated and its sludge reduction efficiency could reached 45.5% as well as its biogas production of 647 l/kg VS. However, the feasibility of this combined method for sludge reduction and energy recovery still needs further investigation.

The objective of this study was to investigate the effects of electrochemical and sodium hypochlorite combination pretreatment on the performance of waste activated sludge pilot-scale anaerobic digestion. The efficiencies of sludge pretreatment, waste activated sludge reduction and the anaerobic digestion performance of the pilot-scale system were investigated. Moreover, corresponding economical analysis was also carried out. The results will benefit the further study and actual application.

2. Material and methods

2.1. Waste activated sludge characteristics

Waste activated sludge used as inoculums and substrates for anaerobic digestion was obtained from Qingpu wastewater treatment plant in Shanghai, China, which had a capacity of 20,000 $m^3\ d^{-1}$ with anaerobic–anoxic–aerobic process. The main characteristics of sludge sample were shown in Table 1.

2.2. Pretreatment experimental procedure

Electrochemical and sodium hypochlorite combination pretreatment was carried out in a 1.5 m^3 digester with a highly stable pulse power supplier and 12 pieces of Ti/RuO_2 mesh plate electrodes of 100.0 × 130.0 cm^2 size. The optimal operation conditions for sludge were as follows according to our previous lab-scale experiment results (Xu et al., 2014): electrolysis time of 45 min, electrolysis voltage of 200 V, current of 25 A, electrode distance of 4 cm and the initial solid content about 40 g l^{-1}. Sodium hypochlorite (NaClO) reagent (5.68 g active chlorine, 32 g sodium hydroxide and 7.8 g sodium carbonate per 100 ml sodium hypochlorite solution) with dosage of 0.4% (v/v) was also introduced to improve the electrochemical process.

2.3. Pilot-scale anaerobic digestion system

Two identical of 15 m^3 active volume digesters with insulating layer were housed in Qingpu wastewater treatment plant in Shanghai, China. Each was approximately 105 cm in radius and 450 cm high. One was fed with unpretreated sludge as control and the other was fed with mixture which was composed of pretreated sludge (30%) and unpretreated sludge (70%). A 1.5 m^3 volume of digested sludge set as inoculums collected from Qingpu wastewater treatment plant was pumped into each digester. The two digesters were operated in mesophilic temperature range (35 ± 2 °C) heated by a water bath. Hydraulic agitation was applied 5 min h^{-1} for sludge mixing. Screw pump was used for the cycle of digestate during hydraulic agitation with a rated flow of 5 $m^3\ h^{-1}$.

Digester internal temperature was monitored by Type J thermocouples whose output to a programmable logic controller allowed the temperature to be controlled by an external thermal jacket. A top-mounted three bladed digester mixer was operated at a nominal shaft speed of 100 rpm in each digester. The biogas volume was measured with a wet-type gas flow meter.

2.4. Analytical methods

A set of standard analysis was performed in order to characterize the sludge samples (TS, VS, TCOD, SCOD, NH_4^+–N, TN and TP) (APHA, 2005). TCOD and SCOD were assessed by the closed reflux

Table 1
The main characteristics of sludge used in this study.

Parameter	Value
pH	6.32 ± 0.08
Total solid (TS) (g l^{-1})	39.5–39.9
Volatile solid (VS) (gl^{-1})	29.0–29.3
Total chemical oxygen demand (TCOD) (mgO_2l^{-1})	32,570–37,640
Soluble chemical oxygen demand (SCOD) (mgO_2l^{-1})	124.0–535.6
Soluble total nitrogen (STN) (mgl^{-1})	104.18–121.8
Soluble total phosphorus (STP) (mgl^{-1})	55.13–98.64