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Enhancement of ultrasonic disintegration of sewage sludge by aeration

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ABSTRACT

Sonication is an effective way for sludge disintegration, which can significantly improve the efficiency of anaerobic digestion to reduce and recycle use of sludge. But high energy consumption limits the wide application of sonication. In order to improve ultrasonic sludge disintegration efficiency and reduce energy consumption, aeration was introduced. Results showed that sludge disintegration efficiency was improved significantly by combining aeration with ultrasound. The aeration flow rate, gas bubble size, ultrasonic density and aeration timing had impacts on sludge disintegration efficiency. Aeration that used in later stage of ultrasonic irradiation with low aeration flow rate, small gas bubbles significantly improved ultrasonic disintegration sludge efficiency. At the optimal conditions of 0.4 W/mL ultrasonic irradiation density, 30 mL/min of aeration flow rate, 5 min of aeration in later stage and small gas bubbles, ultrasonic sludge disintegration efficiency was increased by 45% and one third of ultrasonic energy was saved. This approach will greatly benefit the application of ultrasonic sludge disintegration and strongly promote the treatment and recycle of wastewater sludge.

Introduction

Waste activated sludge produced by wastewater treatment process is continuously increasing and causes various pollution problems (Samolad and Zabaniotou, 2014). To prevent environmental pollution of sludge, many processes were developed. Sludge anaerobic digestion is a cost-effective and energy-saving process that can convert organic pollutants in sludge to biogas. To achieve high anaerobic digestion efficiency, sludge should be disintegrated to release the inner substances (Le et al., 2013b).

Sonication is very efficient for sludge disintegration and has attracted many attentions (Wang et al., 1999; Li et al., 2009). Under ultrasonic irradiation, "hot spots" with high temperature and pressure (5000 K, 1000 atm) pyrolyze sludge, strong shear forces mechanically attack sludge flocs, and hydroxyl free radical (redox potential 2.80 eV) may oxidize sludge (Kang et al., 2006; Koda et al., 2011). Among these mechanisms, hydro-mechanical force is the predominant one for sludge disintegration (Wang et al., 2005). Due to high energy consumption of ultrasonic sludge disintegration, many techniques, including thermal, alkaline, ozone, and acid, were used to improve the ultrasonic efficiency and reduce the energy (Wett et al., 2010; Kim et al., 2010; Liu et al., 2008; Xu et al., 2010). But these methods have disadvantages of high reagent cost and secondary pollution. Aeration is low cost and non-pollution, and thus is a potential method to improve ultrasonic sludge disintegration.

Gas bubbles in the ultrasonic system can act as nucleuses of cavitation bubbles (Eller, 1969). Through aeration, more

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cavitation bubbles were formed. The cavitation effects were then strengthened. Thus ultrasonic sludge disintegration may be enhanced by aeration. As our best knowledge, aeration has not been used to enhance the ultrasonic sludge disintegration.

In this article, the feasibility of aeration to enhance the ultrasonic sludge disintegration was tested. Conditions of aeration were optimized. Energy consumption of aeration-sonication sludge disintegration was analyzed. The aim was to develop an aeration-sonication sludge disintegration method to improve the efficiency and reduce the energy consumption.

1. Materials and methods

Sludge was collected from a local wastewater treatment plant that used A/O process. The sludge had a total solid content (TS) of 1.3%–1.5% and a volatile solid content (VS) of 0.8%–1.1%. The initial soluble chemical oxygen demand (SCOD) was 62–83 mg/L. The pH value was 6.5–8.5.

Aeration was conducted with a LP-20 diaphragm blower (Resun Co. Ltd., China). Aeration flow rate was controlled by a flow meter. Gas bubble size was controlled by aerators with three different pore sizes of 80–100, 180–200 and 250–280 μm. Ultrasonic irradiation was performed with a JY92-II ultrasonic generator (NingboXinzhi Technology Co., China) with an ultrasound frequency of 24 kHz. Each time 250 mL of sludge was tested. The ultrasonic irradiation time was 15 min, which was determined by the preliminary experiments. Temperature of the sludge was controlled below 30 °C with a circulating cooling water system (ST22RC/B-E3000, Hengxing Co., China).

All analyses were performed according to APHA standard methods (APHA, 1995). All experiments were repeated two or three times and the average results were reported. Error bars in the figures refer to the standard deviation of results from repetitive experiments. T-test was used to analyze the significance of the data and all results met the requirement ($\alpha = 0.05$).

2. Results and discussion

In this study, sludge disintegration efficiency was investigated through the determination of soluble chemical oxygen demand (SCOD). The higher the SCOD was, the higher the sludge disintegration efficiency was (Yu et al., 2013). The results are shown in Fig. 1 (inset). The SCOD was increased by 40% from 519 to 711 mg/L at aeration flow rate of 50 mL/min, showing significant enhancement of sludge disintegration by aeration.

In order to obtain the best efficiency of aeration on ultrasonic sludge disintegration, different operation parameters including aeration flow rate, gas bubble size, ultrasonic density and aeration timing were investigated.

2.1. Impact of aeration flow rates on ultrasonic sludge disintegration

Effects of aeration flow rates on ultrasonic sludge disintegration were studied, and the results are shown in Fig. 1. At relative low aeration flow rate (below 30 mL/min), sludge disintegration efficiency was increased obviously. When the flow rate was above 50 mL/min, little increase of sludge disintegration efficiency was observed. Considering the efficiency and energy cost, aeration flow rate of 30 mL/min was the optimal to enhance the ultrasonic sludge disintegration.

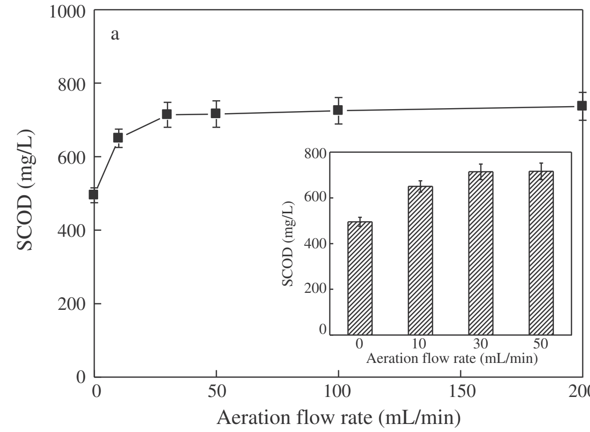

Fig. 1 – Effects of aeration flow rate on ultrasonic sludge disintegration efficiency (15 min aeration time, 0.5 W/mL ultrasonic density, middle size bubble size).

At aeration flow rates below 30 mL/min, large quantities of gas bubbles were introduced into the sludge. Gas bubbles provided more nucleuses of cavitation bubbles and then enhanced the cavitation effects, which led to stronger shear forces. So, ultrasonic sludge disintegration was efficiently improved by higher aeration flow rate. At aeration flow rate above 50 mL/min, more gas bubbles were introduced into the sludge. Due to high concentration of gas, surface tension of the liquid became lower (Lubetkin, 2003). The lower surface tension would decrease the strength for cavitation bubble growth, then the intensity of cavitation effects decreased because of the weaker bubble growth (Brennen, 1995; Jarman, 1959). So, ultrasonic sludge disintegration was hindered by too high aeration flow rate.

2.2. Impact of gas bubble size on ultrasonic sludge disintegration

The induced gas bubbles act as nucleus for cavitation, but cavitation bubbles have fixed resonance size at given ultrasonic frequency (Thompson and Doraiswamy, 1999), so gas bubbles of different sizes might work differently. Small, medium and big gas bubbles which were generated by aerators with pore size of 100–120, 180–200 and 260–280 μm were investigated. Bubbles were generated from the aerator, entered the sludge, aggregated during the movement and were disrupted by ultrasonic waves, so the size of bubbles kept changing. But bubbles from larger pores kept larger than those from smaller pores. Results are shown in Fig. 2. The SCOD of the treated sludge increased from 548 to 779, 722, 636 mg/L respectively, showing a 43.4%, 33.6% and 17.6% improvement with small, medium and big size gas bubbles, respectively. Please note that real waste activated sludge was used. The sludge was different each time and thus the control sample gave different values each time.