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Original Research Paper

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Effects of Combined Pretreatment of Sewage Sludge on Biogas Production in Anaerobic Digestion Process

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ABSTRACT

Biogas recovery by anaerobic digestion was seen as an ideal way to treat biomass waste-sewage sludge, but has some limitations, such as the low efficient biogas production. In this paper, the combined (alkaline and ultrasonic) pretreatment was proposed for effective sludge anaerobic digestion and the effect of these pretreatments was investigated. It can be seen that this treatment effectively led to the increase of soluble chemical oxygen demand (SCOD) and volatile fatty acids (VFA) concentration. The high concentration of VFA led to an increase in biogas production. Under the optimum combined pretreatment condition (under 6000 kJ/kg TS and with 0.15 mol/L NaOH), the biogas production was nearly 8 times higher than the raw sample. Besides, the SV of sludge was reduced and the settling characteristics of sludge were improved. The results indicated that the combined pretreatment could be an effective method for improving biogas yield.

INTRODUCTION

Sewage sludge is the main by-product of wastewater treatment plants. In China, annual production of moist sewage sludge was about 11 million tones in 2010 (Lin et al. 2012), and it is expected that wastewater treatment percentage will reach 75% by 2015, thus production of sewage sludge in China will continuously increase (Deng et al. 2009). Due to the considerable increase in the amount of sewage sludge production, development of new technologies for the reduction of sewage sludge discharge is of great importance. Anaerobic digestion can be considered the most promising way to reclaim energy from materials of high organic matter concentration. This can transform organic matter of sewage sludge into biogas, thereby reducing the amount of final sewage sludge solids that need to be disposed off, while destroying most of the pathogens in the sludge. Other beneficial features include the stabilization of the sludge, the improvement of sludge dewaterability, and the potential to limit odour problems associated with residual putrescible matter. However, the application of anaerobic digestion was often limited due to relatively low digestion efficiencies.

Anaerobic digestion process follows four major steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis (Gavala et al. 2003). Since the hydrolysis of sludge particles is the rate-limiting step, pretreatment to disintegrate the sludge is used to accelerate the sludge anaerobic digestion or increase the degree of degradation in a fixed digestion time. Many pretreatment methods have been suggested in literature, including mechanical (Nah et al. 2000, Hwang et al. 1997, Tedesco et al. 2013), thermal (Dhar et al. 2012, Yang et al. 2010, Guo et al. 2014, Eskicioglu et al. 2006), chemical (Lin et al. 2002, Eskicioglu et al. 2008, Chen et al. 2014) and ultrasonic (Tiehm et al. 1997, Pilli et al. 2011, Le et al. 2013, Xu et al. 2011, Zhang et al. 2013) pretreatments and most of them have been shown to have a positive effect on sludge anaerobic digestion. With the advantages of a simple device, convenient operation and high efficiency, alkaline pretreatment is a commonly used method.

Ultrasound is a sound wave with frequency beyond the normal hearing range of humans (>15-20 KHz). When ultrasound waves propagate in a liquid medium, they can produce cavitation and acoustic streaming. The cavitation will generate powerful shear forces while the acoustic streaming will increase the convection of solution. Based on these merits, ultrasound has been widely utilized in many biological processes to improve the reactions. In most reports, alkaline treatment and ultrasonic pretreatment were studied independently as pretreatment of anaerobic digestion. Since alkaline pretreatment and ultrasonic pretreatment are based on different mechanisms of sludge dissolution, the combination of these two methods may achieve better efficiency and more biogas. In this work, the combined effect of alkaline and ultrasonic treatment on anaerobic digestion of sewage sludge was studied. The objectives of this research were exploring the impact of the pretreatment on anaerobic digestion of sewage sludge and the suitable combination of these two methods for increasing the biogas production.

Table 1: Main characteristics of the sewage sludge.

Moisture [%]	Total solid (TS) [mg/L]	pH	Organic matter[%]
98.5	20200	7.07	79.5

MATERIALS AND METHODS

Sludge sample: The sewage sludge used was collected from the wastewater treatment plant of Hanxi, Wuhan city and stored at 4°C before use. The main characteristics of sludge are listed in Table 1.

Combined alkaline+ultrasonic pretreatment: In the alkaline pretreatment, sewage sludge was performed in a 3.0 L batch mixed reactor, which was placed in a water bath to adjust the reaction temperature to (20±2)°C. The sewage sludge sample was mixed with sodium hydroxide (NaOH) at different doses (0, 0.05, 0.10, 0.15, 0.20, 0.25 mol/L). All samples were put at ambient temperature for 24 h and then pretreated by ultrasonic treatment.

The ultrasonic treatment was performed using a Branson 2000 series bench-scale ultrasonic unit (FS-600, Shanghai Sonxi Co., Ltd., China) for 10 min. The ultrasonic unit had a maximum power output of 2.2 KW and operated at a constant frequency of 20 KHz. The components of the ultrasonic system included the booster (gain 1:2) and the catenoidal titanium horn (gain 1:8) with a flat 13 mm diameter face. For exposure, the horn was put 2 cm deep into 500 mL samples with the specific energy input set to 3000, 6000, 12000, 30000 kJ/kg TS.

Anaerobic digestion experiment: Plastic bottles of 1.5 L size were used as the digesters for anaerobic digestion of the pretreated sludge. 1 L of the pretreated samples were placed in the bottle and mixed with 200 mL activated sludge serving as inoculum. The bottles were capped and closed tightly with tubing protruding from it which is connected to a gas holder. The biogas volume produced was measured by displacement method.

Analytical methods: The digester performance was assessed through the examination of soluble chemical oxygen demand (SCOD), volatile fatty acids (VFA) concentration, settling velocity (SV) and cumulative biogas production. SCOD was determined by the potassium dichromate/ferrous ammonium sulphate method by a detector (ET3150B). VFA concentrations were analysed by a High Performance Liquid Chromatograph (GP40, Dionex, CA) with an absorbance detector (AD20, Dionex) and a 300 mm-7.8 mm Metacarb 67 H column (Varian, CA) using 0.05 M H_2SO_4 as a mobile phase. SV is one of the sludge's most important settling parameter in the routine process control. SV was calculated as the volume ratio of concentrated sludge to the initial sample after 30 min settlement in a 100 mL measuring cylinder. As mentioned above, the cumulative biogas production was measured by displacement method.

RESULTS AND DISCUSSION

Effect of NaOH dose variation on anaerobic digestion process: Fig. 1 and Fig. 2 present the increase of SCOD and VFA concentration of sludge with different NaOH dose when the specific energy input was 3000 kJ/kg TS. As seen in Fig. 1, the SCOD of raw sewage sludge was 210 mg/L. With the increase of NaOH addition, the SCOD climbed rapidly to 350 mg/L, 470 mg/L and 590 mg/L when the NaOH dose increased from 0.05 to 0.15 mol/L. However, the increase in SCOD was very limited when the dose increased further from 0.2 mol/L to 0.25 mol/L. SCOD of sludge after combined pretreatment was greatly improved, suggesting that a large amount of insoluble organics of sludge flocs were transferred into soluble organics and it will promote the biogas production. However, the high dose of NaOH may lead to the recalcitrant soluble organics or toxic/inhibitory intermediates produced. Besides, the increase in SCOD may also result from the destruction of flocs structure after ultrasonic pretreatment, promoting the release of colloidal and soluble organics into the solution. It can be inferred that the optimum dose of NaOH may be 0.15 mol/L.

As seen in Fig. 2, VFA concentration clearly increased with NaOH dose reaching a value of 410 mg/L for sludge pretreated with 0.25 mol/L. In anaerobic digestion process, acidogenic and acetogenic microorganisms transform the soluble organic matter into VFAs and further into acetic acid, thereby causing an increase in VFA concentrations. These VFAs are degraded in the following step by methanogenic microorganisms into methane and CO_2, both determining the volume of the biogas. It is clear that VFA is a critical material for biogas production. However, the high VFA concentration may also be inhibiting microbial activity to some extent, leading to a lower production of biogas. Thus 0.15 mol/L may be a suitable dose for biogas production.

Effect of specific energy input variation on anaerobic digestion process: As in the above experiments, the optimal NaOH dose was 0.15 mol/L, the following combined pretreatment was carried out with 0.15 mol/L NaOH, and the ultrasonic pretreatment was performed with the specific energy input set to 3000, 6000, 12000 and 30000 kJ/kg TS.

The cumulative biogas production results of the combined-pretreated samples and untreated sample in sludge anaerobic digestion experiments are shown in Fig. 3. As it can be observed, the specific biogas production of

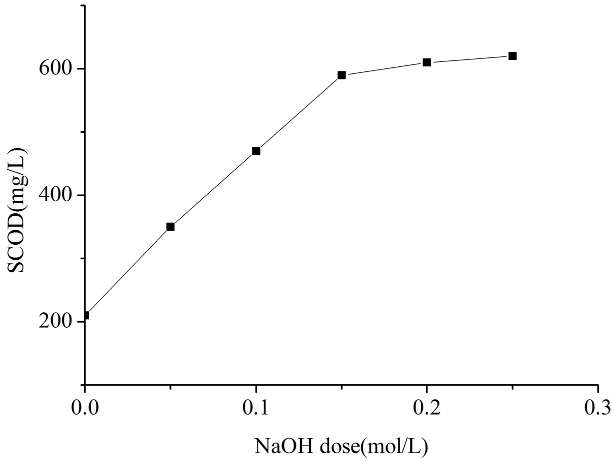

Fig. 1: SCOD of combined pretreated sludge as a function of NaOH dose.

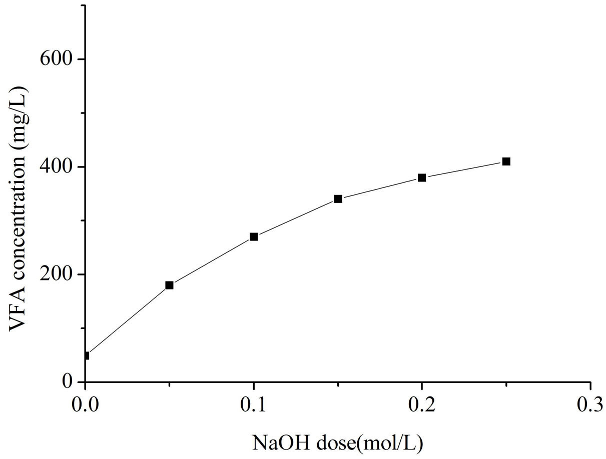

Fig. 2: VFA concentration of treated sludge as a function of NaOH dose.

combined-pretreated sludge was noticeably higher with respect to the one obtained with the same untreated sludge. Under the condition of 3000 and 6000 kJ/kg TS, the biogas productions were nearly 5 times and 8 times of the raw sludge, respectively. The differences of biogas production are great, demonstrating that combined pretreatment greatly affect the sludge anaerobic digestion process. As a consequence of ultrasound action on the treated sludge, an increment in the temperature of the sludge under treatment is observed. Therefore, the effect of ultrasonic treatment may be considered as a joint effect of ultrasound itself and the raise in sludge temperature. The effect of sludge temperature raise on biogas production may be related to the cell structure of the sewage sludge, cells disrupted by the heating process, and massive soluble organic matters released, causing higher biogas production for the treated, rather than the raw sample.

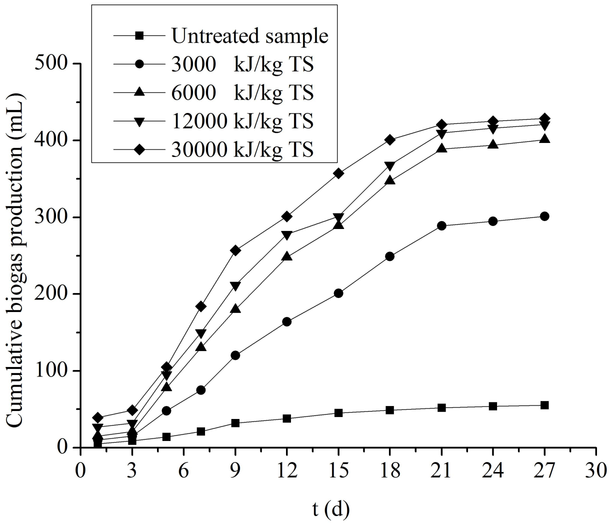

Fig. 3: Cumulative biogas production of different combined-treated sludge samples and raw sludge sample as a function of time.

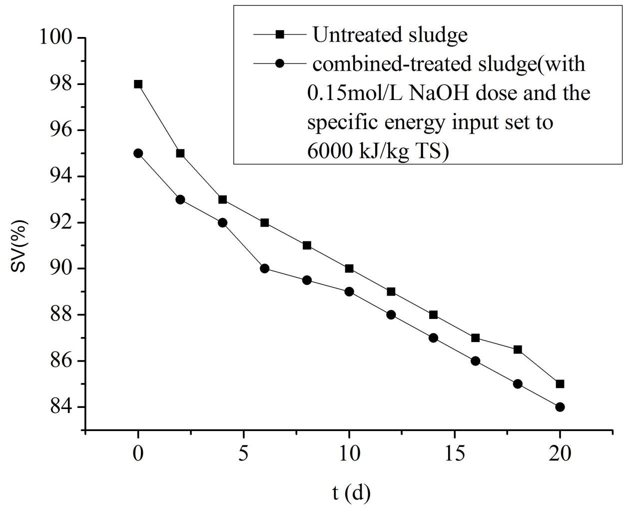

Fig. 4: SV of combine-treated sludge and untreated sludge as a function of time.

As shown in Fig. 3, the biogas production of combined-pretreated samples increased insignificantly in the first three days, followed by a remarkable biogas production increase from day 4 to 21, and no significant increase was observed with further digestion. Besides, the biogas yield increased as the specific energy input. At low specific energy input, the total biogas produced increased significantly by 33.3% when the applied specific energy input was changed from 3000 to 6000 kJ/kg TS. However, the enhancements in the biogas yield were only 6.67% and 2.67% respectively, when the applied specific energy input was changed from 6000 to 12000 kJ/kg TS and 12000 to 30000 kJ/kg TS. It was shown that 6000 kJ/kg TS was the optimum specific energy input for the combined pretreatment.

Effect of combined pretreatment on sludge settling characteristics: In order to evaluate the effect of the combined pretreatment (with 0.15 mol/L NaOH dose and the specific energy input set to 6000 kJ/kg TS) on sludge settling characteristics, one parameter of the sludge, namely, SV was studied. Fig. 4 shows the trend of changes of SV of treated and untreated sludge. According to this graph, sludge using ultrasonic waves reduces SV and therefore, improves the settling characteristics of the sludge.

CONCLUSIONS

The combined (alkaline+ultrasonic) pretreatment of sludge has a significant effect on the sludge biodegradability during the anaerobic digestion that increases the SCOD and VFA concentration as well as biogas generation. The optimum combined pretreatment condition was adding 0.15 mol/L NaOH and with the specific energy input of 6000 kJ/kg TS. Under the optimum condition, the cumulative biogas production was nearly 8 times of raw sludge and the settling characteristic of the sludge was also improved. The results indicated that the impact of the rate-limiting step was reduced by pretreatment, and digestion efficiencies of the sewage sludge were consequently improved. Although both NaOH and ultrasonic pretreatment could cause extra cost, high digestion efficiency means the cost in subsequent sludge dewatering, drying or landfilling could be reduced. Furthermore, current energy prices and targeted reduction of fossil fuel combustion will draw increasingly more attention towards sludge anaerobic digestion.

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