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A new process to improve short-chain fatty acids and bio-methane generation from waste activated sludge

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ABSTRACT

As an important intermediate product, short-chain fatty acids (SCFAs) can be generated after hydrolysis and acidification from waste activated sludge, and then can be transformed to methane during anaerobic digestion process. In order to obtain more SCFA and methane, most studies in literatures were centered on enhancing the hydrolysis of sludge anaerobic digestion which was proved as un-efficient. Though the alkaline pretreatment in our previous study increased both the hydrolysis and acidification processes, it had a vast chemical cost which was considered uneconomical. In this paper, a low energy consumption pretreatment method, *i.e.* enhanced the whole three stages of the anaerobic fermentation processes at the same time, was reported, by which hydrolysis and acidification were both enhanced, and the SCFA and methane generation can be significantly improved with a small quantity of chemical input. Firstly, the effect of different pretreated temperatures and pretreatment time on sludge hydrolyzation was compared. It was found that sludge pretreated at 100°C for 60 min can achieve the maximal hydrolyzation. Further, effects of different initial pHs on acidification of the thermal pretreated sludge were investigated and the highest SCFA was observed at initial pH 9.0 with fermentation time of 6 d, the production of which was 348.63 mg COD/gVSS (6.8 times higher than the blank test) and the acetic acid was dominant acid. Then, the mechanisms for this new pretreatment significantly improving SCFA production were discussed. Finally, the effect of this low energy consumption pretreatment on methane generation was investigated.

Introduction

Primary and secondary sludges are the two different wastes generated in municipal wastewater treatment plants (WWTP). Primary sludge is produced from a mechanical wastewater treatment process, and, excess secondary sludge is a settling material produced at the secondary sedimentation tank of the wastewater treatment plant after biological treatment. Waste activated sludge (WAS) contains amount of non-hydrolyzable particulate materials and biomass due to the biological metabolism process. The activated sludge technology is used widely as an effective biological method of WWTP, so a large amount of WAS is generated from WWTP annually. The WAS containing high levels of organic matter, it may become a plentiful source of inexpensive organic substrate for fermentative short-chain fatty acid (SCFA) and bio-methane production, by which reduction and stabilization of organic wastes can also be accomplished (Wong et al., 2013). In order to

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prevent secondary environmental pollution caused by WAS and reutilize the sludge as a useful resource, the treatment and disposal methods of WAS have been becoming a more and more interesting topic to many researchers in recent years. Among these different treatments and disposal methods of WAS, the anaerobic fermentation technology is considered as an efficient approach to stabilization and sustainable re-utilization of WAS (Gbosh et al., 1975; Liu et al., 2006).

Considering that SCFA is the key intermediate product that can directly influence the bio-methane generation of WAS during the two-phase anaerobic fermentation process, the strategies to enhance SCFA production have become a very heated research topic to many anaerobic fermentation researchers (Carrere et al., 2010; Tyagi and Lo, 2011; Baier and Schmidheiny, 1997; Cuetos et al., 2010; Eskicioglu et al., 2007; Pilli et al., 2011; Li et al., 2012; Zhang et al., 2009; Frigon et al., 2012; Kampas et al., 2007; Tong and Chen, 2007; Zhang et al., 2008; Zhang and Chen, 2009). It is well acknowledged that the four stages, *i.e.*, hydrolysis, acidogenesis, acetogenesis, and methanogenesis, are contained during the sludge anaerobic fermentation process, so varies of pretreatments to improve the production of SCFA and bio-methane from WAS were conducted by many anaerobic fermentation researchers (Carrere et al., 2010; Tyagi and Lo, 2011), including physical pretreated methods (microwave, ultrasonic, mechanic and thermal pretreatments) (Baier and Schmidheiny, 1997; Cuetos et al., 2010; Eskicioglu et al., 2007; Pilli et al., 2011), chemical pretreated methods (Li et al., 2012; Zhang et al., 2009) and biological pretreatment methods (enzyme pretreatment) (Frigon et al., 2012). However, some studies only focused on the hydrolysis stage, the acidogenesis stage had not been actually taken into consideration during the whole anaerobic fermentation process (Kampas et al., 2007; Tong and Chen, 2007; Zhang et al., 2008; Zhang and Chen, 2009). The final bio-methane generation can be improved by these different sludge pretreatments, but energy consumptions of these pretreatment methods, during which the electric energy, thermal energy and chemical energy were consumed, has been scarcely considered.

It has been studied in our previous publication that the methane generation can be enhanced under alkaline condition (Zhang et al., 2010). With pretreated sludge at pH 10 for 8 days, the methane production was improved more significantly than the traditional thermal pretreatment, initial alkaline pretreatment and thermal-alkaline pretreatment. However, it costs too much energy to apply this method to the practical projects due to the large quantity of alkaline added to sustain the alkaline condition and large quantity of acid for pH neutralization process. In this paper, a low energy consumption method to accelerate both the sludge hydrolysis and acidogenesis for significantly enhancing the SCFA production has been investigated. The mechanisms for improvement in SCFA production of the low energy consumption pretreatment were conducted. In order to investigate the effect of this new sludge pretreated method on methane production, two systems of two-phase anaerobic digested reactors were operated semi-continuously and we come to the conclusion that the energy consumption of this new process was more economical than other pretreatment methods, which suggested that it was quite meaningful to the engineering projects.

1. Materials and methods

1.1. Sludges

The WAS was withdrawn from the sedimentation tank of a WWTP in Shanghai, China, and then concentrated immediately by settling at 4°C for 24 hr. The main characteristics of raw sludge are as follows: total suspended solids (TSS) 25,162 ± 505 mg/L, volatile suspended solids (VSS) 17,511 ± 96 mg/L, total chemical oxygen demand (TCOD) 24,828 ± 334 mg/L, soluble chemical oxygen demand (SCOD) 99 ± 4.7 mg/L, total carbohydrate (as COD) 2963 ± 132 mg/L, total protein (as COD) 12,634 ± 431 mg/L, soluble carbohydrate (as COD) 5.3 ± 0.2 mg/L and soluble protein (as COD) 43 ± 1.6 mg/L. The anaerobic digestion sludge, which was obtained from the up-flow anaerobic sludge bed (UASB) reactor of a food wastewater treatment plant in Yixing, China, was used as the inoculums. The main characteristics of anaerobic digestion sludge are as follows: TSS 34,471 ± 1034 mg/L, VSS 24,340 ± 430 mg/L, total carbohydrate (as COD) 3318 ± 128 mg/L, and total protein (as COD) 15,287 ± 611 mg/L.

1.2. Comparison of different thermal pre-treatments affecting WAS hydrolyzation

Twenty anaerobic reactors made of Plexiglas, with 2.0 L working volume each, internal diameter of 100 mm and height of 255 mm were applied in the thermal pretreatment trails. A 36 L portions concentrated WAS was divided equally into the 20 anaerobic reactors. The 20 anaerobic reactors were divided equally into four groups (five reactors in each group), and fermentation temperature of group 1 to 4 was autoclaved respectively (Manufacture Belge de Gembloux, Belgium) at 60°C, 80°C, 100°C and 120°C (1 bar), respectively. Further, the raw sludge of reactors 1 to 5 of each group was pretreated respectively for 15, 30, 45, 60 and 75 min. In order to investigate effects of the thermal pretreatment above on sludge hydrolysis, the SCOD of each reactor was investigated. Meanwhile, soluble protein and carbohydrates were analyzed as they were the dominating soluble organic matters of sludge.

1.3. Comparison of different initial pHs affecting WAS acidification

A series of anaerobic reactors made of Plexiglas, with 2.0 L working volume each, internal diameter of 100 mm and height of 255 mm were conducted in the fermentation experiments to compare different initial pHs affecting WAS acidification. All the reactors were controlled at 35 ± 1°C and stirred at 100 r/min to mix the contents. The WAS no less than 16.2 L was pretreated at 100°C for 60 min, and then divided equally into 1–9 reactors so as to make each reactor contain 1.8 L thermal pretreated sludge. The initial pHs of 1–9 reactors were adjusted to 4, 5, 6, 7, 8, 9, 10, 11 and 12 respectively, by adding 4 mol/L HCl and 5 mol/L $Ca(OH)_2$. Reactor 10 which also contained 1.8 L raw sludge, was controlled as blank test without thermal or pH adjustment. Then each of these reactors was filled with 100 mL anaerobic digestion