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# Effects of total solids content on waste activated sludge thermophilic anaerobic digestion and its sludge dewaterability

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## HIGHLIGHTS

- Estimate the lowest inhibitory FAN and TAN.
- TS influence volumetric biogas production rate and biogas yield.
- Dewaterability do not determine final dewatering effect at different TS.

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## ABSTRACT

The role of total solids content on sludge thermophilic anaerobic digestion was investigated in batch reactors. A range of total solids content from 2% to 10% was evaluated with two replicates. The lowest inhibitory concentration for free ammonia and total ammonia of sludge thermophilic anaerobic digestion was 110.9–171.4 mg/L and 1313.1–1806.7 mg/L, respectively. The volumetric biogas production rate increased with increasing of total solids content, but the corresponding biogas yield per gram volatile solid decreased. The result of normalized capillary suction time indicated that the dewaterability of digested sludge at high total solids content was poor, while solid content of sediment obtained by centrifuging sludge at 2000*g* for 10 min increased with increasing of total solids content of sludge. The results suggest that thickened sludge mixed with dewatered sludge at an appropriate ratio could get high organic loading rate, high biogas yield and adequate dewatering effort.



## 1. Introduction

Owing to the putrescible organic matter, pathogen and high content of water, waste activated sludge (WAS) generated from wastewater treatment plants must undergo some treatments to enhance its stability, kill pathogen and reduce its corresponding volumes prior to final disposal (Appels et al., 2008). Anaerobic digestion (AD) is common method for stabilization of WAS of wastewater treatment plant. WAS treatment via anaerobic digestion results in a reduction of the sludge solids amount and a decrease in odor while produces methane (Duan et al., 2012; Shao et al., 2015; Young et al., 2013). The environmental burdens of sludge would have a remarkable decrease after anaerobic digestion (Dong et al., 2014). Nevertheless, long hydraulic retention time (HRT) and low organic loading rate (OLR) limit the application of traditional anaerobic digester for low solids sewage sludge.

Owing to enhance the treatment capability of digesters, AD of high solids WAS has been regaining attention recently. Duan et al. (2012) reported that mesophilic AD of high solid WAS with total solids (TS) up to 20% could support 4–6 times OLR as high as a traditional low solids system and obtain similar biogas yield at the same HRT. Liao et al. (2014) reported that mesophilic AD of high solids WAS with TS up to 15.67% achieved the same organic degradation rate and slightly decreased the biogas yield from 121 mL/g volatile solids $(VS)_{added}$ at TS 4.47% to 115 mL/g $VS_{added}$. Compared with mesophilic conditions, solubility of the organic compounds, biological/chemical reaction rates and death rate of pathogens increased under thermophilic conditions (Appels et al., 2008). Wang et al. (2014a) reported that thermophilic AD of high solids WAS with TS up to 9.5% achieved the similar organic degradation rate and decreased the methane yield a little from 380 mL/g $VS_{added}$ at TS 7.4% to 320 mL/g $VS_{added}$. These studies focused on the anaerobic digestion process for sludge biodegradation. In fact, the TS of anaerobic digested sludge decreased with the evolution of AD (Dai et al., 2013). Anaerobic digested sludge should be

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dewatered before further disposal. The ideal sludge anaerobic digestion process should be high OLR, high biogas yield and adequate dewaterability of digested sludge. However, there were few reports on the dewaterability of anaerobic digested sludge. Ferrer et al. (2010) evaluated the performance of thermophilic sludge digestion at decreasing HRT and increasing OLR. The results showed that capillary suction time (CST) increased proportionally to the OLR. Moreover, the trends are similar when the CST expressed per gram TS or gram VS. But the TS of sludge was low (19.63–54.61 g/L).

OLR of anaerobic digester rises with the increasing of TS of sludge. Moreover, TS influence the mass transfer effect and inhibitory substances (especially ammonia) (Dai et al., 2014; Dong et al., 2013; Duan et al., 2012). Inhibitory substances are often found to be the leading cause of anaerobic reactor upset and failure since they are present in substantial concentrations in sludge (Chen et al., 2008). Inhibition is usually indicated by a decrease of the steady-state rate of methane gas production and accumulation of organic acids. Inhibitor changed the sludge anaerobic digestion process and influenced the dewaterability of anaerobic digested sludge. Many characteristics are reported to influence the dewaterability of sludge, such as particle size, protein, polysaccharide, and the protein/polysaccharide ratio in EPS of sludge flocs (Lü et al., 2015; Yu et al., 2008). The characteristics of EPS play an important role in sludge dewaterability (Li and Yang, 2007).

In this study, ten identical reactors, with 2% (C1), 4% (C2), 6% (C3), 8% (C4) and 10% (C5) TS, were used to anaerobically digest WAS under thermophilic anaerobic condition based on two parallel experiments. Efforts of TS on sludge digestion and dewaterability of anaerobic digested sludge were investigated. The overall objectives of this study were: (1) to investigate the ammonia inhibitory effect for sludge anaerobic digestion at different TS; (2) to present dewaterability of anaerobic digested sludge and its relationship with EPS at different TS.

## 2. Methods

### 2.1. Sewage sludge

Dewatered sludge and WAS were obtained from a local domestic wastewater treatment plant in Jiujiang, China. The capacity of the plant was 60,000 $m^3$/day and it used a Carrousel oxidation ditch process. The service population of the wastewater treatment plant was about 220,000. TS of dewatered sludge was 16.2 ± 0.1% (w/w) and VS accounted for 44.3 ± 0.5% of TS. The carbon and nitrogen of sludge were 21.84 ± 0.12% and 3.94 ± 0.13%.

The total suspended solids of inoculum sludge was 8.6 ± 0.3 g/L, which was WAS anaerobic digested under thermophilic condition for 25 d.

### 2.2. Experimental setup

Anaerobic digestion was carried out using ten airtight sebc bottle with a working volume of 2.5 L. The sebc bottle was sealed with the rubber stopper. Two hollow steel tubes inserted into a rubber stopper. One hollow steel tube linked with gas bag for collecting biogas. The other hollow steel tube was sampling port. Dewatered sludge inoculated with anaerobic digested sludge at inoculation ratio of 20:1 (w/w dry solid). After that, the mixed sludge was diluted to the TS of 2%, 4%, 6%, 8% and 10% by distilled water. For each sebc bottle, 2.0 L diluted sludge was used for experiment. The digesters were then incubated in a water bath at 55 ± 2 °C without mixing.

### 2.3. Analytical methods

The sludge samples were collected from the sampling ports (on the top of reactors) by using a peristaltic pump. The sludge samples were first centrifuged at 2000*g* for 10 min after which the supernatant was filtered through a 0.45 μm microfiber filter. The filtrate corresponded to the liquid samples in this study.

#### 2.3.1. EPS extraction

A heat extraction method (Li and Yang, 2007) was slightly modified. In brief, all sludge samples were diluted to 2% TS by distilled water. In order to separate the Slime fraction from the solids, the mixture was stirred 5 min with a vortex mixer, and then the suspension was centrifuged at 4000*g* for 5 min. Then the collected sediments were re-suspended to their original volume by using a NaCl solution (0.5% w/w). The mixture was stirred 5 min with a vortex mixer and placed in a water bath at 50 °C for 5 min. After that, the suspension was centrifuged at 4000*g* for 10 min, in order to separate the loosely bound EPS (LB-EPS) from the solids. The collected sediments were re-suspended again by the aforementioned NaCl solution at room temperature and placed in a water bath at 60 °C for 30 min. After that, the suspension was centrifuged at 4000*g* for 10 min for separating the tightly bound EPS (TB-EPS) from the solid. All the EPS fractions were filtered through a 0.45 μm microfiber filter for further analysis.

#### 2.3.2. Physico-chemical analysis

Souble chemical oxygen demand (SCOD) determinations were made using standard methods with: a DRB 200 Hach COD reactor for digestion of the sample, and a DR1010 Hach spectrophotometer for colorimetric determination. Total ammonia nitrogen (TAN) were all measured according to standard methods (APHA, 1998). Free ammonia nitrogen (FAN) was calculated in the same way as described by Østergaard (1985).

Protein of EPS was measured by the modified Lowry method with bull serum albumin as the standard (Markwell et al., 1978). Polysaccharide of EPS was measured by the anthrone method with glucose as a standard (Gaudy, 1962).

The dewaterability of sludge samples were evaluated according to the TS of sediment obtained by centrifuging sludge at 2000*g* for 10 min and CST by instrument (Model 304M, Trition, UK). Normalized CST (NCST) was modified from the CST, which was the ratio of CST to the concentration of the tested material required to eliminate the influence of solid particles.

TS and VS were measured according to the standard methods (APHA, 1998). The percentage contents of carbon, hydrogen and nitrogen of sludge were determined by means of an elementary analyzer (Vario ELcube, Elementar, Germany).

All these tests were conducted in duplicate, and the data had shown that were the averages based on two parallel experiments in this paper.

#### 2.3.3. Statistical analysis

Statistical analysis was performed with the using of SPSS 22.0 for Windows. Pearson's correlation coefficient was used to evaluate the simple correlation between two parameters. Pearson's coefficient is always between −1 and +1, where −1 denotes a perfect negative correlation, +1 a perfect positive correlation, and 0 the absence of a relationship. The correlations were considered statistically significant at $P < 0.05$(*) and highly significant at $P < 0.01$(**).