



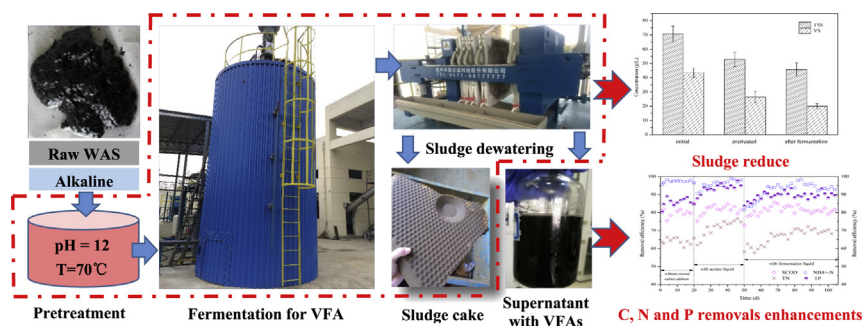
Full-scale production of VFAs from sewage sludge by anaerobic alkaline fermentation to improve biological nutrients removal in domestic wastewater

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GRAPHICAL ABSTRACT



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ABSTRACT

A full-scale project of thermal-alkaline pretreatment and alkaline fermentation of sewage sludge was built to produce volatile fatty acids (VFAs) which was then used as external carbon source for improving biological nitrogen and phosphorus removals (BNPR) in wastewater plant. Results showed this project had efficient and stable performances in VFA production, sludge reduce and BNPR. Hydrolysis rate in pretreatment, VFAs yield in fermentation and total VS reduction reached 68.7%, 261.32 mg COD/g VSS and 54.19%, respectively. Moreover, fermentation liquid with VFA presented similar efficiency as acetic acid in enhancing BNPR, obtaining removal efficiencies of nitrogen and phosphorus up to 72.39% and 89.65%, respectively. Finally, the project also presented greater economic advantage than traditional processes, and the net profits for VFAs and biogas productions are 9.12 and 3.71 USD/m³ sludge, respectively. Long-term operation indicated that anaerobic alkaline fermentation for VFAs production is technically and economically feasible for sludge carbon recovery.

1. Introduction

Volume and mass of waste activated sludge generated in wastewater treatment plants (WWTPs) are expected to increase continuously in the next decades, due to the increasing population connected to sewage networks, the building of new WWTPs and the upgrading of existing

plants to fulfill the more stringent local effluent regulations. In China, the annual production of sewage sludge (80% moisture content) has reached almost 4000 million tons, and 80% of it has not obtained necessary stabilization (Duan et al., 2012). Thus, it is essential to find out a technically and economically feasible way to treat the large amount of sludge.

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Volatile fatty acids (VFAs) have a wide range of applications, such as in the production of bio-energy (Sawatdeenarunat et al., 2017; Jin et al., 2017; Huang et al., 2016) and the biological removal of nutrients from wastewater as carbon source (Zheng and Chen, 2010; Liu et al., 2016). At present, commercial production of VFAs is mostly accomplished by chemical routes (Chen et al., 2017). However, the use of non-renewable petrochemicals as the raw materials has renewed the interest in biological routes of VFAs production by utilizing organic-rich wastes, such as sludge generated from wastewater treatment plant, food waste, organic fraction of municipal solid waste and industrial wastewater (Kuruti et al., 2017). Such transformation of wastes into VFAs also provides an alternative route to reduce the ever increasing amount of waste (Zhou et al., 2014). A lot of laboratory studies have demonstrated that the fermentative production of VFAs from sewage sludge is feasible and can be significantly improved under alkaline conditions of pH 10 controlled by NaOH (Li et al., 2014; Kurahashi et al., 2017; Liu et al., 2012), and the feasibility of the alkaline fermentation liquid as the carbon source for enhanced biological phosphorus removal has also been verified in the laboratory anaerobic-aerobic sequencing batch reactor (Liu et al., 2016; Tong and Chen, 2009; Li et al., 2011). Li et al. (2011) reported the pilot-scale waste activated sludge alkaline fermentation, fermentation liquid separation and application to improve biological nutrient removal. The study demonstrated the feasibility of the alkaline fermentation liquid as the carbon source of enhanced biological phosphorus removal microbes in pilot scale experiment. Gao et al. (2011) investigated the biological sludge reduction and enhanced nutrient removal in a pilot-scale system with 2-step sludge alkaline fermentation and A²/O process, and verified that alkaline pH could significantly improve the VFAs yield during the anaerobic hydrolysis and acidification. However, as far as it was known, no papers have been published so far describing full-scale operation of VFAs production and their application for biological nutrients removal process in WWTPs. The economic feasibility is still uncertain of the VFAs production by anaerobic alkaline fermentation of sewage sludge. In addition, except from the laboratory scale of VFAs production, these studies were conducted with the low concentration of solid (TSS < 3%) content, resulting in the large volume of the anaerobic fermenter and the high operation cost, including the energy and land requirement, etc.

In this study, the full-scale VFAs production from alkaline anaerobic fermentation of high-solid waste activated sludge, separation of fermentation liquid from the sludge fermentor and subsequent application of fermentation liquid to improve municipal biological nitrogen and phosphorus removal were investigated. The objectives of the present study were to develop a novel process in full-scale and to provide detailed descriptions of the process, energy consumption and design considerations for VFAs fermentative production and the application for biological nutrient removal in WWTPs.

2. Materials and methods

2.1. Outline of the full-scale sludge fermentation engineering

The full-scale work included the following four parts as shown in Fig. 1, sludge pretreatment system, sludge alkaline fermentation system, fermentation liquid separation system, and municipal wastewater treatment with an anaerobic-anoxic-aerobic (A²/O) process enhanced by fermentation liquid addition. The sludge fermentation was operated semi-continuously, the sludge pretreatment and the separation of fermentation liquid were operated in batch, but the fermentation liquid was fed into the A²/O process continuously.

A certain volume of fresh sludge was daily pumped from the thickener to the tank for sludge concentration adjustment (1.6 m³) (TK1), in which the TSS is adjusted to about 7.0%. Then, the sludge was pumped into the thermal-alkaline pretreatment tank (1.9 m³) (TK2), which was operated under 70 °C, pH-12 and 2 h for sludge pretreatment. The sludge alkaline fermentation reactor (30 m³) (TK3) was

mechanically stirred at 48 rpm and controlled temperature at 35 °C by water bath jacket. The separation system was composed of two cylinder tanks and a sludge dewatering machine. One tank was used for receiving the sludge-fermentation mixture (TK4) and another for storing the fermentation liquid (TK5), respectively. Sludge dewatering was conducted by the frame filter press with pressure of 0.6 Mpa.

2.2. Sewage sludge and seeding sludge

The full-scale study was conducted in a municipal wastewater treatment plant in Wuxi city of China. This WWTP was operated with an anaerobic anoxic-aerobic (A²/O) process. The activated sludge from the WWTP was used as the seeding sludge of the anaerobic fermenter for VFAs production. The sewage sludge used in the anaerobic alkaline fermentation was dewatered sludge with solid concentration of 70 g/L (93% water content).

A tank with the working volume about 1.9 m³ (the same as TK2) was applied to accumulate and acclimate acidogenic microorganisms. The process of the acclimation and re-activation of seeding sludge were followed as the previous literature (Wang et al., 2013). When the pH of effluent was stable at 4.5, it means the completion of domestication. The characteristics of dewatered sewage sludge (used for the anaerobic fermentation) and the seeding sludge were shown in Table 1. All measurements were conducted in triplicate with average and standard deviation reported.

2.3. The operation of the anaerobic fermentor

The operation of fermentation was divided into three stages in which the first stage (1–6 d) was for sludge canning, the second stage (7–15 d) was for inoculation and start-up, the third one (16–102 d) was semi-continuous operation stage. In the first stage, about 12.0 m³ heat-alkaline pretreated sludge was obtained by 6 days operation of the TK2 and was pumped into TK3 in batches, while in the second stage, 1.5 m³ seeding sludge and 7.5 m³ heat-alkaline pretreated sludge were pumped into TK3 in batches by 4 days. In the third stage, every day, 1.5 m³/d fermented sludge was discharged out from TK3 and then 1.5 m³/d fresh pretreated sludge was pumped into it from TK2. The organic loading rate (OLR) of the fermenter was about 3.0 kg VS/m³.d. The sludge was fermented at pH 10–11 with a sludge retention time of 14 d. The NaOH (400 g/L) was used to control the fermentation pH at 10–11.

The A²/O process consisted of an anaerobic tank, an anoxic tank, an aerobic tank, and a sedimentation tank. Acetic acids and fermentation liquids were added to the A²/O at the second and third stages, respectively. Detailed operating parameters in different operational stages were shown in Table 2.

2.4. Analytical methods

The concentration of total suspended solid (TSS), volatile suspended solid (VSS), soluble chemical oxygen demand (SCOD) and pH were conducted according to Standard Methods (APHA, 1998). The concentrations of proteins and polysaccharides were measured using the Lowry-Folin (Lowry et al., 1951) and phenol-sulfuric method (Dubois et al., 1956), respectively. To measure SCOD, soluble protein and soluble polysaccharides, the samples were first centrifuged at 10,000 rpm for 10 min, and then were filtered with 0.45 μm syringe filters. All the filtered samples were measured immediately after collection.

The VFAs concentration in the filtrate samples was detected by a gas chromatograph (GC-2010, Japan), equipped with a flame ionization detector (FID) and a fused-silica capillary column (PEG-20 M, 30 m × 0.32 mm × 0.5 μm, China). The column temperature was maintained at 80 °C initially. While, the highest temperature was 210 °C, and then was held for 2 min. Both the injection port and detector temperatures were 250 °C. Before GC measurement, 4-methylvaleric acid (acted as internal standard), 3 M phosphoric acid (acidifier)

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