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# Mechanisms of nitrite addition for simultaneous sludge fermentation/nitrite removal (SFNR)

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ABSTRACT

Simultaneous sludge fermentation and nitrite removal (SFNR) was investigated as a novel sludge/wastewater treatment process with high nitrogen concentrations. The results showed that introducing nitrite improved the primary sludge (PS) fermentation system by improving the chemical oxygen demand (COD) yields and the volatile suspend solid (VSS) reduction. At a nitrite dosage of 0.2 g g $SS^{-1}$, the COD production was 1.02 g g $VSS^{-1}$ and the VSS reduction was 63.4% within 7-day fermentation, while the COD production was only 0.17 g g $VSS^{-1}$ and the VSS reduction was only 4.9% in the blank test. Nitrite contained in wastewater was removed through denitrification process in the SFNR system. The solubility of carbohydrate and protein was substantially enhanced, and their contents reached the peak once nitrite was consumed. In addition, the nutrient release and methane generation were inhibited in the SFNR system, which alleviated the environmental pollution. Unlike traditional fermentation systems, neither alkaline condition nor high free nitrite acid (FNA) concentration affected the PS fermentation in the SFNR system. Molecular weight distribution (MWD) and Live/Dead cell analysis indicated that the sludge disruption by nitrite and the consumption of soluble organic substances in sludge might play important roles in SFNR.



## 1. Introduction

Sewage sludge produced from wastewater treatment needs stabilization and minimization, which accounts for up to 60% of the total operational cost of wastewater treatment plants (WWTPs) (Wei et al., 2003). Anaerobic sludge fermentation has been widely used to treat sludge and recycle heat and organic resources (Zhang and Chen, 2009; Schievano et al., 2012; Wang et al., 2013a). But the slow reaction rate of anaerobic fermentation leads to low fermentation efficiency, large sludge treatment volumes, and high treatment costs. The hydrolysis of particulate organic matters to soluble substances is the rate-limiting step during sludge fermentation (Eastman and Ferguson, 1981). Various techniques including ultrasonic (Yan et al., 2010), thermal (Climent et al., 2007), ozone (Yeom et al., 2002), and alkaline treatment (Zhang et al., 2011) have been studied to accelerate the sludge fermentation. However, two major problems, high treatment cost and

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nutrients (nitrogen and phosphorous) release during sludge fermentation (Montusiewicz et al., 2010) should be considered for cost-effective sludge treatment processes.

One of the potential solutions is to introduce inorganic electron acceptors (e.g. oxygen, sulfate and nitrite) to sludge fermentation systems. It had been found that introducing oxygen to sludge digesters improved volatile fatty acid (VFA) production, and achieved high sludge reduction efficiency and better dewatering property (Borowski and Szopa, 2007; Tomei et al., 2011). The hydrolysis of carbohydrates in primary sludge (PS) was enhanced under biosulfidogenic conditions (Whittington-Jones et al., 2006). High-ammonium wastewater has the potential of providing high nitrite ($NO_2^-$–N) concentrations after partial nitrification, which act as a low-cost electron acceptor for sludge fermentation (Wang et al., 2013b). Introducing nitrous acid significantly improved the biodegradability of secondary sludge (Pijuan et al., 2012; Wang et al., 2013c), and suppressed the methane ($CH_4$) production (Sakthivel et al., 2012), thus more organic carbon could be saved in WWTPs and further utilized for other biological processes (e.g. denitrification). This can effectively solve the carbon shortage problem in WWTPs.

Simultaneous sludge fermentation and nitrite removal (SFNR) is a novel approach to treat wastewater and sludge, remove nitrogen, save carbon sources, and reduce operational cost. The feasibility of this strategy was studied in a long-term treatment system over 25 weeks by continuously pumping the partial nitrification wastewater into a PS fermentation reactor (Peng et al., 2012; Zhang et al., 2010). Relatively high nitrogen removal efficiency (83.5%) and sludge degradation efficiency (50%) were achieved. With nitrite being present in the system, sludge fermentation and nitrogen removal improved mutually.

However, the impacts of nitrite on sludge fermentation, including nitrite dosages and dosing modes have not been elucidated yet. The variations of fermentation liquid products and biogas with nitrite addition have not been comprehensively investigated. Even though sludge reduction and cell lysis were studied in nitrite-based sludge treatments (Peng et al., 2012; Pijuan et al., 2012), the simultaneous sludge treatment/nitrogen removal in wastewater has not been conducted at various nitrite dosages and dosing modes. Moreover, most studies have focused on secondary sludge digestion (Wang et al., 2013c; Pijuan et al., 2012). In fact, PS is more difficult to digest than secondary sludge, due to less content of organic substances and biomass. Therefore, this study targeted these challenges by determining the SFNR mechanisms for PS treatment. Lab-scale batch tests were conducted to enhance sludge fermentation using nitrite, achieve nitrite removal in SFNR at different nitrite dosages, compare the SFNR performance at different nitrite dosing modes, and determine liquid products and biogas components and correlate with nitrite mechanisms.

## 2. Materials and methods

### 2.1. Sludge sources

Seed sludge containing fermentative bacteria was collected from a parent fermentation reactor (working volume: 10 L, temperature: 30 °C, feeding sludge: PS, sludge retention time (SRT): 10 d). The PS was collected from the sludge collection pipes of the primary sedimentation tank at the GaoBeiDian WWTP (treatment capacity: 1,000,000 $m^3$ $d^{-1}$) with anaerobic–anoxic–oxic ($A^2O$) process (Beijing, China). The PS was filtered through 0.9 mm screen mesh to remove large particles before being used in the fermentation reactors. Both seed sludge and PS were centrifuged at 100×$g$ for 60 s to remove the liquid contained, washed twice with 0.9% NaCl solution to remove the soluble compounds, and then mixed at a ratio of 1:2 on suspend solid (SS) basis. The main characteristics of the sludge were as follows: SCOD = 110.2 mg $L^{-1}$, TCOD = 13,170 mg $L^{-1}$, $NH_4^+$–N = 6.27 mg $L^{-1}$, $PO_4^{3-}$–P = 20.19 mg $L^{-1}$, SS = 10,910 mg $L^{-1}$, VSS = 6720 mg $L^{-1}$, VSS/SS = 0.616. This sludge was inoculated to batch fermentation reactors for all the tests in this study.

### 2.2. Experiments for studying the effects of nitrite dosage on fermentation systems

Batch experiments were conducted in four fermentation reactors (referred to as A1–A4) with a working volume of 1.5 L each. The total suspended solid (TSS) of sludge in these reactors was adjusted to approximately 4 g $L^{-1}$ by diluting with distilled water. Magnetic stirrers were installed in all reactors for mixing the sludge solutions. pH probes were used to monitor pH of the sludge solution. Aluminum foil gas sampling bags were used to collect biogas from the head space. The reactors were sparged with $N_2$ gas for 5 min to remove oxygen from solutions. $NaNO_2$ was then added to each reactor (A1–A4) at the ratio of 0, 0.05, 0.1, 0.2 g $NO_2^-$–N g $SS^{-1}$, respectively (namely, 0, 200, 400, 800 mg $NO_2^-$–N $L^{-1}$). The batch reactors were operated at 30 °C for 14 days without pH regulation.

### 2.3. Experiments for studying the effects of nitrite dosing modes on fermentation systems

Two nitrite addition modes, termed as one-time spike dosing mode and batch-dosing mode, were studied in four reactors (referred to as B1–B4. Working volume: 1.5 L each) equipped with magnetic stirrers, biogas sampling bags, and pH probes. The TSS concentration of sludge was adjusted to approximately 2.8 g $L^{-1}$ before test. After sparging with $N_2$, $NaNO_2$ was added to B1 and B3 using the one-time dosing mode at the ratio ($NO_2^-$–N dosage: dry sludge) of 0.14 and 0.28 g $g^{-1}$, respectively, and $NaNO_2$ was added to B2 and B4 at the batch-dosing mode (four times dosing) with the total dosage the same as B1 and B3, respectively. Four reactors were operated at 30 °C for over 7 days without pH regulation.

### 2.4. Experiments for studying the FNA and pH effects on fermentation systems

Introducing nitrite to sludge fermentation systems could lead to the accumulation of free nitrous acid (FNA), which inhibits bacteria in wastewater treatment systems. To determine whether high FNA or high pH promoted the PS fermentation, four batch-mode fermentation reactors (referred to as C1–C4. Working volume: 1.5 L each) were filled with the sludge with