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Enhancing post aerobic digestion of full-scale anaerobically digested sludge using free nitrous acid pretreatment

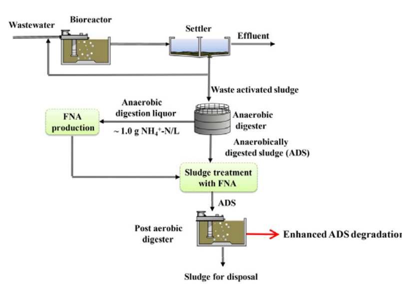
Qilin Wang [1], Xu Zhou [1], Lai Peng, Dongbo Wang, Guo-Jun Xie, Zhiguo Yuan*

Advanced Water Management Centre, The University of Queensland, St. Lucia, Queensland 4072, Australia

HIGHLIGHTS

- FNA pre-treatment could enhance ADS degradation in post aerobic digestion.
- FNA pre-treatment is an economically attractive method.
- FNA pre-treatment is easily implemented in the wastewater treatment plants.

GRAPHICAL ABSTRACT



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ABSTRACT

Post aerobic digestion of anaerobically digested sludge (ADS) has been extensively applied to the wastewater treatment plants to enhance sludge reduction. However, the degradation of ADS in the post aerobic digester itself is still limited. In this work, an innovative free nitrous acid (HNO_2 or FNA)-based pretreatment approach is proposed to improve full-scale ADS degradation in post aerobic digester. The post aerobic digestion was conducted by using an activated sludge to aerobically digest ADS for 4 days. Degradations of the FNA-treated (treated at 1.0 and 2.0 mg N/L for 24 h) and untreated ADSs were then determined and compared. The ADS was degraded by 26% and 32%, respectively, in the 4-day post aerobic digestion period while being pretreated at 1.0 and 2.0 mg HNO_2–N/L. In comparison, only 20% of the untreated ADS was degraded. Economic analysis demonstrated that the implementation of FNA pretreatment can be economically favourable or not depending on the sludge transport and disposal cost.

1. Introduction

Large amounts of sludge are generated in activated sludge processes and substantial costs are required for its disposal and treatment (Canales et al., 1994; Hao et al., 2010). Anaerobic sludge digestion has been widely used for sludge treatment before its disposal. However, sludge reduction above 50% is often difficult to achieve in anaerobic digestion (Parravicini et al., 2008; Novak et al., 2011). Recently, post aerobic digestion of anaerobically digested sludge (ADS) has been extensively studied and applied to the wastewater treatment plants (WWTPs) to enhance sludge reduction (Kumar, 2006; Parravicini et al., 2008; Novak and Kim, 2011; Novak et al., 2011; Tomei et al., 2011a,b). For example, Parravicini et al. (2008) found that the mixed liquor volatile suspended solid (MLVSS) of the ADS was reduced by 16% in a WWTP by implementing post aerobic digestion with a sludge retention time (SRT) of 6 days. Novak and Kim, 2011 obtained an MLVSS removal of

* Corresponding author.
E-mail address: zhiguo@awmc.uq.edu.au (Z. Yuan).
[1] These authors contributed equally to this work.

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Table 1
Sludge concentration of anaerobically digested sludge (ADS) and digesting sludge (with standard errors).

Parameter	ADS	Digesting sludge
MLSS[a] (g/L)	20.0 ± 0.6	8.6 ± 0.1
MLVSS (g/L)	14.7 ± 0.2	6.7 ± 0.1

[a] MLSS: mixed liquor suspended solid.

around 15% in ADS by conducting post aerobic digestion with an SRT of 5 days. Although post aerobic digestion could enhance sludge reduction in the WWTPs, the degradation of ADS in the post aerobic digester itself is still limited.

Free nitrous acid (HNO_2 or FNA), a renewable and low cost chemical that can be produced on site by nitritation of the anaerobic digestion liquor (Law et al., 2014), has been demonstrated to be able to enhance degradation of waste activated sludge (WAS). For instance, it has been found that a WAS reduction of 28% was achieved when a fraction of return sludge was subject to FNA treatment for 24 h at 2.0 mg HNO_2–N/L (Wang et al., 2013a). Recently, Wang et al. (2013b) reported that methane generation was enhanced by about 30% in the case of FNA pretreatment compared with the case without FNA pretreatment. More recently, Wang and Yuan (2015) reported that 50% of the FNA-treated WAS was degraded during the 14-day aerobic digestion in comparison to 32% achieved with the untreated WAS. Additionally, the FNA-based sludge pretreatment approach was demonstrated to be favourable from the economic point of view (Wang et al., 2013b, Wang and Yuan, 2015, Wang et al., 2016).

These findings enabled us to assume that FNA pretreatment of anaerobically digested sludge (ADS) could be an approach to improve ADS degradation during post aerobic digestion. To confirm this assumption, an ADS collected from a local WWTP was treated for 24 h by FNA (1.0 mg N/L and 2.0 mg HNO_2–N/L). The ADS that was not treated by FNA served as a reference. Post aerobic digestion was conducted by using an activated sludge to aerobically digest these ADS for 4 days. The post aerobic digestion time of 4 days is typical in the WWTPs (Parravicini et al., 2008; Novak et al., 2011). Afterwards, degradations of both FNA-treated and untreated ADSs were determined and compared. The economic benefit of the FNA pretreatment approach was evaluated. This is for the first time that a pretreatment method to improve ADS degradation in post aerobic digestion was proposed.

2. Materials and methods

2.1. Sources of sludge

Two kinds of sludge were adopted to conduct the tests.

The anaerobically digested sludge (ADS) was harvested from a mesophilic anaerobic digester (SRT = 20 d) treating the mixture of primary sludge and WAS in a WWTP in Australia. Its sludge concentration was shown in Table 1.

Digesting sludge was harvested from the aerobic reactor of the same WWTP. This sludge was adopted to degrade the ADS aerobically with the details described in part 2.3. Its sludge concentration was shown in Table 1.

2.2. FNA pretreatment of ADS

The full-scale ADS was treated using FNA in the batch tests. 1.6 L of ADS was evenly divided into four batch reactors, with two as the experimental reactors and the other two as references. A $NaNO_2$ solution (50 g NO_2^-–N/L) was dosed to the experimental reactors to obtain the designated nitrite levels of 125 mg NO_2^-–N/L and 250 mg NO_2^-–N/L, respectively. The treatment sustained 24 h pH was maintained at 5.5 ± 0.2 during the treatment period using 1 mol/L HCl. This leads to the FNA concentrations of 1.0 and 2.0 mg N/L, respectively. The FNA concentration was calculated based on the formula $S_{NO_2^- -N}/K_a \times 10^{pH}$), in which the value of Ka was estimated using $K_a = e^{-2,300/(273+T)}$ (T = 22 °C in this work) (Anthonisen et al., 1976). It has been demonstrated that WAS degradation was able to be improved by FNA pretreatment at 1.0 and 2.0 mg N/L at a treatment time of 24 h (Wang et al., 2013a,b; Wang and Yuan, 2015). Therefore, these pretreatment conditions were chosen in this work. In the two reference reactors, pH was not controlled and fluctuated between 7.2 and 7.6 during the 24 h treatment time. The nitrite was not dosed to the reference reactors. These two reference reactors were identical but the ADS in these two reference reactors would be used for different purposes as described in the following section. It should be pointed out that the enhanced WAS degradation is due to FNA instead of nitrite itself (Pijuan et al., 2012) and therefore no nitrite was dosed to the reference reactors. It should also be pointed out that pH in the range of 5.0–6.0 does not affect the sludge biodegradability (Devlin et al., 2011) and thus pH in the reference reactors was not adjusted to 5.5.

2.3. Post aerobic digestion experiments

Post aerobic digestion experiments were performed to evaluate whether the ADS degradation in post aerobic digestion would be improved by FNA pretreatment. Five lab-scale post aerobic digestion reactors (R1–R5) were set up, with 1.2 L of digesting sludge being added to each reactor. 0.4 L of FNA-treated ADS was added to R1 and R2 (see Table 2), respectively, which were used as experimental reactors. Two sets of references were also set up (see Table 2). 0.4 L of ADS without FNA pretreatment was dosed to R3, which served as reference I. Reference II (i.e. R4) was identical to reference I except with the dosage of nitrite stock solution (50 g N/L), which led to an initial NO_2^-–N concentration of around 62.5 mg N/L. This was to make sure that the NO_2^-–N level in Reference II was similar to the highest nitrite level in the two experimental reactors, thereby evaluating the effect of nitrite on the performance of the post aerobic digestion reactor. 0.4 L of autoclaved supernatant from the centrifuged original ADS was added to R5, which was a blank. pH was maintained at 7.0 ± 0.3 during the post aerobic digestion time using 1 mol/L NaOH in all reactors. Dissolved oxygen (DO) concentration was kept at above 5 mg/L. Post aerobic digestion experiments sustained approximately 4 days. This was in accordance with the SRT that typically

Table 2
Experimental conditions applied in the post aerobic digestion tests.

Reactor	Experimental conditions
R1	1.2 L digesting sludge + 0.4 L FNA-treated ADS at 2.0 mg HNO_2–N/L
R2	1.2 L digesting sludge + 0.4 L FNA-treated ADS at 1.0 mg HNO_2–N/L
R3	1.2 L digesting sludge + 0.4 L untreated ADS
R4	1.2 L digesting sludge + 0.4 L untreated ADS+NO_2^- (62.5 mg N/L in R4)
R5	1.2 L digesting sludge+0.4 L supernatant from original ADS