Chemosphere 205 (2018) 484–492

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Free ammonia-based sludge treatment reduces sludge production in the wastewater treatment process

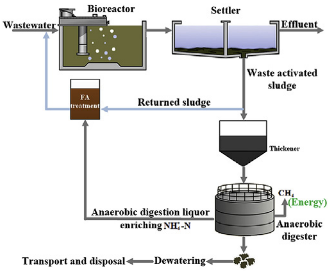
Guojing Yang [a, b, c], Qiuxiang Xu [a, b], Dongbo Wang [a, b, *], Li Tang [c], Jingfen Xia [c], Qilin Wang [d], Guangming Zeng [a, b], Qi Yang [a, b, **], Xiaoming Li [a, b]

[a] *College of Environmental Science and Engineering, Hunan University, Changsha 410082, PR China*
[b] *Key Laboratory of Environmental Biology and Pollution Control (Hunan University), Ministry of Education, Changsha 410082, PR China*
[c] *College of Biological and Environmental Sciences, Zhejiang Wanli University, Ningbo 315100, PR China*
[d] *Griffith School of Engineering & Centre for Clean Environment and Energy, Griffith University, QLD, Australia*

HIGHLIGHTS

- A new strategy was developed for sludge reduction from wastewater treatment process.
- The strategy was implemented through treating part of the sludge with FA.
- 16 mg N/L FA caused ~20% of sludge reduction in the experimental reactor.
- Reactor performance and sludge properties were not affected by FA treatment.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 20 February 2018
Received in revised form
14 April 2018
Accepted 21 April 2018
Available online 23 April 2018

Handling Editor: A Adalberto Noyola

Keywords:
Wastewater treatment plants
Sludge reduction
Biological nutrient removal
Free ammonia

ABSTRACT

Excessive sludge production is one of the major challenges for biological wastewater treatment plants. This paper reports a new strategy to enhance sludge reduction from the wastewater treatment process. In this strategy, 1/5 of the sludge is withdrawn from the mainstream reactor into a side-stream unit for sludge treatment with 16 mg/L free ammonia (FA) for 24–40 h. The FA-treated sludge mixture is then returned to the mainstream reactor. To demonstrate this concept, two reactors treating synthetic domestic wastewater were operated, with one serving as the experimental reactor and the other as the control. Experimental results showed that the experimental reactor exhibited 20% lower in sludge production than the control. FA treatment effectively disintegrated a portion of extracellular or intracellular substances of sludge cells in the FA treatment unit and lowered the observed sludge yields in the mainstream reactor, which were the main reasons for the sludge reduction. Although FA treatment decreased the activities of nitrifiers, denitrifiers, and polyphosphate accumulating organisms in the FA treatment unit, this strategy did not negatively affect the reactor performance and sludge properties of the experimental reactor such as sludge settleability, organic removal, nitrogen removal and phosphorus removal. Further investigation showed that the organics released from the FA treatment process could be used by PAOs and denitrifiers for carbon sources.

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* Corresponding author. College of Environmental Science and Engineering, Hunan University, Changsha 410082, PR China.
** Corresponding author. College of Environmental Science and Engineering, Hunan University, Changsha 410082, PR China.
E-mail addresses: w.dongbo@yahoo.com (D. Wang), yangqi@hnu.edu.cn (Q. Yang).

https://doi.org/10.1016/j.chemosphere.2018.04.140
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1. Introduction

Wastewater treatment plants (WWTPs) are extensively used for biological wastewater treatment to protect natural water bodies from pollution (Chen et al., 2016; Li et al., 2015; Wang et al., 2012a, 2012b; 2017a). Despite their effective in environmental protection, they are often upset by excessive sludge production (Li et al., 2016; Hu et al., 2018; Wang et al., 2017b, 2017c; 2018a). For instance, it was reported that ~34 million metric tons of sludge (~20% of solids) were produced in China in 2015 (Feng et al., 2015; Xu et al., 2017). The treatment and disposal of excessive sludge is costly, accounting for up to 60% of the total operational cost of a WWTP (Appels et al., 2008; Wang et al., 2013a; Zhao et al., 2017; Xu et al., 2018). To enhance sludge reduction, several sludge reduction technologies such as anaerobic fermentation and anaerobic digestion were successfully developed and extensively implemented in the sludge treatment line in the past decades (Li et al., 2011; Appels et al., 2008; Rittmann et al., 2008; Wang et al., 2015a, 2015b).

Reducing sludge production in the wastewater treatment process (i.e., sludge return line) also attracts much attention, because this method allows sludge reduction in the first place (i.e., source reduction) and decreases the costs of subsequent sludge management (Mahmood and Elliott, 2006; Wang et al., 2013b). Besides, sludge contains high levels of organic matters, thus the organics released from sludge reduction in the sludge return line are returned and reused in microbial metabolisms in the wastewater treatment process.

Several sludge treatment methods such as thermal, mechanical, and chemical treatments have been tested and implemented in the sludge return line to disrupt the extracellular polymeric substances and cell envelops (Saby et al., 2002; Dytczak et al., 2007; Wang et al., 2013b). Among them, free nitrous acid (FNA) based technology seems to be promising, as free nitrous acid is a waste-generated, renewable chemical that can be produced in situ in WWTPs by side-stream nitritation of the anaerobic digestion liquor (Law et al., 2015; Wang et al., 2016a, 2016b; 2017d). Wang et al. (2013b) treated 50% of the excess sludge with 2.0 mg/L FNA for 24–42 h, achieving a 28% reduction in sludge production. Compared with untreated sludge, the internal organics, denitrification efficiency, and sludge reduction were demonstrated to be increased by 50%, 76%, and 88%, respectively, in a simultaneous fermentation and denitrification reactor fed with sludge pretreated by FNA (2.04 mg/L) for 24 h (Ma et al., 2015). Despite its effective, this free nitrous acid based technology requires a side-stream nitritation reactor implemented in WWTPs to produce free nitrous acid. Unfortunately, the side-stream nitritation reactor is generally non-existed in most of the current WWTPs.

Free ammonia (FA), the unionized form of ammonium (i.e., NH_3), can be obtained up to ~500 mg NH_3-N/L directly from anaerobic digester effluent, which usually contains 1.0–2.0 g NH_4^+-N/L at a pH of 7.5–8.6 and 33 °C (Cervantes, 2009; Fux et al., 2006). Recently, Wei et al. (2017a) found that the sludge biodegradability was enhanced after FA treatment at 420–680 mg NH_3-N/L for 24 h. Based on the findings, it is assumed that sludge reduction might be also achieved using sludge treatment by FA through incorporating a FA treatment unit in the sludge return line to treat part of the return sludge. Unlike free nitrous acid based technology, this FA method does not require the side-stream nitritation reactor, which thereby has significant benefits in real-word applications. To date, however, this hypothesis has never been tested.

The aim of this work is to evaluate whether this FA-based technology can reduce sludge production and to assess whether this strategy affect the performance of wastewater treatment. Two bench scale anaerobic-low dissolved oxygen (DO) sequencing batch reactors receiving synthetic domestic wastewater were operated to demonstrate the feasibilities. One was carried out as the control, and the other included a side-stream FA treatment unit was performed as the experimental reactor. When the experimental reactor achieved in stable operation, FA treatment was implemented through treating 1/5 of the sludge with 16 mg/L FA for 24–40 h. After steady-state operation, sludge reduction between the two reactors was first assessed and compared. Then, details of how FA-based sludge treatment enhances sludge reduction were explored. Finally, the potential impact of FA treatment on the performance of wastewater treatment (e.g., sludge settleability, organic carbon removal and nutrient removal) was also assessed.

2. Materials and methods

2.1. The composition of synthetic wastewater

The synthetic wastewater was used in this study. The synthetic wastewater, unless otherwise described, contained 320 mg CH_3COONa/L, 136 mg NH_4Cl/L, and 22 mg KH_2PO_4/L yielding an influent chemical oxygen demand (COD), NH_4^+–N, and PO_4^{3-}-P of approximately 250, 35, and 5 mg/L, respectively. These values are close to those measured in the real wastewaters in Central South, China. The concentrations of other nutrients in the synthetic wastewater were prepared as below (per liter): 0.01 g $MgSO_4 \cdot 7H_2O$, 0.005 g $CaCl_2$, and 0.5 mL of a trace metal solution. The trace metal solution was detailed in our previous publication (Wang et al., 2008).

2.2. The operations of the control and experimental reactors

Two replicate sequencing batch reactors with a working volume of 10 L each were operated and maintained at 25 ± 1 °C in a temperature controlled room. One reactor was set as the control while the other was selected as the experimental reactor to examine sludge reduction and nutrient removal by introducing an FA treatment unit (Fig. 1). Both the reactors were carried out with three cycles daily. Each 8 h cycle of the control reactor (or the experimental reactor) consisted of approximately 120 min anaerobic and 180 min low DO (0.2–0.5 mg/L) periods, followed by 55 min settling, 5 min decanting, and 120 min idle periods. Waste activated sludge, which was withdrawn from the secondary sedimentation tank of a municipal wastewater treatment plant in Changsha, China, was used as the inocula for both two systems.

In the decanting period, 6 L of the supernatant was discharged from both reactors and replaced with 6 L of the synthetic wastewater in the initial 10 min of the anaerobic period. In the low DO period, air was intermittently supplied into the two reactors through using on/off control systems with online DO detectors to maintain the DO level between 0.2 and 0.5 mg/L. The reactors were constantly mixed with magnetic stirrers except for the settling, decanting, and idle periods. The hydraulic retention time (HRT) and sludge retention time (SRT) in both reactors were the same and maintained at approximately 13.3 h and 20 d, respectively. The two reactors were operated for about 5 months, which were divided into two phases:

Phase I (Baseline phase: Day 0–50): In Phase I, FA treatment was not implemented in the experimental reactor. The two reactors were operated the same regime as described above for about 50 d to achieve steady state. SRT in both reactors were maintained at 20 d.

Phase II (Experimental phase: Day 51–150): The control reactor in Phase II was operated the same as in Phase I. Sludge treatment by FA was implemented in the experimental reactor. Approximately 2 L sludge mixture was daily withdrawn from the experimental reactor at the end of the aerobic period and thickened to 400 mL by