Bioresource Technology 139 (2013) 375–378

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

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

Short Communication

Achieving nitritation and phosphorus removal in a continuous-flow anaerobic/oxic reactor through bio-augmentation

Bin Ma [a], Shuying Wang [a,*], Shujun Zhang [b], Xiyao Li [a], Peng Bao [a], Yongzhen Peng [a]

[a] Key Laboratory of Beijing for Water Quality Science and Water Environment Recovery Engineering, Beijing University of Technology, Beijing 100124, China
[b] Beijing Drainage Group Co. Ltd., Beijing 100022, China

HIGHLIGHTS

- ▶ Nitritation/anammox is thought to make sewage treatment energy-neutral.
- ▶ Nitritation is the key for successful anammox in sewage treatment.
- ▶ Nitritation could be quickly start-up, and reconstructed by using bio-augmentation and controlling DO at below 0.96 mg/L.
- ▶ Phosphorus could be removed biologically by 96.43% when nitrite accumulation rate was above 78.60%.
- ▶ Sludge settleablity was good even under high nitrite accumulation rate.

ARTICLE INFO

Article history:
Received 20 December 2012
Received in revised form 18 February 2013
Accepted 20 February 2013
Available online 1 March 2013

Keywords:
Bio-augmentation
Sewage
Nitritation
Biological phosphorus removal
Continuous flow anaerobic/oxic (A/O) reactor

ABSTRACT

The feasibility of achieving nitritation and phosphorus removal using bio-augmentation was investigated in a continuous-flow anaerobic/oxic (A/O) reactor treating sewage. The results indicated that nitritation could be quickly start-up, and reconstructed with an increase in the nitrite accumulation rate (NAR) from 1% to 89% within 15 days by using bio-augmentation and controlling DO at 0.96 mg/L. Biological phosphorus removal could be achieved with the average phosphorus removal efficiency of 96.43% when the NAR was maintained above 78.60%. Meanwhile, sludge settleablity was good with a sludge volume index (SVI) of between 62 and 102 mL/g even under high NAR. After nitritation and biological phosphorus removal were achieved, this A/O reactor has the potential to supply appropriate influent for the anammox UASB reactor.

1. Introduction

Nitrogen removal from sewage is very important for controlling eutrophication. Currently in wastewater treatment plants (WWTPs) nitrification/denitrification is widely used to remove nitrogen from sewage. Recently, nitritation/anammox was thought to be a promising process for making wastewater treatment energy-neutral or even energy-generating, since this technology could reduce the consumption of oxygen and the organic carbon source (Kartal et al., 2010). Nitritation, a key step in this process, was achieved by eliminating or inhibiting nitrite oxidizing bacteria (NOB) and retaining ammonium oxidizing bacteria (AOB). For the treatment of sewage, nitritation is mainly performed in sequencing batch reactors (SBR) (Peng et al., 2004), and has rarely been achieved in continuous-flow reactors which are employed worldwide in WWTPs.

The combination of low DO levels (0.3–0.7 mg/L) and controlled sludge retention time (SRT) were found to be a suitable method to establish nitritation in a continuous-flow reactor treating sewage (Ma et al., 2009; Zeng et al., 2010). However, a low DO level would lead to a long start-up time (approximate 2 months) and be vulnerable to fluctuations (Ma et al., 2009). Therefore, it would be very beneficial to develop solutions that result in stable and robust nitritation in continuous-flow reactors treating sewage.

It has been reported that bio-augmentation can be used to quickly startup nitritation of sewage (Ma et al., 2011; Zhang et al., 2012). However, in these two studies, nitritation was still maintained by controlling DO at a low level (below 0.2 mg/L) (Ma et al., 2011), where nitritation sludge containing more AOB than NOB was only added to sewage treatment systems at the beginning of the study. In sewage treatment plants, nitritation could be achieved easily in the reject water treatment system

* Corresponding author. Tel./fax: +86 10 67392627.
E-mail addresses: mady7802@163.com (B. Ma), wsy@bjut.edu.cn (S. Wang).

0960-8524/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.biortech.2013.02.077

(Fux et al., 2003; Zhang et al., 2011), where nitritation sludge is discharged every day due to excess sludge. So to enhance the nitritation performance the excess nitritation sludge could be added each day into sewage treatment system. At the same time, this strategy could reduce the minimum SRT of the sewage treatment system (Salem et al., 2003), so biological phosphorus removal may also be achieved as the SRT was low.

This work aims to study (1) if nitritation could be achieved and maintained in a continuous-flow anaerobic/oxic (A/O) reactor through the adding of nitritation sludge every day. And if it needs to control DO level? (2) If biological phosphorus removal could be achieved in this continuous-flow reactor when nitritation was maintained.

2. Methods

2.1. Experiment setup

A lab-scale A/O reactor was used in this study. This reactor has 24 L working volume that is divided into six equal chambers. The first chamber represents the anaerobic zone of the reactor and the next five chambers were supplied with compressed air to provide oxic conditions. The temperature in the A/O reactor was controlled at 26 ± 1 °C with a thermostatic heater. The influent flow rate was controlled by a peristaltic pump.

This reactor was investigated for 110 days divided into four successive phases (Table 1). The apparent SRT was calculated by the following equation:

$$\text{Apparent SRT} = V_r \times X_r/(Q_w \times X_w + Q_e \times X_e - V_a \times X_a) \tag{1}$$

where V_r is reactor volume, X_r is mixed liquor suspended solids (MLSS) in reactor, Q_w is the flow rate of excess sludge, X_w is the MLSS concentration of excess sludge, Q_e is effluent flow rate, X_e is the suspended solids (SS) concentration in the effluent, V_a is the volume of the nitritation sludge added per day, and X_a is the MLSS concentration of the added nitritation sludge.

2.2. Wastewater and sludge

The sewage taken from the primary clarifier of the Beijing Gaobeidian WWTP was used to feed the A/O reactor. The characteristics of the sewage were as follows: soluble chemical oxygen demand ($COD_{soluble}$) = 121.50 ± 21.68 mg/L (Sample No.: 40), NH_4^+–N = 41.61 ± 5.40 mg/L (Sample No.: 46), NO_2^-–N = 0.14 ± 0.25 mg/L (Sample No.: 46), NO_3^-–N = 0.68 ± 0.31 mg/L (Sample No.: 46) and PO_4^{3-}–P = 4.00 ± 1.31 mg/L (Sample No.: 8). The seed sludge of the A/O reactor was all obtained from an anoxic/oxic nitritation reactor that treated ammonium-rich wastewater. Nitrite accumulation rate (NAR) was above 95% in this anoxic/oxic nitritation reactor. The properties of this nitritation sludge were as follows: MLSS = 5268.43 ± 656.26 mg/L, SVI = 111.20 ± 12.43 mL/g, SCOD = 56.63 ± 11.96 mg/L. During the phase I, III and IV of this study, nitritation sludge was added daily. The quantity of nitritation activated sludge added to the A/O reactor was controlled by adjusting the adding rate of nitritation sludge (ARN), which was the ratio of the nitritation activated sludge added daily to the total activated sludge in the A/O reactor. The ARN was shown in Table 1.

2.3. Analysis methods

All the samples were filtered with a 0.45 μm filter before analyzing. $COD_{soluble}$, NH_4^+–N, NO_2^-–N, NO_3^-–N and PO_4^{3-}–P were measured according to standard methods (APHA, 1998). The COD was corrected due to nitrite exerting a COD of 1.1 gCOD/g NO_2^-–N. DO, pH and temperature were measured by an oxygen, pH and temperature meter (WTW 340i, WTW Company).

3. Results and discussion

3.1. Achieving nitritation in A/O reactor treating sewage using bio-augmentation

The nitrogen concentrations and NAR of the A/O reactor are shown in Fig. 1 and Table S1. Due to the addition of nitritation sludge at the start, by the second day NAR had reached to 96%. Nitritation sludge obtained from the lab-scale anoxic/oxic nitritation reactor contained more AOB (1.79×10^{10} copies/g MLSS) than NOB (1.34×10^7 copies/g MLSS). At the same time, the DO concentration in the aerobic chambers was controlled at a low level with an average DO concentration of 0.64 mg/L. ARN was controlled at approximately 6.5%. Under the above condition, NAR was maintained above 94% for the whole of stage I.

In phase II, the addition of nitritation sludge and DO control were stopped. This resulted in the deterioration of nitritation with a decrease of NAR from 95% to 11%. During this phase, the average DO concentration increased to 1.34 mg/L. In order to reconstruct nitritation, nitritation sludge was added with the ARN of 6.0% in phase III. The DO concentration was not controlled and the average DO concentration reached 1.55 mg/L. However, nitritation was not reconstructed with the NAR below 30%. In phase IV, aeration was controlled, and the average DO concentration decreased to 0.96 mg/L. After 15 days, nitritation was reconstructed with an increase in NAR from 1% to 89%. At the end of this phase, NAR had reached 94%.

A high ratio of AOB to NOB is a key for achieving nitritation. Bio-augmentation, adding nitritation sludge containing more AOB (1.79×10^{10} copies/g MLSS) than NOB (1.34×10^7 copies/g MLSS), can promote an increase in the ratio of AOB to NOB. Under low DO concentration levels (0.64 mg/L), nitritation could be quickly started up and maintained by using a bio-augmentation strategy (phase I). However, when the DO concentration was at a high level (1.34 mg/L) in phase III, bio-augmentation failed to reconstruct nitritation. This was attributed to the growth rate of NOB being higher than that of AOB under the high DO concentration levels (Bae et al., 2001; Ma et al., 2009). In phase III, the average DO of five aerobic chambers were as follows: 0.72 mg/L, 1.05 mg/L, 1.63 mg/L, 1.91 mg/L and 2.41 mg/L. The DO concentrations of last three

Table 1
Experimental plan and operational conditions of the anaerobic/oxic (A/O) reactor.

Phase	Time (day)	ARN (%)	[a]DO (mg/)	Flow rate (L/d)	HRT (h)	[b]SRT (day)
I	0–20	6.5	0.64	140	4.11	6.0
II	21–40	0.0	1.34	140	4.11	12.0
III	41–60	6.0	1.55	140	4.11	6.0
IV	61–110	5.6	0.96	184	3.13	4.5

[a] DO is the average DO of all oxic chambers.
[b] SRT is apparent SRT.