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The nitritation performance of biofilm reactor for treating domestic wastewater under high dissolved oxygen

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ABSTRACT

The objective of this study was to investigate the nitritation performance in a biofilm reactor for treating domestic wastewater. The reactor was operated in continuous feed mode from phases 1 to 3. The dissolved oxygen (DO) was controlled at 3.5–7 mg/L throughout the experiment. The biofilm reactor showed excellent nitritation performance after the inoculation of nitrifying sludge, with the hydraulic retention time being reduced from 24 to 7 hr. Above 90% nitrite accumulation ratio (NAR) was maintained in phase 1. Afterwards, nitratation occurred with the low NH_4^+–N concentration in the reactor. The improvement of NH_4^+–N concentration to 20–35 mg/L had a limited effect on the recovery of nitritation. However, nitritation recovered rapidly when sequencing batch feed mode was adopted in phase 4, with the effluent NH_4^+–N concentration above 7 mg/L. The improvement of ammonia oxidizing bacteria (AOB) activity and the combined inhibition effect of free ammonia (FA) and free nitrous acid (FNA) on the nitrite oxidizing bacteria (NOB) were two key factors for the rapid recovery of nitritation. Sludge activity was obtained in batch tests. The results of batch tests had a good relationship with the long term operation performance of the biofilm reactor.

Introduction

Wastewater that contains a large amount of ammonium will cause a serious eutrophication problem for the receiving water. Biological nitrification–denitrification is commonly used to remove the nitrogen from wastewater. However, these practices usually lead to the need for a large volume reactor and high operating costs. Partial nitritation/anammox (PNA) installations were already successfully operated worldwide in side-stream treatment to reduce aeration energy for nitrogen removal (Gut et al., 2006; Zekker et al., 2013; Lackner et al., 2014). The research focus has now moved to possible applications of PNA in mainstream treatment. Current research suggests that anammox could be achieved at low temperature (about 20°C) and that the biofilm reactor was efficient in the cultivation of anammox bacteria (Zekker et al., 2012b, 2015a; Gilbert et al., 2014). Some measures for the recovery of anammox under adverse conditions were also reported (Jin et al., 2013; Bi et al., 2014; Zekker et al., 2015b). Nevertheless, it is still difficult to achieve nitritation in mainstream wastewater due to the low temperature and low nitrogen concentration. Therefore, it is necessary to investigate the feasibility of partial nitrification measures for treating sewage.

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Nitritation has been achieved by controlling several operational factors, such as low dissolved oxygen (DO) (Blackburne et al., 2008a), high pH (Villaverde et al., 1997), high temperature (Hellinga et al., 1998), and heavy free ammonia (FA) and free nitrous acid (FNA) concentrations (Anthonisen et al., 1976; Vadivelu et al., 2007; Park and Bae, 2009). For low-strength, municipal or domestic wastewater, almost all experiments have been conducted in sequencing batch reactors (SBRs) with an activated sludge system (Blackburne et al., 2008b; Yin et al., 2014). On the other hand, it would be a feasible option to achieve nitritation with low DO. The oxygen saturation coefficients of ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB) are known to be 0.3 and 1.1 mg/L, respectively (Wiesmann, 1994). When oxygen is limiting, AOB were suggested to outcompete NOB (Bernet et al., 2001; Blackburne et al., 2008a). Tokutomi (2004) observed that the growth rate of AOB was 2.6 times faster than that of NOB when the DO was below 1.0 mg/L. However, it was also reported that NOB could be outcompeted at high DO bulk concentrations, since the oxygen supply to the biofilm could be reduced by a thick external boundary layer (Antileo et al., 2007; Brockmann and Morgenroth, 2010; Rathnayake et al., 2013; Zekker et al., 2014). So far, there is little information about the nitritation performance of biofilm reactors for treating domestic wastewater.

It was reported that an alternating aeration strategy was effective in achieving nitritation (Kornaros et al., 2010; Ge et al., 2014). Kornaros et al. (2010) reported that AOB were not affected by anoxic disturbance, while the NOB were seriously inhibited, with a reduced growth rate. Ge et al. (2014) pointed out that NOB adjusted more slowly than AOB to aerobic conditions after anoxic periods. Slow-growing organisms are suggested to grow in the inner part of the biofilm, whereas faster growing organisms are towards to the outer part of the biofilm (Brockmann and Morgenroth, 2010; Rikmann et al., 2012; Zekker et al., 2012a). Moreover, reports have shown that the growth rate of AOB was higher than that of NOB at temperatures above 25°C (Hellinga et al., 1998). Hence, it should be feasible to achieve nitritation rapidly in a biofilm reactor at high temperature.

Based on the above discussion, the aim of the present study was to investigate the nitritation performance in a biofilm reactor. For this purpose, the fast achievement of excellent nitritation performance and the effect of ammonium concentration on the nitritation performance were investigated. Additionally, the effect of the sequencing batch feed mode on the recovery performance of nitritation was also investigated. It is expected that the knowledge obtained in this study will be critical for developing a novel nitritation process and lay the foundation for the application of PNA in mainstream autotrophic nitrogen removal processes.

1. Materials and methods

1.1. Reactor and experimental setup

Fig. 1 shows the reactor configuration scheme of the experimental set-up. A biofilm reactor with a working volume of 89.5 L was used. Dimensions of the unit were: a height of 79 cm and inner diameter of 38 cm. Kaldnes rings (K3 carriers, AnoxKaldnes, Beijing) were used as biomass carriers. The volume of the carriers was 38% of the working volume of the reactor. The carriers had a cylindrical shape (diameter of 25 mm) with a grid of 4 mm. Fig. 6 shows a picture of the carriers. The temperature was controlled at 30°C by three heating rods immersed in the reactor (GM1616, Jiyin, China). No pH adjustment was adopted. The air was supplied by an air diffuser with a constant rate of 500 L/hr at the bottom of the reactor. A programmable logic controller (PCL-812, Advantech, USA) was installed to perform automatic process control. The DO and pH were detected by online instruments.

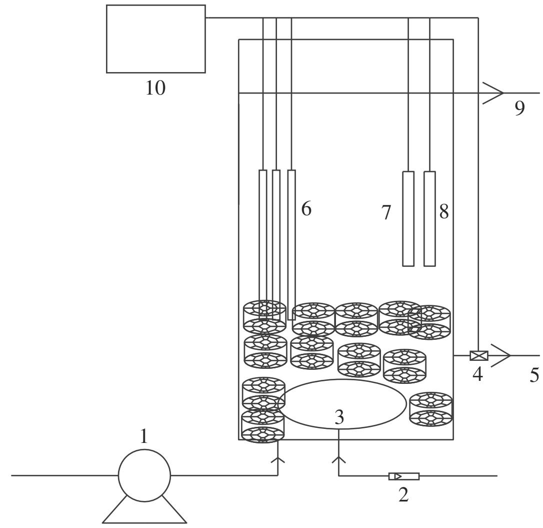

Fig. 1 – Reactor configuration scheme of biofilm reactor. (1) Influent pump; (2) air flowmeter; (3) air diffuser; (4) electromagnetic valve; (5) effluent of sequencing fed batch mode; (6) heating rod; (7) pH electrode; (8) dissolved oxygen (DO) electrode; (9) effluent of continuous fed mode; (10) programmable logic controller (PLC).

1.2. Wastewater and operational conditions

The reactor was operated in four phases. During phases 1 to 3, the reactor was operated in continuous feed mode. The influent was pumped into the bottom and the effluent was discharged at the top of the reactor. In phase 1 (days 1 to 33), the hydraulic retention time (HRT) was shortened from 24 to 7 hr. The HRT in phase 2 (days 34 to 52) and phase 3 (days 53 to 76) was maintained at 7 and 4.6 hr, respectively. In phase 4 (days 77 to 95), the reactor was operated in sequencing batch feed mode with a volume exchange ratio (VER) of 81%. Each cycle contained: feeding (3 min), aerobic reaction (180 min), settling (10 min), decanting (10 min), and idling (1 min). During phase 4, the floc sludge would be withdrawn from the reactor with the effluent since the settling time was 10 min and the VER was 81%. No additional sludge was discharged from the biofilm reactor.

The seeding sludge was obtained from an original SBR in our lab with excellent nitritation performance. The mixed liquor suspended solids (MLSS) and the volume of the seeding sludge were 8000 mg/L and 7 L, respectively. The aerobic NH_4^+–N and NO_2^-–N oxidation activities of the seeding sludge were 0.135 and 0.001 g N/(g VSS · day), respectively (Appendix A Fig. S1). As for