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Aerobic N₂O emission for activated sludge acclimated under different aeration rates in the multiple anoxic and aerobic process

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ABSTRACT

Nitrous oxide (N₂O) is a potent greenhouse gas that can be emitted during biological nitrogen removal. N₂O emission was examined in a multiple anoxic and aerobic process at the aeration rates of 600 mL/min sequencing batch reactor (SBR_L) and 1200 mL/min (SBR_H). The nitrogen removal percentage was 89% in SBR_L and 71% in SBR_H, respectively. N₂O emission mainly occurred during the aerobic phase, and the N₂O emission factor was 10.1% in SBR_L and 2.3% in SBR_H, respectively. In all batch experiments, the N₂O emission potential was high in SBR_L compared with SBR_H. In SBR_L, with increasing aeration rates, the N₂O emission factor decreased during nitrification, while it increased during denitrification and simultaneous nitrification and denitrification (SND). By contrast, in SBR_H the N₂O emission factor during nitrification, denitrification and SND was relatively low and changed little with increasing aeration rates. The microbial competition affected the N₂O emission during biological nitrogen removal.

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Introduction

Biological nitrogen removal has been applied widely to remove nitrogen from wastewater to protect water bodies from eutrophication. In conventional biological nitrogen removal processes, ammonia is oxidized to nitrite and nitrate under aerobic conditions, and then nitrate is reduced sequentially to nitrite, nitric oxide, nitrous oxide (N₂O) and dinitrogen (N₂) under anoxic conditions with organic carbon as the electron donor. Pre-denitrification is usually applied in conventional biological nitrogen removal processes. Therefore, the nitrogen removal efficiency is mainly dependent on the ratio of recycling nitrified mixed liquor from the aerobic reactor to the anoxic reactor and the influent organic carbon to nitrogen ratio. In

particular, the nitrogen removal percentage is relatively low for wastewater with limited organic carbon sources. Therefore, some new processes, such as partial nitrification/denitrification and anaerobic ammonia oxidation, have been developed and applied (Hellenga et al., 1998). Among these processes, the multiple anoxic/aerobic (AO) or intermittently aerated process, as a new enhanced nitrogen removal process, has also been examined for the treatment of various types of wastewater, such as domestic wastewater, pig slurry and slaughterhouse wastewater (Beline and Martinez, 2002; Zeng et al., 2003; Pan et al., 2015). The conventional AO process is modified to the multiple AO process through intermittent aeration in time (for a single reaction tank) or in space (for multiple reaction tanks). With alternative anoxic and aerobic conditions applied in the

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multiple AO process, energy can be saved by removing the recycling of mixed liquid from the aerobic phase to the anoxic phase. In addition, when switching from the anoxic to the aerobic phase, the recovery of nitrite oxidizing bacteria (NOB) activity lags behind that of ammonia oxidizing bacteria (AOB), which may induce partial nitrification and denitrification and eventually improve the nitrogen removal efficiency (Kornaros et al., 2010; Zhang et al., 2011).

During biological nitrogen removal, the greenhouse gas N_2O may be produced and emitted. The global warming potential of N_2O is about 300 times that of carbon dioxide (CO_2); N_2O can last about 114 years in the atmosphere and is one of the most important substances depleting the ozone layer in the 21st century (Ravishankara et al., 2009). The main processes contributing to N_2O emission during biological nitrogen removal include nitrifier denitrification and hydroxylamine oxidation by AOB under aerobic conditions, and heterotrophic denitrification by denitrifiers under anoxic conditions (Kampschreur et al., 2009; Wunderlin et al., 2012). In the multiple AO biological nitrogen removal process, intermittent aeration may enhance N_2O emission, which would limit its sustainable application. De Mello et al. (2013) found that in a full-scale intermittently aerated urban wastewater treatment plant (WWTP), the N_2O emission factor was 0.10% to the influent total nitrogen and N_2O emission mainly occurred through air stripping under aeration conditions. By using the intermittently aerated system, Zhang et al. (2012) found that the N_2O emission factor to the total nitrogen removed was 15.6% when treating effluent from anaerobically digested pig manure and 10.1% when treating synthetic wastewater, showing the highest N_2O emission potential of the system; aerobic emission was the major source and contributed to 92% of the total N_2O emission. Therefore, most studies have demonstrated that in intermittently aerated systems, N_2O is mainly emitted under aerobic conditions. In addition, dissolved oxygen (DO), nitrite and the ratio of anoxic/aerobic phase are also important factors influencing N_2O emission in intermittently aerated processes. Zhang et al. (2006) investigated swine manure treatment by a two-step fed sequencing batch reactor (SBR) and found that N_2O was mainly emitted during the secondary feeding and anoxic/aerobic phases, in which the accumulation of nitrite and low concentration of DO and carbon sources enhanced N_2O emission from both nitrification and denitrification. Kong et al. (2013) investigated the N_2O emission in an intermittently aerated sequencing batch biofilm reactor with a controlled DO concentration of 1.5 mg/L, and the results showed that partial nitrification occurred in the system and 1.5% of the influent nitrogen was emitted as N_2O . Zeng et al. (2003) adopted a low DO (0.5 mg/L) intermittently aerated system to achieve simultaneous nitrogen and phosphorus removal, and discovered that the end product of denitrification was N_2O instead of N_2 . Jia et al. (2012) achieved simultaneous nitrification and denitrification (SND) successfully through low DO intermittent aeration, and the N_2O emission in the SND process was almost four times higher than that of the sequential nitrification and denitrification process with continuous aeration. Therefore, it is also necessary to examine the effect of aeration rate on aerobic N_2O emissions from different pathways in the multiple AO process.

Nutrient removal from wastewater derives from functions of various microbial communities. The interaction of different microbial communities not only affects the performance of nutrient removal, but also the N_2O emission during biological nitrogen removal. Shen et al. (2015) found that heterotrophic activity had a significant effect on N_2O emission in a biological nitrogen removal process, and high heterotrophic activity induced a high N_2O emission during nitrification. Park et al. (2000) examined N_2O emission in two intermittently aerated (aeration on/off of 60 min/30 min) reactors with and without biofilm, and the results showed that the N_2O emission factor to the influent total nitrogen was 4.57% in the suspension reactor and 3% in the biofilm reactor. Moreover, addition of sufficient methanol for denitrification could reduce the N_2O emission factor to less than 0.2%; since the cooperation among microbial communities reduced the emission of N_2O , and a biofilm consisting of different microbial communities is beneficial for the control of N_2O emission (Park et al., 2000). Therefore, it is important to investigate N_2O production and emission mechanisms during biological nitrogen removal process from the viewpoint of microbial ecology (competition or synergism), and by this means, effective strategies for mitigating N_2O emission may be brought forward. However, to date, only a few related studies have been carried out in this field.

In this study, characteristics of N_2O emission from multiple AO SBRs under different aeration rates were investigated through simulated reaction cycle and batch experiments for nitrification, denitrification and SND. The aerobic N_2O emission was analyzed from the viewpoint of microbial ecology, so as to provide guidelines for the mitigation of N_2O emission during biological nitrogen removal from wastewater.

1. Materials and methods

1.1. SBRs

Two parallel 6-L SBRs were operated under aeration rates of 600 mL/min (SBR_L) and 2400 mL/min (SBR_H), respectively. Both SBRs included four reaction cycles per day and each reaction cycle consisted of 120 min anaerobic phase (including 10 min filling), 120 min intermittent aeration (aeration on/off of 30 min/30 min), 60 min extended aeration and 60 min of settlement, decanting and idle phases. The reactors were inoculated with activated sludge taken from a WWTP in Shenzhen, China. Once a day, 0.4 L of mixed liquor from both reactors was discharged just before the settlement phase, resulting in a sludge retention time (SRT) of 15 days. In each reaction cycle, 3 L of treated supernatant (in the sludge removal reaction cycle of 2.6 L) was discharged and 3 L of synthetic wastewater was pumped into the reactor by peristaltic pumps, resulting in a hydraulic retention time (HRT) of 12 hr. The reactors were mixed by mechanical stirrers except during the phases of settlement, decanting and idle. During the aerobic phase, aeration was achieved by micro-pore stones placed at the bottom of the reactors. The filling, withdrawal, aeration and mixing of the reactors were controlled by timers. Temperature inside the reactors was controlled at 25°C.

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