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Profile of organic carbon and nitrogen removal by a continuous flowing conventional activated sludge reactor with pulse aeration

Bao-Cang Han[a,b], Wei-Li Jiang[b], Yong Zhang[a,b,c,d,*], Wei Wei[a,e], Jiao Chen[a]

[a] School of Environment, Nanjing Normal University, Nanjing 210023, China
[b] Jiangsu Provincial Key Laboratory of Environmental Engineering, Nanjing 210000, China
[c] Jiangsu Center for Collaborative Innovation in Geographical Information Resource Development and Application, Nanjing 210023, China
[d] Key Laboratory of Virtual Geographic Environment (Nanjing Normal University), Ministry of Education, Nanjing 210023, China
[e] State Key Laboratory Cultivation Base of Geographical Environment Evolution (Jiangsu Province), Nanjing 210023, China

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ABSTRACT

This study aimed to investigate the effect of pulse aeration (on/off time 5/10 min) on the pollutants removal efficiencies and on the evolution of the denitrifying bacteria communities of a continuous flowing completely mixed activated sludge reactor. Organic matters and nitrogen removal were evaluated and the denitrifying bacteria community structure was analyzed by MiSeq sequencing technology. Results showed that the TOC removal rates were steadily above 81.6% and the NH_4^+-N removal rates were 92.1% ± 0.5% when the pulse aerated activated sludge reactor was operated with the optimized pulse aeration cycle (PAC) of 5/10 min. There was no significant impact on both TOC and NH_4^+-N removal efficiencies, while the average TN removal rate of the pulse aerated reactor (58.4%) was significantly higher than that of the constantly aerated one (30.6%). The removal efficiencies of both organics and nitrogen were stable during the 60-day acclimation period regardless of the changing DO concentration fluctuated in pulse mode. Although the denitrifier bacterial compositions varied between the pulse aerated group and the constantly aerated group, the denitrifier community richness and diversity were similar. Boost of the TN removal was mainly due to the anoxic denitrifying environment provided by the non-aerated phase in each PAC.

1. Introduction

It is widely recognized that nitrogen in wastewater has become one of the major pollutants in water resources. For wastewater nitrogen removal, the most economic method is the biological treatment via activated sludge or biofilm systems (Yuan et al., 2000). Conventional activated sludge (CAS) systems operating in stable aerobic conditions have met with the requirement of organic matter degradation and nitrification. However, the denitrification process is always not ideal due to the high DO concentration environment where denitrifying bacteria would shift their electron accepter from nitrate or nitrite to oxygen (Guadie et al., 2014). Typical nitrogen removal systems, such as A/O nitrogen removal technology, accomplished nitrogen removal by aerobic nitrification step followed with anaerobic denitrification process. The disadvantages of these systems include intensive energy consumption for recirculation, more space demanding, and massive sludge generation, etc. (Bagchi et al., 2012). In recent years, simultaneous nitrification and denitrification (SND) process, which could combine both processes in one reactor, has been studied extensively (Fu et al., 2009). SND could be achieved in several bioreactors, e.g. biofilm reactor (Zhang et al., 2007), membrane bioreactor (MBR) (Arabi and Nakhla, 2009), sequencing batch reactors (SBR) (Guo et al., 2016), biological treatment with intermittent aeration (Sun et al., 2017), etc.

Compared with A/O nitrogen removal process, intermittent aeration achieved aerobic nitrification and anoxic denitrification sequentially by aeration on/off instead of water flow between reactors, thus a large amount of energy consumption for both aeration and recirculation could be saved, which led to a significant reduction of the operational cost (Lim et al., 2012; Lee et al., 2015;). The intermittent aeration has been demonstrated to have significant advantages for constructing alternative aerobic/anoxic conditions to achieve nitrification/denitrification successfully (Lindgerg and Carlsson, 1996), and it has been reported to be applied in con-

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* Corresponding author at: School of Environment, Nanjing Normal University, 1 Wenyuan Road, Nanjing 210023, China.
E-mail address: zy@njnu.edu.cn (Y. Zhang).

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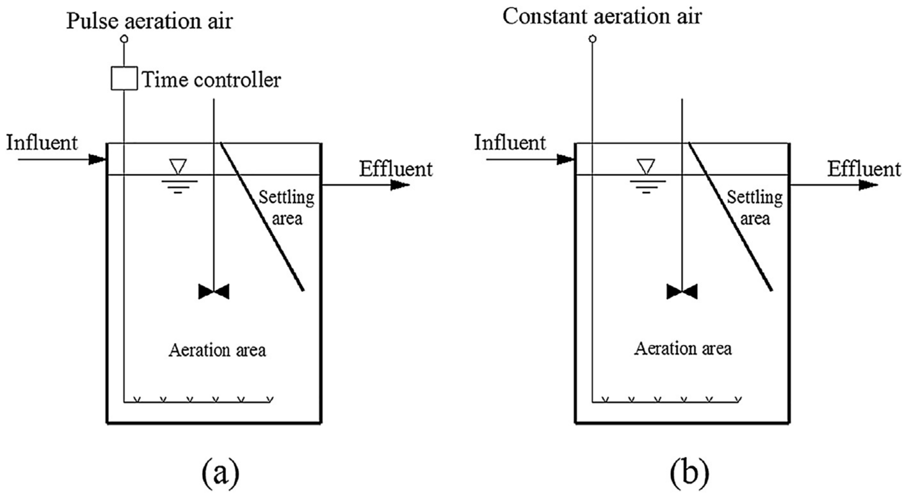

Fig. 1. Schematic diagram of the pulse aeration reactor (a) and the control reactor (b).

structed wetland (Uggetti et al., 2016), fixed bed reactor (Moura et al., 2012), moving bed biofilm reactor (Yang et al., 2015), subsurface wastewater infiltration systems (Pan et al., 2016), SBR (Li et al., 2013; Liang et al., 2014) and MBR (Guadie et al., 2014; Guglielmi and Andreottola, 2011; Lim et al., 2007), etc. The reported length of aerobic-anoxic phase varied widely according to the periodic duration of the on/off aeration times, mainly distributing between 30 min and 2 h (Guadie et al., 2014; Capodici et al., 2015; Pan et al., 2016), thus a continuous stirring was needed to prevent sludge precipitation during the anoxic period in the intermittently aerated reactors. Recently, some researchers attempted to shorten the intermittent cycle to a considerable high frequency, e. g., pulse aeration. Shao et al. (2015) found that the COD removal efficiency was barely reduced when the aeration on/off time was reduced to 1 min/4 min. Wang et al. (2016) even observed a simultaneous partial nitrification, ANAMMOX and denitrification (SNAD) process in a membrane bioreactor with pulse aeration of 1 min/(2.5–3.1) min on/off time. Besides, the most extensively reported reactors with intermittent aeration were SBR and MBR (Lim et al., 2007; Li et al., 2013; Liang et al., 2014; Guadie et al., 2014;). When regarding the traditional continuous flowing CAS, it was still widely used in municipal wastewater treatment plants (WWTPs) facing increasingly stringent demands of decreasing energy consumption mostly attributed to the aeration system (Lee et al., 2015). Nevertheless, the stability of effluent quality and the nitrogen removal profile of the traditional continuous flowing CAS with pulse aeration were still rarely reported.

The community of denitrifying and nitrifying bacteria, which played a key role in biological nitrogen removal, was also much sensitive to fluctuations in dissolved oxygen (Kim et al., 2015). Lim et al. (2007) found that the specific denitrification rate would increase when the on/off aeration time was changed from 60 min/60 min to 40 min/80 min. Guadie et al. (2014) also demonstrated that different intermittent aeration cycles led to shifts of microbial communities in activated sludge. However, the community dynamics of denitrifiers in activated sludge with pulse aeration still need to be further probed into.

The objective of this study was to investigate the pollutants removal efficiencies and the denitrifying bacteria community of a continuous flowing completely mixed activated sludge with pulse aeration system. Activated sludge was acclimated in a bench-scale continuous flowing reactor with pulse aeration for 60 days. Simultaneously, another identical reactor was operated with constant aeration system as control reactor. The stability of continuous flowing effluent was evaluated and the impact of pulse aeration on the denitrifying bacteria community structure was analyzed with MiSeq sequencing technology. Based on both energy saving and enhanced nitrogen removal, this work intended to serve as a reference for the feasibility of aeration system modification of traditional continuous flowing CAS.

2. Materials and methods

2.1. Seed sludge adaptation

The seed activated sludge was taken from a sewage treatment plant (Nanjing, China) and cultured with the synthetic wastewater in a 150 L plastic container for over 3 months until the seed sludge has adapted to the synthetic wastewater composed of 170 mg/L CH_3COONa, 80 mg/L glucose, 15 mg/L peptone, 100 mg/L NH_4Cl, 12 mg/L KH_2PO_4, 24 mg/L $NaHCO_3$, 24 mg/L $CaCl_2$ and 95 mg/L $MgSO_4{\cdot}7H_2O$. The concentrations of main indices of the wastewater were as follows: 150–200 mg/L of chemical oxygen demand (COD), 60–80 mg/L of total organic carbon (TOC), 20–30 mg/L of total nitrogen (TN), 15–20 mg/L of ammonia nitrogen (NH4+-N). The seed cultivation was conducted in sequencing mode with four cycles each day (Zhang et al., 2017). The cultured activated sludge was then used to inoculate the reactors.

2.2. Reactors set-up and operation

The experiment was carried out in two identical reactors with 350 mm of length, 350 mm of width and 450 mm of depth. Both reactors were fed with the synthetic wastewater, and there was a mixer in each reactor working continuously to avoid the sedimentation of the sludge. One reactor was aerated in pulse mode by a time controller at variable pulse aeration cycle (PAC) (on/off = 5/5, 5/10, 10/10, and 10/15 min), another reactor was running simultaneously with constant aeration as control reactor. A schematic diagram of both reactors is shown in Fig. 1. A sloping baffle was set at the top-right area of the reactor as the sedimentation area, where the mixture was separated and the activated sludge was circulated to the reaction region. The working volumes of the aeration area and the settling area of each reactor were 40 L and 10 L, respectively.

The concentrations of mixed liquor suspended solid (MLSS) of both reactors were controlled at 2400–2800 mg/L and the average solid retention time (SRT) was maintained at 12 days by discharging a certain amount of excess sludge from each reactor manually every day. The hydraulic retention time (HRT) was controlled at 4 h by adjusting the influent flow rate at 10 L/h. The aeration rates