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Full nitration-denitration versus partial nitration-denitration-anammox for treating high-strength ammonium-rich organic wastewater

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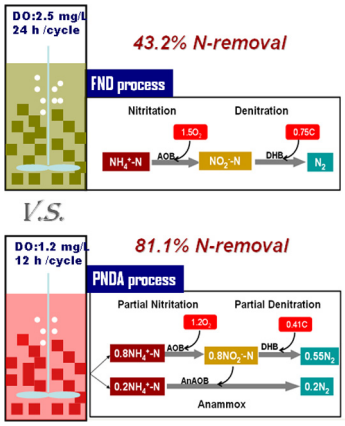
GRAPHICAL ABSTRACT



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ABSTRACT

This study investigated the performance of full nitration-denitration (FND) and partial nitration-denitration-anammox (PNDA) in treating a synthetic wastewater with 300 mg/L NH_4^+-N and 600 mg/L COD. It was found that approximately 40% higher total nitrogen removal was achieved via PNDA than via FND. Meanwhile, high-throughput sequencing also revealed that aerobic heterotrophic bacteria were predominant in the FND process, while facultative and even anaerobic bacteria including anammox bacteria were dominant in PNDA process. Furthermore, the mass balance on nitrogen showed that 44% of nitrogen was removed by partial nitration-denitration, while 36% via nitritation-anammox pathway in the PNDA process, with the significant saving in aeration and demand of organic carbon source. Compared to the FND process, it is obvious that the PNDA process will offer a more cost-effective alternative with easy operation for treating ammonium-rich organic wastewater.

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1. Introduction

The cost-effective treatment of high-strength ammonium wastewater has always been a global challenge in wastewater engineering. The conventional nitrification-denitrification (CND) process has been most commonly applied for low concentration wastewater (e.g. municipal wastewater) treatment (Ahn, 2006; Van Hulle et al., 2010). However, for high-strength ammonia wastewater with a low carbon/nitrogen ratio such as coking wastewater (Zhou et al., 2014), intensive aeration and external organic carbon source are inevitably needed (Carrera et al., 2003), leading to a considerable increase in the operating cost.

To overcome these challenges associated with CND process, various original nitrogen removal processes including nitritation-denitritation and partial nitritation-anammox have been explored with the aims to reduce energy consumption and supply of external organics (Peng and Zhu, 2006). In the full nitritation-denitritation (FND) pathway, ammonia is completely oxidized to nitrate which is further denitrified to nitrogen gas. As such, the demands on aeration and organic matter are can be reduced in the FND process compared to full nitrification-denitrification. Recently, extensive effort has been dedicated to anaerobic ammonium oxidization (anammox) in which NH_4^+-N is oxidized to N_2 with NO_2^--N as the electron acceptor under anoxic conditions (Kartal et al., 2010). As dissolved oxygen and organic carbons are not required, the anammox process has been shown to be the most economically viable pathway for high-efficient nitrogen removal (Cao et al., 2017; Kartal et al., 2010). It has been known that partial nitritation is essential for anammox (Lackner et al., 2014; Wells et al., 2017), while denitritation should be accomplished prior to anammox in order to avoid the competition on nitrite between anammox and denitrifying bacteria. The integration of partial nitritation-denitration-anammox (PNDA) in one-single biofilm reactor had been reported (Zhou et al., 2018). However, it should be noted that high-concentration effluent ammonia was observed in the PNDA process (Ali and Okabe, 2015; van der Star et al., 2007). So far, little attention has been given to compare the overall performances and microbial features of FND and PNDA in a holistic manner.

Therefore, this study aimed to 1) investigate the feasibility to treat high-strength ammonium organic wastewater in a sequencing batch biofilm reactor (SBBR) using FND and PNDA pathways; 2) evaluate the treatment efficiency and microbial community structures of the two processes; 3) elucidate the COD and nitrogen mass flows in the PNDA process with the focus on the engineering implications on its future application.

2. Materials and methods

2.1. Experimental system

A lab-scale cylindrical SBBR with a working volume of 5 L was implemented. The polyurethane foam was used as the carrier and the filling ratio was 50% (V/V). The influent was pumped into the SBBR system via a peristaltic pump. The air was continuously supplied by the compressed pump and the propeller fixed at the side of the reactor bottom provided enough mixing. The temperature was kept at 30 ± 1 °C via a thermostat during the experiment. And the aeration supply was precisely controlled by a micro-gas mass flow control system. A cycle for the SBR system consisted 2 min feeding; 11.5/23.5 h aeration; 25 min settling followed by 3 min discharging. The volume exchange ratio was 1/3. No sludges were withdrawn during the whole experiment.

2.2. Seed sludge and wastewater

To rapidly establish nitration, the lab-scale SBBR system was directly inoculated with the shortcut nitrifying seeding sludge (4.3 ± 0.2 g MLSS/L) obtained from the aerobic tank of an actual full-scale A^2/O system treating ammonia-rich coking wastewater in Shanxi province, China. The high concentrations of NH_4^+-N and COD in the form of ammonium chloride and glucose added into the synthetic wastewater were fixed at 300 mg/L and 600 mg/L with a constant influent C/N ratio of 2. The specific compositions of synthetic wastewater were referred to the reference (Zhou et al., 2018). The pH of influent wastewater was adjusted to 7.6 ± 0.1.

2.3. Reactor start-up and operation

The collected activated sludge was firstly filtered to remove impurities. The 3.5 L inoculated sludge and 1.5 L wastewater were mixed together and pumped into the reactor for 24 h. Then 12 h aeration and 12 h stewing were followed by decanting 3 L supernatant so as to rapidly inoculate the microorganisms onto the surface of the carriers. Afterwards, the fresh wastewater was introduced into the SBR reactor operated at 5-day per cycle and then gradually shortened to 1 day per cycle. Finally, above 85% nitritation efficiency was achieved in approximately two weeks.

After the start-up of the system, the steady operation was immediately initiated. As the dissolved oxygen (DO) and influent loading rate (ILR) were the most decisive factors in shortcut nitrogen removal performance as well as economic efficiency, two different long-term phases consisting of Phase 1 (days 0–80): 2.5 ± 0.2 DO mg/L; 24 h-cycle and Phase 2 (days 81–141): DO: 1.2 ± 0.2 mg/L; 12 h-cycle were designed by regulating aeration supply and cycle period. The system was operated for 141 days in total.

2.4. Chemical analysis

The effluent were sampled every three days and analyzed immediately. COD, ammonia, nitrite and nitrate concentrations were rapidly measured with HACH Lange cuvette kits. The temperature and DO/pH were monitored by an online DO/pH meters (Multi 3420, WTW, Germany). The ammonia removal efficiency (ARE), nitrite accumulation ratio (NAR), total nitrogen (TN), nitrogen removal efficiency (NRE), nitrogen loading rate (NLR), organic loading rate (OLR), ammonia removal loading rate (ARLR), nitrogen removal loading rate (NRLR) and free ammonia (FA) were calculated according to Eqs. (1)–(9).

$$\mathrm{ARE} = \frac{[\mathrm{NH_4^+}\text{–N}]_{\mathrm{inf}} - [\mathrm{NH_4^+}\text{–N}]_{\mathrm{eff}}}{[\mathrm{NH_4^+}\text{–N}]_{\mathrm{inf}}} \times 100\% \quad (1)$$

$$\mathrm{NAR} = \frac{[\mathrm{NO_2^-}\text{–N}]}{[\mathrm{NO_2^-}\text{–N}] + [\mathrm{NO_3^-}\text{–N}]} \times 100\% \quad (2)$$

$$\mathrm{TN_{eff}} = ([\mathrm{NH_4^+}\text{–N}] + [\mathrm{NO_2^-}\text{–N}] + [\mathrm{NO_3^-}\text{–N}])_{\mathrm{eff}} \quad (3)$$

$$\mathrm{NRE} = \frac{[\mathrm{NH_4^+}\text{–N}]_{\mathrm{inf}} - \mathrm{TN_{eff}}}{[\mathrm{NH_4^+}\text{–N}]_{\mathrm{inf}}} \times 100\% \quad (4)$$

$$\mathrm{NLR(kg/m^3d)} = \frac{0.024 \times [\mathrm{NH_4^+}\text{–N}]_{\mathrm{inf}}}{\mathrm{HRT}} \quad (5)$$

$$\mathrm{OLR(kg/m^3d)} = \frac{0.024 \times [\mathrm{COD}]_{\mathrm{inf}}}{\mathrm{HRT}} \quad (6)$$

$$\mathrm{ARLR(kg/m^3d)} = \frac{0.024 \times ([\mathrm{NH_4^+}\text{–N}]_{\mathrm{inf}} - [\mathrm{NH_4^+}\text{–N}]_{\mathrm{eff}})}{\mathrm{HRT}} \quad (7)$$

$$\mathrm{NRLR(kg/m^3d)} = \frac{0.024 \times ([\mathrm{NH_4^+}\text{–N}]_{\mathrm{inf}} - \mathrm{TN_{eff}})}{\mathrm{HRT}} \quad (8)$$

$$\mathrm{FA(mg/L)} = \frac{17}{14} \times \frac{[\mathrm{NH_4^+}\text{–N}]_{\mathrm{inf}} \times 10^{\mathrm{pH}}}{\exp[6334/(273+\mathrm{T})] + 10^{\mathrm{pH}}} \quad (9)$$