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Achieve efficient nitrogen removal from real sewage in a plug-flow integrated fixed-film activated sludge (IFAS) reactor via partial nitritation/anammox pathway

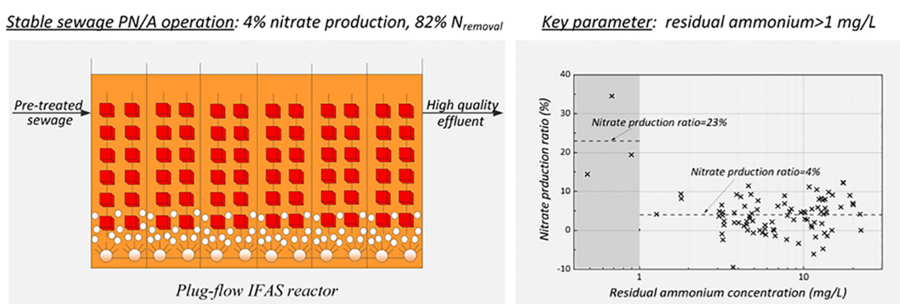
Yandong Yang [a], Liang Zhang [a,b,*], Jun Cheng [b], Shujun Zhang [c], Baikun Li [b,d], Yongzhen Peng [a,b]

[a] State Key Laboratory of Urban Water Resource and Environment, Harbin Institute of Technology, Harbin 150090, China
[b] National Engineering Laboratory for Advanced Municipal Wastewater Treatment and Reuse Technology, Key Laboratory of Beijing for Water Quality Science and Water Environment Recovery Engineering, Beijing University of Technology, Beijing 100124, China
[c] Beijing Drainage Group Co. Ltd (BDG), Beijing 100022, China
[d] Department of Civil and Environmental Engineering, University of Connecticut, 8 Storrs, CT 06269, USA

HIGHLIGHTS

- Partial nitritation/anammox was established in an IFAS reactor treating sewage.
- Efficient nitrogen removal ($TN_{effluent}$ = 7.9 mg/L and 82% $TN_{removal}$) was achieved.
- Stable PN/A operation was achieved when residual ammonium was higher than 3 mg/L.
- Nitrate accumulated and PN/A performance declined when residual ammonium <1 mg/L.

GRAPHICAL ABSTRACT



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ABSTRACT

This study tested the feasibility of plug-flow integrated fixed-film activated sludge (IFAS) reactor in applying sewage partial nitritation/anammox (PN/A) process. The IFAS reactor was fed with real pre-treated sewage (C/N ratio = 1.3) and operated for 200 days. High nitrogen removal efficiency of 82% was achieved with nitrogen removal rates of 0.097 ± 0.019 kg N/(m^3·d). Therefore, plug-flow IFAS reactor could be an alternative to applying sewage PN/A process. Besides, it was found that the stability of sewage PN/A process was significantly affected by residual ammonium. Nitrate accumulated in effluent and PN/A performance deteriorated when residual ammonium was below 1 mg/L. On the contrary, long-term stable PN/A operation was achieved when residual ammonium was over 3 mg/L.

1. Introduction

Partial nitritation/anammox (PN/A) is a novel biological nitrogen removal (BNR) process. In PN/A process, part of ammonium in wastewater is firstly oxidized to nitrite by ammonium-oxidizing bacteria (AOB) and then the remaining ammonium and nitrite were converted to nitrogen gas by anammox bacteria. As a completely autotrophic pathway, PN/A reduces aeration consumption by 60% and organic carbon demand by 100% for nitrogen removal compared to the conventional nitrification/denitrification process (Mulder, 2003). The application of PN/A process to sewage treatment could reduce the energy consumption and enhance the biogas production, making great advances towards an energy

* Corresponding author at: Harbin Institute of Technology, Harbin 150090, China.
E-mail address: zhangliang_1986@126.com (L. Zhang).

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self-efficient wastewater treatment plant (WWTP) (Siegrist et al., 2008; Kartal et al., 2010).

The feasibility of sewage PN/A process has been proven by increasing bench scale experimental evidences (De Clippeleir et al., 2011; Zhang et al., 2013; Gilbert et al., 2014; Gao et al., 2015; Malovanyy et al., 2015a). To retain anammox bacteria under low ammonium conditions (typically < 70 mg N/L), biofilm- or granule-based systems were opted to provide a long solid retention time (SRT). Overall, favorable nitrogen removal rates of 0.015–0.97 kg N/(m^3·d) was obtained, which was advantageous as compared to conventional nitrification/denitrification process (0.05–0.1 kg N/(m^3·d) (Cao et al., 2017). So far, stringent discharge standard and long-term operational stability remain great challenges to the full-scale application of sewage PN/A. In previous studies, PN/A performance was often limited by the high effluent nitrate due to the enrichment of nitrite-oxidizing bacteria (NOB) (De Clippeleir et al., 2011; Lotti et al., 2015; Malovanyy et al., 2015b). Various strategies such as controlling residual ammonium (Regmi et al., 2014), applying intermittent aeration (Miao et al., 2016) and bio-augmentation (Al-Omari et al., 2015) have been proposed to repress NOB. However, it is difficult to eliminated NOB while retain anammox bacteria in pure biofilm or granular PN/A system (Gilbert et al., 2014; Malovanyy et al., 2015b).

Recently, the use of integrated fixed-film activated sludge (IFAS) reactor for PN/A, has gained research interests. In PN/A system based on IFAS, anammox bacteria preferentially grow in the biofilm while the aerobic AOB and NOB are prone to grow in activated sludge due to less oxygen transfer limitation (Veuillet et al., 2014; Hubaux et al., 2015; Zhang et al., 2015b). Thus IFAS reactor provides opportunity to selectively washout NOB while retaining anammox bacteria by SRT separation of activated sludge and biofilm (Han et al., 2016). Till now, IFAS reactor has been successfully applied to the pilot- and full-scale sidestream PN/A treatment (Veuillet et al., 2014; Zhang et al., 2015a, 2015b). While the reports of applying IFAS to sewage PN/A treatment are rather limited (Malovanyy et al., 2015a; Laureni et al., 2016). Besides, IFAS has advantages when applying sewage PN/A to the established WWTPs with plug-flow process since IFAS requires no major retrofit of current configuration (Ge et al., 2014). However, there are no reports on applying plug-flow IFAS reactor to sewage PN/A process so far.

This study tested the feasibility of plug-flow IFAS reactor in applying sewage PN/A process. The reactor was fed with real pre-treated sewage and operated under ambient temperature (24–26 °C). Nitrogen removal performance and process stability in the long-term operation were investigated. Based on these results, the key factors affecting the stability of PN/A system was discussed and the strategy to achieve stable operation was proposed.

2. Material and methods

2.1. Reactor setup

A lab-scale plug-flow IFAS reactor with a working volume of 160 L was used in this study (Fig. 1). The reactor was divided into 6 equal chambers by bafflers. All the chambers were aerated to provide microaerobic conditions and DO concentrations ranged from 0.15 to 0.36 mg/L. The pre-treated sewage was pumped into the reactor with a flow rate of 16.0–22.5 L/h, resulting in a hydraulic retention time (HRT) of 7–10 h. The reactor was operated at ambient temperature (22–25 °C). The cylindrical settler of the IFAS reactor had a working volume of 36 L. Concentrated sludge was recycled back to the reactor at a constant ratio (80%) of the inflow rate. The bioreactor was operated for 200 days.

2.2. Wastewater and seeding sludge

Wastewater used in this study was real sewage collected from Gaobeidian WWTP. Before fed to the IFAS reactor, sewage was pre-treated in an enhanced biological phosphorous removal (EBPR) reactor. The EBPR reactor was operated at short HRT (2.4–3.6 h) and sludge retention time (SRT, 3–4 d) to remove organic matter and phosphorous, and provide a favorable feeding to IFAS reactor. The main characteristics of the sewage before and after pre-treatment were illustrated in Table 1.

The activated sludge and biofilm collected from a pilot-scale IFAS anammox reactor treating reject water were used as seeding sludge (Zhang et al., 2015b). The respective proportion of AOB, anammox bacteria and NOB were 54.6%, 2.4% and 0.01% in activated sludge, and 2.6%, 87.8% and 0.01% in biofilm (Zhang et al., 2015b). The biofilm carriers were cubic sponge polyesters. In the

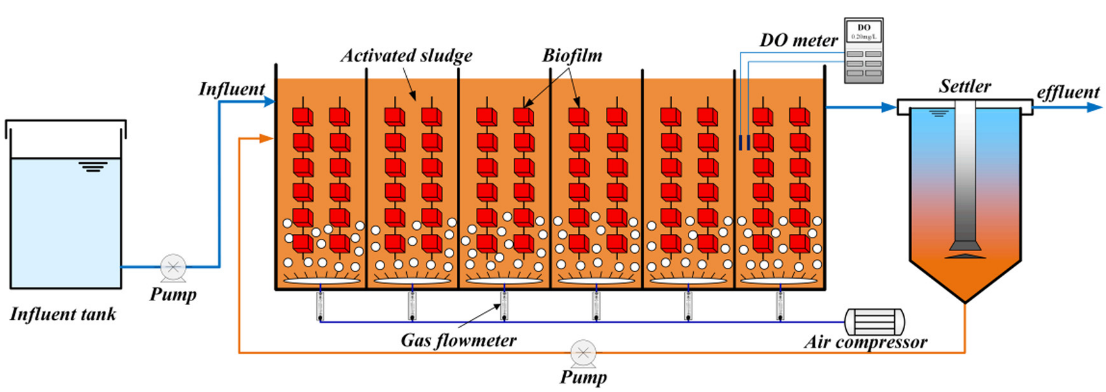

Fig. 1. The schematic of the plug-flow IFAS reactor.

Table 1
The main characteristics of sewage and pre-treated sewage.

Wastewater	COD (mg/L)	TN (mg/L)	NH_4^+-N (mg/L)	NO_2^--N (mg/L)	NO_3^--N (mg/L)	PO_4^{3-}-P (mg/L)	C/N ratio
Sewage	237.5 ± 51.0	54.7 ± 6.4	45.0 ± 5.2	0.1 ± 0.1	0.2 ± 0.3	5.9 ± 1.4	4.3
Pre-treated sewage	56.1 ± 18.6	44.2 ± 4.9	40.5 ± 5.0	1.1 ± 1.0	0.7 ± 0.6	0.5 ± 0.4	1.3