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Biological nutrient removal in a continuous anaerobic–aerobic–anoxic process treating synthetic domestic wastewater

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HIGHLIGHTS

- A continuous post-anoxic process (AOA) with low DO level was established.
- Nutrient removal was improved by controlling aerobic HRT and DO concentration.
- TN was removed efficiently via SND and denitrifying phosphorous removal.
- Denitrification was mainly driven by poly-β-hydroxybutyrate (PHB).

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ABSTRACT

A continuous anaerobic–aerobic–anoxic (AOA) process was established to remove nutrients from domestic wastewater without the addition of external carbon source. The AOA process was based on an enhanced biological phosphorous removal (EBPR) system with influent COD, NH_4^+—N and PO_4^{3-}—P concentrations of 300, 50 and 3.8 mg/L, respectively. Nitrogen and phosphorous were removed simultaneously driven by internal carbon sources under low dissolved oxygen (DO) condition. The removal efficiencies of total nitrogen (TN) and PO_4^{3-}—P reached above 90% and 99% when the DO concentration of the aerobic unit was controlled at 1.2 ± 0.2 mg/L and the HRT of the aerobic and anoxic units were at 2 h and 4 h, respectively. Denitrification was mainly driven by poly-β-hydroxybutyrate (PHB), which increased via shortening the aerobic HRT. Results demonstrated that TN was removed via simultaneous nitrification and denitrification (SND) and denitrifying phosphorous removal in the continuous AOA process.

1. Introduction

The discharge of municipal wastewater has been increasing rapidly along with the fast development of urbanization in China. Although a number of wastewater treatment plants (WWTPs) have been built up in recent years, their treating capacity is still far less than the amount of the disposed wastewater. Meanwhile, many WWTPs could not remove nutrients effectively from wastewater because the carbon source needed for nutrient removal is often insufficient. Thus, it is urgent to build new WWTPs and retrofit the old ones with efficient biological nutrient removal (BNR) processes.

Most WWTPs adopt pre-anoxic BNR processes, such as the anaerobic–anoxic–oxic (A^2O) process, the University of Cape Town (UCT) process and BCFS process [1]. In a pre-anoxic system, the anoxic reactor is placed before the aerobic reactor and mixed liquor containing nitrate is recirculated from the aerobic reactor to the anoxic reactor and in this kind of system complete removal of TN is almost unattainable. In order to improve TN removal performance the nitrate recirculation rate must be increased to a very high level, which leads to high energy consumption and dissolved oxygen (DO) return from the aerobic reactor [2]. On the contrary, in a post-anoxic process the anoxic reactor is placed after the aerobic reactor and mixed liquor recirculation is not necessary, but organic substrates which are essential for denitrification are usually depleted in the aerobic reactor and it is necessary to add external carbon source for the post-anoxic reactor [3], which also increases operating costs. Furthermore, the dose of the external carbon source must be carefully controlled to avoid increase of effluent COD concentration. Therefore, it is of great interest to find some new solutions to provide carbon sources for the post-anoxic reactor and utilize the carbon sources more efficiently so that the operating costs of post-anoxic

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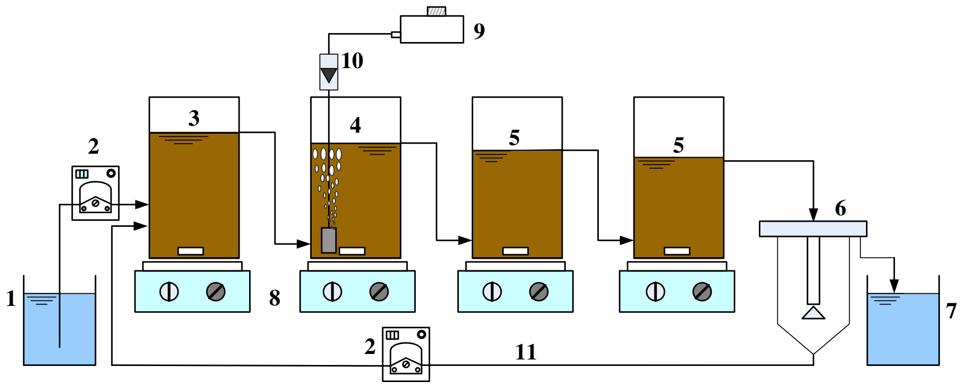

Fig. 1. Schematic diagram of the AOA process (Run 2). 1 – Influent tank, 2 – peristaltic pump, 3 – anaerobic basin, 4 – aerobic basin, 5 – anoxic basin, 6 – settler, 7 – effluent tank, 8 – mixer, 9 – air pump, 10 – air flow meter and 11 – return sludge.

Table 1
Design parameters and operational conditions of the AOA process.

Parameters	Run 1	Run 2
Influent flow rate (L/d)	50	
Return sludge flow-rate (L/d)	50	
Sludge return ratio (R)	1.0	
Reactor operational volume (L)	16	
Settler volume (L)	8	
Total HRT (h)	8	
Anaerobic HRT (h)	2	
Aerobic HRT (h)	4	2
Anoxic HRT (h)	2	4
DO (mg/L)	0.4 ± 0.1	1.2 ± 0.2
SRT (d)	20	
MLSS (mg/L)	3400	
Operational temperature (°C)	28.0 ± 1.7	
pH	7.0–7.5	

processes can be lowered greatly and these processes can be used widely in WWTPs.

In the field of biological phosphorous removal, volatile fatty acids (VFAs) in the influent are usually taken up and stored as polyhydroxyalkanoates (PHAs) by phosphate accumulating organics (PAOs), so that these VFAs would not be utilized by ordinary heterotrophic organisms (OHOs) in the downstream aerobic phase. Besides, glycogen accumulating organisms (GAOs) often coexist with PAOs with comparable physiologies except that GAOs cannot assimilate phosphate excessively. Under anoxic condition, denitrifying PAOs (DNPAOs) and denitrifying GAOs (DNGAOs) can use nitrate/nitrite as electron acceptors to degrade PHAs, which means that PHAs can be used as internal carbon sources for denitrification [4]. It is well known that DNPAOs could be used in denitrifying phosphorous removal processes, such as A_2N–SBR and DEPHANOX processes to remove nitrogen and phosphorous simultaneously [5–8]. These processes adopted two-sludge system in which DNPAOs and nitrifiers were cultivated separately, resulting in complex process configuration.

Recently it has been reported that internal carbon sources could be used for denitrification in some other processes. For example, in an anaerobic/aerobic sequencing batch reactor (SBR) process with a low DO condition (0.5 mg/L), simultaneous nitrification and denitrification (SND) via nitrite was combined with enhanced biological phosphorous removal (EBPR) and denitrification was accomplished by DNGAOs using PHAs as carbon sources [9,10]. In an aerobic/anoxic (low DO) SBR process proposed by Third et al. [11], VFAs were stored as PHAs at the beginning of the aerobic stage, then ammonia was removed by SND and PHAs were used as carbon sources for denitrification. By controlling DO concentration and aerobic HRT, SND performance was improved and TN removal efficiency increased from 65% to 85% [12]. Coats et al. [13] proposed a post-anoxic SBR process, where denitrification was achieved using glycogen as internal carbon source. However, all these processes were operated in SBRs and the HRTs were often longer than 10 h. Besides, when treating real municipal wastewater it is often necessary to add VFAs in the influent [13–15], implying that the carbon utilization efficiency of these processes is yet to be increased further.

The utilization of internal carbon sources, such as PHAs and glycogen, makes it possible to achieve nutrient removal in a post-anoxic process through denitrifying phosphorous removal, SND and denitrification by DNGAOs without addition of external substrates. In this way, carbon sources are utilized more efficiently and nutrient removal performance could be improved. Except some DEPHANOX-type processes which adopted two-sludge system [6–8], very few continuous post-anoxic processes achieving nitrogen removal via denitrifying phosphorous removal and SND have been reported. In the previous research, a continuous anaerobic–aerobic–anoxic (AOA) process with conversion of internal carbon source was set up to achieve denitrifying phosphorous removal [16]. The objective of this study is to optimize the AOA process without mixed liquor recirculation and achieve excellent nutrient removal via efficient SND and denitrifying phosphorous removal driven by internal carbon sources.

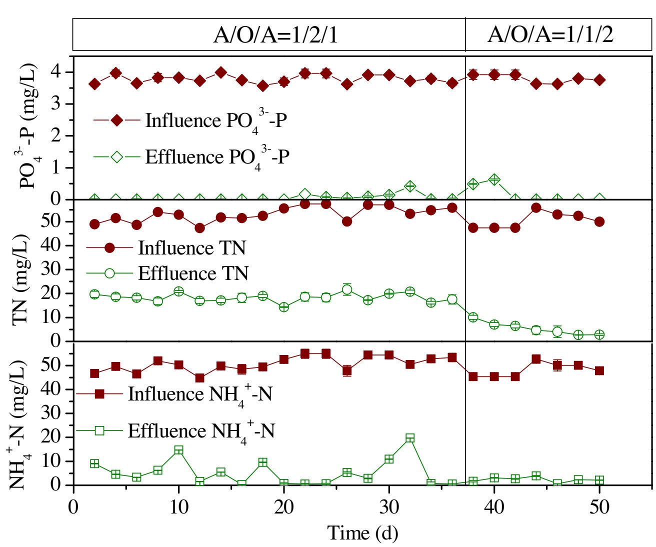

Fig. 2. Performance of the AOA process regarding PO_4^{3-}—P, TN and NH_4^+—N removal.