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Biological nutrient removal in a sequencing batch reactor operated as oxic/anoxic/extended-idle regime

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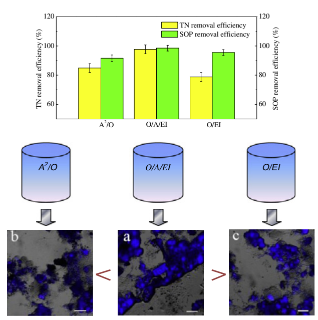
HIGHLIGHTS

- TN and P removal efficiencies in O/A/EI regime were kept above 98% and 99%.
- O/A/EI regime performs better N and P removal than A^2/O and O/EI processes.
- O/A/EI regime provides PAOs advantage over GAOs.

GRAPHICAL ABSTRACT

This paper showed oxic/anoxic/extended-idle (O/A/EI) regime drove superior biological nutrient removal than conventional anaerobic/anoxic/aerobic (A^2/O) and oxic/extended-idle (O/EI) processes.



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ABSTRACT

Previous researches have demonstrated that biological phosphorus removal from wastewater could be induced by oxic/extended-idle (O/EI) regime. In this study, an anoxic period was introduced after the aeration to realize biological nutrient removal. High nitrite accumulation ratio and polyhydroxyalkanoates biosynthesis were obtained in the aeration and biological nutrient removal could be well achieved in oxic/anoxic/extended-idle (O/A/EI) regime for the wastewater used. In addition, nitrogen and phosphorus removal performance in O/A/EI regime was compared with that in conventional anaerobic/anoxic/aerobic (A^2/O) and O/EI processes. The results showed that O/A/EI regime exhibited higher nitrogen and phosphorus removal than A^2/O and O/EI processes. More ammonium oxidizing bacteria and polyphosphate accumulating organisms and less glycogen accumulating organisms containing in the biomass might be the principal reason for the better nitrogen and phosphorus removal in O/A/EI regime. Furthermore, biological nutrient removal with O/A/EI regime was demonstrated with municipal wastewater. The average TN, SOP and COD removal efficiencies were 93%, 95% and 87%, respectively.

1. Introduction

N and P are the two most important nutrients for organisms, while the excessive accumulation of N and P discharged into water can cause eutrophication which has become a severe water pollution problem all around the world. Almost all wastewater treatment plants (WWTP) worldwide achieve N removal by alternately exposing a population of bacteria including nitrifiers and denitrifiers to oxic environments for nitrification and anoxic conditions for denitrification (Lee et al., 2010). Enhanced biological phosphorus removal (EBPR) processes are commonly conducted to remove P from wastewater by exploiting the ability of polyphosphate accumulating organisms (PAOs) to accumulate P and to store

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it as intracellular polyphosphate (poly-P) under alternating anaerobic/aerobic conditions (Chen et al., 2004; Mullan et al., 2006). To achieve wastewater biological N and P removal, some wastewater treatment processes such as anaerobic/anoxic/aerobic (A^2/O) process have been developed and applied (van Loosdrecht et al., 1998).

In EBPR systems, PAOs store P through sequential anaerobic–aerobic conditions. While another group of microorganisms known as glycogen accumulating organisms (GAOs) are able to compete with PAOs for the available organic substrate without contributing to P removal (Zeng et al., 2002). In many cases, process upsets and P removal deterioration in EBPR plants can be explained by the microbial competition of GAOs with PAOs (Thomas et al., 2003). In nitrification process, ammonium is converted to nitrite by ammonium oxidizing bacteria (AOBs) and then is further oxidized to nitrate by nitrite oxidizing bacteria (NOBs). Then nitrate is reduced into nitrite and then into molecular nitrogen through denitrification (Zhou et al., 2011).

Recently, achieving high wastewater N and P removal efficiency with less energy consumption has become a very urgent great task for WWTP. Though high rates of denitrification can be achieved in pre-anoxic regime under sufficient supply of biodegradable carbon, the energy cost from mixed liquor recycle flows is enormous (Coats et al., 2011). Therefore, many post-anoxic processes have been developed to decrease the energy consumption during wastewater biological nutrient removal (Metcalf and Eddy, 2003). As an example, an innovative static/oxic/anoxic activated sludge process characterized by static phase as a substitute for conventional anaerobic stage was proposed to enhance biological nutrient removal (Xu et al., 2013). Moreover, the anoxic zone is placed before the aerobic zone in pre-anoxic processes. However, the available carbon source in municipal wastewater is mainly in the form of volatile fatty acids (VFAs), which are limited and scarcely satisfy the demand of denitrification and EBPR simultaneously. So far, a novel anaerobic/aerobic/anoxic process has been proposed to realize denitrifying phosphorous removal (Xu et al., 2011). And post-anoxic denitrification driven by polyhydroxyalkanoates (PHAs) and glycogen was achieved within EBPR, which dramatically reduced the need for external carbon augmentation in biological nutrient removal (Coats et al., 2011).

It has been proved that biological P removal can be well achieved by oxic/extended-idle (O/EI) regime (Wang et al., 2008). As compared to conventional EBPR processes, O/EI regime realized biological P removal without experiencing specific anaerobic pools but extending the idle period to 210–450 min (Wang et al., 2012a). Thus, O/EI regime had several advantages such as improved phosphorus removal efficiencies and reduced operational costs (Wang et al., 2012b). However, those previous studies described the general performance in terms of P removal without specifying the importance of improving N removal efficiency. And denitrification capacity of the extended-idle was limited, resulting in the low total nitrogen (TN) removal efficiency. Therefore, it is important to enhance the TN removal of O/EI process through simple strategies.

In the previous study, introducing an anoxic period after the aeration to realize post anoxic denitrification driven by storage compounds was proved to be feasible in an activated sludge process (Chen et al., 2013). However, the accumulation of PHAs was prematurely finished at about the initial 30 min of aeration and the synthesized PHAs were consumed gradually in the remaining oxic stage. It was observed that just half of the synthesized PHAs were left at the beginning of the anoxic phase, which could not provide enough electron donors for denitrification. Though a high P removal efficiency averaging 99% was achieved, TN removal efficiency was only obtained at 83%.

The purpose of this work was to report a new wastewater treatment regime, i.e., oxic/anoxic/extended-idle (O/A/EI) regime, which could achieve excellent wastewater biological nutrient removal in a sequencing batch reactor (SBR). Firstly, the N and P removal performance in O/A/EI regime was compared with that in A^2/O and O/EI processes during the long-term operation. Then, the mechanism for O/A/EI regime driving high N and P removal efficiencies was explored. Finally, the feasibility of using O/A/EI regime to achieve N and P removal was tested in municipal wastewater.

2. Materials and methods

2.1. Sequencing batch reactor setup and operation

Experiments were performed in three lab-scale SBRs each with a working volume of 12 L. Seed sludge was inoculated into the three SBRs to achieve biological N and P removal. Aeration and mixing were supplied through an air diffuser placed in the bottom of the SBRs, and a mechanical stirrer was used to attain sound liquid mixing during anaerobic and anoxic phases. The dissolved oxygen concentration during the oxic phase is about 4 mg L^{-1}. The pH values were controlled at 7.0 ± 0.2 by dosing 1 M HCl or 1 M NaOH. All SBRs were operated sequentially in 6 h-cycle. One of the SBRs was operated as O/A/EI regime, each cycle of which was consisted of 120 min aeration and 90 min anoxic mix, followed by 55 min settling, 5 min decanting and 90 min idle periods.

The other two SBR were operated as conventional A^2/O and O/EI regimes. Each cycle of the A^2/O-SBR consisted of 90 min anaerobic, 120 min oxic and 90 min anoxic periods, followed by 55 min for settling and 5 min for decanting. The cycling profile of O/EI-SBR comprised 120 min aeration, followed by 55 min settling, 5 min decanting and 180 min idle periods. 10 L supernatant was discharged at the end of settling phase and was replaced with 10 L synthetic medium. 1.5 L of sludge mixtures from the SBRs was discharged once per day at the end of aerobic zone, resulting in a sludge retention time of 8 d and a hydraulic retention time of 8 h.

2.2. Wastewater and sludge

The synthetic feeding medium used as influent in this study contained 15 mg PO_4^{3-}–P L^{-1}, 40 mg NH_4^+–N L^{-1} and 300 mg L^{-1} of COD. Acetate was selected as the sole carbon source because it was the most common VFAs in domestic wastewaters (Chen et al., 2004). The concentrations of the other nutrients in the synthetic wastewater were listed as follows: 0.005 g L^{-1} $CaCl_2$, 0.01 g L^{-1} $MgSO_4 \cdot 7H_2O$ and 0.5 mL L^{-1} trace element solution which contained (g L^{-1}): 1.50 $FeCl_3 \cdot 6H_2O$, 0.03 $CuSO_4 \cdot 5H_2O$, 0.12 $ZnSO_4 \cdot 7H_2O$, 0.12 $MnCl_2 \cdot 4H_2O$, 0.06 $Na_2MoO_4 \cdot 2H_2O$, 0.15 $CoCl_2 \cdot 6H_2O$, 0.18 KI, 0.15 H_3BO_3 and 10 EDTA.

The seed sludge was collected from the WWTP in Changsha, P.R. China, which was operated as A^2/O process. The initial concentration of mixed liquor suspended solids (MLSS) was about 4000 mg L^{-1}.

2.3. Nitrogen and phosphorus removal from municipal wastewater

The investigation was performed in a SBR with a working volume of 12 L. The SBR was operated as O/A/EI regime and was inoculated with seed sludge to achieve biological nutrient removal. Each cycle of the SBR consisted of 210 min aeration and 90 min anoxic mix, followed by 55 min settling, 5 min decanting and 120 min idle periods. The other operational conditions of the two SBRs were the same as that described in Sections 2.1 and 2.2 except that the SBR here received real municipal wastewater, which was collected from the first wastewater treatment plant in Changsha, P.R. China. The main characteristics of the municipal wastewater