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Influence of pH on short-cut denitrifying phosphorus removal

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Abstract

Through a series of experiments using denitrifying phosphorus-accumulating sludge in sequencing batch reactors (SBRs), the variations of the intracellular polymers during the anaerobic phosphorus release process at different pH values were compared, the probable reasons for different performances of phosphorus removal were examined, and system operations in a typical cycle were investigated. The results show that the phosphorus removal rate was positively correlated with pH values in a range of 6.5−8.5. When the pH value was 8.0, the anaerobic phosphorus release rate and anoxic phosphorus uptake rate of the activated sludge were 20.95 mg/(g•h) and 23.29 mg/(g•h), respectively; the mass fraction of poly-β-hydroxybutyrate (PHB) increased to 62.87 mg/g under anaerobic conditions; the mass fraction of polyphosphate was 92.67 mg/g under anoxic conditions; and the effluent concentration of total phosphorus (TP) was 1.47 mg/L. With the increase of pH, the mass fraction of acetic acid and PHB also increased, and the absorption rate of acetic acid was equal to the disintegration rate of polyphosphate. When the pH value was above 8.0, biological phosphorus removal was achieved by chemical phosphorus precipitation, and the phosphorus removal rate decreased.

Keywords: Denitrifying phosphorus removal; pH; Removal rate; PHB

1. Introduction

Short-cut denitrifying phosphorus removal technology is regarded as a novel hotspot in the field of wastewater treatment with the goals of energy conservation, emission reduction, and environmental protection (Deng, 2011; Li et al., 2011; Wang et al., 2011a). In the short-cut denitrifying phosphorus removal process, short-cut denitrifying phosphorus-removing bacteria (SDPB) transform poly-β-hydroxybutyrate (PHB) into a potential carbon source under anoxic conditions using nitrite (NO_2^-) as an electron acceptor rather than O_2 (Wang et al., 2011b, 2014; Zeng et al., 2011; Zhou et al., 2010), thereby solving the conflict of carbon source competition in processes of denitrification and phosphorus removal, achieving double utilization of carbon, and avoiding unnecessary consumptions of oxygen and energy (Wang et al., 2011c; Jabari et al., 2014).

The acetic acid-based phosphorus release reaction equations (Wu, 2010) are as follows:

$$(CH_3COOH)_{\frac{1}{2}} + 0.5(C_6H_{10}O_5)_{\frac{1}{6}} + 0.36HPO_{3(\text{poly-P})} + 0.023H_2O \rightarrow 1.33(C_4H_6O_2)_{\frac{1}{4}} + 0.17CO_2 + 0.36H_3PO_4 \tag{1}$$

$$HPO_{3(\text{poly-P})} + H_2O \rightarrow ATP + H_3PO_4 \tag{2}$$

where $C_6H_{10}O_5$ is glycogen, $C_4H_6O_2$ is PHB, HPO_3 is polyphosphate (poly-P), and ATP is adenosine triphosphate.

Aerobic phosphorus uptake reaction equations with O_2 as an electron acceptor are as follows:

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$$H_3PO_{4(in)} + ATP \rightarrow HPO_{3(poly\text{-}P)} + H_2O \quad (3)$$

$$\varepsilon_0 H_3PO_{4(out)} + NADH_2 + 0.5O_2 \rightarrow \varepsilon_0 H_3PO_{4(in)} + H_2O \quad (4)$$

where the subscript (in) means intracellular, the subscript (out) means extracellular, $NADH_2$ means coenzyme, and ε_0 is the amount of phosphorus absorbed by oxidizing $NADH_2$.

As shown in the equations above, the proton transfer resulted in a decrease of pH during anaerobic phosphorus release and an increase of pH in the phase of aerobic/anoxic phosphorus uptake. pH is regarded as a parameter indicating the potential of biological phosphorus removal. It is also an important control parameter that can affect the permeability and surface chargeability of microbial cell membrane and is closely related to the growth and reproduction of microorganisms (Yang et al., 2010; Ding et al., 2010; Zafiriadis et al., 2011).

Previous studies (Wang et al., 2005) have shown that, when the influent pH values were 8.0 ± 0.1 under anaerobic conditions and 7.2 ± 0.1 under anoxic conditions, the optimal performance of the short-cut denitrifying phosphorus removal process was achieved using the sequencing batch reactor (SBR) activated sludge process, while the COD concentration was 400 mg/L and the NO_2^--N concentration was maintained at 35 ± 5 mg/L. Nittami et al. (2010) found that pH has an important impact on acetic acid absorption and anaerobic phosphorus release. When the pH value was in the range of 6.5–8.0, the acetic acid absorption was maintained in a constant range but the phosphorus release amount persistently increased.

In this study, an experiment was designed to investigate the influence of pH on the performance of denitrification and phosphorus removal, explore the correlation of pH with SDPB mechanisms, and provide theoretical evidence and technical support for the application of short-cut denitrifying phosphorus removal technology.

2. Materials and methods

2.1. Experimental equipment

A two-stage SBR installation made of plexiglass, including an anaerobic-anoxic sequencing batch reactor (A^2-SBR) and a nitrification sequencing batch reactor (N-SBR), was used in this study (Fig. 1). The seeding sludge of A^2-SBR was obtained from a sedimentation pond at the Shenyang Northern Sewage Treatment Plant with mixed liquor suspended solids (MLSS) of 3000–4000 mg/L. Wastewater flowed into the two SBRs separately. The short-cut nitrification took place in the N-SBR with an effective volume of 5 L with three cycles per day. The operation parameters of the N-SBR were that MLSS was 3000 mg/L, the solids retention time (SRT) was 14 d, the hydraulic retention time (HRT) was 3 h, and the dissolved oxygen (DO) concentration was 0.3 mg/L. The effluent from the N-SBR was then fed to the 25-L A^2-SBR for denitrifying phosphorus uptake under anoxic conditions. The concentration of nitrite as the electron acceptor in the A^2-SBR was 18–21 mg/L. The A^2-SBR ran three cycles per day, each for 5.5 h, and stood for 2.5 h at the end of each cycle. The daily sewage treatment capacity was 45 L, and the SRT was 20 d. Each operation cycle included an instantaneous filling phase, a 2-h anaerobic phase, a 2.5-h anoxic phase, a 0.5-h settling phase, and a 0.5-h withdrawing phase.

2.2. Experimental procedure

Activated sludge taken from the A^2-SBR in a stable stage was used to investigate the effects of pH on denitrifying dephosphatation. Batch experiments were conducted after the SBR circulated steadily and showed a strong performance. The activated sludge was cleaned and put in four 1-L sealed glass bottles

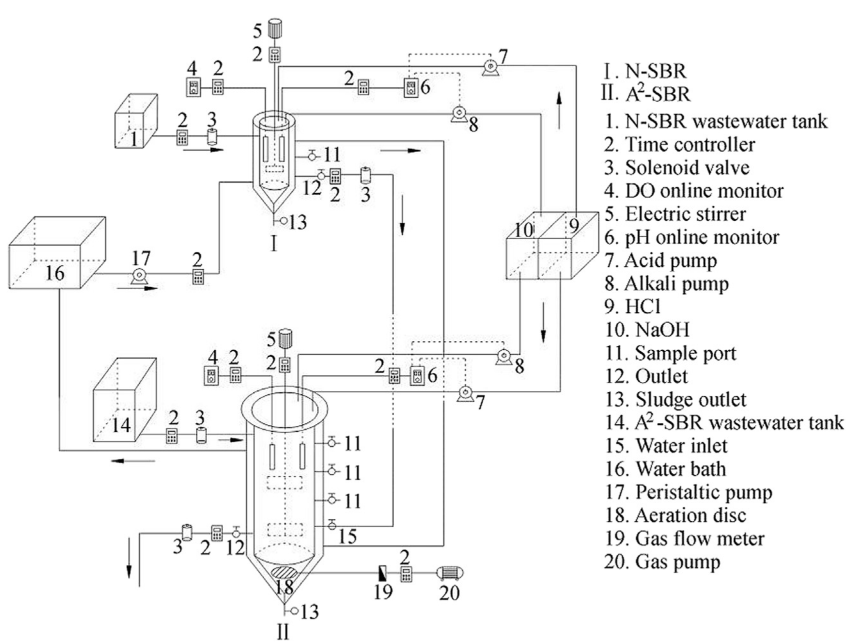

Fig. 1. Sketch of SBR installation.