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ScienceDirect
Bioresource Technology 99 (2008) 4400–4407
BIORESOURCE TECHNOLOGY

The effect of propionic to acetic acid ratio on anaerobic–aerobic (low dissolved oxygen) biological phosphorus and nitrogen removal

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Received 15 June 2007; received in revised form 19 August 2007; accepted 21 August 2007
Available online 4 October 2007

Abstract

In this paper, three lab-scale sequencing batch reactors (SBR-A, B, and C) operated with anaerobic/aerobic (low dissolved oxygen, 0.15–0.45 mg L^{-1}) configuration were long-term cultured, respectively with single acetic acid and propionic/acetic acid of 1/1 and 2/1 (carbon molar ratio), and the comparisons of anaerobic and aerobic transformations of phosphorus and nitrogen among them were made. With the increase of propionic/acetic acid, lower anaerobic phosphorus release and higher phosphorus release to short-chain fatty acids uptake ratio were observed, and less anaerobic and aerobic transformations of glycogen and poly-3-hydroxybutyrate as well as total polyhydroxyalkanoates occurred, but the transformations of poly-3-hydroxyvalerate and poly-3-hydroxy-2-methyvalerate increased. The phosphorus removal efficiency was respectively 81, 94 and 97% in SBR-A, B and C. Almost all ammonium was removed and no significant nitrite was accumulated at different propionic/acetic acid ratios. However, the nitrate accumulation and total nitrogen removal were observed to be affected by propionic/acetic acid ratio. The total nitrogen removal efficiency was 61, 68 and 82%, and the aerobic end nitrate concentration was 8.05, 6.40 and 3.54 mg L^{-1} in three SBRs, respectively. All the above studies indicated that the sole acetic acid caused more nitrate accumulation than propionic and acetic acids mixture, and a pertinent increase of wastewater propionic/acetic acid ratio was of benefit to both nitrogen and phosphorus removal in an anaerobic/aerobic (low dissolved oxygen) biological wastewater treatment process.

Keywords: Anaerobic/aerobic (low dissolved oxygen); Acetic acid; Propionic acid; Phosphorus; Nitrogen

1. Introduction

Nitrogen and phosphorus removal from wastewater is an important strategy to control eutrophication. The conventional biological nitrogen removal process involves separate aerobic and anoxic phases in separate bioreactors (Metcalf and Eddy, 1991; Panswad and Anan, 1999; Mulkerrins et al., 2004). Recently, simultaneous nitrification and denitrification (SND) has gained significant attention, in which the nitrification and denitrification occur in one reactor under low dissolved oxygen (DO) conditions (Von Mûch et al., 1996). Nitrogen removal via SND under lower DO conditions has been recognized as one strategy for saving energy consumption (low oxygen supply) in biological wastewater treatment process, but there are very few studies concerning the transformation of phosphorus in SND system (Bertanza, 1997; Helmer and Kunst, 1998; Yoo et al., 1999; Mosquera-Corral et al., 2005). Phosphorus can be removed biologically through anaerobic–aerobic enhanced biological phosphorus removal (EBPR) (Mino et al., 1998; Obaja et al., 2003; Obaja et al., 2005; Tanwar et al., 2007). As biological phosphorus removal does not require chemical precipitants and produces less waste sludge, it forms a good alternative to chemical phosphorus removal in wastewater treatment plant. Empirical metabolic models suggested that EBPR is generally linked to the synthesis and consumption of intracellular storage polymers of phosphorus and carbon (Pereira et al., 1996). In the anaerobic phase, the responsible microorganisms utilize energy derived from

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doi:10.1016/j.biortech.2007.08.032

polyphosphate (poly-P) hydrolysis for carbon substrates, such as acetic and propionic acids uptake and subsequently stored them as polyhydroxyalkanoates (PHA), which mainly include poly-3-hydroxybutyrate (PHB), poly-3-hydroxyvalerate (PHV) and poly-3-hydroxy-2-methyvalerate (PH2MV). During the aerobic stage, the previously stored carbon is used for biomass growth and poly-P formation. The excellent phosphorus removal efficiency can be achieved by EBPR, but the DO concentration in aerobic phase is higher (usually above 2 mg L^{-1}), and the change of nitrogen is little discussed (Zeng et al., 2003a; Oehmen et al., 2005a).

In order to reduce the air supply in aerobic stage, it is necessary to investigate the behaviors of both phosphorus and nitrogen transformations in the anaerobic/aerobic (low DO) system, so that a low energy consumption biological wastewater treatment process can be developed. Nevertheless, as seen from the literature, there are very few studies discussing the biological nitrogen and phosphorus removal under anaerobic/aerobic (low DO) conditions (Zeng et al., 2003b; Meyer et al., 2005). Zeng et al. (2003b) reported that the combination of SND and EBPR had the potential of achieving both nitrogen and phosphorus removal with a minimal requirement for wastewater COD. However, the studies of Meyer et al. (2005) showed that there is some inorganic nitrogen (nitrate) still remained at the end of the reactor cycle. It seems that nitrification and denitrification occurred incompletely in the anaerobic/aerobic (low DO) biological nitrogen and phosphorus removal system. Until now, however, these studies relevant to anaerobic/aerobic (low DO) biological nitrogen and phosphorus removal focused on using acetate as the carbon source, although both acetic and propionic acids are the main short-chain fatty acids (SCFA) present in real sewage (Von Müch, 1998; Naik, 1999).

In the anaerobic/aerobic (DO > 6 mg L^{-1}) EBPR system (without nitrification and denitrification due to the use of thiourea), Chen et al. (2004) found that the increase of propionic/acetic acid ratio in wastewater had a positive effect on phosphorus removal. Nevertheless, the influence of propionic/acetic on biological phosphorus and nitrogen transformations under anaerobic/aerobic (low DO) conditions has not been documented. It is therefore the purpose of this paper to investigate the effect of wastewater propionic/acetic acid on the performances of anaerobic/aerobic (low DO, 0.15–0.45 mg L^{-1}) biological phosphorus and nitrogen removal, in which three lab-scale sequencing batch reactors (SBRs) were cultured respectively with acetic and propionic/acetic acid of 1/1 and 2/1 (carbon molar ratio).

2. Methods

2.1. Reactor set-up and operation

Biomasses were enriched in three lab-scale anaerobic/aerobic SBRs. The three SBRs, with working volume of 3.5 L each, were seeded with sludge from a wastewater treatment plant in Shanghai, China. This plant was operated with biological nutrient removal process. All SBRs in this study were maintained at 21 ± 1 °C and operated under anaerobic/aerobic (low DO) conditions with a cycle time of 8 h. Each cycle consisted of 2 h anaerobic and 3 h aerobic period, followed by 1 h settling, 10 min decanting and 110 min idle period. The synthetic wastewater (1.75 L) was pumped into the reactor during the initial 7 min of the anaerobic stage. In the aerobic (low DO) period, air was provided intermittently using an on/off control system with on-line DO detector to keep the DO level at 0.15–0.45 mg L^{-1}. 10 min before the end of aerobic stage, the sludge was wasted to keep the sludge retention time (SRT) at approximately 22 d. After settling, 1.75 L of supernatant was removed, resulting in a hydraulic retention time (HRT) of 16 h in three SBRs. The reactor was constantly mixed with a magnetic stirrer except for the settling, decanting and idle periods. The mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) in three SBRs were around 3500 mg L^{-1} and 2200 mg L^{-1}, respectively. It took about three months before a stable nitrogen and phosphorus removal was achieved in three SBRs.

2.2. Synthetic wastewater

The feed of 1.75 L of synthetic wastewater consisted of 0.09 L of solution A, 1.65 L of solution B and 0.01 L of SCFA aqueous solution. Solution A contained (per liter): 1 g $MgSO_4 \cdot 7H_2O$; 0.45 g $CaCl_2 \cdot H_2O$; 2.34 g NH_4Cl; 0.15 g peptone; and 6 ml of nutrient solution. Solution B contained (per liter): 29 mg KH_2PO_4 and 33 mg K_2HPO_4. One liter of nutrient solution contained: 1.5 g $FeCl_3 \cdot 6H_2O$; 0.15 g H_3BO_3; 0.03 g $CuSO_4 \cdot 5H_2O$; 0.18 g KI; 0.12 g $MnCl_2 \cdot 4H_2O$; 0.06 g $Na_2MoO_4 \cdot 2H_2O$; 0.12 g $ZnSO_4 \cdot 7H_2O$; 0.15 g $CoCl_2 \cdot 6H_2O$ and 10 g ethylenediamine tetraacetic acid (EDTA). The SCFA concentration in three SBRs is shown in Table 1. The feeding of three SBRs contained SCFA COD 300 mg L^{-1}, ammonium (NH_4^+–N) 35 mg L^{-1} and soluble *ortho*-phosphate (SOP) 12 mg L^{-1}.

2.3. Analytical methods

Activated sludge samples from three SBRs were immediately filtered through a Whatmann GF/C glass microfiber filter (1.0–1.5 μm pore size), and the filtrate was immedi-

Table 1
Composition of main carbon sources and their concentrations in three SBRs

Reactor	Acetic acid (mmol-C L^{-1})	Propionic acid (mmol-C L^{-1})	Propionic/Acetic (mol-C mol-C^{-1})
SBR-A	9.37	0	–
SBR-B	4.33	4.33	1/1
SBR-C	2.79	5.63	2/1