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Simultaneous denitrification and denitrifying phosphorus removal in a full-scale anoxic–oxic process without internal recycle treating low strength wastewater

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A B S T R A C T

Performance of a full-scale anoxic–oxic activated sludge treatment plant (4.0×10^5 m^3/day for the first-stage project) was followed during a year. The plant performed well for the removal of carbon, nitrogen and phosphorus in the process of treating domestic wastewater within a temperature range of 10.8°C to 30.5°C. Mass balance calculations indicated that COD utilization mainly occurred in the anoxic phase, accounting for 88.2% of total COD removal. Ammonia nitrogen removal occurred 13.71% in the anoxic zones and 78.77% in the aerobic zones. The contribution of anoxic zones to total nitrogen (TN) removal was 57.41%. Results indicated that nitrogen elimination in the oxic tanks was mainly contributed by simultaneous nitrification and denitrification (SND). The reduction of phosphorus mainly took place in the oxic zones, 61.46% of the total removal. Denitrifying phosphorus removal was achieved biologically by 11.29%. Practical experience proved that adaptability to gradually changing temperature of the microbial populations was important to maintain the plant overall stability. Sudden changes in temperature did not cause paralysis of the system just lower removal efficiency, which could be explained by functional redundancy of microorganisms that may compensate the adverse effects of temperature changes to a certain degree. Anoxic–oxic process without internal recycling has great potential to treat low strength wastewater (*i.e.*, TN < 35 mg/L) as well as reducing operation costs.

Introduction

Domestic wastewater contains compounds including nutrients and organic matter that if not properly treated, can increase water eutrophication (Gulati and van Donk 2002), alter the ecological balance of water systems, threaten aquatic organisms, and risk public health. Therefore, adequate removal of nutrient and organic matter removal are major concerns for wastewater treatment plants (WWTPs) that need to meet increasingly stringent discharge requirements. These increased requirements are often combined with needs to reduce the energy consumption and minimize operational costs of wastewater treatment (Guerrero et al. 2012; Plosz 2007). Many existing full-scale WWTPs must be adapted to improve the efficacy of existing processes or new treatment facilities must be designed and constructed; a better understanding of

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the process is essential to make systems more effective and efficient.

Conventional biological nutrient removal (BNR) processes require chemical oxygen demand (COD), which is often the limiting substrate in the incoming wastewater (Zeng et al. 2003). Several methods have been examined to enhance nitrogen removal, including internal carbon source addition (Biradar et al. 2010; Kampas et al. 2007; Park et al. 2011a) and external carbon source addition (Gong et al. 2013; Modin et al. 2007; Quan et al. 2005). However, carbon source addition could increase operation cost and carbon footprint. Simultaneous nitrification and denitrification (SND) is an attractive pathway for nitrogen reduction in comparison with traditional method because of saving carbon source and reducing aeration consumption. Zhao et al. (1999) found that the nitrogen loss due to SND in the aeration tank, contributed 10% to 50% of the total Kjeldahl nitrogen to the overall nitrogen removal.

As a method of removing phosphorus biologically by polyphosphate-accumulating organisms (PAOs) rather than chemically, enhanced biological phosphorus removal (EBPR) has stimulated much interest in the study of the removal mechanisms and the microbiology of the systems (Henze et al. 2008; Oehmen et al. 2007). Recent research has shown that phosphorus uptake in the presence of nitrate (*i.e.*, under anoxic conditions) does occur, and simultaneous denitrification and phosphorus removal can be achieved. Several denitrifying phosphorus removal systems have been developed including the sequencing batch reactor (SBR) system (Merzouki et al. 2001), the University of Cape Town (UCT) system (Kuba et al. 1997), and the Anaerobic/Anoxic/Oxic (A/A/O) multiple reactor system (Kishida et al. 2006; Xu et al. 2011). The importance and overall benefits of denitrifying PAO (DPAO) in activated sludge systems has also been widely recognized (Kuba et al. 1994). However, studies on DPAO's anoxic activities in full-scale anoxic/oxic (A/O) WWTPs are rare.

Plenty of intensive studies were carried out on the performance of full-scale BNR WWTP to evaluate the effect of operating parameters and environmental conditions on nutrient removal (Fernandes et al. 2013; Lopez-Vazquez et al. 2008). Nevertheless, the factors that may influence full-scale BNR WWTPs are far from being fully understood leading to unacceptable discharge levels of pollutants. Therefore, it is important to deepen the understanding of biochemical transformation and degradation processes in full-scale WWTPs and increase the detailed knowledge on the process and control.

Understanding the impact of temperature change on bioreactor performance could allow for the evaluation of the microorganisms' interaction with the environmental conditions. The wastewater treatment in A/O processes can contain a quite diverse microbial community whose activity depends on temperature for nutrient removal. The knowledge of the temperature involved in wastewater purification becomes relevant for the efficiency of treatment. However, the question of how temperature variation influence on the plant stability is an uncertain issue.

The objective of the present article is to evaluate the overall performance and wastewater characteristics may influence the carbon and nutrient removal at a full-scale BNR WWTP. These findings then are applied in a discussion of pollutant removal mechanisms and factors affecting plant performance. This work was performed to gain a better fundamental understanding of nutrient removal and to provide insights into new strategies for future optimization of this exciting technology.

1. Materials and methods

1.1. *Wastewater treatment plant*

The Jiangxinzhou full-scale WWTP in this study is in operation and treating domestic wastewater in Nanjing, central east China. A performance assessment of this WWTP was conducted recently, and design parameters are presented in Table 1.

The plant began operation in 1996, and was upgraded in 2003 to include BNR systems. The first-stage project has an average flow rate at 4.0×10^5 m^3/day. Wastewater from primary clarifiers (PCs) is fed to the anoxic tanks (ATs) with mechanical mixers, where denitrification takes place. In the oxic tanks (OTs), nitrification is performed, where adequate air is uniformly distributed across the length of the tanks with air diffusers. The settled sludge from the secondary clarifiers (SCs) is recycled to the head of the anoxic zones to keep the microbial biomass active. The excess sludge is disposed in the sludge treatment room and then transported outside. The sludge recycling flow rate was 0.8 times the influent flow rate at 3.2×10^5 m^3/day. The mixed liquor suspended solid (MLSS) varied from 3800 to 6000 mg/L in the biochemical pools. The total hydraulic retention time (HRT) of the wastewater in the system (including anoxic and aerobic zones) was 6.7 hr. The sludge retention time (SRT) was maintained at 8–12 days by controlling excess sludge. Dissolved oxygen (DO) concentrations in the anoxic and oxic zones were less than 0.25 mg/L and more than 0.50 mg/L, respectively. Fig. 1 shows a flow diagram of the biological treatment units of the WWTP.

Table 1 – Design parameters of the full-scale WWTP (the first-stage project).

Process unit	Volume (m^3) for each	Number	Depth (m)	HRT (H)	Main equipment
Aerated grit chambers	350	4	4	0.083	Jet aerator
Primary clarifiers	8333	4	4.7	2	Mud scraper
Anoxic tanks	7000	4	6	1.7	Mixers
Oxic tanks	21,000	4	6	5.0	Micropore aerators
Secondary clarifiers	6250	8	4.8	3	Mud scraper
Sludge thickening tanks	5000	6	10	720	None

WWTP: wastewater treatment plant; HRT: hydraulic retention time.