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Composition of extracellular polymeric substances in a partial nitrification reactor treating high ammonia wastewater and nitrous oxide emission

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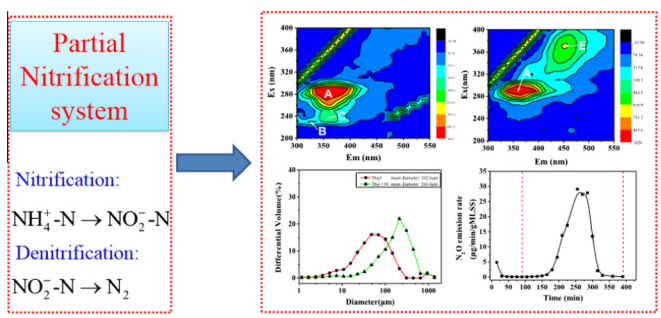
HIGHLIGHTS

- N-removal via nitrite was achieved in a SBR by controlling low DO.
- PN and PS contents increased during the achievement of PN.
- The key components of EPS changed according to 3D-EEM.
- N_2O emission accounts for 11.67% of removed nitrogen.

GRAPHICAL ABSTRACT



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ABSTRACT

The objective of this study was to characterize the composition of extracellular polymeric substances (EPS) during the achievement of partial nitrification and subsequent nitrous oxide (N_2O) emission treating high ammonia wastewater. After operation of 120 days, the reactor achieved high ammonia removal efficiency and stable nitrite accumulation. The average size of sludge flocs in the reactor increased from 102.6 to 258.5 μm. The main compositions of EPS, including protein (PN) and polysaccharide (PS), increased to 65.46 ± 3.27 and 21.63 ± 1.08 mg/g VSS, respectively. Results of three-dimensional excitation-emission matrix spectroscopy implied that EPS transferred to tryptophan PN-like and humic acid-like substrates. N_2O emission accounts for 11.67% of removed nitrogen during the steady state of partial nitrification reactor. The obtained results could contribute a better understanding the achievement of partial nitrification through the composition changes of EPS, and provide more information to determine nitrogen removal by considering N_2O emission.

1. Introduction

Recently, partial nitrification is regarded as one of new biological nitrogen removal processes based on the fact that nitrite is an intermediate compound in both nitrification and denitrification steps (Khin and Annachhatre, 2004). Compared with conventional nitrification–denitrification process, partial nitrification via nitrite (100% NH_4^+-N conversion to NO_2^--N) theoretically saves approximately 25% of oxygen consumption in aerobic nitrification stage, 40% of carbon source requirements in anoxic denitrification stage and achieves a lower sludge production (Peng and Zhu, 2006). Therefore, it plays an important role in the development of cost-effective and energy-saving nitrogen removal system, especially when treating high strength ammonia wastewater.

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The key operational strategy to achieve partial nitrification is the enrichment of ammonia oxidizing bacteria (AOB) and limitation-inhibition-washout of nitrite oxidizing bacteria (NOB). Many influencing factors have been reported to achieve partial nitrification, including dissolved oxygen (DO), solid retention time (SRT), temperature, free ammonia (FA) and free nitrous acid (FNA). It has been well reported that these factors are closely correlated with the production and component of extracellular polymeric substances (EPS). EPS are one of complex high-molecular-weight mixture of polymers, where the microorganisms are embedded and more or less immobilized (Lin et al., 2014). EPS are major composed of protein (PN), polysaccharide (PS), nucleic acid, lipids, and other components, carrying ionizable functional groups such as carboxyl, phosphoric, and hydroxyl groups in activated sludge, granular sludge, and biofilms (Wei et al., 2014a). Due to the distinct structure, EPS have a significant influence on the physicochemical properties of sludge in the field of wastewater treatment, including structure, surface charge, flocculation, settling properties, dewatering properties, and adsorption ability (Sheng et al., 2010). Feng et al. (2012) researched the influent chemical oxygen demand/nitrogen (COD/N) ratio on the effect of performance and membrane fouling in a submerged bioreactor, showing that the contents of EPS increased by increasing COD/N from 5 to 10. Wei et al. (2014a) evaluated the formation of aerobic granules for simultaneous treating nitrogen and phosphorus, indicating that the chemical compositions of sludge EPS were significantly changed during granulation process. Therefore, considering the important role of EPS in the function of biological wastewater treatment, it is essential to explore in-depth and identify the changes of major EPS components in order to better understand the achievement of partial nitrification process from the structure of EPS. However, until now, little information is available for this point.

Although partial nitrification has expressed great advantages in application, nitrite accumulation is commonly considered as an important factor causing nitrous oxide (N_2O) production (Ahn et al., 2011). N_2O is one of important greenhouse gases, whose global warming potential is more effective about 300 times than that of carbon dioxide. N_2O emission is produced in both nitrification and denitrification processes, in which is influenced by aeration, temperature, COD/N ratio and toxic compounds, etc. Li et al. (2013) investigated the influence of short-term organic shock loading on N_2O production during denitrifying phosphorous removal process, implying that N_2O-N production amount increased by switching influent COD concentrations. Therefore, it is desirable to research the N_2O emission in partial nitrification process in order to better understand the sources and mechanisms of N_2O production. However, limited research has been conducted to characterize N_2O emission of partial nitrification process treating high ammonia wastewater.

Based on the above discussion, the objective of this study was to: (a) evaluate the composition changes of EPS in a partial nitrification sequencing batch reactor (SBR); (b) investigate N_2O emission after the partial nitrification reactor reached to steady state. Three-dimensional excitation-emission matrix (3D-EEM) spectroscopy was used to characterize EPS samples under different stages. The obtained results could provide a better understanding of partial nitrification in the development of new biological nitrogen technology.

2. Methods

2.1. Experimental set-up

The experimental work was performed in a lab-scale SBR with a working volume of 3.4 L. The internal diameter and working height of the reactor were 12 and 30 cm, respectively. The influent wastewater was prepared in a storage tank (25 L) and introduced into the reactor using a water pump. Oxygen concentration was controlled between 0.3 and 0.8 mg/L by using an air diffuser at the bottom of reactor.

The reactor was operated by alternating anoxic and aerobic reaction with a successive cycle of 8 h each. Each cycle consisted of successive phases including: 5 min for filling influent, 85 min for anoxic process, 300 min for aeration reaction, 15 min for settling, 5 min for decanting the effluent and the rest of the time for idling. Idling time was used to control the HRT of the reactor depending on the requirement of treatment, as similar reported by Seesuriyachan et al. (2009). Moreover, it also has certain ability to enhance phosphorus removal but with low N_2O generation (Chen et al., 2014). The temperature was maintained at room temperature (25 °C).

2.2. Nitrogen-rich wastewater and seeding sludge

The synthetic nitrogen-rich wastewater was prepared as follows (mg/L): chemical oxygen demand (COD, as sodium acetate), 600 mg/L; NH_4^+-N (as ammonium chloride), 300 mg/L; K_2HPO_4, 112 mg/L; $CaCl_2$, 40 mg/L; $MgSO_4{\cdot}2H_2O$, 20 mg/L; $FeSO_4{\cdot}2H_2O$, 20 mg/L and trace element solution 1.0 ml/L. The composition of element solution could be found elsewhere (Wei et al., 2014b). The influent pH values were adjusted to 7.5–8.0 by using $NaHCO_3$ and HCl. The initial mixed liquor suspended solids (MLSS) concentration and sludge volume index (SVI) of seeding sludge in the reactor were 3.12 g/L and 135.4 mL/g, respectively.

2.3. EPS extraction

A heat extraction method was used to extract EPS samples and the detailed procedures of EPS extraction were described in a previous study (Li and Yang, 2007). The PS concentration was measured using the anthrone-sulfuric acid method using glucose as the standard (Frølund et al., 1996), while PN concentration in EPS was measured using the modified Lowry method using bovine serum albumin as the standard (Fr et al., 1995).

2.4. Analytical methods

To monitor the performance of reactor, NH_4^+-N, NO_2^--N, NO_3^--N, SVI were tested using the standard methods (APHA, 2005). The pH value and DO concentration were measured using a pH meter (PB-10, Sartorius scientific instruments Co. Ltd. Beijing) and a DO meter (WTW Multi 3420, Germany), respectively. The size distribution of a sludge floc was determined by using a laser scattering particle size distribution analyzer (LS13320, Beckman Coulter, Inc., USA). 3D-EEM spectra of EPS samples were measured using a luminescence spectrometer (LS-55, Perkin-Elmer Co., USA). The detailed spectra were set as emission wavelength (Em) from 300 to 550 nm at 0.5 nm increments by varying the excitation wavelength (Ex) from 200 to 400 nm at 10.0 nm increments. N_2O concentration was measured by a gas chromatography (SP-3410, China) with an electron capture detector (ECD) and a Poropak Q column, and the detailed method could be found in previous literature (Hu et al., 2011).

2.5. Calculations

The emission rate and quantity of N_2O were calculated using the following equation described by Hu et al. (2010). The N_2O-N conversion ratio was calculated by the following equation (Eq. (1)):