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Effects of tourmaline on nitrogen removal performance and biofilm structures in the sequencing batch biofilm reactor

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ABSTRACT

The effects of tourmaline on nitrogen removal performance and biofilm structures were comparatively investigated in two identical laboratory-scale sequencing batch biofilm reactors (SBBRs) (denoted SBBR1 and SBBR2) at different nitrogen loading rates (NLRs) varying from (0.24 ± 0.01) to (1.26 ± 0.02) g N/(L·day). SBBR1 was operated in parallel with SBBR2, but SBBR1 was filled with polyurethane foam loaded tourmaline (TPU) carriers and another (SBBR2) filled with polyurethane foam (PU) carriers. Results obtained from this study showed that the excellent and stable performance of SBBR1 was obtained. Ammonia nitrogen removal and total nitrogen removal were higher in SBBR1 than that in SBBR2 with increase of NLR. At an NLR of (0.24 ± 0.01) g N/(L·day), the majority of the spherical and elliptical bacteria were surrounded by the extracellular polymeric substance (EPS) and bacillus or filamentous bacteria in two SBBRs biofilms. When NLR increased to (1.26 ± 0.02) g N/(L·day), the clusters were more obvious in the SBBR1 biofilm than that in the SBBR2 biofilm. Bacteria in SBBR1 were inclined to synthesis more EPS, and the formed EPS could protect the bacteria from free ammonia (FA) under extreme condition NLR (1.26 ± 0.02) g N/(L·day). The results of polymerase chain reaction-denaturing gradient gel electrophoresis analysis showed that the microbial community similarity in SBBR2 decreased more obviously than that in SBBR1 with the increase of NLR, which the microbial community in SBBR1 was relatively stable.

Introduction

Biofilm process is one of biological nitrogen removal technology in wastewater treatment (Liang et al., 2010; Zou et al., 2016; Ahmad et al., 2017). Higher sludge retention time and different oxic and anoxic zones are advantages of biofilm systems for the slowly growing bacteria. Besides, biofilms provide better protection for the functional bacteria participating in the nitrogen removal (Zekker et al., 2017). During this process, the biological carrier has significant influences on the growth, structure, and activity of the biofilm. Therefore, the development of the new carrier has been a hot topic in the field of wastewater treatment. It is a good option to use highly porous three dimensional carriers, which could provide the desired microenvironment for microbial growth (Ali et al., 2015; Luo et al., 2016). Polyurethane foam (PU) as the carriers with high mechanical strength present the ideal performances in this regards for the growth of biomass (Le et al., 2016). Therefore, PU carrier has been extensively used in the wastewater treatment due to its physicochemical properties

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such as high porosity, appropriate pore size, low density, and so on (Li et al., 2016; Moawed et al., 2017). A biofilm reactor equipped with PU carriers has been proven as an efficient and inhibition-tolerant system to perform the nitrification and denitrification process (Tan et al., 2013).

Tourmaline is characterized by a cyclic structure of boron silicate mineral that possesses unique physical–chemical properties, including the continuously releasing the ions (Ca^{2+}, Mg^{2+}, *etc.*), producing an electrostatic field and releasing rare microelements (Fe^{2+}, Mn^{3+}, *etc.*) (Nakamura and Kubo, 1992; Emme et al., 2005). The general chemical formula of tourmaline can be written as $XY_3Z_6Si_6O_{18}(BO_3)_3W_4$, where X is Na, Ca, K, or vacancies; Y is Mg^{2+}, Fe^{2+}, Mn^{2+}, Al, Fe^{3+}, Mn^{3+}, or Li; Z is Al, Fe^{3+}, Cr^{3+}, or Mg; and W is OH, F, or O (Yavuz, 1997). The spontaneous and permanent pole is one of the most important properties of tourmaline, which can produce an electric dipole, especially in small granules with diameters of several microns or less (Liu et al., 2016). Tourmaline has been paid more attention in the environmental field in recent years. Many studies have attempted to combine tourmaline and PU into a single reactor (Yang et al., 2013; Tan et al., 2017). However, most studies mentioned above have focused on pollutant removal efficiency (Zhang et al., 2011), fast start-up of reactor (Yang et al., 2013), strategies to stabilize the process (Qiu et al., 2011), and bacteria activity (Wei et al., 2008; Wang et al., 2016; Tan et al., 2017). However, there are few reports related to the effect of tourmaline on biofilm structures and microbial community.

In this study, we focused on the comparative investigation of effects of tourmaline on sequencing batch biofilm reactors (SBBRs). The aims of this study were to (1) investigate the effects of tourmaline on the nitrogen removal performance, (2) investigate the effects of tourmaline on the biofilm structures, and (3) demonstrate population dynamics of the microbial community. The research is expected to provide useful information on enhancing the nitrogen removal process by tourmaline.

1. Materials and methods

1.1. Materials

The tourmaline in 0.4-μm-sized powder was purchased in Chifeng region (China). Polyurethane foam loaded tourmaline (TPU) carrier was prepared using waterborne polyurethane and tourmaline powder as described in our previous study (Yang et al., 2013). The loading of tourmaline powder was 150–175 kg/m^3 PU.

1.2. Reactor

The experiments were performed in two identical laboratory-scale SBBRs (denoted SBBR1 and SBBR2) and each reactor composed of plexiglass with heights of 50 cm and internal diameters of 30 cm corresponding to an effective volume of 35 L. The filling ratio of the carriers in SBBRs was 80%. SBBR1 was operated in parallel with SBBR2, but SBBR1 filled with TPU carriers and another (SBBR2) filled with PU carriers. The influent was pumped into a network of distribution holes at the bottom of biofilm system using a peristaltic pump, and the effluent was collected through the sampling hole at the middle of the system. The operational temperature of the reactors was maintained at 20°C by thermostatic water jackets.

1.3. Influent

In order to modify influent nitrogen loading rate (NLR) accurately, the reactors were fed with synthetic wastewater. Ammonia nitrogen was supplemented to mineral medium as required in the form of NH_4Cl. The concentrations used varied depending on the experimental periods. The unaltered compositions of synthetic wastewater in this study were (in g/L): glucose 0.35, KH_2PO4 0.01, $CaCl_2{\cdot}2H_2O$ 0.00565, $MgSO_4{\cdot}7H_2O$ 0.3, $KHCO_3$ 1.25, $FeSO_4$ 0.00625, EDTA 0.00625 (Trigo et al., 2006), and 1.25 mL/L of trace elements solution (van de Graaf et al., 1996). The pH of the synthetic wastewater was adjusted between 7.5 and 7.8 by 1 mol/L HCl and 1 mol/L Na_2CO_3 before feeding into the reactors.

1.4. DNA extraction and PCR-DGGE analysis

Biofilms were detached from TPU and PU by 1-min sonication (45 W, 50/60 Hz). Genomic deoxyribonucleic acid (DNA) from the above biomass was extracted using a Bacterial Genomic DNA Extraction Kit (50 T, TaKaRa, China) according to the supplier instructions. In order to reveal the population dynamics in both reactors, the microbial community structure of these biofilm were investigated by polymerase chain reaction-denaturing gradient gel electrophoresis (PCR-DGGE) analysis. The V3 regions of 16S rDNA genes were amplified using universal primers F_{338} GC (5′-CGCCCGCCGCGCGCGGCGGGCGGGGCGGGGGCACGGGGGGA-CTCCTACGGGAGGCAGCAG-3′) and R_{518} (5′-ATTACCGCGGCTGC TGG-3′) as previous report (Tan et al., 2013). A gel document system equipped with a digital graphic printer (UP-897MD, Sony, Japan) was used to visualize the PCR-DGGE band profile. DGGE profiles were analyzed by Quantity One 4.3.0 (DGGE gel image analysis software, Bio-Rad, USA) at different operational periods. Bands with a relative intensity of less than 0.2% of the sum of all band intensities were discarded. Similarity matrix on the DGGE profiles were calculated according to Dice coefficients.

1.5. Experimental process

According to the influent NLR, the whole operational process of both the reactors was divided into four periods, namely, period-I, II, III, and IV. The reaction was performed with the progressively increasing nitrogen loadings (Table 1). As the seeding sludge was inoculated with activated sludge obtained from a biological tank of Taiping municipal wastewater treatment plant, the start-up period of SBBRs wouldn't need an adaptive period. The seeding sludge was brown with loose morphology, mean size of (82.5 ± 6.4) μm, and sludge volume index after 30 min of sedimentation (SVI_{30}) of (71.6 ± 5.5) mL/g. The seeding sludge had a total suspended solids (TSS) concentration of (6260 ± 211) mg/L and volatile suspended solids (VSS) concentration of (4650 ± 175) mg/L, corresponding to a VSS/TSS ratio of 74.3%. For these two reactors, each operational cycle consisted of 10-min feeding, 180-min aerobic reaction, 40-min settling, and 10-min decanting. Wastewater in these reactors was intermittently aerated by an air-blower to improve oxygen transfer to wastewater, in which the dissolved oxygen was adjusted to a

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