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Study on nitrogen removal performance of sequencing batch reactor enhanced by low intensity ultrasound

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ABSTRACT

Sequencing batch reactor (SBR) was widely used in the treatment of various wastewater. The effects of low intensity ultrasound on the nitrogen removal performance of SBR were studied. The optimum operation conditions were determined to be 35 kHz, 0.15 W cm^{-2}, and irradiation time of 10 min. Compared with those of the control reactor, the organic, NH_4^+-N, NO_2^--N and NO_3^--N loads of the ultrasound enhanced reactor (UER) were improved by 16.5%, 35.0%, 41.7% and 61.9%, respectively. Increased 2,3,5-triphenyl tetrazolium chloride-dehydrogenase and nitrification activities were observed with sludge in UER. Furthermore, negligible negative effects of ultrasound irradiation on the settle ability and sludge concentration were found, which resulted in no decrease of the nitrogen removal performance of the UER.

1. Introduction

More and more domestic wastewater was generated with elevating population in cities and exceeded the assimilative capacities of some natural environments. There are generally high concentrations of nitrogen and phosphorus present in the domestic wastewater. The discharge of these nutrients into natural water systems promotes the growth of algae and results in eutrophication of lakes and streams (Debik and Manav, 2010). Therefore, nitrogen and phosphorus removal from domestic wastewater has attracted more interests recently (Coats et al., 2011; Ge et al., 2010; Rodríguez et al., 2011; Shi et al., 2011).

Sequencing batch reactor (SBR) has been widely used as an alternative to the conventional activated sludge process for both organic matter and nitrogen removal (Rodríguez et al., 2011; Shi et al., 2011). The removal of nitrogen in the SBR system can be achieved by alternating aerobic and anoxic periods during the reaction to complete the nitrogen removal (Mahvi, 2008). During the processes of nitrogen removal, ammonia was converted to nitrite, and then to nitrate (nitrification) in the presence of the oxygen (Budakoglu and Pratt, 2005; Koops and Pommerening-Roser, 2001). Subsequently, nitrate was reduced to nitrogen and/or nitrogen oxide (denitrification) in the absence of the oxygen (Bamforth and Singleton, 2005). Previous study indicated that stable partial nitrification performance (NO_2^- accumulation ratio higher than 90%) could be obtained in SBR (Guo et al., 2010). In addition, nitrification rates between 0.11 and 0.18 g NH_4^+-N g VSS^{-1} d^{-1} were obtained for real industrial wastewater treatment using SBR (Carrera et al., 2003).

Recently, some studies have indicated that ultrasound could be used to enhance the performance of wastewater treatment (Ji et al., 2010; Sangave and Pandit, 2004; Xiang et al., 2005; Yoon et al., 2004). Ultrasound is defined as acoustic energy or sound waves with frequencies above 20 kHz. It was suggested that low frequency ultrasound could increase the transport of oxygen and nutrients to the cells and the transport of waste products away from the cells, thus enhancing the growth and activities of microbial cells (Pitt and Ross, 2003). In recent years, many researchers employed low frequency (<100 Hz) and low intensity (<2 W cm^{-2}) ultrasound for excess sludge reduction (Liu et al., 2005; Pitt and Ross, 2003; Tiehm et al., 2001). It was observed that at short ultrasound application time, sludge floc agglomerates were dispersed without cell destruction. However, at longer treatment time or higher ultrasound intensities, the microbial cell wall was broken and intracellular materials were released to the liquid phase (Tiehm et al., 2001).

Currently, however, studies of the effects of low intensity ultrasound on nitrogen removal are rarely reported. In this study, the effects of low energy ultrasound irradiation on nitrogen removal from domestic wastewater were investigated in an SBR. The optimum frequency, intensity and irradiation time of ultrasound treatment were determined. The parameters of water (the organic, NH_4^+-N, NO_2^--N and NO_3^--N loads in influent and effluent) and properties of sludge (sludge volume index (SVI), mixed liquor suspended solid (MLSS), 2,3,5-triphenyl tetrazolium chloride (TTC)-dehydrogenase)

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and nitrification activities of the sludge were investigated to reveal the ultrasonic effects on nitrogen removal.

2. Methods

2.1. Experimental apparatus and parameters

The ultrasound enhanced reactor (UER) had a working volume of 10 L, and contained 3–5 g L^{-1} sludge. The reactor was aerated with an air pump through aeration tubes set at its bottom. The ultrasound transducer was set at the bottom of the reactor and powered by the ultrasound generator (SK5200 LHC, Sonics and Materials Inc., Shanghai), which was operated at frequencies of 35 kHz or 53 kHz, various intensities (0–0.17 W cm^{-2}) and irradiation time (2–15 min). An additional SBR that without ultrasound treatment was used as a control.

The operation cycle of the system was 5.5 h, of which 3 h was for aeration and 2 h was for sludge settling. Dissolved oxygen (DO) in SBR was kept at 2.0–5.0 mg L^{-1}. COD, NH_4^+-N, NO_2^--N and NO_3^--N loads in influent and effluent, and parameters of the sludge, including SVI, MLSS, TTC-dehydrogenase and nitrification activities of the sludge were measured in each operation cycle.

2.2. Experimental procedures

Ten liters of synthetic domestic wastewater was fed into the reactors. And the reactor operation consisted of three phases and was briefly summarized in Table 1.

2.3. Characteristics of seed sludge and wastewater

The seed sludge was collected from the secondary clarifier of the Chunliu River municipal wastewater treatment plant in Dalian. The synthetic wastewater was prepared as follows, 300–450 mg L^{-1} glucose, 45.4–200 mg L^{-1} NH_4Cl, 1.75 mg L^{-1} $CaCl_2$, 2.3 mg L^{-1} $MgCl_2$, pH 7.5–8.0.

2.4. Analytical and calculating methods

The analyses of COD, NH_4^+-N, NO_2^--N, and NO_3^--N were performed according to standard methods (APHA, 2005). The measurement of DO was carried out with a dissolved oxygen meter (Mottler-Toledo, YSI-SG6).

TTC was used as a hydrogen receiver in cell respiration, which would be reduced to red triphenyl formazone (TF). After cultivation of the sludge, 2 mL sludge was sampled from the UER and the control reactor, and added to tubes containing 1.5 mL Tris–HCl buffer (pH 8.4, 0.05 M), respectively. Then the sludge samples were treated with 0.5 mL TTC (0.4%), and 0.5 mL 1% glucose solution for measurements of exogenous dehydrogenase activities or 0.5 mL water for measurements of endogenous dehydrogenase activities. After mixing, the sample tubes were placed into a shaker (150 rpm, 35 °C) for 2 h. A drop of sulfuric acid (98%) was added to sample tubes after the reaction finished. Five microliters of methylbenzene was supplemented to the sample and control tubes separately. All samples were mixed thoroughly and extracted for 10 min. The absorbance values of sample supernatants determined at 486 nm were used to calculate the TTC-dehydrogenase activities of the samples (μg TF(g MLSS $h)^{-1}$) according to a standard curve.

Floc rupture was measured by analyzing the particle sizes of the ultrasound-treated and -untreated sludge, with a laser particle size analyzer (Malvern size 2000, Germany). Particle size was analyzed by the volume weighted mean.

Specific oxygen uptake rate (SOUR) measurement setup consisted of a 150 mL bottle, a dissolved oxygen meter and a magnetic stirrer. Prior to a test, a portable air pump was activated to inject air into the setup so as to maintain a high initial DO level. All the tests were conducted for 15 min when the DO concentration was lower than 1 mg L^{-1}. Once the test was completed, the suspended solid concentration in the setup was analyzed. From the DO reduction slope and the suspended solid concentration measured, the SOUR value of the sewage phase was then determined using SOUR = 60*f*/MLSS, where *f* is the ratio of DO (Rai et al., 2004).

The ammonia oxidation rate and the nitrite oxidation rate were measured to identify the nitrification activity of the sludge. And the oxidation rates were monitored separately by dosing with the selective inhibitors allythiourea (ATU) and sodium chlorate ($NaClO_3$) during the respirometer monitoring. The respirometer was first operated with the mixed liquid samples of the sludge. Twenty millimole of $NaClO_3$ and 5 mg L^{-1} ATU were injected into the samples when the DO was reduced to 3 mg L^{-1} and 2 mg L^{-1}, respectively (Kim et al., 2001). The ammonia oxidation rate and the nitrite oxidation rate were defined as:

$$\text{ammonia oxidation rate} = \text{SOUR}_1 - \text{SOUR}_2 \quad (1)$$

$$\text{nitrite oxidation rate} = \text{SOUR}_2 - \text{SOUR}_3 \quad (2)$$

where $SOUR_1$ was the total SOUR of the sludge, $SOUR_2$ was the SOUR obtained after the addition of the $NaClO_3$ to the sludge, $SOUR_3$ was the SOUR obtained after the addition of the $NaClO_3$ and ATU to the sludge.

3. Results and discussion

3.1. Effects of ultrasound frequency, intensity, irradiation time, irradiation cycle on wastewater treatment

After the activated sludge was treated with ultrasound for 10 min at an intensity of 0.15 W cm^{-2}, organic loads varied at different ultrasound frequencies. Compared with that of the control reactor (363.4 mg COD (g MLSS $d)^{-1}$), the organic load was increased by 44.0% at a frequency of 35 kHz. However, when the frequency was increased to 53 kHz, the organic load decreased by 20.0%. Low frequency ultrasound might improve the growth of microbial cells through increasing the transport of oxygen and nutrients to the cells, and the transport of waste products away from the cells (Pitt and Ross, 2003). High frequency ultrasound could kill microbial cells in the sludge, shatter the sludge granular, and thus decline the settle ability of the sludge. Thus, 35 kHz was chosen as the optimal ultrasound frequency.

Generally, high-intensity ultrasound could restrain biological activity and destroy microbial cells, and low intensity ultrasound treatment could enhance biological activity. However, extremely

Table 1
Procedures at each stage of operation of UER and the control reactor.

Phase	Running conditions
I. Sludge acclimation (days 1–30)	3–5 g L^{-1} Sludge, 300–450 mg L^{-1} COD, 15–20 mg L^{-1} NH_4^+-N
II. Optimization of ultrasound conditions (days 30–100)	35 kHz or 53 kHz, 0.11–0.17 W cm^{-2}, 2–15 min irradiation
III. Stable operation under optimum ultrasound conditions (days 100–160)	35 kHz, 0.15 W cm^{-2}, 10 min irradiation