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Alternating shortcut nitrification-denitrification for nitrogen removal from soybean wastewater by SBR with real-time control *

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Abstract: A novel treating technology for nitrogen removal from soybean wastewater was studied. The process for nitrogen removal was achieved by alternating aeration and mixing, combined with real-time control strategies. Results showed that the COD and total nitrogen removal rates are more than 90% and 92% at COD and total nitrogen loads of 1.0 - 1.2 kg COD/(kgMLSS·d) and 0.20 - 0.27 kg TN/(kgMLSS·d), respectively. In addition, it could improve sludge settling property. *SVI* value is less than 70 g/ml during the whole cycles. The method not only may be adapted to treat soybean wastewater with high nitrogen, but also may be applied to treat other high nitrogen wastewater.

Keywords: real-time; shortcut nitrification-denitrification; ORP; pH; SBR

Introduction

The removal of nitrogen from wastewater has become one of the most important concerns in water pollution control. Biological nitrification and denitrification have been the most available process for removal of ammonium from wastewater. In general, nitrification requires an aerobic environment for oxidation of ammonium to nitrite (phase Ⅰ) and then to nitrate(phase Ⅱ), whereas, denitrification occurs by utilizing electron donors under an anoxic condition. Therefore, the conventional treatment processes are achieved either by separate aerobic and anoxic reactors or by temporal division of the condition in case of a one-sludge system such as the sequencing batch reactor. However, it was reported recently that there were many problems in constructing and operating these wastewater treatment plants by applying above technologies. The outstanding problems of them were higher construction investment and operational cost. Up to now all efforts aimed at optimization of both processes had in view the selection of the proper parameters allowing for full nitrification and denitrification. These measures result in very low concentration of intermediate products of both processes, for instance nitrite nitrogen. A lot of research carried out explained which mechanisms are responsible for stimulation and inhibition of particular phases of both processes. This gives an extra new possibility consisting of shortening of nitrification and denitrification(Alleman, 1984). This shorter nitrification consists of inhibition of activity and grown of Nitrobacter bacteria. In consequence, phase Ⅱ nitrification has been eliminated and the nitrification process has been shorten from the oxidation of ammonia nitrogen only to nitrite nitrogen. Next shorter denitrification occurs and nitrite nitrogen is reduced to free nitrogen. So the traditional phase Ⅰ of nitrate nitrogen reduction to nitrite nitrogen has been avoided(Joanna, 1997). Shortcut nitrification-denitrification has much more advantage in comparison with the traditional method of nitrogen removal (Hellinga, 1998; Mulder, 2001). This method can save energy source, organic carbon and alkalinity, and shorten reaction time and reduce the amount of excess sludge production(van Dongen, 2001; van Kempen, 2001).

In the biological reactors, protons and hydroxyl ions are currently exchanged and ORP of ionic species can also be changed. During the anoxic phase, pH increases due to the production of hydroxyl ions that can mask the impact of the production of carbon dioxide. So the oxidation-reduction potential(ORP) and pH are the widest diffused parameters for on-line monitoring and control of activated sludge process, and instruments and sensors are easy to be used and the low costs(Spagni, 2001; Li, 2002).

The specific objective of this study was to investigate feasible operation condition and real-time control strategy based on alternating shortcut nitrification-denitrification. At present, shortcut nitrification-denitrification was studied seldom for specific industry wastewater, and synthetic wastewater was used in majority research. And the study of shortcut nitrification-denitrification for strong nitrogen soybean wastewater was not reported. Based on the objective, sequencing batch reactor(SBR) was selected in this research, and traditional technology of nitrogen removal from soybean wastewater by SBR and the new technology of that by using alternating shortcut nitrification-denitrification in SBR process

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were investigated. Alternation shortcut nitrification-denitrification was controlled by fixed-time and real-time. The oxidation-reduction potential (ORP) and pH on-line monitoring parameters were selected to develop a feasible sequential control strategy of alternating shortcut nitrification-denitrification.

1 Materials and methods

Raw wastewater taken from the soybean mill was used as influent feed. The seeding sludge for the laboratory reactors was taken from the Waste Water Treatment Plant of Harbin City. Sometimes, nutrition concentration of influent feed was adjusted by adding tap water to the raw wastewater. Owing to bicarbonate alkalinity is deficient in soybean wastewater, sodium bicarbonate was added so as to increase alkalinity in the raw wastewater. During the experiment, the concentration of soluble COD and ammonia in influent wastewater was maintained at 350 to 400 mg/L and 55 to 57 mg/L(TN is about 90 mg/L), respectively. At the moment, the concentration of free ammonium is less than 2 mg/L, and pH is about at 6.5.

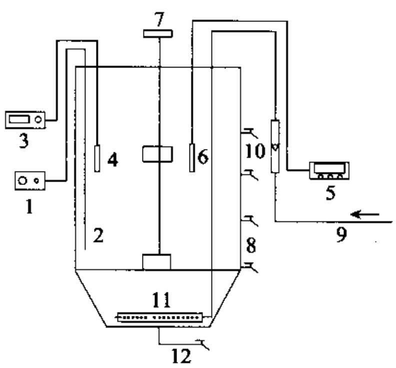

Fig.1 The schematic diagram of experimental system with control equipment in SBR process

1. temperature controller; 2. temperature probe; 3. pH meter; 4. pH probe; 5. ORP meter; 6. ORP probe; 7. mixer; 8. outlet; 9. compressed air; 10. air flow controller; 11. air diffuser; 12. waste sludge

Continuous studies were performed in three identical bench-scale reactors. The reactors are made of acrylic fiber plastics and have a working volume of 38 L(Fig.1). An air compressor was used for aeration. A mechanical mixer was used to provide liquid mixing when the compressor stopped working. During the reaction, ORP(Ag/AgCl as reference) and pH were continuously monitored and recorded. The temperature in reactor was kept at 28 ± 0.5℃. According to the variations of ORP and pH, these batch tests involved a time series of filtered samples for COD, NH_3-N, NO_2-N, NO_3-N, MLSS and alkalinity. Chemical analyses were carried out according to Standard Methods(APHA, 1995).

2 Results and discussion

In order to optimize and select operation condition, three kinds of operation condition were applied for nitrogen removal from high nitrogen soybean wastewater, of which one is operated by traditional shortcut nitrification-denitrification, the others are operated by shortcut nitrification-dentrification under alternation oxic-anoxic. Alternating oxic-anoxic was controlled by fixed-time and real-time control, respectively. Three kinds of operation condition were compared in aspect of nitrification and denitrification rates; as a result, the optimal operation condition was developed for nitrogen removal from high nitrogen soybean wastewater. Operating conditions in each method for nitrogen removal is outlined in Table 1.

Table 1 Operating conditions in each method for nitrogen removal

The method for nitrogen removal	Operation condition
Traditional shortcut nitrification-denitrification in SBR process	Filling → aeration(11 h) → mixing(1 h) → settling(0.5 h) → decanting (0.5 h)
Shortcut nitrification-dentrification controlled by alternating oxic-anoxic under fixed-time	Filling → aeration(4 h) → mixing(0.5 h) → aeration(3.5 h) → mixing(1 h) → settling(0.5 h) → decanting(0.5 h)
Shortcut nitrification-dentrification controlled by alternating oxic-anoxic under fuzzy control	Filling → aeration and mixing time controlled by the change of ORP and pH in SBR → settling(0.5 h) → decanting (0.5 h)

2.1 Traditional operation condition

The result of traditional shortcut nitrification-denitrification is shown in Fig.2. During one hour after reaction, nitrification was not happened according to NOx-N concentration in SBR, also the NH_3-H and COD concentration were removed due to assimilation. With continuing aeration, nitrification begin to be happen, and nitrosation rate(NO_2-N/NOx-N) was more than 50%, so the type of nitrification in this study belonged to nitrification via nitrite. The nitrosation rate (NO_2-N/NOx-N) was not basically changed when nitrification go to end. Total reaction time is about 720 min during traditional nitrification and denitrification. However, Fig.2 shows that nitrification has been finished at 550 min, at the moment, NH_3-H concentration in SBR approximated to 0 mg/L, and NO_2-N and NO_3-N concentration reached to maximum. So the time about 110 min was wasted. Owing to excess aeration not only wastes energy source but also can influence the characteristic of activated sludge. To study and develop real-time control strategy of shortcut nitrification-denitrification is important.

2.2 Alternating oxic-anoxic under fixed-time

The result of alternating shortcut nitrification-denitrification under fixed-time control is reported in Fig.3. Whole process of nitrification-denitrification in SBR was divided into two stages, each stage contains a process of nitrification-denitrification. A new phenomenon was discovered in this study, namely, COD and NH_3-H concentration were decreased during the first mixing(Fig.3), in this way, the second aeration time will be shorten. On the other hand, alkalinity produced by mixing will be reused during the second aeration, and the alkalinity will quicken

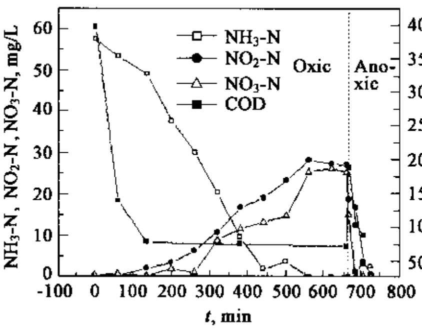

Fig.2 Shortcut nitrification-denitrification in SBR

the rate of nitrification. So shortcut nitrification-denitrification under alternating oxic/anoxic save about 120 min compared with traditional operation condition. However, it also brings some problem in operating and management. If aeration and mixing time are designed inconsequently, the effluent will be influenced.

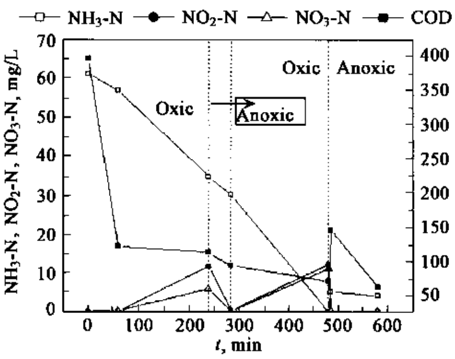

Fig.3 Nitrification-denitrification via nitrite by alternating oxic/anoxic under fixed-time control

2.3 Alternating oxic-anoxic under real-time control

For solving above problem, on the previous works (Gao, 2002; 2003), a real time control strategy was developed for alternating oxic/anoxic process instead of fixed time control. Research results showed the end of nitrification is denoted when pH in reactor changes from fall to platform or rise and ORP changes from rise to platform, at the same time, the end of denitrification is denoted when pH change from rise to platform or fall (Fig. 4). On the basis of collecting and analyzing numerous experiment data, and based on the change of ORP and pH in reactor, an real-time controller was built. Through real-time controller, accurate and stable treating method for high nitrogen soybean wastewater was performed after 10 cycles. Results are shown in Fig. 4. Alternating oxic/anoxic can be reasonably controlled by real-time control. Under the same treatment effect, total reaction time of this operation pattern is merely 460 min.

2.4 Comparison among three kinds of operation condition

In order to appraise the three kinds of operation condition accurately, rates and time of nitrification and denitrification were calculated, respectively. Results are

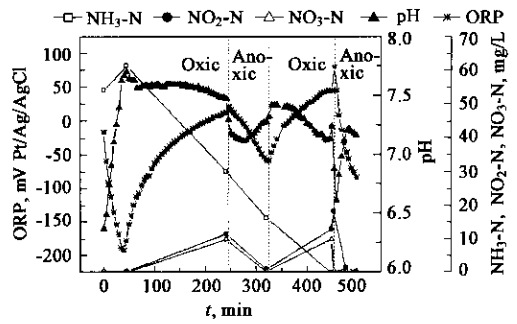

Fig.4 Shortcut nitrification-denitrification by alternating oxic/anoxic under real-time control

shown in Table 2. Nitrification-denitrification via nitrite by alternating oxic/anoxic under real-time control is the best. Its nitrification rate was 1.29 times of traditional SBR process and 1.23 times of alternating oxic/anoxic controlled by fixed time. But its denitrification rate was lower than traditional SBR process. In addition, its nitrification time is shortest, which saved 190 min and 65 min than traditional SBR and alternating oxic/anoxic controlled by fixed time, respectively. Conclusion, using ORP and pH as real-time control parameters for alternating shortcut nitrification-denitrification process is feasible, and the new technology not only improve nitrification rate (Table 2), but also reduce operation cost and construction invest.

Table 2 Observed nitrification and denitrification rates

Technology	Nitrification		Denitrification	
	Rate	Time, min	Rate	Time, min
Traditional nitrification-denitrification via nitrite in SBR process	0.0268	560	0.2268	65
Alternating nitrification-denitrification via nitrite controlled by fixed-time	0.0282	435	0.0802	145
Alternating nitrification-denitrification via nitrite controlled by ORP and pH	0.0373	325	0.1419	90

Notes: unit for all rates in mg NOx-N/(g MLSS·min)

In the activated sludge process, the sludge settling property is very important to wastewater treatment plants. However, the characteristic of activated sludge will be changed by competitive growth of flocforming bacteria and filamentous bacteria. Sludge bulking was occurred easily at low organic loading condition through previous research (Wang, 2000). Furthermore, excess aeration is prone to bring low organic loading, so the sludge settling property will be influenced under lasting aeration in SBR. Aim at this problem, a test was carried in above three reactor (Fig.5). Results showed that the sludge settling property of alternating shortcut nitrification-denitrification controlled by ORP and pH was the best, and *SVI* value was less than 70 g/ml. Traditional shortcut nitrification-denitrification was the worst, and *SVI* value was more than 110 g/ml, and with the amount of cycles increased, *SVI* value increased gradually (Fig.5). The sludge settling property of alternating shortcut nitrification-denitrification controlled by fixed time was in the middle of them. So sludge settling property could be improved by alternate aeration and mixing.

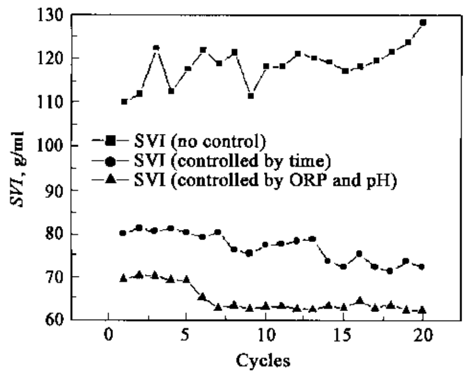

Fig.5 Effect of different control pattern on *SVI*

3 Conclusions

The shortcut nitrification-denitrification was performed in three kinds of operation condition, and removal rate for nitrogen is very high when the concentration of free ammonium is not high (< 2 mg/L); pH is at 6.5; temperature in reactor is at 28 ± 1 ℃.

In three kinds of operation condition, shortcut nitrification-denitrification under alternating oxic/anoxic is the better in comparison with traditional nitrification-denitrification, which of alternating oxic/anoxic under real-time control is the best. This operation pattern not only can improve both nitrification and denitrification rates and decrease total reaction time, but also, saves the amount of adding carbon source and alkalinity. In addition, it could improve sludge settling property.

The change of ORP and pH denotes the process of nitrification and denitrification. So on-line monitoring the change of ORP and pH in reactor can control the course of shortcut nitrification-denitrification when using ORP and pH as real-time control parameter. Real-time control aeration and mixing time can shorten reaction time and save operation cost.

The COD and total nitrogen removal rate were more than 90% and 92% at COD and total nitrogen loads of 1.0—1.2 kgCOD/(kgMLSS·d) and 0.20—0.27 kgTN/(kgMLSS·d) during shortcut nitrification-denitrification under alternating oxic/anoxic by real-time control.

Shortcut nitrification-denitrification by alternating oxic/anoxic under real-time control not only may be adapted to treat soybean wastewater with high nitrogen, but also may be applied to treat other high nitrogen wastewater.

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