Experimental study on shortcut simultaneous nitrogen removal in treating domestic sewage

ZHENG Pengsheng*, XIAO Yan, YANG Jianchao, HONG Fei
Hangzhou Research Institute of China Coal Technology & Engineering Group, Hangzhou, Zhejiang, China
Corresponding author: zhengpengsheng@126.com

Abstract. To treat domestic sewage with high efficacy and low cost, the technology of shortcut simultaneous nitrogen removal was used with a new biofilm reactor. The influences on nitrogen removal effect by start-up procedure, nitrogen transformation characteristics and main factors (hydraulic retention time, dissolved oxygen, carbon-nitrogen ratio) were analyzed. The results indicate that: The reactor finished start-up of shortcut simultaneous nitrogen removal in 14 days of cultivation time after the biofilm cultured in the carrier. The ammonia nitrogen removal rate, simultaneous nitrification-denitrification rate and cumulative nitrite nitrogen rate respectively reached 91.3%, 82.7% and 63.4% in the last phase of start-up procedure. To remove ammonia nitrogen with the technology of shortcut simultaneous nitrogen removal efficiently and steadily, hydraulic retention time, dissolved oxygen, carbon-nitrogen ratio should be controlled in 3.56 hours, 1.5 mg/L and 5~8.

1. Introduction
At present, the effluent water quality of domestic sewage treatment plants generally meets Class A of Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB 18918-2002). Common nitrogen removal technology includes A/O, A^2/O, SBR, oxidation ditch, bio-contact oxidation and BAF [1]. The effluent of secondary biochemistry used the conventional technology contains a certain amount of organics, nitrogen and phosphorus. Organics and phosphorus can be removed by advanced treatment, but the nitrogen removal still relies on the biological treatment unit [2]. Shackled by low carbon-nitrogen ratio and simple technology form, conventional biological treatment technology is facing many problems such as inefficiency, long hydraulic retention time (HRT), high energy consumption and incapable resistance shocking [3]. Drug consumption will rise if the deficiency of raw water is only supplied with adding external organic carbon source [4]. To further improve treatment efficiency, running mode and combination form are researched by many scholars. Although the pollutant burden and stability were improved, the problems of energy consumption and cost aren’t solved [5]. Nitration process is controlled in the nitrite nitrogen stage via shortcut nitrification and denitrification, so the oxygen demand, carbon source and sludge production can be reduced in the percentage of 25%, 40% and 24%~40% [6]. The research about shortcut nitrification and denitrification focused on SBR. Shortcut nitrification and denitrification is realized in discontinuous running of SBR, and the control method is agile. On the other hand, there are many unresolved problems such as high idle rate of the equipment, complex control method and long HRT [7]. Case about shortcut nitrification and denitrification under the condition of continuous flow was rarely seen. In fact, reactors with continuous
flow have advantages in stability and operation guidance. Therefore, in order to simplify process flow and increase the capacity, we take advantages of shortcut and simultaneous nitrification and denitrification to develop biofilm reactors with continuous flow.

2. Materials and methods

2.1 Test device
As shown in Figure 1, the reactor of shortcut simultaneous nitrogen removal was made with organic glass. The reactor is configured with regulating tank, thermostat, electromagnetic fan, peristaltic pump and online monitoring equipment. The total volume and biocarrier area volume are respectively 432 L and 252 L. The sewage was initially introduced into the regulating tank, and pumped into the reactor after appropriate compound. The biocarrier area filled with porous carrier at the filling rate of 60%. The thermostat was used to control reaction temperature. To keep proper dissolved oxygen (DO) concentration, air was delivered into the reactor through aeration pipe by rotary fan. Excess sludge was discharged through mud pipe at regular intervals. The DO and pH were monitored by online monitoring equipment.

Fig.1 Experimental device of shortcut simultaneous nitrogen removal

2.2 Test method
The test water was acquired from regulating reservoir in a domestic sewage treatment station. The raw water quality during the test period: NH$_4^+$-N 26.9~37.6 mg/L, TN 27.2~38.8 mg/L, TP 1.86~2.45 mg/L, COD 142~189 mg/L, pH 7.56~7.81. In the reactor start-up phase, after inoculation with compound microbial inoculum, the aeration begun. After the biofilm cultured in the carrier, the inlet water flow was gradually increased according to the actual treatment effect of the reactor. In the stable operation stage, the influent flow rate was 100 L/h (HRT=3.56h), and the DO concentration was controlled to 2±0.2 mg/L. The removal effect of the reactor on the main pollutants was analyzed. In the parameter optimization stage, the treatment effect was further optimized by adjusting the adjustment of HRT, DO and carbon-nitrogen ratio.

Analysis and test methods: NH$_4^+$-N, TN, COD and TP were determined by Nessler reagent colorimetry, TNT persulfate digestion method, rapid digestion spectrophotometry and ammonium molybdate spectrophotometric method.

3. Results and discussion

3.1 Start-up procedure analysis
Under the conditions that HRT, DO and temperature were respectively controlled in 3.56 hours, 1.2~2 mg/L and 25±1°C, the nitrogen removal effect is shown in Fig.2. In the initial phase of acclimation,
the removal rate of ammonia nitrogen reached 95.7% and the effluent ammonia nitrogen met Class A of GB 18918-2002. On the other hand, the nitrification-denitrification rate (SND rate) and cumulative nitrite nitrogen rate (NAR) still remained to rise. After continuous influent acclimation for 14 days, the nitrogen removal could be efficiently actualized by shortcut simultaneous nitrogen removal. To further improve the simultaneous nitrification-denitrification rate (SND rate) and cumulative NAR, the DO concentration was gradually reduced from 2mg/L. Different from the traditional way of nitrogen removal, nitrification and denitrification both happened in this reactor without sequencing batch. Under continuous aeration and DO control, organic carbon source of the sewage was utilized in denitrification for the existence of microcosmic anoxic zone about interior bio carrier (Fig.3). Moreover, SND rate could be increased from 68.0% to 82.7% with the biomembrane enhancement. Rapid start is emphasis and difficulty of shortcut nitrogen removal technology. In the acclimation test, NAR could be increased from 26.5% to 63.4% at normal operating temperature. Differentiate from activated sludge method, DO area distribution was optimized by porous carrier. Aerobic zone, internal anoxic zone and internal anaerobic zone formed in this reactor. Ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB) were enriched in aerobic zone while the denitrifying bacteria reproduced in anoxic zone. Existing analysis indicates that AOB and NOB can respectively well breed in pH range of 7.0~8.5 and 6.0~7.5[8]. Basic conditions are available for shortcut simultaneous nitrogen removal with the raw water quality. In order to improve nitrogen removal efficiency, key parameters such as HRT, DO concentration and carbon-nitrogen ratio should be further researched.

Fig.2 Nitrogen removal effect at the stage of acclimation

Fig.3 Scanning electron microscope pictures of carriers
3.2 Effect of HRT on shortcut simultaneous nitrogen removal

Under the conditions that DO and temperature were respectively controlled in 1.3~1.8 mg/L and 25±1°C, the effect of HRT on shortcut simultaneous nitrogen removal is shown in Fig.4. Prolonging HRT can reduce effluent ammonia nitrogen concentration and improve the removal rate. The concentration and removal rate of ammonia nitrogen were respectively 0.63 mg/L and 98.2% in the HRT of 5.93. Conversely, prolonging HRT reduced NAR. In past biological technology researches of nitrogen removal, prolonging HRT was an important method to improve nitrogen removal efficiency. For shortcut simultaneous nitrogen removal technology, we should pay attention to nitrogen removal mode rather than effluent pollutant concentration. Generally speaking, nitrite nitrogen and nitrate nitrogen need sufficient time to be transformed into nitrogen. But only nitrate nitrogen concentration showed a decrease trend as the HRT prolonging. The SND rate went up in the range of 2.97 hours to 3.56 hours, and the effluent nitrate nitrogen went down firstly, then up with inflection point of 3.56 hours. This is supposed to connected with limited organic carbon source and quantity change of AOB. Without enough organic carbon source, the removal efficiency of total nitrogen can’t be further improved. Prolonging HRT means more time for AOB to remove ammonia nitrogen, but the NOB can transform nitrite nitrogen to nitrate nitrogen. Moreover, NOB won’t be discharged from the reactor. In conclusion, Prolonging HRT can improve removal rate of ammonia nitrogen, but reduce NAR. To remove nitrogen with shortcut and simultaneous mode, the HRT should be controlled in a certain range. To remove ammonia nitrogen with the technology of shortcut simultaneous nitrogen removal efficiently and steadily, hydraulic retention time should be controlled in 3.56 hours.

Fig.4 Effect of HRT on shortcut simultaneous nitrogen removal

3.3 Effect of DO on shortcut simultaneous nitrogen removal

Under the conditions that HRT and temperature were respectively controlled in 3.56 hours and 25±1°C, the effect of DO on shortcut simultaneous nitrogen removal is shown in Fig.5. DO rise can reduce effluent ammonia nitrogen concentration and improve the removal rate. The concentration and removal rate of ammonia nitrogen were respectively 2.13 mg/L and 93.7% in DO of 3 mg/L. Nitrosation was restrained by DO rise, so the nitrite nitrogen and nitrate nitrogen of effluent showed opposite changing trend. The SND rate went up firstly, then down with inflection point of 1.5 mg/L. Generally speaking, oxygen saturation constants of AOB and NOB are respectively 0.2~0.4 mg/L and 1.2~1.5 mg/L. In this experiment, the optimal parameter of DO for shortcut simultaneous nitrogen removal is 1.5 mg/L. Besides aeration intensity control, DO subregion inside porous carrier is very important for improving nitrogen removal efficiency.
3.4 Effect of carbon-nitrogen ratio on shortcut simultaneous nitrogen removal

Under the conditions that HRT, DO and temperature were respectively controlled in 3.56 hours, 1.6±1 mg/L and 25±1℃, the effect of carbon-nitrogen ratio on shortcut simultaneous nitrogen removal is shown in Fig.6.

Carbon-nitrogen rise is unfavourable for ammonia nitrogen removal rate to a certain extent. In the carbon-nitrogen ratio of 10, The effluent concentration of ammonia nitrogen was above Class A of GB 18918-2002. On the contrary, carbon-nitrogen ratio rise is beneficial to denitrification. Both nitrite nitrogen and nitrate nitrogen showed a decrease trend as carbon-nitrogen ratio rise. Consequently, SND rate showed an uptrend as the rise of HRT prolonging carbon-nitrogen ratio in the case of 5~8. In contrast, NAR is not relevant to the variation of carbon-nitrogen ratio. The growth of denitrifying bacteria was promoted by adding carbon source, and the denitrification demands of electron transfer denitrification and energy transformation were met. However, nitrification was restrained by excessive multiplication of heterotrophic bacteria in the limited HRT. For this reason, the carbon-nitrogen ratio should be controlled in 5~8.

4. Conclusion

To treat domestic sewage with high efficacy and low cost, the technology of shortcut simultaneous nitrogen removal was used with a new biofilm reactor. The reactor finished start-up of shortcut
simultaneous nitrogen removal in 14 days of cultivation time after the biofilm cultured in the carrier. The ammonia nitrogen removal rate, SND rate and NAR respectively reached 91.3%, 82.7% and 63.4% in the last phase of start-up procedure. To remove ammonia nitrogen with the technology of shortcut simultaneous nitrogen removal efficiently and steadily, hydraulic retention time, dissolved oxygen, carbon-nitrogen ratio should be controlled in 3.56 hours, 1.5 mg/L and 5~8. In future, multistage biofilm reactor should be used to improve the ammonia nitrogen removal rate, SND rate and NAR in different stages. Moreover, the effluent pollutant concentration can meet high standard of emissions.

Acknowledgments
Authors would like to acknowledge the financial support from Technology Innovation and Entrepreneurship Fund of China Coal Technology & Engineering Group (2020-MS001).

References
[1] Lou H W, Lei X, Chen Y C, et al. (2019) Research progress in biological nitrogen removal. Industrial Water Treatment, 39: 1–4.
[2] Hao X D, Fang X M, Li T Y, et al. (2018) Misunderstandings on Upgrading Wastewater Treatment Plants. China Water & Wastewater, 34: 10–15.
[3] Tian X D, Ru L F, Lü X T, et al. (2020) Research progresses and prospect of partial denitrification process. China Water & Wastewater, 36: 7–15.
[4] Cheng J H, Wu P, Cheng C Y, et al. (2015) Shortcut nitrosation-denitrifying phosphorus removal based on high-quality carbon source in combined process of CAMBR. Environmental Science, 36: 4539–4545.
[5] Hu B, Zhao J Q, Chen Y, et al. (2011) Operation performance of step feeding A/O biofilm process. China Environmental Science, 31: 1644–1650.
[6] Liu A D, Zhao K L, Liu H, et al. (2019) Short-cut nitrification start-up and optimization of operating conditions under different control strategies. Environmental Science, 40: 4569–4577.
[7] Mu J N, Wu Z J, Du Y F, et al. (2019) The study on real-time control strategy of short-cut nitrification SBR and microbial community. Industrial Water Treatment, 39: 23–29.
[8] Ren Y H, Li X K, Sheng J B, et al. (2013) Research on partial nitritation for domestic sewage by biological aerated filter. Journal of Harbin Institute of Technology, 45: 14–19.