Optimization of A^2/O—MBR Integrated Process for High Standard of Reclaimed Water Quality in Beijing, China

Hao Wang[1,2a], Ning Ma[1,3b], Maosheng Ye[4c], Cao Liu[1,3]*, Qingyi Meng[1,3] and Qijun Li[1,3]

[1] Beijing Water Science and Technology Institute, Beijing 100048, China;

[2] College of Resource Environment and Tourism, Capital Normal University, Beijing 100048, China;

[3] Beijing Key Laboratory of Water Environmental and Ecological Technology for River Basins, Beijing 100048, China;

[4] Tongzhou District Beijing Water Bureau, Beijing 101100, China.

[a] 1214863523@qq.com, [b] ningmabwa@foxmail.com, [c] 78256510@qq.com

*Corresponding author. Tel.: (+86)10-68731626; E-mail: lc@bwsti.com

Keywords: Wastewater reclamation; A^2/O process; Membrane bioreactor (MBR); Reclaimed water quality; Local standard of Beijing

Abstract. The effectiveness of A^2/O—MBR integrated process has been studied for domestic wastewater reclamation to meet the latest Beijing pollutant emission standards. Experimental results showed that high DO concentrations in the aerobic tank improved COD_{Cr}, NH_3-N, and TP removals, whereas the TN removal increased initially and then decreased. Increasing the internal reflux ratio promoted the removal of TN, howbeit negligibly affected the removals of COD_{Cr}, NH_3-N, and TP. The removals of COD_{Cr}, NH_3-N, and TN rose with HRT, but the extent of rising became limited as HRT larger than 9 h. Membrane fouling rate increased with running time, and accelerated by improving membrane flux. When the system parameters are set at optimized conditions, i.e. the DO concentration of 2.0 mg/L, the internal reflux ratio of 250%, HRT of 9 h, and ozonation for 20 min, the major water quality of outlet remains stable and meets Grade A of Beijing local standards for new wastewater treatment plant (DB 11890-2012).

Introduction

As the capital of China, Beijing is now facing a striking and critical challenge to find a balance between its large population and limited resources. Urban water cycle, including water resources, water environment, water ecology, and water security suffered huge stress from the rapid growing urbanization. According to the results of the first Beijing Water General Investigation in 2013, more than 40% of water bodies in Beijing are less than Grade V limited by national standard of China for Surface Water Quality (GB3838-2002). In terms of China's national standard for Discharge of Pollutants to Municipal Wastewater Treatment Plants (GB18918-2002), the municipal wastewater treatment plant should strictly follow the protocol for Class 1(A) standard during wastewater reclamation since 2003.

The surface water in Beijing city mostly comes from unconventional water supplement which composed of effluent from urban wastewater treatment plant, scattered sewage, and rain flood. Therefore, advanced purification on the effluent from traditional urban wastewater treatment plant has been recognized as one of the most effective approaches to improve current surface water quality. Regarding the situation of environmental pollution and the requirement of surface water quality standard, Beijing issued China's most stringent local standard − Discharge standard of pollutants for municipal wastewater treatment plant (DB 11890-2012), with an insight to upgrade the surface water environmental quality. In addition, Beijing implemented a Three-Year Plan for Accelerating the Construction of Wastewater Treatment Plant and Reclaimed Water Facilities (2013-2015) since 2012, requiring the reclaimed water plants to improve their standards and rebuild their facilities.

During the stage of demonstration, membrane process was exhibited as an efficient, fast, and stable technique in comparison with several other traditional methods. This technique has a great potential for extensive practical applications worldwide. Specifically, membrane bioreactor (MBR), a typical membrane-based process, has the capability to upgrade the Grade V surface water to Grade IV [1, 2]. Furthermore, the cost of this process is relatively low. The combination of MBR with traditional A^2/O technique has the potential to not only further improve the effectiveness of wastewater treatment, but also improve the quality of reclaimed water. In addition, it is easy to upgrade wastewater treatment facilities and only requires light workloads by integration [3, 4].

In this paper, A^2/O and MBR techniques have been integrated for domestic wastewater reclamation. The main focus of this study is to optimize the effect of dissolved oxygen (DO) concentration, internal reflux ratio, and the hydraulic retention time (HRT) on the removal of pollutants, as well as membrane fouling. The feasibility of rebuilding reused-water plants by using the A^2/O—MBR technique to meet new water standards has been primarily studied.

Experimental Section

Materials and Method. Experimental setup included a 500-L raw wastewater tank, a 90-L anaerobic/anoxic tank (aerobic/anoxic capacity ratio is 1/2), a 150-L jointly-built aerobic tank/membrane unit, and a 500-L clean water reservoir. The aeration system applied microporous aeration diffuser in aerobic tank/membrane unit. The aeration intensity and operation pressure are controlled by the gas flow meter and vacuum pressure gauge. An intelligent controlling system was set up to automatically control the integrated process. A plate-like microfiltration membrane component is submerged inside the aerobic tank, which is made from polytetrafluoroethylene (PTFE). The average pore size of the membrane was 0.2 μm, the number of membrane component was 20 pieces, the effective membrane area per slice was 0.12 m^2, the membrane flux was 8～17 L/(m^2 h), and the operating pressure was about 35 kPa.

Domestic wastewater was firstly pumped into the raw wastewater tank which was controlled by auto-level meter. A peristaltic pump was then used to pump wastewater into the anaerobic tank, the anoxic tank, and the following aerobic tank. The membrane module of aerobic tank permits water intermittently by low pressure pump. The liquid level controller and the backwashing system are installed inside the aerobic tank. The aeration device is installed below the membrane component. The water that flows out of the membrane tank passes to the clean water tank, reacts with the ozone contact reactor, gets sterilized by ozone and then gets discharged or reused.

Domestication Test. During this experiment, domestication of active sludge divided into two stages both lasted for 15 days. During the first stage, domestic wastewater was used at the beginning. MLSS was stabilized at 2000 mg/L, corresponding to C/N ratio 3:1. As insufficient carbon source to the active microorganisms, dextrose was added to the inlet during the second stage. The second stage was finished until the outlet water quality of integrated system reached at relative stable conditions.

Table 1 General parameters during domestication test

Cultivation Period	Stage 1	Stage 2
Time (days)	15	15
COD_{cr} of raw water (mg/L)	65~180	210~370
TN of raw water (mg/L)	18~34	20~40
NH_3-N of raw water (mg/L)	10~32	
TP of raw water (mg/L)	~2.5	
DO concentration (mg/L)	2.6~2.7	
pH	7.2~8.6	
Water inflow (L/h)	~10	
Temperature (℃)	25 ± 3	
Pumping/Halting	Pumping for 10 min, and halting for 1 min	
Hydraulic retention time, HRT (h)	3:3:9 (Anaerobic: Anoxic: Aerobic)	

Sampling and Analysis. Water quality of both inlet and outlet was constantly collected and monitored throughout the whole experiment, which including DO, pH, COD_{Cr}, TN, TP, NH_3-N, NO_3-N, MLSS, SVI, and temperature. Analytical method for water quality was implemented according to standard method by Monitoring and Analyzing Water and Wastewater (fourth edition). All these data were collected and averaged for at least 7 consecutively stable days.

Results and Discussions

Effect of the DO Concentration of Aerobic Tank on the Removal of Major Pollutants. During this period, the DO concentration of aerobic tank was regulated at 3.0, 2.0, 1.5, and 1.0 mg/L for each 10 days, respectively (Table 2). The average concentrations of COD_{Cr}, TN, and TP already reached Class 1B of GB18918-2002 standard under all these conditions. Fig. 1 showed that COD_{Cr} removals decreased slightly (from 85.3% to 80.2%) with decreasing DO concentrations, suggesting an insignificant effect of DO on COD_{Cr} removal. However, TN removals were 47.9%, 51.0%, 47.8%, and 42.0% at the four DO concentrations. A possible reason for TN removal at 3.0 mg/L DO slightly lower than 2.0 mg/L is that the back flow of higher amount of DO into the aerobic tank and thus high DO concentration in the digestive juices in the anoxic tank may damage the anoxic environment. When the DO concentrations of the aerobic tank were set to 3.0, 2.0, and 1.5 mg/L, the TP removal in the outlet were 71.5%, 68.9%, and 64.8%, respectively. The TP and NH_3-N removals only reached 54.1% and 70.2% when the DO concentration was further reduced to 1.0 mg/L. As a result, DO concentration should be at least 1.5 mg/L to achieve satisfactory TP, TN, COD_{Cr}, and NH_3-N removals, and system performance was optimized in the case of 2.0 mg/L DO concentration.

Table 2 The measured DO concentrations under DO1~DO4 stages

Stages	DO concentration (mg/L)		
	Anaerobic tank	Anoxic tank	Aerobic tank
DO1	0.12~0.19 (0.15)	0.35~0.63 (0.45)	2.70~3.30 (2.97)
DO2	0.10~0.20 (0.14)	0.28~0.56 (0.38)	1.61~2.49 (2.07)
DO3	0.08~0.18 (0.12)	0.24~0.45 (0.31)	1.33~1.91 (1.56)
DO4	0.05~0.11 (0.08)	0.21~0.38 (0.28)	0.80~1.33 (1.00)

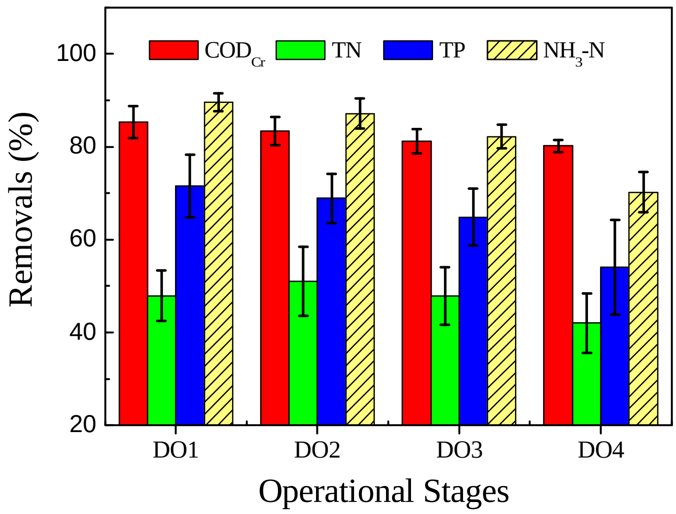

Fig.1 Effects of DO concentrations on the removal of major pollutants

Effect of Internal Reflux Ratio on the Removal of Major Pollutants. For a given external reflux ratio of 100%, the removals of major pollutants were studied at three different internal reflux ratios of 150%, 250%, and 350%. Each condition was maintained for 10 d, and the experimental system proceeded to the next internal reflux ratio after it stabilized for 3d. As shown in Fig. 2, COD_{Cr}, NH_3-N and TP removals remained relatively stable by changing internal reflux ratios. The DO concentration of anoxic tank increased as internal reflux ratio increased. TN removal increased with increasing internal reflux ratios, mainly attributed to the fact that low nitrate load refluxes inhibits the denitrification process, and high refluxes caused nitrate load almost saturated. Additionally, high internal reflux ratio resulted in large amounts of DO in the refluxing mixture, damaging the anoxic environment of the anoxic tank and reduce the removal of TN. As a result, the internal reflux ratio was optimized at 250% under carefully consideration.

Table 3 The measured DO concentrations under IR1~IR3 stages

Stages	DO concentration (mg/L)		
	Anaerobic tank	Anoxic tank	Aerobic tank
IR1	0.10~0.20 (0.14)	0.28~0.56 (0.38)	1.61~2.49 (2.07)
IR2	0.12~0.23 (0.14)	0.35~0.67 (0.44)	1.88~2.48 (2.03)
IR3	0.11~0.21 (0.13)	0.40~0.72 (0.51)	1.87~2.31 (2.01)

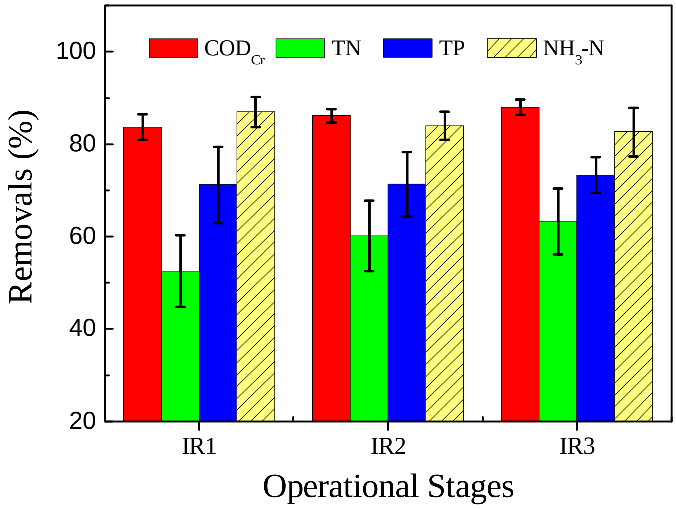

Fig.2 Effect of internal reflux ratio on the removal of major pollutants

Effect of Hydraulic Retention Time on the Removal of Major Pollutants. Four overall HRT conditions (18 h, 12 h, 9 h, and 6 h, anaerobic: anoxic: aerobic = 1: 1: 3) were evaluated in the experiment, as shown in Fig. 3. The corresponding COD_{Cr} removals were 86.1%, 84.7%, 83.8%, and 80.5%, respectively, suggesting that COD_{Cr} removal increases with HRT. However, COD_{Cr} removal will be stable if increase HRT even further. NH_3-N removal became high as HRT last longer. Denitrification and nitration processes would be incomplete for a short HRT. When HRT was doubled from 9h to 18h, the TN removal rate was increased by only 5.6%. However, TN removal decreased by 10.6% by decreasing HRT to 6 h, indicating incomplete nitration process for an HRT shorter than 9 h.

When HRT decreased, the removal of TP increased initially and then decreased, indicating that long HRT was detrimental to TP removal. One possible reason is that a longer HRT tends to cause sludge bulking. Under the overall HRT of 9 h, COD_{Cr}, NH_3-N, and TP concentrations in the outlet were less than 40, 5.0, and 0.5 mg/L, respectively, which already satisfied Grade 1(A) of national standard GB18918-2002. This was consistent with stable and good quality outlet, which limited in Grade 1(A) of national standard, could be achieved under HRT 9.2 h by A^2/O membrane bioreactor-based wastewater process reported by Lin et al. [5-7]. Hence, an overall HRT 9 h is recommended for A^2/O—MBR integrated system.

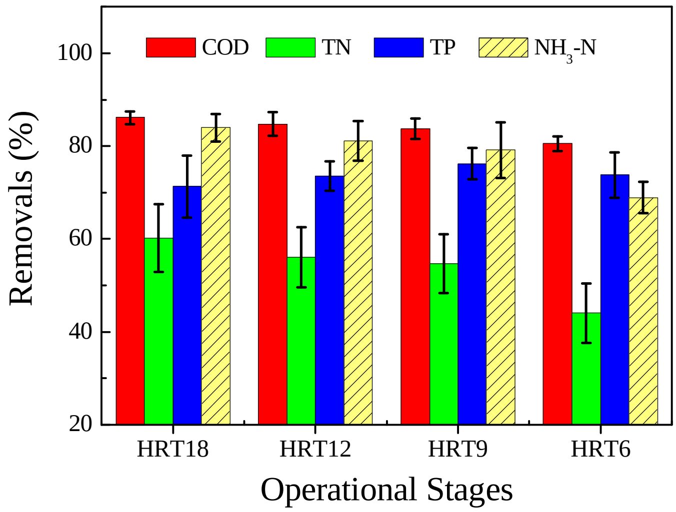

Fig. 3 Effect of overall HRT on the removal of major pollutants

Membrane Fouling under Different Membrane Flux. Fouling is a challenge that is always associated with the membrane technique for water treatment. According to Darcy's law, for a given membrane flux, higher trans-membrane pressure (TMP) indicates more serious membrane fouling. Therefore, three stages with different constant membrane flux were conducted in this study.

Fig. 4 showed the relation between TMP and membrane flux during three stages. In the first stage, the membrane flux was set to 6.0 L/(m^2.h), and the membrane pressure increased to 24 kPa. The operation time lasted for 47 days. The membrane was renewed in the second stage, and the membrane flux was set to 8.0 L/(m^2.h), and the membrane pressure increased to 32 kPa, the operations lasted for 105 days. In the third stage, the membrane component was renewed again, and when the membrane flux was set to 10 L/(m^2.h), and the membrane pressure increased to 30 kPa the operation lasted for 145 days. Therefore, TMP showed an increment and the rate of membrane pollution also increased when membrane flux increased.

Extensive researches have demonstrated that the accumulation of extracellular polymer substances (EPS) was the major contributor for membrane fouling [8, 9]. We deduce that the dissolved substances generated during metabolism and accumulate constantly in membrane unit, resulting in a large quantity of cell debris and EPS. Additionally, the aeration bubbles can clip the mud particles, thus breaking the activated sludge floc, generating more EPS and reducing the filtration performance of the mixture.

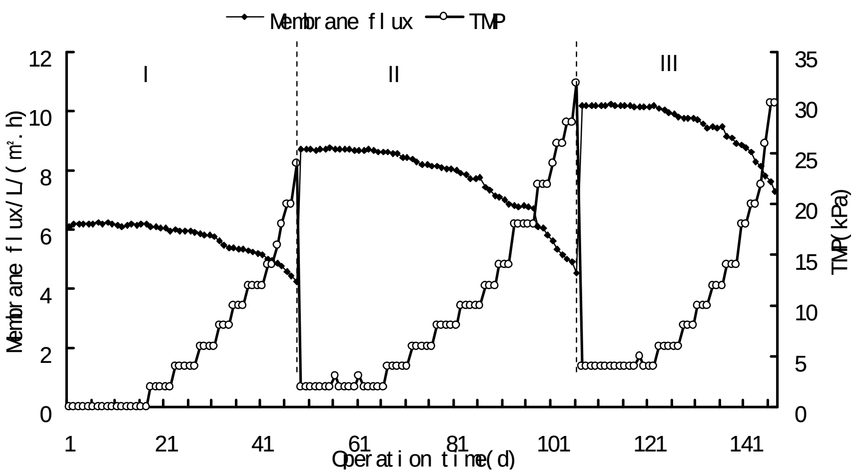

Fig. 4 Variation of TMP with varying membrane flux

Ozonation after A^2/O—MBR Integrated Process. According to previous investigation, the integrated system were optimized at 2.0 mg/L DO concentration of aerobic tank, 250% internal reflux ratio, and 9h overall HRT. Besides, DO concentrations in the anaerobic and anoxic tanks were accurately maintained below 0.2 mg/L and around 0.5 mg/L, respectively. Outlet water quality has been finally stabilized by means of PAC coagulation, where COD_{Cr} 32 mg/L, NH_3-N 1.23 mg/L, TN 6.33 mg/L, and TP 0.15 mg/L.

To ensure the whole system meet Grade A of Beijing local standards (DB 11890-2012), ozonation was chosen as disinfection unit in current process with 0.1 g/L ozone dosage and 0.06 L/min addition rate. No significant contribution of ozonation on TN and TP removal was found. However, COD_{Cr} increased initially and then decreased by increasing ozonation time (Fig. 5a), possibly attributed to part of macromolecular or non-biodegradable organic compounds in effluent of MBR. Similarly, NH_3-N increased and stabilized by ozonation time, mainly due to oxidation nature of ozone. Both COD_{Cr} and NH_3-N concentrations remained relatively low after 20 min ozonation and stable even more than one week (Fig. 5b). Therefore, it is evident that the optimized A^2/O-MBR process followed by ozonation effectively ensured the major indexes of outlet water quality meet Grade A of Beijing local standards (DB 11890-2012), specially for new reclaimed water plants.

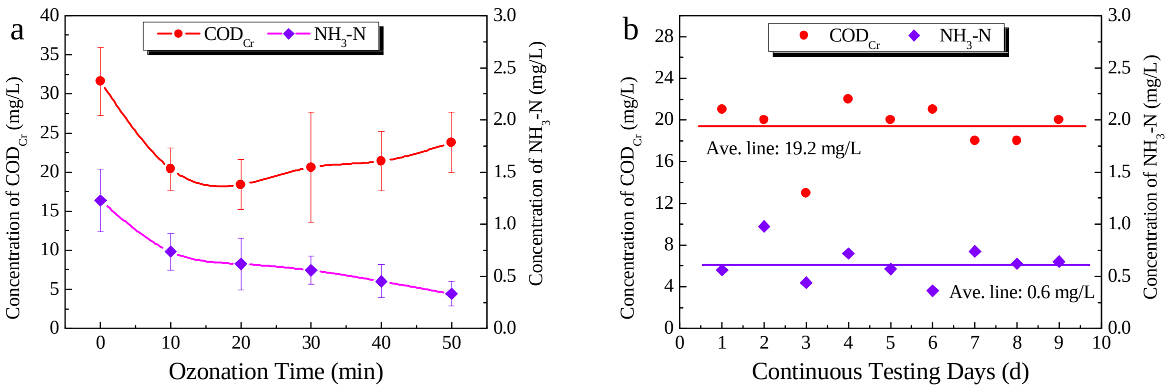

Fig. 5 Performance on COD_{Cr} and ammonia nitrogen index after ozonation

Conclusions

(1) Considering NH_3-N, TN and TP removals, the concentration of DO in the aerobic tank should be maintained at appropriately 2.0 mg/L.

(2) From the perspective of both TN removal and energy efficiency, the internal reflux ratio was optimized at 250%.

(3) Longer HRT is detrimental to TP removal, while higher hydraulic load is prefer to accelerate membrane fouling by EPS accumulation.

(4) Under optimized condition, i.e. DO 2.0 mg/L, internal reflux ratio 250% and HRT 9 h, the integrated process followed by ozonation ensured that reclaimed water meet Grade A of Beijing local standards (DB 11890-2012).

Acknowledgements

This work was supported by the National Science and Technology Major Project of China: Water Pollution Control and Treatment (project no. 2012ZX07203-001).

References

[1] X. Y. Li, H. P. Chu, Membrane bioreactor for the drinking water treatment of polluted surface water supplies. Water Research 37 (2003) 4781-4791.

[2] L. Mo, X. Huang, Powdered activated carbon-MBR process for treatment of micro-polluted raw water. China Water & Wastewater 18 (2002) 16-19.

[3] Z. Wang, X. Wang, P. Jin, X. Wang, Study on operation characteristics of A^2/O-MBR wastewater treatment system. Water and Wastewater Engineering 37(2011)31-34.

[4] J. Zhang, Z. Yan, Application of A^2/O—MBR in municipal wastewater treatment. Water and Wastewater Engineering 39(2013) 225-229.

[5] L. Lin, J. Huang, H. Bai, W. Zhang, Design points of A^2/O- MBR wastewater treatment process. China Municipal Engineering 3(2009)61-64.

[6] S. Han, Q. Yue, M. Yue, B. Gao, Y. Zhao, W. Cheng, Effect of sludge - fly ash ceramic particles (SFCP) on synthetic wastewater treatment in an A/O combined biological aerated filter. Bioresource Technology 100(2009) 1149-1155.

[7] L. M. C. Daniel, E. Pozzi, E. Foresti, F. A. Chinalia, Removal of ammoniumvia imultaneous nitrification denitrification nitrite - Shortcut in a single packed bed batch reactor. Bioresource Technology 100(2009)1100-1107.

[8] M. D. Williams, M. Pirbazari, M. Pirbazari, Membrane bioreactor process for removing biodegradable organic matter from water. Water Research 41(2007)3880-3893.

[9] S. Liang, C. Liu, L. Song, Microbial products in membrane bioreactor operation: Behaviors, characteristics, and fouling potential. Water Research 41(2007)95-101.