Effect Analysis of Sequential Batch Membrane Bioreactor on Mixed Municipal Sewage Treatment

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Abstract: The removal efficiency of pollutants and the development of membrane fouling were investigated by using sequencing batch membrane bioreactor (SBMBR) to treat mixed municipal wastewater without membrane cleaning. The results showed that under the condition of DO 1.0 ~ 2.0 mg/L and operating cycle 6h, the system operated continuously for 89d, and the pollutant removal effect was good. The average removal rates of COD, TN, NH₃-N, TP and turbidity were 89.4%, 70.6%, 89.9%, 91.1% and 99.4%, respectively. In addition, the enhanced removal of COD and turbidity was significant, and the removal of nitrogen and phosphorus was stable. Moreover, the membrane filtration pressure difference rose slowly, and the membrane filtration performance was relatively stable during the continuous operation of the system.

1. Introduction
As an efficient sewage treatment technology, membrane bioreactor (MBR) has many advantages, such as good effluent quality, small area, high activated sludge concentration and less residual sludge, and shows a good development prospect in many improved processes of enhanced nitrogen and phosphorus removal [1-3]. The C/N of municipal wastewater in China is generally low, and the effect of nitrogen and phosphorus removal by the single form of MBR is unstable, so it is difficult to meet the more and more strict discharge standard. Therefore, many scholars [4-8] combined the traditional denitrification and phosphorus removal processes A²/O, oxidation ditching and other MBR processes, and carried out a lot of experimental studies, which had been well applied in practical projects, and provided technical support for the upgrading of urban sewage plants.

Sequential batch membrane bioreactor (SBMBR) can improve the hydraulic conditions of membrane filtration process, change the characteristics of the mixture, and maintain a lower membrane fouling rate [9-10]. In this experiment, the removal efficiency of chemical oxygen demand (COD), total nitrogen (TN), Ammoniacal nitrogen (NH₃-N), Total phosphorus (TP), turbidity and other pollutants was investigated by using SBMBR to treat actual mixed municipal sewage without cleaning the membrane module, the stability of membrane filtration performance was analyzed by measuring the change of membrane filtration pressure difference during operation.
The aim of this study is to enrich the nitrifying bacteria with long generation period by membrane interception, and to improve the effect of denitrification and phosphorus removal by controlling low concentration of DO, the stability of membrane filtration can be maintained by using polyvinylidene fluoride (PVDF) hollow fiber membrane module to filter the supernatant at the later stage of SBR settling stage, which can provide a reference for the sewage treatment upgrading project.

2 Materials and methods

2.1 Experimental device
In the experiment, an integrated MBR is used, and the test device is shown in Figure 1. The MBR has a size of 500mm×500mm×800mm and an effective volume of 150L. A separator is installed in the MBR and the reactor is divided into two parts with roughly equal volume, which the membrane module is placed on one side of the separator and a stirring device is installed on the other side. A perforated aerator is used to supply oxygen to the reactor, and the aeration rate is controlled by a rotameter. In order to slow down the pressure rise caused by membrane pollution, constant current operation and intermittent pumping are adopted for the system [11], with the pumping set for 3 min and the pumping stopped for 1 min. The test membrane module is made of PVDF hollow fiber microfiltration membrane, the membrane aperture is 0.1μm, the surface area of the single membrane module is 0.6 m², and 6 pieces in total.

2.2 Experimental method
The test was carried out in a sewage treatment plant. The sewage was taken from the collecting well of the sewage treatment plant and the main parameters of sewage water quality were shown in Table 1. The residual sludge from the secondary sedimentation tank of an operating sewage treatment plant was used as the inoculation sludge. The process operation mode is as follows: instantaneous water inlet, anaerobic stirring for 1.5 h, aeration for 2.5 h, precipitation for 0.5 h, membrane outlet for 1.0 h, idling for 0.5 h, the whole test system automatically operated by PLC control. In order to reduce the pressure rise caused by membrane pollution, intermittent suction was used for the membrane effluent, with suction for 3 min and withdrawal for 1 min. In addition, System operation cycle for 6 h, running every day 4 cycles, the DO control in 1.0 ~ 2.0 mg/L, sludge concentration is 3000 ~ 4000 mg/L, the membrane flux of 20 L·m⁻²·h⁻¹, drainage than 1:3, sludge age 18 d. What’s more, no physical or chemical cleaning is performed on the membrane module during operation, and the TMP variation is investigated.
Table 1. Main parameters of mixed sewage quality

| Parameter       | Range      | COD (mg/L) | TN (mg/L) | pH       | Turbidity (NTU) | NH₃-N (mg/L) | TP (mg/L) | Temperature (°C) |
|-----------------|------------|------------|-----------|----------|-----------------|--------------|------------|------------------|
| Range           | 99.97~361.40 | 13.20~30.20 | 7.04~7.52 | 112~328  | 10.69~25.52     | 1.41~5.65    | 20~28      |

2.3 Analytical tools

A Hach DRB200 digestor and DR3900 spectrophotometer are used to quickly determine the COD. TN is measured via potassium persulfate oxidation–UV spectrophotometry. NH₃-N is measured using the salicylic acid method. TP is determined via the alkaline potassium persulfate digestion–ascorbic acid method. Turbidity is measured using a WGZ-1 digital turbidity meter. Mixed liquor suspended solids (MLSS) is determined using the loss-on-drying (LOD) method. pH is measured using a Delta 320 pH meter. Dissolved oxygen (DO) is determined using a Hach HQ30d portable dissolved oxygen meter.

3 Results and discussion

After 89 days of continuous operation, the membrane was not cleaned, and TMP rose slowly from the initial 8 KPa to 38 KPa, so the membrane fouling developed slowly.

3.1 COD removal efficiency

According to Figure 2, during the stable operation of the system, the COD value of the effluent from the system membrane was 5~27mg/L, the total COD removal rate was 74.4~96.6% (89.4% on average). The COD concentration of the superfluid was 6~59mg/L, and the COD removal rate of the bioreactor was 64.7~95.8% (82.4% on average). The comparison of COD removal rate between membrane effluent and superfine solution showed that two of them had the same change trend, membrane its own contribution to the COD removal rate was 0 ~ 12.0% (7.0% on average). It is further proved that the membrane can effectively retain the organic macromolecular substances in the bioreactor, and enhance the removal effect of COD by the system, so that the bioreactor of the membrane has a strong resistance to shock loading, which plays an important role in the stable operation of the system [12, 13].

![Figure 2. COD removal efficiency](image-url)
3.2 Removal efficiency of NH$_3$-N and TN

The removal effect of NH$_3$-N and TN is shown in Figure 3. The experimental results show that the membrane bioreactor to generation cycle long interception of nitrate bacteria and nitrite bacteria have greatly improved the nitrification performance of the system [14, 15], the system effluent NH$_3$-N is 0.54 ~ 2.34 mg/L, total ammonia nitrogen removal rate is in 79.4 ~ 96.5% (89.9% on average), the membrane itself has little interception of NH$_3$-N, and the removal of NH$_3$-N is mainly achieved by biological nitrification and assimilation. The TN in the effluent is 3.8-7.6mg /L, which the rate is 58.7-84.6% (70.6% on average). The membrane itself has little effect on TN removal.

3.3 TP removal efficiency

The system alternated anaerobic/aerobic operation which provided a selective advantage for the metabolic growth of polyphosphorous bacteria (PAOs) [16-17], and the TP removal effect of the system was good. As shown in Figure 4, the TP concentration of the system membrane outlet was 0~0.82 mg/L, with an average of 0.25 mg/L, and the TP removal rate was 73.4~100.0% (91.1% on average). The TP concentration of the superfluid in the reactor ranged from 0.04 to 0.86mg/L, with an average of 0.33mg /L, and the TP removal rate in the reactor ranged from 64.63 to 99.3% (89.3% on average). The contribution of TP removal rate of membrane itself was 0~8.5% (1.9% on average). The effect of membrane itself on TP enhancement was not significant. The concentration of TP in the supernatant and membrane effluent was below 0.5 mg/l after 19 days of continuous operation of the system, indicating that the phosphate accumulating bacteria in the reactor had adapted to the environment of anaerobic/aerobic alternate operation and the removal effect of TP was good, which the effluent could meet the Discharge standard of pollutants for municipal wastewater treatment plant (GB18918-2002) of level A standards.
3.4 Turbidity removal efficiency

As can be seen from Figure 5, turbidity of the bioreactor supernatant was relatively unstable during the whole test period. Turbidity ranged from 24 to 58, and turbidity removal rate of the bioreactor was 70.5 ~ 90.2% (83.0% on average). In addition, the turbidity of system membrane outlet is stable, which is between 0.7 and 2.1, the total turbidity removal rate is 99.0~99.7% (99.4% on average). Besides, the turbidimetry removal rate was 9.1~24.6% (16.5% on average). This indicates that the membrane’s efficient interception improves the effluent water quality of the system.

4 Conclusions

(1) SBMBR process was used to treat the actual mixed municipal sewage. The system operated continuously for 89d, and the average removal rates of COD, TN, NH$_3$-N, TP and turbidity were 89.4%, 70.6%, 89.9%, 91.1% and 99.4%, respectively. The removal efficiency of nitrogen and phosphorus by denitrification was improved by controlling low concentration of DO, and the removal efficiency of COD and turbidity by the membrane itself was 7.0% and 16.5%, respectively. Therefore,
the membrane separation process enhances the removal of COD and turbidity and improves the effluent quality.

(2) This test process is simple, which brings the advantages of SBR and MBR into full play. The membrane module is used to pump and filter the supernatant in the settling stage of SBR, which reduces the development speed of membrane pollution and keeps the stability of membrane filtration performance, it can provide reference for the upgrading and reconstruction of the existing sewage treatment.

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References

[1] Naghizadeh, A., Mahvi, A. H., Mesdaghinia, A. R., Alimohammadi, M. (2011) Application of MBR Technology in Municipal Wastewater Treatment. Arab J Sci Eng, 36:3-10.
[2] Bagheri, M., Mirbagheri, S. A. (2018) Critical review of fouling mitigation strategies in membrane bioreactors treating water and wastewater. Bioresource Technology, 258: 318-334.
[3] Pulido, J. M. (2016) A review on the use of membrane technology and fouling control for olive mill wastewater treatment. Science of the Total Environment, 563/564:664-675.
[4] Liu, S.G., Dai, S.P., Ke, Y.W. (2014) Pilot test on biological nitrogen and phosphorus removal by using reverse A2O-MBR process to treat wastewater. Membrane Science and Technology, 34(1):91-95.
[5] Zhu, J. Q., Jiang, L. L., Cheng, W., Zhang, W. L. (2014) Study on nitrogen and phosphorus removal by A2O/A - MBR process. China Water & Wastewater, 30 (14): 11-13.
[6] Li, Y.H., Zhong, Y.J., Su, H. (2018) Application of A2 O/A-MBR Process in WWTP. Technology of water treatment, 44(6):130-133, 140.
[7] Yu, L.J., Wu, P., Wang, Z.P., Chen, Y., Chen, J. (2020) Membrane fouling characteristics of the mixed liquids from different stages of A2O process. Chinese Journal of Environmental Engineering, 14(6): 1481-1487.
[8] Gao, F.Y., Li, J.H. (2019) Application of Bardenpho and MBR Process in the Upgrading and Reconstruction of a WWTP. China Water & Wastewater, 2019, 35(6): 134-136.
[9] Yuan, X.Y., Shen, H.G., Sun, L., Wang, L., Li, S.F. (2011) Comparison Research on Two-stage Sequencing Batch MBR and One-stage MBR. Environmental Science, 32(1):206-211.
[10] Seo, G.T., Lee, T.S., Moon, B. H. (2000) Two stage intermittent aeration membrane bioreactor for simultaneous organic, nitrogen and phosphorus removal. Water Science and Technology, 2000, 41(10/11) :217-225.
[11] Bae, T. H., Han, S. S., Tak, T. M. (2003) Membrane sequencing batch reactor system for treatment of dairy industry wastewater. Process Biochemistry, (2):221-231.
[12] Gagliardo, P., Adham, S., Merlo, R. P. (2001) Water reclamation with membrane bioreactors. Water Science &Technology, (1/2): 293-302.
[13] Krampe, J., Krauth, K. (2001) Sequencing batch reactor with submerged hollow fiber membranes for the biomass separation. Water Sci Technol, 43(3)195-199.
[14] Ma, Y., Peng, Y., Wang, S., Yuan, Z.G., Wang, X.L. (2009) Achieving nitrogen removal via nitrate in a pilot-scale continuous pre-denitrification plant. Water Research, 43(3):563-572.
[15] Kornaros, M., Dokianakis, S. N., Lyberatos, G. (2010) Partial nitrification/ denitrification can be attributed to the slow response of nitrite oxidizing bacteria to periodic anoxic disturbances. Environmental Science and Technology, 44(19):7245-7253.
[16] Xu, D. C., Chen, H. B., Li, X. M., Yang, Q., Zeng, T. J., Luo, G., Peng, B., Wang, Z. L., Xie, J. C. (2014) Biological phosphorus and nitrogen removal in a sequencing batch reactor (SBR) operated in static/aerobic/ anoxic regime. Acta Scientiae Circumstantiae, 34(1): 152-159.
[17] Winkler, M., Coats, E.R., Brinkman, C.K. (2011) Advancing post-anoxic denitrification for biological nutrient removal. Water Res, 45(18): 6119-6130.