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A compact A²O MBR system for water reclamation in the northwestern China – a case study

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ABSTRACT

Based on the successful adoption of A²O membrane bioreactor (MBR) system with 2.5 times treatment capacity (5,000 m^3/d) rather than conventional activated sludge process (2,000 m^3/d), A domestic wastewater treatment plant in the northwestern China was greatly upgraded that can effectively meet the requirements of wastewater treatment and reclamation. In the A²O process, with high-depth aeration (11.0 m), high organic and ammonia nitrogen removals were achieved synchronously in a wide range of sludge retention time. This system could be also strategically controlled to achieve high-phosphorous removal by optimized discharge of excess sludge. This project provided the first case study of A²O MBR system in the cold region and showed the advantages of membrane technology for water reclamation in water-deficient areas of China.

Keywords: A²O MBR; Domestic wastewater; Membrane; Water reclamation

1. Introduction

Located in the northwestern China, Ansai County is the place where the natural environment is very harsh with low rainfall but relative high-evaporation capacity. A wastewater treatment plant (2,000 m^3/d) with conventional activated sludge (CAS) process has been built up in 2007 in Ansai. Though the ability to adapt to the water quality changes is not strong and the effluent quality is fluctuant, the CAS process operated stably, the effluent can meet related standard overall. However, with the rapidly development of urbanization, the wastewater discharged has increased to almost 5,000 m^3/d, which means the current treatment capacity cannot meet the demand for domestic wastewater treatment. Because of the limited initial planning construction area, it would be impossible to build a similar process based on the original plant. In addition, water shortage has become a constraint of the local development. Therefore, wastewater reuse is a feasible option to reduce the demand for total water resource.

As mentioned above, current wastewater treatment facility has to be updated based on a reasonable economy consideration, including making full use of existing infrastructure, taking into account the shortage of water resources and the demand of regenerated water usage in Ansai County. Due to the advantages

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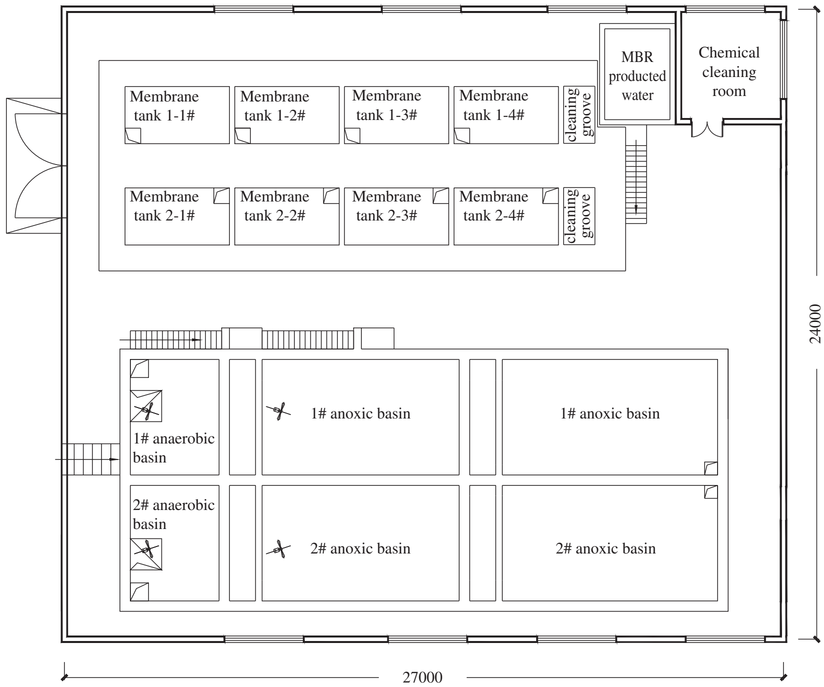

Fig. 1. Plane layout of biological treatment process.

including small covering area, easy updating and better effluent quality [1], the membrane bioreactor (MBR) has become the preferred process to upgrade the domestic wastewater treatment plant [2–5]. However, membrane fouling hindered widespread application of MBR process, because membrane fouling increased the operation and maintenance cost [6,7]. Therefore, membrane fouling and transmembrane pressure (TMP) have been the focus of research [8–12]. Meanwhile, various transformation processes based on MBR, such as Integrated Vertical MBR [13] and moving bed MBR [14,15], also draw more attentions. This paper will introduce the updated program of Ansai wastewater treatment plant from CAS process to A^2O MBR system. Besides, the treatment efficiency, economic evaluation and technical feasibility of the A^2O MBR process in cold area are also investigated.

2. System configuration

Due to the limited available space and low temperature in winter, the biological treatment process should be placed indoors (the original wastewater treatment building, the size of which is length × width = 27 × 24 m). An A^2O process combined with MBR was applied for upgrading current plant to make full use of the original wastewater treatment buildings and achieve biological denitrification, phosphorus removal and better sludge separation performance.

The treatment building was divided into two parts (shown in Fig. 1): the first part was used for A^2O biological treatment which is consisted of two lines with treatment capacity of 2,500 m^3/d/line. The hydraulic retention time is 10 h (1.5 h anaerobic, 4 h anoxic and 4.5 h aerobic); the second part was used for membrane separation with the treating time of about 1 h, which also has the aerobic treatment function due to the aeration provided underneath the membranes, so the total aerobic treatment time of the system is 5.5 h.

As shown in Fig. 1, the biological treatment portion only covers half of the total area; in order to satisfy the requirements of total hydraulic retention time, the depth of biological treatment tanks (including aerobic tank, anoxic tank and anaerobic tank) was increased to 11 m with the effective depth of 10.5 m

Table 1
Raw wastewater quality

Parameter	Analysis
pH	7.2 ± 0.6
SS/mg L^{-1}	63 ± 41
TP/mg L^{-1}	5.5 ± 1.2
COD_{Cr}/mg L^{-1}	350 ± 136
BOD_5/mg L^{-1}	216 ± 49
NH_3-N/mg L^{-1}	48 ± 17

Table 2
Main parameters of the membrane module

Parameter	Description
Type of membrane tube	Hollow-fiber
Membrane material	Polyvinylidene fluoride (PVDF)
Membrane pore size (mm)	0.1
Outer/inner diameter (mm)	1.2/0.7
Mean membrane flux at 15℃ (LMH)	17
Operation of pH	1–10
Total membrane area (m^2)	25

and the depth of membrane tanks was fixed to 4.0 m with the effective depth of 3.5 m.

3. Experiment

3.1. Operational conditions

In the part of biological treatment, the sludge concentration was 5,000 mg/L in the anaerobic tank and 8,000 mg/L in both the aerobic tank and anoxic tank. The DO concentration was controlled under 0.5 mg/L in the anoxic tank and about 3.0 mg/L in the aerobic tank, while the aeration in the aerobic tank is 10–13 m^3/min with the air–water ratio about 1:6–1:8. Based on the nitrogen concentration in the raw water, the inner sludge circulation ratio between the aerobic tank and anoxic tank was controlled from 100 to 250%; According to the phosphorus concentration, 20–50% of the sludge in the aerobic tank is reflowed to the anaerobic tank; In order to maintain appropriate sludge concentration, the sludge in the membrane tank is reflowed to the anaerobic tank, aerobic tank and anoxic tank (50% for each one) with the sludge circulation ratio of 300%. Submerged hollow fiber Polyvinylidene fluoride microfiltration modules with pore size of 0.1 μm were applied for the MBR, which is provided by Asahi Kasei Corporation, Japan. Four hundred and eighty membrane modules were submerged in the bioreactor with a total filtration area of 12,000 m^2, and the membrane permeate flux is 19.3 L/m^2h for each module. Aeration was provided continuously under the membranes so as to control membrane fouling and supply air to the bioreactor. The membrane-filtered effluent was continuously removed with a suction pump and periodic 1 min backwashing after 9 min permeation by time control device was adopted to reduce membrane fouling. Chemical cleaning (soaking for 2–3 h in 0.5% NaClO solution) was provided every 3 d. The membrane modules were conducted off-line chemical cleaning every half year using NaOH, $NaHSO_3$, NaClO and citric acid as the cleaning solutions. In this study, a long term test was carried out to investigate the effects of sludge retention time (SRT), DO, pH and mixed liquor suspended solids on the effluents qualities of updated treatment plant.

3.2. Raw wastewater quality

The raw wastewater of Ansai wastewater treatment plant was entirely domestic wastewater, the water quality was shown in Table 1.

3.3. Characteristics of membranes

The membrane module submerged in the tank was manufactured by Asahi Kasei Corporation, Japan. Its main parameters are summarized in Table 2.

4. Results and discussion

4.1. Effect of SRT on pollutants removal

Before the long-time operation, the impact of SRT on the total phosphorus (TP) removal was investigated from June to September. Fig. 2 shows that the TP removal was related to SRT in the system. When SRT was longer than 10 d, the TP removal decreased significantly and the TP concentrations of effluent was higher than 0.5 mg/L (treated water discharge control

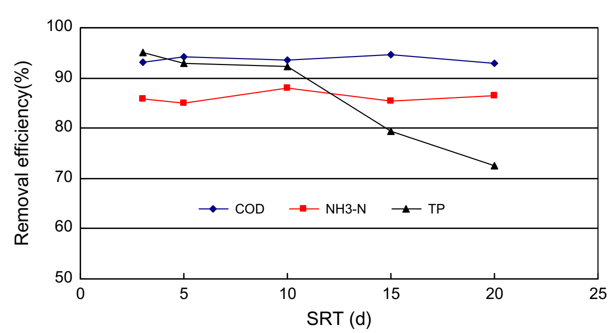

Fig. 2. Effect of SRT on pollutants removal.

targets of China). Moreover, the longer the SRT was, the worse the TP removal became. The reason is that phosphorous removal is achieved by discharging excess sludge, so the shorter the sludge age, phosphorus removal effect is better. At the same time, the impact of SRT on COD and NH_3-N removal was also investigated as shown in Fig. 2. It can be found that the COD removal efficiency was more than 90% and almost independent of SRT, which indicates that membrane separation play an important role in maintaining high and stable COD removal. For NH_3-N, average removal efficiency was maintained about 85% even at short SRT. This implies that membrane retention of slow-growing nitrifying micro-organisms is effective and complete nitrification could be achieved at short SRT. However, SRT has significant effects on phosphorus removing bacteria and affecting the removal efficiency of phosphorus in wastewater [16–18]. Therefore, the system could be strategically controlled in about 5–10 d to realize high-phosphorous removal through an optimized scheme of periodical discharge of excess sludge.

4.2. COD and NH_3-N removal

Figs. 3 and 4 indicate the COD and NH_3-N removal during the long-time operation, respectively. As shown in Fig. 3, the total COD removal efficiency was excellent for more than six months running time. No matter how the COD values and temperature of influent changed, the effluent COD values were stable between 20 and 30 mg/L. In Fig. 4, NH_3-N removal efficiency has a great relationship with water temperature. The NH_3-N removal efficiency decreased obviously when the water temperature was below 15℃. Especially, when the water temperature was below 10℃, the total NH_3-N removal efficiency was less than 40%. Once the water temperature was higher than 15℃, the NH_3-N removal efficiency increased

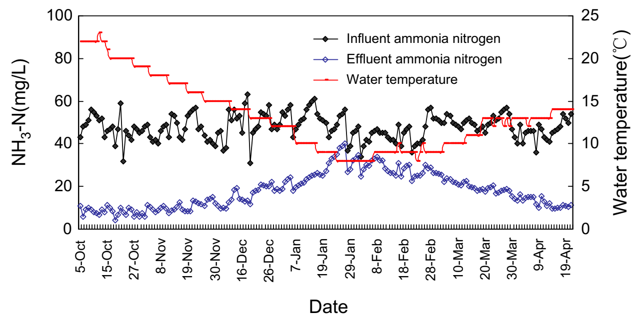

Fig. 4. Variation of influent and effluent NH_3-N.

significantly, and more than 85% removal of the total NH_3-N was observed. As many studies pointed out, the growth of the nitrifying bacteria can be affected and even be stopped in cold water. Therefore, some measures should be provided to enhance NH_3-N removal, such as increasing oxygen utilization and activated sludge concentration, and by which higher NH_3-N removal efficiency could be realized in very cold season.

4.3. Variation of TMP

Fig. 5 shows the TMP alternations with different operation time. From Fig. 5, it can be found that the TMP ratchet up while the operation time extended which can be divided into four periods by the variations of TMP analysis for six months: phase one is the rapid growth period from the initial stage to about one month later; phase two, in this phase, the rapid increases of TMP should be related to adsorption, membrane pore jam, gel layer formation and comprehensive pollutions of concentration polarization in the initial period; Henceforth, the TMP gone to stable stage and the value kept around 40 kPa for about a month; phase three last about two months time. In this period, the TMP further increased but relatively stable

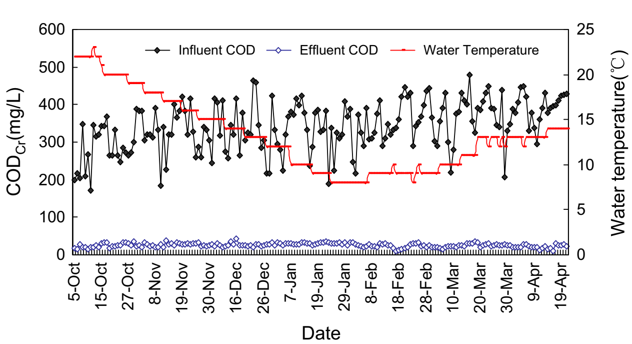

Fig. 3. Variation of influent and effluent COD.

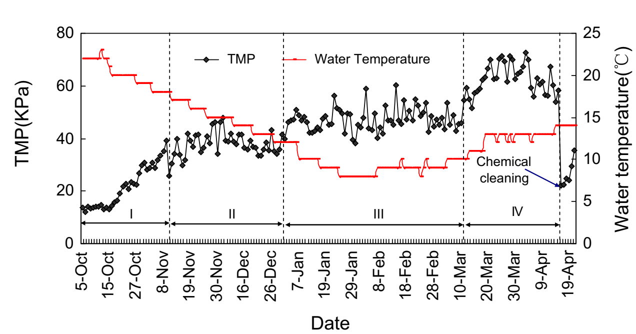

Fig. 5. Variation of TMP.

and the value maintained around 50 kPa. The TMP had risen sharply to 70 kPa while water temperature rises gradually, the phenomenon indicated that the membrane was seriously foul, and should implement chemical cleaning immediately; after chemical cleaning, the TMP dropped significantly to about 30 kPa.

4.4. Treated water quality evaluation

According to the requirements of Ansai wastewater treatment plant, the treated water should be reused for urban water consumption, such as toilet flushing, scenic environment, gardening and washing. The specific water quality standards are listed in Table 3 (National Technical Committee of Standardization Administration of China) [19,20]. As shown in Table 3, the reuse of recycling water quality standard for scenic environment use is the strictest among the three fields.

The effluent water quality of upgraded Ansai wastewater treatment plant has been monitored for seven months continuously. The average values are also listed in Table 3. It can be found that almost all of the items, except NH_3-N, could meet the requirements of urban water consumption, which implied that the water quality was somewhat unfit for the using of scenic environment. For this reason, the treated water in Ansai domestic treatment plant was suggested to be reused for toilet flushing, gardening and road washing.

4.5. Economic evaluation

Due to the limited construction area, Ansai wastewater treatment plant had to use deep water aeration (water depth: 10.5 m), which led to extremely high-oxygen utilization efficiency and great reduction of oxygen demand. Compared with the CAS process (water depth: 5 m normally), oxygen utilization efficiency of deep water aeration was twice of the CAS process. The increase of air blower power due to high-air pressure was offset by the decrease of air demand due to high-oxygen transformation efficiency, the aeration energy costs of these two processes were essentially the same.

Compared with CAS process, the treated water of A^2O MBR process used in updated Ansai wastewater treatment plant could meet the requirements of direct reclamation. Moreover, when the effluent from CAS process is reused, additional advanced treatment comprising coagulation, sedimentation and filtration is necessary. Table 4 enumerates the comparison of performance cost between A^2O MBR system and CAS process combined with advanced treatment (coagulation, sedimentation and filtration). As shown in Table 4, the treatment cost of A^2O MBR system was roughly at the same level of that in the conventional wastewater treatment and reclamation process. However this process shows remarkable advantages such as short process flow and high quality of reuse water.

Table 3
Different reuse purposes of recycling water for urban water quality standard (unit: mg L^{-1})

Parameter	Reuse purpose			Monitoring data of treated water
	Toilet flushing	Scenic environment	Gardening and washing	
BOD_5	10	6	20	<10
TN	–	15	–	<20
NH_3-N	10	5	20	<10 (at 15℃ or above)
TP	–	0.5	–	<0.5
SS	5	5	10	<3
Colour	30	30	30	<10

Table 4
Comparison of the cost between compact A^2O system combining with MBR and CAS with advanced treatment process (unit: RMB m^{-3})

Item	A^2O MBR system		CAS with advanced treatment process	
	A^2O system	MBR	CAS	Advanced treatment
Electricity	0.507	0.26	0.493	0.19
Chemicals	–	0.03	–	0.33
Membrane changing	–	0.395	–	–
Sludge dewatering	0.025	–	0.07	0.05
Total	1.217		1.133	

5. Conclusions

(1) The long-term operation results show that the compact A^2O MBR system could realize high-COD removal and get stable effluent (COD around 20 mg/L). The treated wastewater could be reused for toilet flushing, gardening and road washing.
(2) Water temperature plays an important role in NH_3-N removal and the TMP in the A^2O MBR system. The NH_3-N removal dramatically declined when water temperature was below 15℃, and the TMP increased significantly in very cold water temperature.
(3) The SRT in system had less effect on the removal efficiency of COD and NH_3-N, but it showed great impact on TP removal. The SRT should be controlled within 5–10 d in the system to maintain the high-TP removal efficiency.
(4) This project provided the first case study of A^2O MBR system in the cold region and demonstrated the advantages of membrane technology for water reclamation in water shortage area of China.

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