MBBR+two-stage AO in upgrading and rebuilding project Of a sewage treatment plant in north China

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Abstract. A sewage treatment plant is located in the middle of Inner Mongolia. There is a large amount of slaughtering wastewater in the influent with high COD, SS, low annual temperature, poor nitrogen removal effect, and the effluent quality is only grade B. In order to solve the above problems, A/A/O-MBBR + high efficiency sedimentation tank continuous sand filter process was adopted to establish a new anaerobic tank and a first stage AO-MBBR bioreactor. The selection tank and partial oxidation ditch were transformed into the second stage A pool (anoxic pool), and the remaining part of the existing oxidation ditch was transformed into the second stage O pond (aerobic pool), which further removed phosphorus and reduced the SS in the sewage, and solved the problem of low temperature biological treatment in winter in the north of China. The quality of the effluent reached level A after the upgrading.

1 Introduction

Biological nitrogen removal is the most common treatment method. Environment temperature not only affects the growth of nitrifying bacteria, but also affects the activity of nitrifying bacteria. Previous studies have shown that the optimal growth temperature of nitrifying bacteria was 25-30 °C [1], i.e., the nitrifying rate decreases significantly when the growth temperature was less than 15 °C, and the activity of nitrifying bacteria also decreases significantly; while its temperature is less than 5 °C, the life activity of nitrifying bacteria had almost ceased. U. Sudarno et al. [2] investigated the effect of temperature variation with nitrification, and the results showed that when the temperature increased from 12.5 °C to 40 °C, the ammonia oxidation rate increased; while the temperature decreased to 6 °C, the activity of nitrifying bacteria was very low.

Low temperature has a significant inhibition effect on denitrification. Zhong et al. [3] investigated the denitrification in Taihu Lake sediment. It was found that denitrification rate showed seasonal change after several months of experimental analysis. U. Welander et al. [4] conducted the operation performance of denitrification process at low temperature (3-20 °C), which showed that the denitrification rate of the reactor at 3 °C was only 55% of that at 15 °C. The winter water temperature in the north of China was about 10 °C, which was quite different from the suitable growth temperature of nitrification and denitrification functional bacteria, resulting in the decline of biological denitrification treatment effect in winter and even unable to reach the standard [5].

According to national energy conservation and emission reduction, more and more urban sewage treatment plants have raised their emission standards from the original level B in GB18918-2002 to the level A or higher standard. That is to say, the quasi emission limits of NH₄⁺-N and TN are 8 mg/L and 20 mg/L, respectively, to 5 mg/L and 15 mg/L. Therefore, many sewage plants have been transformed. In this paper, we take a sewage plant in north China into consideration and achieve the national standard level A by the renovation [6-8].

2 Project introduction

A sewage plant is located in the central part of Inner Mongolia, which is characterized by the semi-arid continental climate in the middle temperate zone, with 1.7 °C average annual temperature and 287.2 mm average annual precipitation. The surface water system is underdeveloped and water-deficient zone, where the main water supply aquifer is made of the quaternary upper pleistocene series sand, gravel, sand and gravel layer, as shown in Fig. 1.

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Fig. 1. The sewage plant location layout

The inflow scale of sewage has not reached the expected 40000 m³/D design scale after the operation. In fact, there were a lot of slaughtering wastewater in the influent, which had high SS value and complex pollutant types. And the main pollutant indexes were much higher than the original design values. In this zero, the ambient temperature is low all the year round, which resulted in the poor denitrification effect, and the effluent quality only met the first level B of GB18918-2002. In order to realize the sustainable development of water resources, as well as the low temperature, little rain all year round and the shortage of water resources, the effluent of the sewage plant would be used as the water source of the regeneration water purification plant, which was to provide industrial water for the power plants and open-pit coal mines in the city. Therefore, the sewage plant is in urgent need of upgrading, and raising the effluent standard to level A.

3 The original process and the existing problems

The DE oxidation ditch process was adopted in the first stage of the sewage plant, and the excess sludge is mechanically dewatered after being concentrated. The specific process flow is shown in Fig. 2.

Fig. 2. Original process flow chart of sewage plant.

The sewage inflow was only about 28,000 m³/d, which was far lower than the expected design scale of 40,000 m³/d after the operation of the sewage plant. The pollutant index was much higher than the designed index due to the fact that the actual inlet water of this sewage plant contained a large amount of slaughterhouse waste water. According to the measurement, the maximum inlet water COD_{cr} and ammonia nitrogen reached 2000 mg/L and 120 mg/L, respectively. The high inlet water load and the 1.7 °C average annual temperature in this

zero were not conducive to biochemical treatment, which resulted in the failure to reach the effluent level A. Meanwhile, the following problems often occurred in operation: (1) the high COD concentration of inlet water, the high ammonia nitrogen, and the low annual average temperature affected the removal of ammonia nitrogen. (2) the composition of slaughterhouse wastewater is complex, i.e., the high content of organic pollutants, and high SS value. Hence, the existing biochemical treatment system was difficult to effectively remove to a low level. (3) the alternating operation mode of DE oxidation ditch was not conducive to sewage treatment at low temperature.

4 The upgrading and reconstruction selection

4.1 The original inlet water quality

It has an important influence on the process selection of sewage plant, which included the influent water quality, effluent water quality as well as sewage treatment degree of urban sewage plant. In recent years, the monitoring index of sewage plant were shown in Fig.3. Combined with the historical manual monitoring and water quality test data in July 2015, the inlet water quality was designed by the sewage treatment plant of this project, and the results were shown in Table 1.

Fig. 3. Water quality monitoring index of sewage plant.

Table 1. The designed inlet water quality of the sewage plant.

S.N.	Items	Designed inlet water quality
1	Chemical oxygen demand(COD _{Cr})	≤2000
2	Biochemical oxygen demand(BOD ₅)	≤800
3	Total nitrogen(TN)	≤130
4	Ammonia nitrogen(NH ₃ -H)	≤110
5	Total phosphorus(TP)	≤14.0
6	Suspended solids(SS)	≤380
7	Animal and vegetable oil	≤190

According to the analysis of Fig. 3 and Table 1, the annual COD was maintained between 500-1000, which was easy to cause investment waste if designed in term of high load. Influenced by slaughterhouse wastewater, the COD of the second half year (slaughterhouse was busy in mass production) was higher than that of the first half year; and most of BOD₅ was in the range of 300-600 mg/L; as well as the annual influent NH₃-N was mostly in the range of 80-100 mg/L, in which the total days of exceeding 100 mg/L, 120 mg/L were 9 days and 2 days, respectively; and most of the influent SS were in the range of 200-400 mg/L and more than 380 mg/L was 16 days.

4.2 Selection of process route

According to the characteristics of the influent water quality and the local characteristics of the sewage plant, and the above sewage plant has the following characteristics:(1) it was the key and difficulty of high ammonia nitrogen removal and sludge concentration increase at low temperature,(2) insufficient phosphorus content in raw water,(3) the influence of hair and grease in slaughterhouse wastewater on the treatment process should be fully considered,(4) the value of B/C was mostly between 0.4 and 0.6, and the biological denitrification could be realized when BOD₅/TN was more than 3. Thus, the key point was to increase the biomass under low temperature. In this paper, two schemes will be used for comparison. And compare the two schemes, as shown in Table 2.

Scheme 1: A\A\O-MBBR + High efficiency sedimentation tank + Continuous sand filter process. New oil separation sedimentation tank and air flotation tank pretreatment process, new anaerobic tank and primary AO-MBBR biological tank; transformation of existing selection tank and partial oxidation ditch into secondary a tank (anoxic tank); transformation of the remaining part of the existing oxidation ditch into secondary O tank (aerobic tank). In order to further remove phosphorus and reduce SS in sewage, a high efficiency sedimentation tank and a continuous sand filter were added for further treatment [9-11].

Scheme 2: A\A\O-MBR + Chemical phosphorus removal process. New oil separation sedimentation tank, membrane grid and air flotation tank pretreatment process; transformation of the original selection tank and oxidation ditch into 20000 m³/D biochemical tank I (A/A/O + A/O); new 20000 m³/D biochemical tank II (A/A/O + A/O). Membrane bioreactor (MBR) process was used to replace the original final sedimentation tank for sludge water separation. In order to ensure the phosphorus removal effect, chemicals were added to the effluent of O tank for chemical phosphorus removal [6, 12].

Table 2. Comparison of process schemes

S.N.	Comparative items	Sewage treatment schemes	
		Scheme 1	Scheme 2
1	Effluent quality	Conducive to the growth of nitrifying bacteria, low temperature resistance, good nitrogen removal effect, Chemical phosphorus removal alone, appropriate control, good effect, water stable standard.	The denitrification effect is greatly affected by activated sludge process in winter; Chemical phosphorus removal needs to be done in the biological section; Good SS and COD of effluent.
2	Environmental adaptability	Good low temperature adaptability	Common low temperature adaptability
3	Floor area	Large	Small
4	Utilization of existing facilities	Make almost full use of existing facilities	Remove secondary tanks
5	Engineering cost	Common	High
6	Operation cost	Increase 0.22 yuan/ton sewage	Increase 0.5 yuan/ton sewage
7	Construction difficulty	Almost no impact on production, small difficulty, short time	Impact on production, larger difficulty
8	operational circumstances	Simple management, small difficulty	easy to block the membrane module, needs frequent flushing and complicated operation management.
9	Maintenance Management	Low maintenance requirements and small workload	High maintenance requirements, high workload

It can be seen that there are many technical adaptability applications of the two schemes through the comparison of the above **Table. 2**. However, MBBR scheme had strong adaptability to low temperature because of good effluent quality, low cost, small construction, small difficulty in construction, operation and maintenance. Although it covered a large area, the water plant had enough site to meet the MBBR Process. Many successful cases were employed at home and abroad due to mature design method. Therefore, the MBBR scheme was finally selected, and the flow chart of upgrading scheme is shown in **Fig. 4**.

5 Design of main parameters

According to the description in Section 2, MBBR Process was selected for the project to build or reconstruct the existing structures. And the project would build 6 new buildings and 3 new ones, and the specific structures were shown in **Table. 3**.

Fig. 4 The flow chart of upgrading MBBR scheme**Table 3.** Newly-built and renovated structures

Items	Construction	Technical parameters(length×width)	Num-ber
New-ly-built	Grease trap	25.4 m×42.05 m+10.2 m×16.1 m	2
	Air flotation workshop	42.8 m×26.7 m+13.2 m×3.0 m	1
	Biological pool	62.9 m×97.3 m	1
	High efficiency sedimentation tank	15.7 m×6.3 m+27.8×21.5 m	1
	Continuous sand filter	17.7 m×21.6 m +3.0×3.95 m	1
Reno-vated	Blower room	36 m×9 m	1
	Select pool	22.35 m×10.9 m(Replaced with a pre-dispensing well)	1
	DE oxidation ditch	Transformed into a second stage hypoxia/second stage aerobic pool	1
	Sludge dewatering room	37.2 m×9 m	1

It should be noted that a newly built oil separation sedimentation tank was divided into two grids, in which the average water surface load and hydraulic retention was 2.56 m³/(m².h), 1.1 h, respectively. In view of the high content of total nitrogen in inlet water, two-stage AO process is adopted for sewage biological treatment in this project. The effluent from partial air flotation treatment exceeds the first stage AAO-MBBR biological tank and directly enters the second stage AO biological tank. Sludge concentration: 4000mg/L, anaerobic residence time: 2.0h, facultative residence time: 6.2h.

6 Results analysis

6.1 Analysis of operation effect

The project has been completed and put into operation in the second half of 2015. So far, the sewage plant has been good result in operation. In this section, we will compare and analyze the effect before and after the sewage plant transformation. The operation of the transformed sewage plant on May 30, 2018 was shown in **Table 4**. It can be seen that the COD and BOD₅ met the level A of discharge standard for GB18918-2002, the ammonia nitrogen and SS effluent met the national standard, the total phosphorus content of effluent is high, and chemical agent can be added to assist phosphorus removal..

Table 4. Monitoring parameters of the sewage plant.

Items	Total influent	Total effluent	Effluent standard	Removal rate (%)
COD	836	42	50	94
BOD ₅	278	10	10	96
TN	124	40	15	67
TP	7.49	0.73	0.5	90
NH ₃ -N	87.7	0.16	5	99.8
SS	13	4	10	69

6.2 Pollutant reduction

The construction of upgrading project can further remove pollutants in water, such as SS, phosphate and other nutrients. It not only protects the ecological environment, but also beautifies the urban environment through the implementation of transformation. After the completion of the project, the amount of pollutants will be reduced every day, which was discharged into the surrounding waters, as shown in **Table. 5** (with a scale of 40,000 m³/d). It can be seen that the completion of the project significantly improved and protected the water environment of the surrounding River Basin, reduced the pollution of urban sewage to the water environment, and more conducive to the realization of the water environment goal of the river basin.

Table 5. List of pollutant removal amount.

Items	BOD ₅	COD _{Cr}	SS	NH ₃ -N	TN	TP
Designed water inflow(mg/L)	2000	800	380	130	120	14
Designed water outflow(mg/L)	50	10	10	15	8	0.5
Total removal(t/d)	78	31.6	14.8	4.6	4.48	0.54

7 Conclusion

After a period of operation, the operation result is good and the expected goal is achieved. The several conclusions are drawn as follows:

(1) MBBR+two-stage AO process can effectively resist low temperature, improve sludge concentration, and strengthen denitrification effect. The effluent meets the level A standard of GB18918-2002, which provide water source for regeneration water purification plant, and realizing high efficiency and sustainable utilization of water.

(2) The original structure was made full use of the treatment process, therefore, the transformation cost was moderate, and the operation cost is low. It is suitable for the project of low temperature water shortage and reuse of water in North China.

(3) Considering the large proportion of industrial sewage in the sewage planning within the service scope of the project, the sewage discharge index of each enterprise in the area shall be strictly controlled, and the sewage can be discharged into the drainage pipeline only after reaching the index required by the state.

(4) The content of phosphorus in the effluent was too high. It was necessary to improve the process, assist chemical phosphorus removal and reduce the content of phosphorus.

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