

Technical Investigation on the Application of Ultrafiltration Membrane Process in the Upgrading and Reconstruction Project of Urban Sewage Plant

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Abstract. In recent years, for environmental quality requirements of our country continue to increase, the effluent quality of urban sewage treatment plants has improved correspondingly. A sewage treatment plants in Zhonglou District, Changzhou City originally used the traditional AAO treatment process, complying with the first level B standard of "Discharge standard of pollutants for municipal wastewater treatment plant"(GB18918-2002). However, according to the newest requirements of discharge standard, this sewage plant needs to be upgraded, improving to the first level a standard. The main measures include transforming the former treatment process into a two-stage A/O process (A-O-A-O), which focuses on nitrogen removal to strengthen the nitrogen removal capacity; adding a ultrafiltration membrane system to increase the removal rate of effluent SS and the refractory organic matter. After the completion of the upgrading project, the sewage treatment plant has been operating stably for 12 months. The effluent quality is stable and up to standards, meeting the design standards. This example of transformation can provide a technical reference for the transforming and upgrading projects of other sewage treatment plants, which share the same type of tight land use.

Keywords: upgrading, transforming, nitrogen removal, ultrafiltration membrane system, the first level a standard.

1. Introduction

Such as shortage of total water quantity and low per capita possession, in recent years, the country has resolutely abandoned the original development pattern of "sacrificing the environment for development", and greatly improved the quality of water environment. Therefore, the effluent disposal standards of sewage treatment plants in every city have been improved correspondingly. The sewage treatment plant in Zouqu Town, Zhonglou District, Changzhou City is located to the west of the Beijing-Hangzhou Canal, where the disposal water is discharged after the A2O treatment. The effluent standards originally comply with the first level B standard of "Discharge standard of pollutants for municipal wastewater treatment plant"(GB18918-2002) [1]. Due to economic development and the continuous expansion of the city, the amount of domestic sewage and the industrial wastewater in this area has also increased [2]. At present, the sewage treatment rate of this plant is not high, and part of the sewage and wastewater is discharged into the surrounding rivers, binging great pressure to the local water environment. In addition, Changzhou City promulgated in 2018 the "2018 Citywide Fight for Pollution Prevention and Control and the Special Action Plan for "Two Reductions, Six Controls and Three Improvements"", demanding all urban sewage treatment plants in Changzhou City to complete the first-level A Standard upgrade transformation in an all-round way. At present, some equipments and facilities of this plant are aging, and the process operation is unstable, which means the actual processing capacity can no longer meet the standards.

Therefore, it is necessary to be upgraded to meet the requirements of the effluent quality standards and ensure the quality of regional water environment.

On the issue of upgrading sewage treatment plants, urban sewage plants at home and abroad have made many explorations and attempts. For example, a sewage treatment plant in Ordos City use the method of adding the new intermediate lift pump, high-density sedimentation tank, and ultrafiltration as the advanced processing unit, further remove the pollutants such as COD, SS and TP in wastewater[3]. On the other hand, the sewage treatment plant in Sanmen County, Zhejiang Province adopt the concept of “implant”, applying the MBBR process to the original SBR biochemical pond, transforming to an improved SBR-MBBR-deep-bed denitrification filter process. It has a significant effect under the circumstances of short construction period and tight land use. Afterwards, the effluent quality is stable, and reaches the effluent standard [4].

The theories and methods of upgrading and transforming are different according to the characteristics and main issues of different sewage treatment plants. Measures should be taken according to local conditions and the actual problems should be analyzed and solved. Take ultrafiltration membrane as an example, the transformation technology with the ultrafiltration membrane process as the core has obvious advantages in projects with tight land use and small transformation space, and it has a short production cycle and extremely high pollutant removal rate [5]. The research about the upgrading and transforming project of the sewage treatment plant in Changzhou City aims to carry out as small a renovation as possible, without changing the original operation mode and process route of existing equipment. Ultrafiltration membrane technology has been added to improve the quality of effluent to further remove pollutants such as SS and refractory COD. In the meantime, a transformation of the process has been used, changing the former treatment process into a two-stage A/O process (A-O-A-O), which strengthen the original nitrogen removal capacity. Afterwards, the effluent quality meets the first level A standard of “Discharge standard of pollutants for municipal wastewater treatment plant”(GB18918-2002). This project has improved the water treatment capacity of this plant, meeting the required effluent standards and the regional water environment quality requirements. It also provide both theoretical and technical reference for other similar types of upgrading projects.

2. Analysis of Original Process Operation

2.1. Introduction of the Research area

Changzhou is located in the south of Jiangsu Province, between the Taihu Lake Basin and the Yangtze River Basin and close to the Beijing-Hangzhou Grand Canal. Water resources in Changzhou exist in various forms, mainly in the water environment system composed of “rivers, lakes and reservoirs”. Since the 1980s, Changzhou has stepped into a period of high-speed development, and industry, agriculture and service industry have developed rapidly. The influences to the environment from development, however, are brought unavoidably.[6-7] The current situation of water environment in Changzhou mainly includes the following aspects: (1). The direct discard of industrial wastewater and domestic sewage is serious; (2). Changzhou water network system is complex and staggered with high water network density, small river scale and low water environment capacity; (3). The current effluent quality cannot meet the level I A standard in the Discharge Standard of Water Pollutants for Urban Sewage Treatment Plants (GB18918-2002). There are problems in the original process. Therefore, the reconstruct of Changzhou wastewater treatment plant is imminent.

2.2. The Problems of Original Process Operation

2.2.1. The effluent quality exceeds the standard.

The effluent quality indexes of Zouqu town sewage treatment plant in Zhonglou District, Changzhou in 2018 are shown in Table 1. When the effluent indexes are assessed by level I B standard,

SS and TN don't meet the standard. When level I A standard is adopted, SS, TN and TP don't meet the standard, which will be assessed as key indicators.

In addition, according to the current operation situation, there are still the following problems: (1). BOD5/COD is about 0.34, which implies that the biodegradability of the system is not good enough. There are some refractory organics in the influent, and non-degradable COD or non-dissolved COD in the effluent needs to be removed by physical or chemical filtration; (2). It can be seen according to SS (suspended solid) that the current process flow cannot meet the emission requirements, so it is necessary to add a process for SS advanced treatment. (3). The process of removing TN (total nitrogen) needs a strict anoxic environment, and the oxidation-reduction potential (ORP) in the anoxic section is generally about -100mV, which is the lower the better. At the same time, sufficient carbon source is needed to ensure the complete denitrification process of TN.

Table 1. The effluent quality indexes of Zouqu town sewage treatment plant in 2018

	Unit: mg/L					
	COD	BOD	SS	AN	TN	TP
Jan.	29.4	9.5	23.8	2.77	18.2	0.56
Feb.	25.2	8.2	19.6	3.5	21.2	0.69
Mar.	26.8	7.9	18.8	1.9	19.3	0.65
Apr.	23.5	8.5	20.4	2.45	18.5	0.55
Level I A	50	10	10	5	15	0.5
Level I B	60	20	20	8	20	1

2.2.2. Aging of the plant equipment.

Through the investigation of the current sewage treatment plant, as the sewage treatment plant has been operating about 10 years, some equipment and facilities have been aged, leading low efficiency and degraded performance, which make the effluent is unable to reach the requirements of stable water quality and standard discharge. These problems affect the later operation efficiency as follows: (1). The aeration grit separator is shut down, sand-lifting pump and slag-skimming device cannot work properly because there is no aeration and there are many scum and oil slicks in the pool; (2). One of the primary sedimentation tank is in maintenance and the operation load of this facility is heavy; (3). The aeration in bio-tank is not uniform; (4). The reflux sludge in the secondary sedimentation tank is not enough and some sludge runs off; (5). The static pipeline mixer of rapid filter has poor operation effect and the effect of phosphor removal is unstable; (6). The band pressure filter in sludge dehydrating room is aged, the water content in sludge is high after dehydrating and the sludge treatment capacity cannot meet the need of water inflow, resulting in poor phosphor removal effect and increased power consumption.

3. Technical Method of the Upgrading

According to the requirements of Changzhou Ecological and Environmental Protection Bureau, since 2019 all the sewage treatment plants in Changzhou city are required to execute the Discharge standard of pollutants for municipal wastewater treatment plant (GB18918-2002) level 1 A standard. The original process in the sewage disposal plant of Zouqu was A/A/O process. Overall consideration of target pollutants and the cost of investment, this upgrading process should make use of the original structures to conduct some slight modifications under the original process conditions, to improve TN and SS removal rate in biochemical treatment stage, at the same time, the capacity to remove the refractory organics needs to be enhanced, in order to achieve the purpose of the upgrading standards. The designed inflow and effluent water quality of the reconstruct is shown in Table 2.

Table 2. Water quality index of inflow and effluent of the sewage disposal plant

Units: mg/L				
Number	Project	Designed inflow water quality index		Designed effluent water quality index
1	COD	300		50
2	SS	200		10
3	NH-N	35		5
4	TN	60		15
5	TP	4		0.5

Considering that SS and TN in the effluent water of original process exceed the designed effluent water quality indexes, in order to achieve the designed effect of emission reduction, the original A/A/O process is transformed into a two-stage A/O process which the ultrafiltration membrane was regarded as the core of the upgrading process. The process flow after modifications is shown in Figure 1.

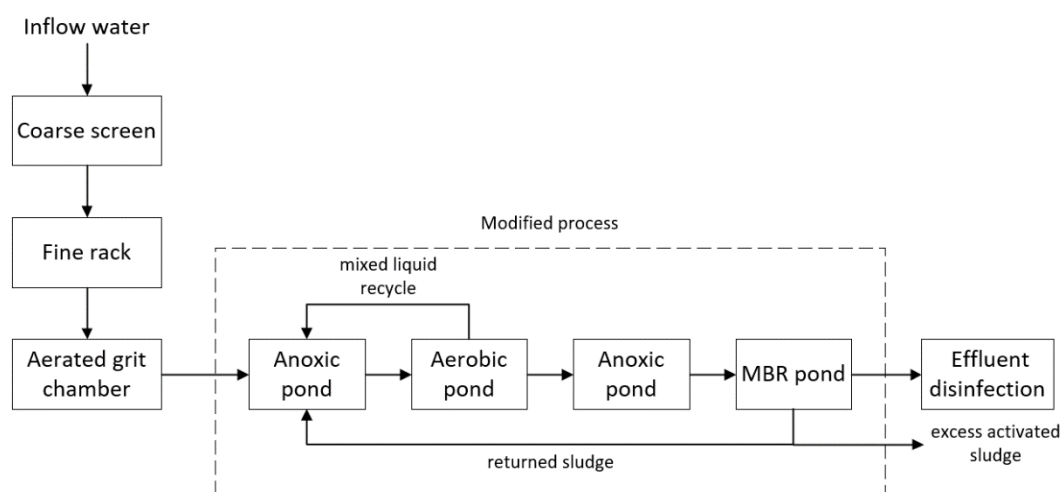


Figure 1. Upgrading process flow diagram.

The first stage of this upgrading process is an anoxic pond. The denitrifying bacteria in anaerobic or hypoxia conditions, the organic matter in the inflow water was used as carbon source, oxygen atoms in NO_3^- in the mixed liquid from aerobic pond backflow to anoxic pond was regarded as electron acceptors, NO_3^- was reduced to N_2 . Second stage is an aerobic pond. The pre-denitrification stage consumes the organic matter content in the inflow water and produces a little alkalinity. Therefore, it eased off the organic matter load in the nitrification stage and reduced the amount of the alkali dosage. The third is another anoxic pond. After the internal recycle in previous A/O period, sewage in this stage was further denitrified the nitrogen, solved the effluent of aerobic nitrification stage which containing a bit concentration of nitrate problem, effectively improved the removal rate of TN. The MBR pond in the fourth stage is under aerobic condition, this stage is in the case of low total nitrogen concentration, by way of phosphorus enrichment of phosphate accumulating organisms under aerobic conditions, to discharge high phosphorus sludge to achieve further phosphorus removal effect. The MBR pond adopts ultrafiltration membrane system, it combined biochemical treatment stage with depth treatment stage, trap insoluble macromolecular organic matter and high phosphorus sludge in MBR pond, indexes such as SS and TP removal capacity has evidently increased.

The ultrafiltration membrane system in the MBR pond adopts piping-main scheme, divide into 4 sets in operation, each ultrafiltration system produces $208.34\text{m}^3/\text{h}$ of water. The average flux of ultrafiltration membrane is $45\text{L}/\text{m}^2\cdot\text{h}$. The minimum membrane area of each ultrafiltration system should not be less than 5145m^2 , the total area of ultrafiltration membrane should not be less than $20,580\text{m}^2$. Considering that operational and maintenance cost, the ultrafiltration system component selects the high strength, good anti-fouling performance, backwash thoroughly and convenient, high water use efficiency.

The ultrafiltration system is designed to automatic operation, and the control system is integrated into the total treatment control system of sewage treatment plant. A set of chemical cleaning device is set for the ultrafiltration membrane system, including cleaning box, cleaning pump, membrane cleaning liquid security filter. The piping set for the cleaning system is a permanent connection system. In order to ensure the normal operation of ultrafiltration system, set sodium hypochlorite, citric acid and other dosing devices, It includes storage tank, dissolving tank, metering pump and corresponding connecting pipe. For the modified process, the average sludge concentration of all stages is higher, the carbon source in the inflow water is also keep a high-usage, very little need add other carbon source, and less excess sludge. In the treatment effect, the removal capacity of TN, SS and TP is improved, and the treatment capacity of COD also improved. At the same time, the MBR pond is no need to add sedimentation basin after, and designed the automatic operation system for the ultrafiltration membrane system. It has the advantages of cover a small area, low capital construction cost and simple operation maintenance in later period.

4. Operating Parameters of Upgrading and Reconstruction

The corresponding parameters of effluent quality shall reach the following standards after Upgrading and Reconstruction: (1). The average dissolved oxygen concentration in the aeration tank should be controlled at about 3mg/L, ranging from 2~5mg/L. Therefore, the supply balance on both sides of the fan / air duct of the aeration tank shall be maintained, in order to avoid structural dispersion of sludge flocs; (2). According to the calculation, sludge concentration should be controlled at about 4.5g/L, which can improve the efficiency of pollutant removal from sludge and shock load resistance of sludge; (3). According to the actual display value at present, the oxidation reduction potential (ORP) in the anoxic tank should be controlled at -100mV, while that in anaerobic tank should be controlled at -250mV, and the lower the better; (4). The internal return flow of sludge should be controlled at 200%~400%, which shall be adjusted according to the nitrogen removal effect. The external return flow is controlled at 50%~100%, mainly to maintain the sludge concentration and ensure the amount of sludge; (5). At present, the effluent index of TP is high, so chemical reagents are needed to assist phosphor removal. It is recommended to replace the phosphorus removal reagent from aluminum sulfate with iron salt (ferric sulfate or ferric chloride) to obtain better phosphor removal effect and certain sludge flocculation and sedimentation capacity.

5. Results and discussion

The upgrading and reconstruction of Zouqu sewage treatment plant are completed in August, 2019, and the commissioning was completed on January 1, 2020. At present, the outlet water quantity is stable, and the daily capacity of the plant is maintained in the range of 15,000-20,00m³. The outlet of the facility is installed with the online monitoring instruments which could monitor indicators include COD, NH₃-H, TN and TP. According to the results of online monitoring, except for several days, all the outlet water indicators have reached the grade A standard of the water discharge. In addition to the reuse part of the tail water, the rest is discharged into Beijing-Hangzhou Canal. Besides, it is estimated that the annual pollutant reduction amount of COD NH₃-H, TN and TP are 90487.17kg, 3580.65kg, 80716.10kg and 324.85kg respectively. The upgrading reconstruction is beneficial for purification and protection of surface water and groundwater resources and reduces the total amount of pollution in the local water environment after completing the upgrading project and put into operation. The upgrading reconstruction ensures the sustainability of local water environment, and is beneficial to the overall improvement of water environment quality in Taihu Basin.

Table 3. Quality of monthly average discharged water from January to April 2021

Indicators	Units: mg/L			
	COD	NH3-H	TN	TP
January	11.34	0.68	12.86	0.10
February	13.10	0.49	11.74	0.04
Thursday	12.35	0.76	11.11	0.03
April	11.81	0.45	12.19	0.07
standard	50	8	20	1

After the upgrading and reconstruction, each indicator of outlet water has reduced obviously than before. Figure 2 shows the comparison of the monthly average removal rate of sorts of water pollution before and after the reconstruction. The detection mainly focuses on the indicators involved COD, NH3-H, TN and TP. Taking the data in April as an example, the removal rates increased to 92.90%, 97.89%, 79.69% and 98.30% and respectively compared with 92.16%, 93.00%, 69.16% and 86.25% in 2018 before the reconstruction, in which the removal effect of TP and TN were significant. The results of the text illustrate that the water treatment capacity has been improved remarkably through the reformation of A/O/A/O process with ultrafiltration membrane as the core technology. In general, every outlet water indicator has reached the expected effect, which means that the pollutant content of outlet water is reduced significantly, and the effluent quality is improved significantly.

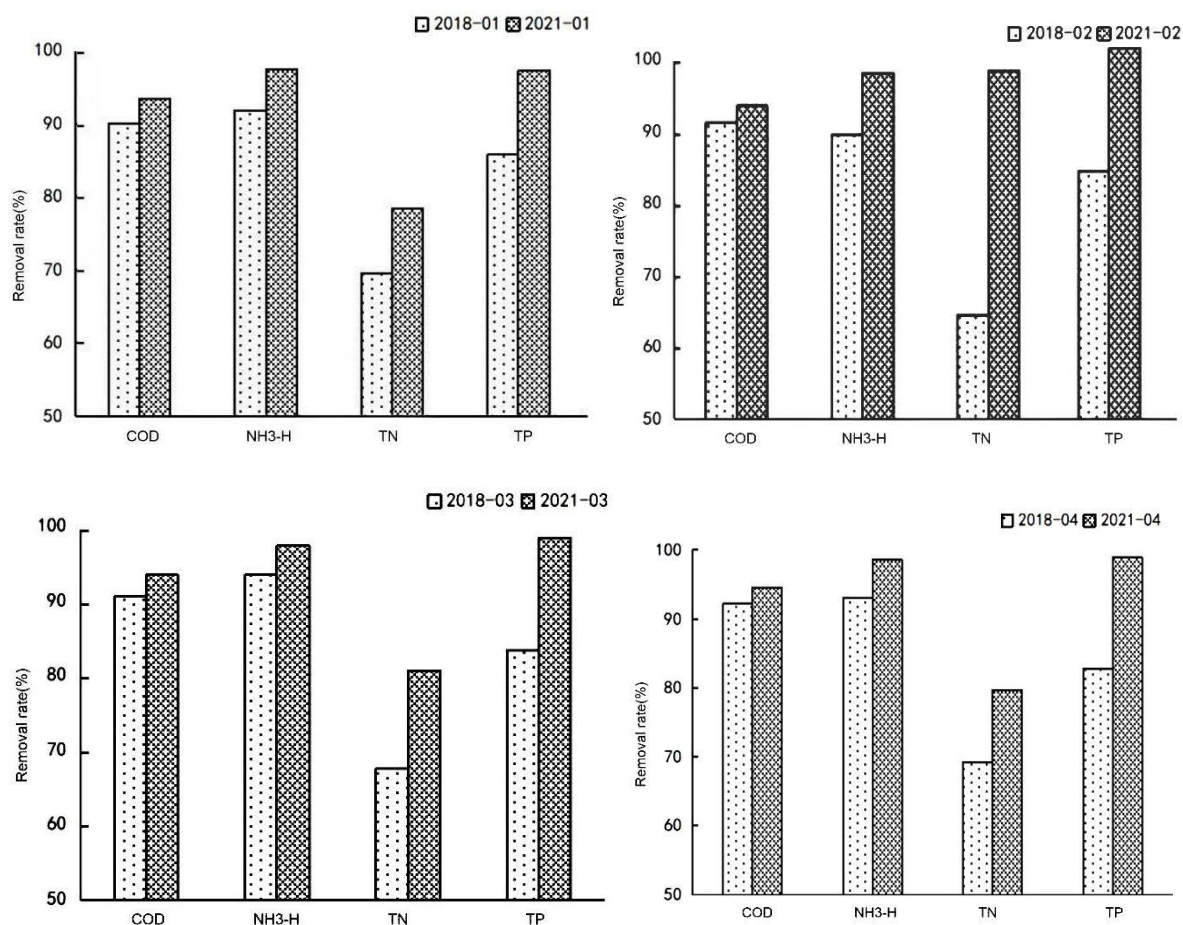


Figure 2. The comparison of the monthly average removal rate of water pollution.

In 2015, the National Action Plan for Water Pollution Prevention and Control proposed to improve the quality of water environment, make overall plans for waterways and give consideration to rivers and seas, and systematically promote water pollution prevention and control, water ecological protection and water resources management, which put forward higher requirements for the emission

concentration of pollutants in sewage. At present, most of China's urban sewage treatment plants implement level 1 A standard of GB18918—2002 <Discharge standard of pollutants for municipal wastewater treatment plants > (hereinafter referred to as "level 1 A" standard), and the processes such as membrane bioreactor, magnetic flocculation technology, denitrification filter, biological aerated filter(BAF) and artificial wetland are widely used at present. According to the existing case of upgrading the standard of sewage treatment, the above processes are compared and analyzed respectively, and the discussion results are shown in Table 4.

Table 4. Comparison of upgrading and transformation processes.

	membrane bioreactor	Magnetic flocculation	Denitrifying filter	Biological aerated filter (BAF)	Artificial wetland
Main target pollutants	COD、SS	SS, total phosphorus	Total nitrogen, SS	Ammonia nitrogen and total phosphorus	Total nitrogen, total phosphorus and SS
floor area	small	small	medium	small	big
construction costs	low	low	medium	low	low
Operation cost and maintenance	The amount of excess sludge is small, so backwashing is needed and the operation cost is moderate.	The amount of sludge and the moisture content of sludge are low, the magnetic powder can be recycled and the operation cost is low.	The filter has no moving parts, and its operation and maintenance are simple, so it needs the pretreatment of traditional sedimentation tank.	Low aeration quantity, low energy consumption, convenient operation and management and low operation cost.	Simple process, convenient management and low operation cost.
Major advantages	High sludge concentration, no problem of poor sludge settling performance, no need of traditional secondary sedimentation tank and filtration unit, and stable effluent quality.	The treatment effect on SS and total phosphorus is good, the flocculation settling rate is fast, and the dosage of reagent is small.[8]	It can be used for multiple purposes and integrates nitrogen and phosphorus removal and SS removal. When the total nitrogen reaches the standard, it can only be used as a common filter to remove total phosphorus and SS.	Easy to film, no sludge bulking, good impact resistance.	There are indirect economic benefits such as landscape value[9], large buffer capacity and low construction and operation costs.

According to the foregoing, considering the actual situation of Zouqu Town Sewage Treatment Plant and the specific pollutants exceeding the standard, the membrane bioreactor treatment process with ultrafiltration membrane as the core is organically combined with the original process of the sewage treatment plant to form a two-stage A/O process, which enhances the nitrogen and phosphorus removal capacity and SS removal capacity on the basis of the original process, and meets the index requirements of upgrading and reconstruction. At the same time, considering the capital construction investment and the convenience of operation and maintenance, the ultrafiltration membrane system saves the traditional sedimentation basin in the advanced treatment stage and integrates the dosing system with the maintenance system, so that the automation degree of operation and maintenance is high, the occupied area also meets the limited space requirement of the sewage treatment plant. Therefore, the upgrading and reconstruction of A/A/O under high emission standards should combine the actual water quality, treatment scale and floor space, maximize the use of the original process, reduce the impact of upgrading and reconstruction, and save economic costs.

6. Conclusions

The upgrading project is based on adding ultrafiltration membrane as the core technology. In the design process, the sewage treatment plant was optimized reasonably and the appropriate parameters were selected. The actual operation results show that the effluent quality has been greatly improved compared with before the upgrading project and reaching the 1A discharge standard. The upgrading and reconstruction significantly reduce water pollution and improves the local water environment effectively, which is of great significance to the stability of water environment in Taihu Basin. Generally speaking, the characteristics and the treatment capacity of pollutants of each process should be fully considered aiming at the current upgrading of urban sewage plant. At the same time, it is necessary to combine the process sections organically in order to make the sewage treatment meet the discharge requirement finally. The smooth implementation of the transformation by using the ultrafiltration membrane technology provides technical reference for the upgrading project of the same type of wastewater treatment plant with the land-strained problem.

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