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# **Optimization of urban wastewater treatment plants process with low C/N ratio**

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Abstract. In southern China, the inflow of water to wastewater treatment plants has a lower concentration of organic matter. This causes treatment plants to face issues in the denitrification and phosphorus removal processes such as deficient carbon sources, high energy consumption, and unstable nitrogen removal. To resolve these issues, we propose the reconstruction of the internal reflux port, improvement of the internal reflux ratio to 200%, the addition of carbon source to anoxic zone, and the addition of phosphorus removal agents in secondary settling tank. The results of study show significantly improved efficiency of nitrogen and phosphorus removal, which ensures the stability of subsequent supply of reused water.

#### 1. Introduction

The concentration of organic matter of influent water is oftenlow in many wastewater treatment plants in southern China, and therefore the actual water quality of outlet is far lower than the designed value [1]. Anaerobic-anoxic-oxic (AAO) is a commonly used process for the biological removal of nitrogen and phosphorus [2, 3]. Inlet with a low C/N ratio could result in several problems, including insufficient carbon source for denitrification, high energy consumption of nitrification and denitrification, and unstable nitrogen removal [4, 5]. This paper illustrates the problems encountered during the actual operation process of a sewage treatment plant in Changzhou, Jiangsu, China. Through partial reconstruction and optimization of operations, the plant improved its nitrogen and phosphorus removal performance, ensuring the stability in subsequent supply of reused water.Furthermore, this reconstruction and optimization can provide a reference for the operation management of other sewage treatment plants.

#### 2. Project overview

The designed total treatment capacity of the sewage treatment plant was 50,000m3/d (construction occurred in two phases, the scale of every independent system, excluding the adjoining inlet water pump, each phase was 25,000 m3/dfor each phase). The biochemical unitsused the traditional AAO process. Figure 1 shows the flow of process. The total design coefficient of variation (diurnal coefficient of variation \* temporal coefficient of variation) Kzwas1.38. After chlorine dioxide disinfection, part of the effluent water was reused as cooling water in the steel industry. Other effluent water was discharged after passing through the ozone contact unit. The effluent water quality was assessed in accordance with the Class A standard of the 'Discharge standard of pollutants for municipal wastewater treatment plant' (GB18918-2002). The design and actual water quality of influent water and design quality of outletare shown in Table 1.



Figure 1. The flowsheet of wastewater treatment process.

Table 1. The design and actual water quality of influent water and design
quality of outlet(notes: actual inlet water quality is the annual average).

Water quality index	Design inletquality	Actualinlet quality(minimum- maximum)	Design outletquality
COD <sub>cr</sub> (mg/L)	400	206(164-305)	≤50
BOD <sub>5</sub> (mg/L)	180	70.6(60.4-78.8)	≤10
SS(mg/L)	250	80(76-80)	≤10
TN (mg/L)	45	40.7(28.8-46.9)	≤15
$NH_3-N(mg/L)$	35	33.5(24.7-43.7)	$\leq 5$
TP(mg/L)	4	4.15(2.52-9.27)	≤0.5

### 3. Operational conditions and issues

The flap valve of the internal reflux port is located at the entrance of the anoxic zone, which leads to the occurrence of a vortex on the water surface (Figure 2).In addition, the Oxidation-Reduction Potential (ORP) theoretical control value of the anaerobic tank is -200to-400mv, but the actual values measured by an ORP meter were all around -112mv.



Figure 2. Vortex at the entrance of anoxic zone.

Additionally, the water quality indicators of water samples from differentuntis were also continuously determined (from date1 to date6, 2015.5.4-2015.5.9). The results are shown in Figure 3. Figure 3 shows that since the internal reflux port cannot keep the anaerobic environment of the anaerobic zone, the AAO process turns into the AO process.Due to the lack of anaerobic phosphorus release, the total phosphorus in the secondary sedimentation tankis high, approximately1.0mg/L, which increases the energy consumption of chemical phosphorus removal in the subsequent advanced treatment process. We also observed that concentration of  $NO_3$ -N in the anoxic zone increased, indicating nitrification. Therefore, the anoxic results are not fully achieved, which elevates the outlet  $NO_3$ -N. This possecertain risks for the stable compliance and stability of subsequent supply of reusedwater.



**Figure 3.** Total phosphorus and nitrate nitrogen indicators of each unit before reconstruction (a. phosphorus indicators, b. nitrate nitrogen indicators).

In order to ensure thestable compliance and the stability of reused water supply, the following measures were adopted.

#### 4. Adopted measures and results

#### 4.1. Reconstruction of internal reflux port

According to phosphorus removal theory, to achieve higher phosphorus removal, phosphorus release must be sufficient [6]. At the same time, phosphorus accumulating bacteria can only release a large amount of phosphorus under strict anaerobic conditions, remaining in a hungry state, which will create a condition for massive phosphorus absorption in the aerobic zone [7]. Since the flap valve was used at the internal reflux port, part of internal reflux nitrification liquid flowed into the anaerobic zone. The ORP measured in that zone was -112mv (theoretical control vale -200to-400mv) due to the  $NO_3$ -N it carried, and the anoxic zone was -90mv (theoretical control vale -50to-110mv), which was unfavorable for phosphorus release.

Therefore, the internal reflux port was reconstructed in a manner in which the position of the original inner reflux port was extended to a certain distance beyond the anoxic zone to prevent water from returning to the anaerobic zone and destroying the anaerobic environment. The internal reflux ports before and after the reconstructions are shown in Figure 4.



**Figure 4.**The internal reflux ports before and after the reconstruction. (a. beforereconstruction b. afterreconstruction).

After the reconstruction of the anaerobic inner reflux pipelinein phase I, the anaerobic conditions of phaseIsignificantly are improved. ORP was -380mvand -60mv in anaerobic tank and the anoxic tank. After the reconstruction, a strict anaerobic environment was ensured, which provided a good environment for subsequent regulation.

#### 4.2. Improvement of internal reflux ratio

Through the internal reflux system, from aerobic zone, and then to the anoxic zone, nitrate nitrogen is provided for denitrification. When the nitrate load in the anoxic zone exceeds the load of ordinary heterotrophic denitrification, denitrification is stimulated to remove phosphorus [8]. From this perspective, a higher reflux ratio is better for phosphorus removal by denitrification. Therefore, the reflux ratio is closely related to the nitrogen removal by denitrification [9]. There exists the relationship of the denitrification rate $\eta$  and reflux ratio R, as shown in equation 1, equation 2 and equation3:

$$\eta = \frac{\text{TN}_{inlet} - \text{TN}_{outlet}}{\text{TN}_{outlet}} \tag{1}$$

$$R = \frac{V_{return}}{V_{inelt}}$$
(2)

$$\eta = \frac{R}{1+R} \times 100\% \tag{3}$$

Where TN inlet TN value of inlet water, TN outlet TN value of outlet water, Vreturnamount of water returned from the aerobic zone to the anoxic zone, Vinelt amount of inlet water flow.

The relationship reveals that a larger internal reflux ratio R could lead to better nitrogen removal by denitrification. However, the effect of the internal reflux ratio R is not always better as R increases. When R is too high, the power consumption and dynamic costs will significantly increase as well. Furthermore, if the reflux ratio is too high, it shortens the hydraulic retention time in the anoxic zone, affecting the performance of phosphorus removal by denitrification. Moreover, when R is higher, more DO is brought to the anoxic section, which will destroy the anoxic environment to a certain extent. The dissolved oxygen brought to the anoxic section will replace the NO3--N and consume the carbon source in the water, resulting in decreasing total nitrogen removal. However, if the reflux ratio is too low, a large amount of nitrification liquid cannot return to the anoxic pond. Excessive nitrification liquid not only affects the removal rate of total nitrogen but also might cause nitrate nitrogen to undergo denitrification in the secondary sedimentation, which could destroy the sedimentation process of the sludge and affect the performance of discharge [10].

Originally, a 100% internal reflux ratio was used, but the nitrogen and phosphorus removal performance was poor. Under the premise of assured anaerobic environment through reconstruction, the internal reflux ratio increased to 200%.

#### 4.3. Carbon dosing point

The carbon dosing in the anaerobic section showed poor nitrogen and phosphorus removal performance. This may be caused by the added acetic acid being first excessively absorbed by phosphorus accumulating bacteria prior to entering the anoxic section for denitrification, resulting in limited addition of carbon source for the denitrifying bacteria in the anoxic section. Therefore, adjustments were made to add acetic acid in the anoxic section. After running the adjustment measures, i.e., the aforementioned reconstruction of internal reflux port and increased internal reflux ratio, 35mg/L of acetic acid was added to the anoxic and anaerobic zones (anoxic and anaerobic zones in phase I; only the anaerobic zone in phase II) to compare its performance upon nitrogen and phosphorus removal in phase I and phase II.

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The monitoring results of the whole process are shown in Figure 5(1-3 were at a different date). The fluctuation of thenitrogen indicator shows that when the carbon source was added to the anaerobic section, the concentration of NO3--N of the anaerobic section decreased due to the absorption of phosphorus by denitrification. The anoxic section continued to absorb phosphorus by denitrification until the absorption of phosphorus and nitrification in the aerobic section occurred. Because priority was given to removal of phosphorus indicator, the NO3--N indicator of that process in the aerobic section was instantaneously increased to 14mg/L, and thus the pressure of the outlet waterto comply with the standard was greater. After a high-quality carbon source was added to the anoxic section, nitrification took place first instead of absorption of phosphorus via denitrification. The concentration of nitrates even decreased to approximately 0.14mg/L. After the nitrification in the aerobic section, the aerobic section, the added carbon source, while the compliance safety of thenitrogen indicator increased.



The flow of process

**Figure 5.** The NO<sub>3</sub><sup>-</sup>-N values of the entire process when the arbon source was added to the anaerobic section and anoxic section.

After several days of comparison of the outlet water (Figure 6), the results showed that when the carbon source was added to the anaerobic section, with the addition of the carbon source to the inlet water, anaerobic phosphorus release and absorption of phosphorus by denitrification occurred and the nitrogen and phosphorus indicators lowered. After the carbon dosing point changed, priority was given to the removal of nitrogen. Although PO43- increased, the nitrogen indicator significantly lowered. This showed that the changes in the carbon adding point not only provided the necessary carbon for denitrification, but also effectively reduced the nitrates in the effluent water. On the other hand, the addition of the carbon source reduced the impact of anaerobic phosphorus release by the nitrates in the external influx, which can effectively improved the TN removal without affecting the TP of effluent.



**Figure 6.** The performance of nitrogen and phosphorus removal when the carbon source was added in the anaerobic section and anoxic section.

#### 4.4. Changing chemical phosphorus removal from V type filter dosingto the multi-point dosing

In the process of phosphorus removal by chemical precipitation, according to the relative position of dosing point of chemical agents and the biological processing unit, the dosing stages can be divided into pre-dosing, central dosing, post-dosing, dosing before filter chamber and multi-point dosing. Originally, a chemical phosphorus removal agent was added before the V type filter. As a result of thehigh fluctuation of TP in the influent water, if the maximum TP of the influent water reached9.27mg/L, then chemical phosphorus removal could not ensure the quality of the effluent water. Therefore, in order to ensure the quality of effluent, multi-point dosing method was adopted where chemical agents were added in the influent of secondary sedimentation and the influent before V type filter respectively. The partial dosing before the secondary sedimentation causes the precipitate formed in the secondary sedimentation to be discharged with the sludge. Comparing the processes before and after the adjustment, when the phosphorous removal agent was added to the inlet water before the V type filter, the TP of the outlet water of the secondary settling tank fluctuated to 1.0mg/L. However, when adding the agent to the secondary settling tank inlet water and before the V type filer, the TP of the outlet water of the secondary settling tank decreased to less than 0.5mg/L, which had a minimal impact on the removal of nitrogen in the biological section. This dosing method can also strengthen emergency phosphorus removal by adding phosphorus removal agents in the secondary sedimentation when abnormal inflow is discovered.

#### 5. Conclusions

This study focused on a sewage treatment process in Changzhou, Jiangsu, China. Through reconstruction and optimization of treatment operations, the results revealed:

• Before the reconstruction, the actual ORP measurement of the treatment plant was around-112mv. In addition, the integrity of the anaerobic environment of the anaerobic zone could not be guaranteed.By extending the original internal reflux port to a certain distance beyond the anoxic zone, the phase I processing after the reconstruction of the anaerobic reflux pipeline significantly improved the anaerobic conditions. ORP was -380mv in anaerobic tank, and - 60mv in the anoxic tank. After the reconstruction, a strict anaerobic environment was ensured, which provided a good environment for subsequent regulation.

• The system experienced the following benefits by utilizing biological nutrient removal theory targeting phosphorus and nitrogen: increased internal reflux ratio, carbon dosing in the anoxic section and multi-point dosing of chemical phosphorus removal agents. The results showed that both nitrogen and phosphorus removal efficiency improved. These results ensure the stability of the subsequent supply of reclaimed water.

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