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Analysis of water quality characteristics and test of the whole functioning process at a sewage treatment plant

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With the stead development of society and economy, protecting of water environment and improving the drainage standards are more paid attention to in China. Therefore, the existing sewage treatment plants are studied in detail to analyze water quality characteristics and their operating status. Combined with the water quality analysis results, the water quality conditions of contaminations, such as organic matter, COD, BOD_5, nitrogen, phosphorus and others, were investigated in detail. Also, based on the results analysis of water quality characteristics, the whole test of process functioning is carried out to explore the removal effect for contamination in different functional areas (anaerobic area, anoxic area, aerobic area). Through the analysis of process operation and existing problems, the optimal measures are put forward to provide effective guarantee for the efficient operation of a sewage treatment plant.

Keywords: wastewater treatment, water quality characteristics, process functioning test, sewage treatment plant.

УДК 628.3

Анализ характеристик качества воды и проверка всего процесса функционирования на очистных сооружениях

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С устойчивым развитием общества и экономики в Китае всё больше внимания уделяется защите водной среды и улучшению стандартов дренажа. Поэтому существующие очистные сооружения подробно изучаются для анализа характеристик качества воды и оценки их работоспособности. Совместно с результатами анализа качества воды были подробно исследованы условия загрязнения воды органическими веществами, азотом, фосфором и другими соединениями, а также показатели ХПК и $БПК_5$. Кроме того, на основе результатов анализа характеристик качества воды проводится тестирование полного процесса функционирования очистных сооружений для изучения эффекта удаления загрязнений в различных функциональных областях (анаэробная область, бескислородная область, аэробная область). Благодаря анализу работы процесса и существующих проблем водоочистки предлагаются оптимальные меры для обеспечения гарантии эффективной работы очистных сооружений.

Ключевые слова: очистка сточных вод, характеристики качества воды, тест функционирования процесса, очистные сооружения.

Water environment protection concerns the vital interests of people in production and life [1–4]. Analysis of water quality characteristics is conducive to environmental monitoring, water pollution control and environmental management [5–7]. Under the requirements of building "resource-saving + environment-friendly" society and the guidance of the goals of "Carbon peak and carbon neutralization" [8], with the concept of comprehensive treatment, different wastewater treatment processes are adopted for polluted water bodies through different components and characteristics. Appropriate technological routes are formulated to improve the capacity of sewage treatment plants for various types of sewage, which has significant social and practical importance [9–12].

According to the State Environmental Protection Administration issued by the "Urban Sewage Treatment Plant Pollutant Discharge Standards" (GB 18918-2002) [13] and Liaoning provincial standard "Liaoning Provincial Sewage Comprehensive discharge standards" (DB 21/1627-2008) [14], the effluent from the sewage treatment plant needs to be complied with the requirements of GB 18918-2002. The Grade A standard of GB 18918-2002 has more strict requirements for the stable operation of sewage plants [15]. In order to comprehensively improve the technical level of the sewage plant, the technical assessment and analysis of the whole process of operation of Shenyang Zhenxing Sewage Treatment Plant were carried out. Through the analysis of the preliminary data and the quality of the incoming and outgoing water in the calendar year, the whole process analysis of the sewage treatment plant was analyzed. Meanwhile, the operation status and existing problems of the sewage treatment plant were also researched, and the feasible measures to optimize their operation were proposed.

Objects and methods of research

Research object. Shenyang Zhenxing Sewage Treatment Plant (ZXSTP) as one of the representative sewage treatment plants on treating environmental waste water, is located in the east side of the chemical industry park in Shenyang of China, which has the designed scale of the sewage treatment at the level of 250 thousand m^3/d. Its east, west and north sides are close to the highway, and the south is near to the railway, covering an area of 24.74 thousand m^2. The sewage treatment plant mainly treats the tail water of the pharmaceutical factory (70 thousand m^3/d) and the untreated municipal sewage (180 thousand m^3/d). The effluent quality meets the grade GB 18918-2002, and the tail water is discharged into the river after treatment. The satellite image of the ZXSTP location is shown in Figure 1 (see color insert VI). The design and actual operation parameters of the ZXSTP are displayed in Table 1.

Wastewater treatment process. The complex composition of pharmaceutical factory tail water, containing a variety substances, is difficult for biodegradability because it inhibits microbial growth and the waste water content of aromatic hydrocarbons and heterocyclic hydrocarbons in sewage is high.

In order to reduce COD and increase BOD_5/COD to a certain extent, the pharmaceutical wastewater is pretreated by "Ozonation + hydrolytic acidification process". The municipal sewage contains industrial wastewater, so

Table 1

The biological tank design and actual running parameters of the ZXSTP

Contents Number of biological tanks	Design parameters Two seats in four groups	Actual parameters Two seats in four groups
Total design flow	250 thousand m^3/d, 2.60 thousand m^3/h single pool	200 thousand m^3/d, 2.083 thousand m^3/h single pool
Total HRT under design flow (h)	20.50	25.6
HRT of anterior anoxic pool (h)	1.06	1.32
HRTof anaerobic phase (h)	1.59	1.98
HRT of anoxic phase (h)	5.93	7.4
HRT of aerobic phase (h)	11.87	14.82
Designed aerobic sludge age (d)	12.5	no data
Sludge concentration (mg/L)	3000	8000
Sludge load (kgBOD_5/kg MLSS·d)	0.061	no data
nitrate recirculation ratio (%)	100–300	150
External reflux ratio (%)	50–150	80

"aeration sand settling + hydrolytic acidification process" was used for pretreatment. After pretreatment, the two kinds of wastewater are mixed. The mixed sewage enters the improved A^2/O biological treatment section to complete the biological phosphorus removal, nitrification/denitrification nitrogen removal and organic matter removal. The effluent from the secondary sedimentation tank passes through the high-efficiency sedimentation tank and fiber bundle filter to further remove the pollutants in the water. Then, the effluent is discharged after ultraviolet disinfection.

Results and discussion

Analysis of water quality characteristics. In order to further grasp the current operation status of ZXSTP, the water quality characteristics and the variation rules of organic matter, nitrogen, phosphorus and other pollutants in the inlet and outlet water from January to December 2019 are analyzed in detail. The analysis results of the water quality characteristics, the COD, BOD_5, TN, NH_3-N, TP, SS concentration change in the influent and effluent of ZXSTP, are as follows (Fig. 2, see color insert VI).

From the analysis of the historical data about the inlet and outlet water quality, it can be found that the chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), NH_3-N, total nitrogen (TN), total phosphorus (TP) and suspended solids (SS) in the effluent can reach the Grade A standard of "Discharge Standards for Water Pollutants from Municipal Sewage Treatment Plants" [15]. In this case, the removal effect of contaminants is satisfactory. In order to make clear whether SS, degradable COD and biochemical BOD_5/COD are improved after pretreatment, through the distribution point, the whole process analysis is carried out to investigate the variation characteristics of the related pollutants along the process. Table 2 presents the data of effluent standards for ZXSTP.

Analysis of the whole process test. Combined with the production process and the analysis of historical data in ZXSTP, the distribution of sampling points in the whole process includes: influent from the chemical park, effluent from the aerobic tank of the chemical park and effluent from the sedimentation tank; inlet water of the pharmaceutical factory, fine grid outlet water of the pharmaceutical factory, effluent from the aeration grit chamber of the pharmaceutical factory, ozonation effluent of the pharmaceutical factory and hydrolytic acidification tank outlet water; municipal line inlet water, fine grid outlet water, effluent from the municipal aeration grit chamber and effluent from the municipal hydrolysis acidification tank, as well as the biochemical section front anoxic tank, the anaerobic tank, the anoxic tank, the aerobic tank, secondary sedimentation tank outlet water, the coagulation sedimentation tank, the fiber bundle filter tank and final effluent. The test indicators include dissolved oxygen (DO), TN, NH_3-N, NO_3-N, TP, PO_4-P and COD. The sampling layout of ZXSTP is shown in Figure 3.

Problems and improvement methods. 1. Change in DO along the process. The control of DO in each process stage plays an important role in the effect of nitrogen and phosphorus removal. From Figure 4, the values of DO in the former-anoxic tank and posterior anoxic pool are at the range of 0.018~0.86 mg/L, which is higher than the normal value. The main reason is that the influent and return sludge carry some dissolved oxygen. The DO at the inlet of the former-anoxic tank is as high as 0.86 mg/L, and at the outer return port is 0.5 mg/L, which destroys the anoxic environment in this area. However, the DO concentration at the end of the anoxic tank is basically close to 0 mg/L. The DO at front-end and middle stage of the aerobic section are over 0.8 mg/L, which is lower than the normal value (2 4 mg/L). Then DO concentration of the terminal section (deoxygenation zone) is 2.8 mg/L, which is so high that the deoxygenation effect is not obvious. It is easy to make a large amount of DO carried in the reflux of activated sludge and is not conducive to denitrification of the anoxic tank.

Table 2

The data of effluent standards at sewage treatment plants

Project	COD	NH_3-N	TN	TP
Grade A standard (GB 18918-2002) (mg/L)	50	5 (8)*	15	0.5
Control rates (%)	100	100	100	100
Coverage rate (%)	86.8	85	98	98.4

*Note: * The value outside the parentheses is the control index when the water temperature is >12 °C; The value inside the bracket is the control index when water temperature is ≤ 12 °C.*

Fig. 1. The satellite image of ZXSTP's location and structure

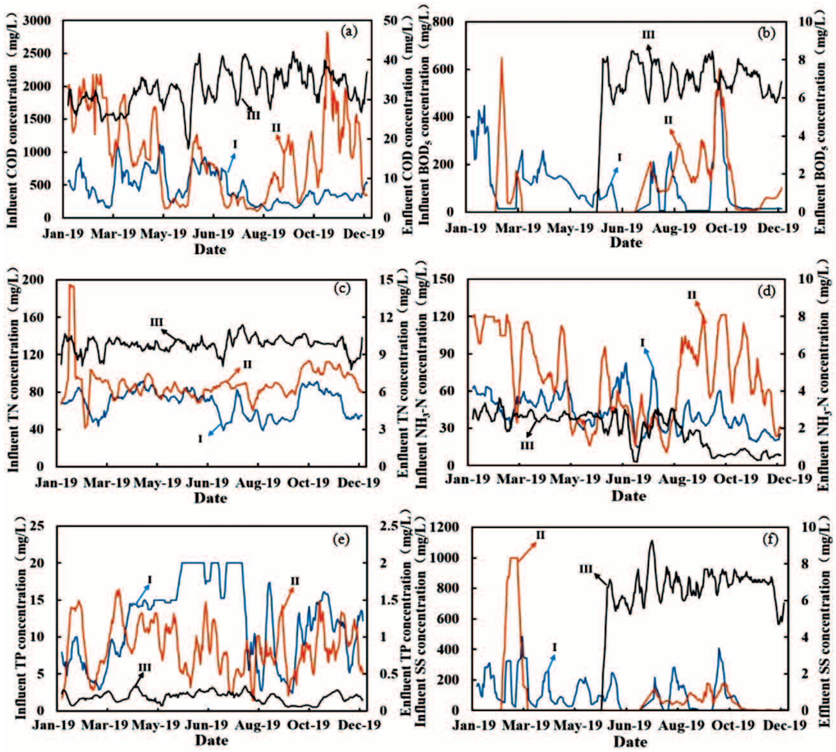

Fig. 2. (a) COD concentration changes; (b) BOD_5 concentration changes; (c) TN concentration changes; (d) NH_3-N concentration changes; (e) TP concentration change; (f) SS concentration changes in inlet and effluent of ZXSTP (I: municipal sewage, II: pharmaceutical wastewater, III: effluent)

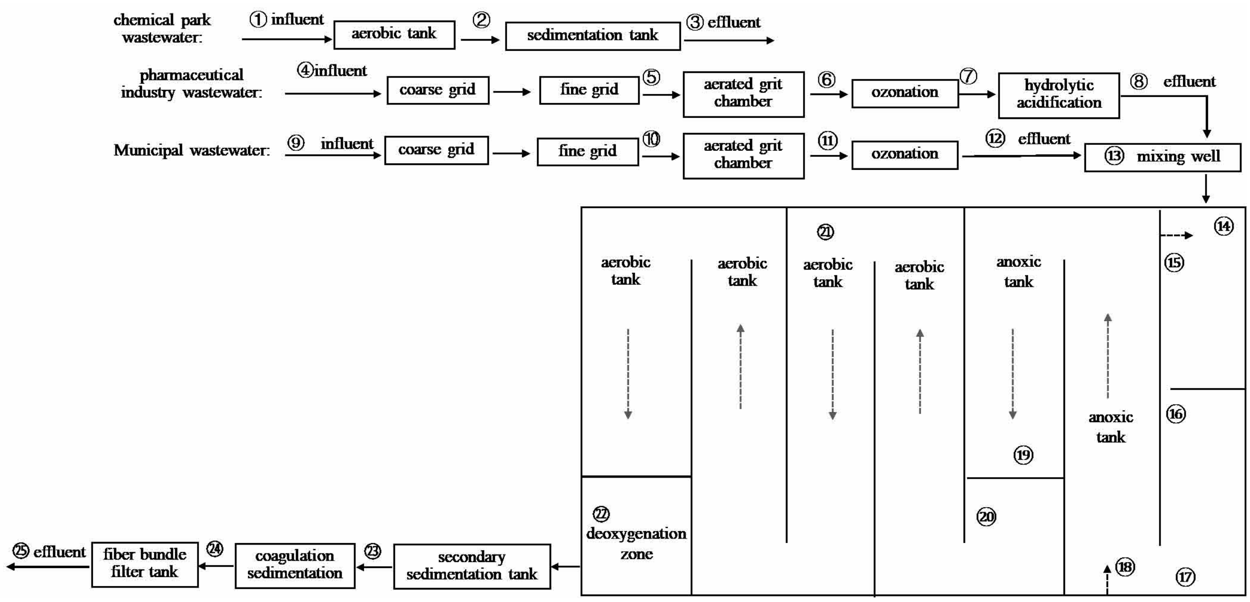

Fig. 3. Sampling distribution diagram of the entire process of water purification at the ZXSTP
1 – Influent from the chemical park, 2 – Effluent from the aerobic tank of the chemical park, 3 – Effluent from the sedimentation tank, 4 – Inlet water of the pharmaceutical factory, 5 – Fine grid outlet water of the pharmaceutical factory, 6 – Effluent from the aeration grit chamber of the pharmaceutical factory, 7 – Ozonation effluent of the pharmaceutical factory, 8 – Hydrolytic acidification tank outlet water of the pharmaceutical factory, 9 – Municipal line inlet water, 10 – Fine grid outlet water, 11 – Effluent from the Municipal aeration grit chamber, 12 – Effluent from the Municipal hydrolysis acidification tank, 13 – Mixing water after pretreatment, 14 – Inlet water of the front anoxic tank, 15 – Anterior anoxic pool outflow orifice, 16 – Influent of the anaerobic tank, 17 – Effluent of the anaerobic tank, 18 – Influent of the anoxic tank, 19 – Effluent of the anoxic tank, 20 – Influent of the aerobic tank, 21 – Middle section of the aerobic tank, 22 – Effluent of the aerobic tank, 23 – Effluent of the secondary sedimentation tank, 24 – Effluent of the coagulation sedimentation tank, 25 – Effluent of the fiber bundle filter tank

2. Change in COD along the process. From Figure 5, it can be seen that the amount of COD changes along the process of wastewater treatment in ZXSTP. The COD concentration of municipal influent is relatively low, around 102 mg/L, and the influent is mainly soluble COD (SCOD) with the proportion of 78%. Through the filtration and precipitation of the pretreatment unit equipment and facilities of the municipal line, the SCOD concentration is 120 mg/L after mixing with the pretreated pharmaceutical wastewater. Compared with the design value (≤300 mg/L), the additional carbon source needs to be added because the available carbon source is limited after entering the biochemical system. After the biochemical system and the advanced treatment unit, the final effluent COD concentration is 49 mg/L, which can meet the Grade A standard of “Urban Sewage Treatment Plant Pollutant Discharge Standard”. But there is also a risk of exceeding the standard, so the sewage treatment process must be further optimized.

3. Change in Nitrogen along the process. It can be seen from Figure 6, the soluble total nitrogen (STN) concentration of the effluent from the mixing well, that is, the influent from the biochemical system, is 21.5 mg/L. The main component of STN is NH_3-N with the concentration of 19.9 mg/L, accounting for about 92.6% of STN. The concentrations of NO_3-N in the former-anoxic tank and the outer reflux are 1.45 mg/L and 2.02 mg/L, respectively. It is mainly because NO_3-N is carried in the outer reflux and denitrification occurs in the tank by using the carbon source in the influent. A large amount of NO_3-N is carried in the reflux to the anoxic tank, and the concentration of NO_3-N at the front end of the anoxic tank is 3.81 mg/L. After denitrification, the concentration of NO_3-N in the effluent of the anoxic tank decreases to 1.92 mg/L. The nitrification effect of the aerobic segment is satisfactory, and the content of NH_3-N decreases significantly.

4. Change in Phosphorus along the process. As shown in Figure 7, the situation of phosphorus change along the process is given. The TP concentration of the effluent from the mixing well, namely the influent from the biochemical system, is 1.09 mg/L. The TP concentrations at the front end and the end of the anaerobic tank

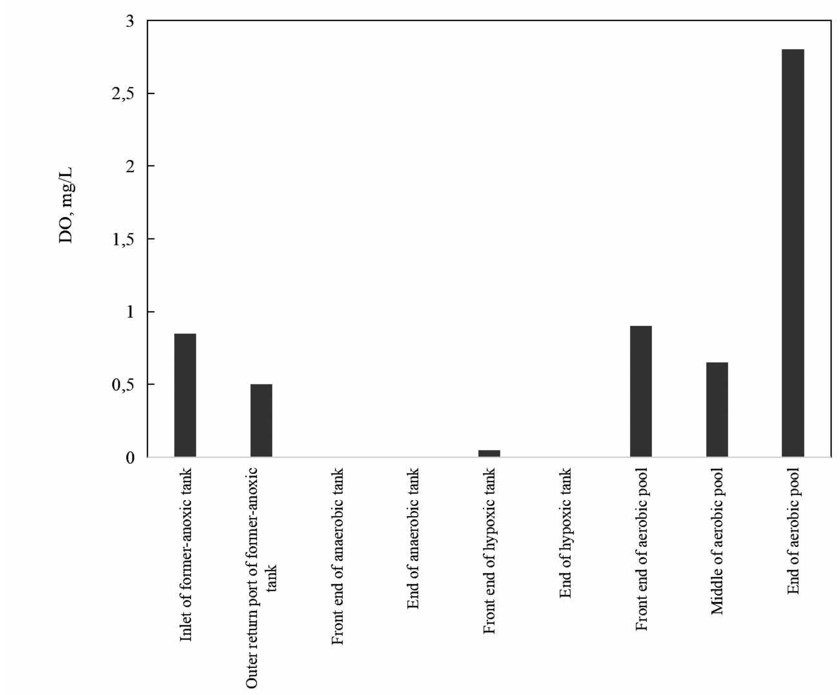

Fig. 4. DO change along the process of ZXSTP

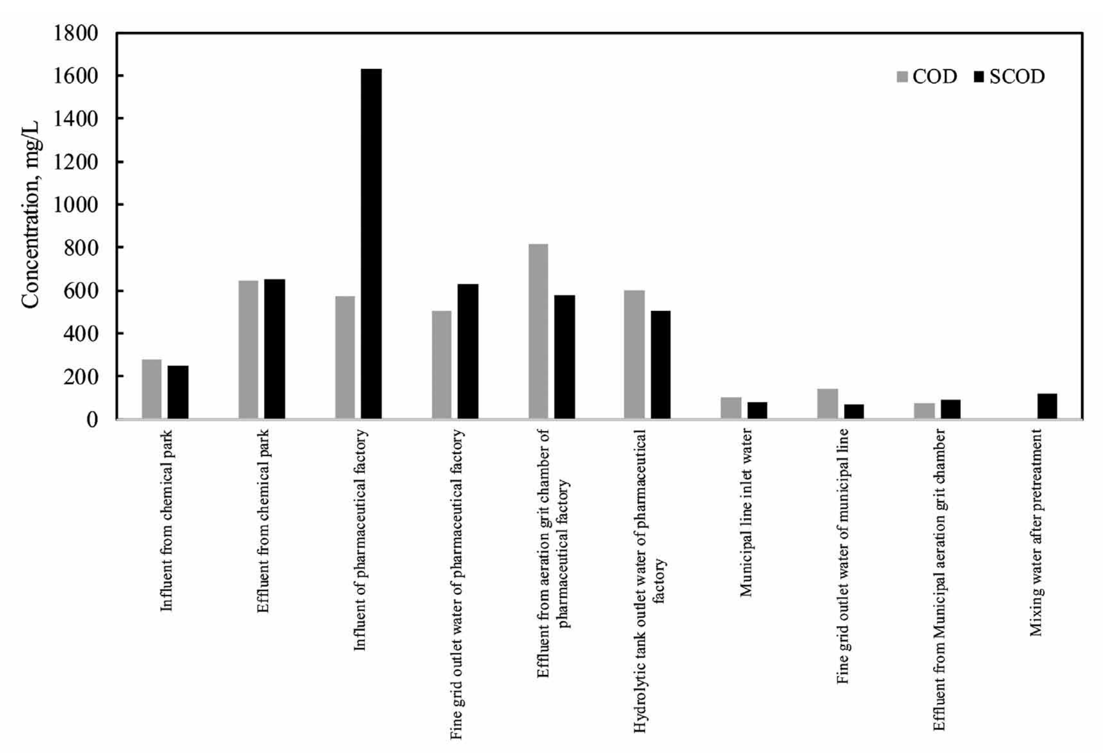

Fig. 5. COD change along the process of ZXSTP

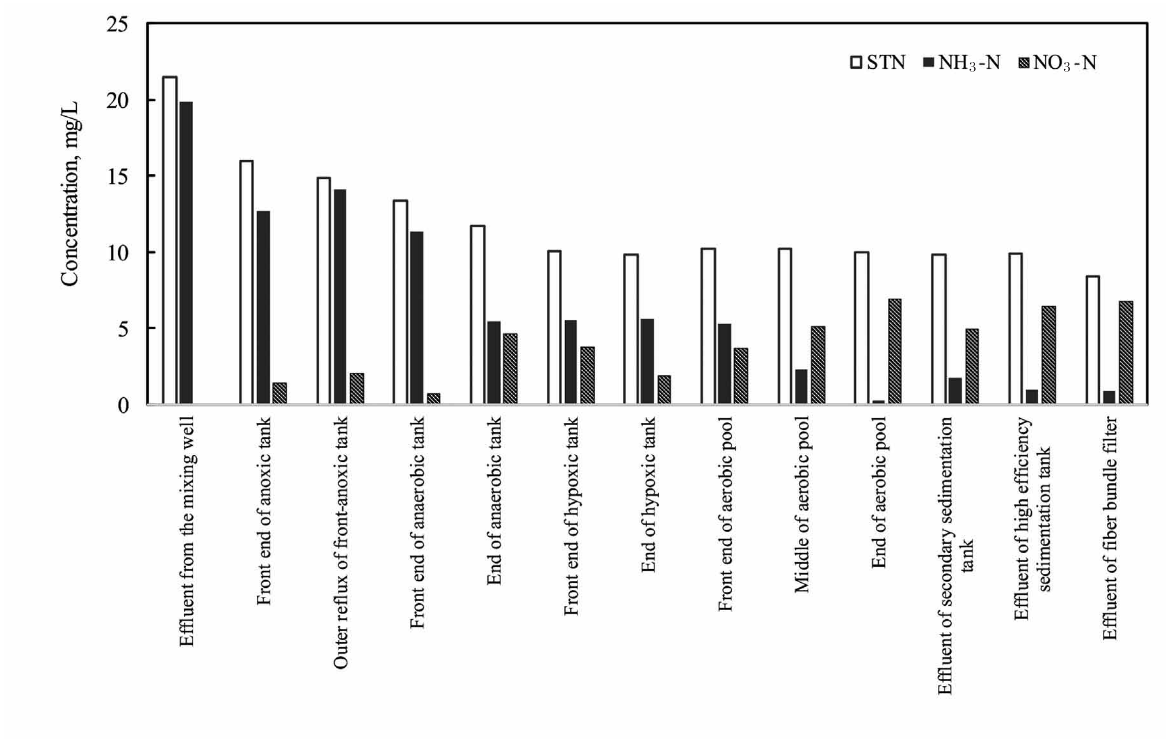

Fig. 6. Nitrogen change along the process of wastewater treatment of ZXSTP

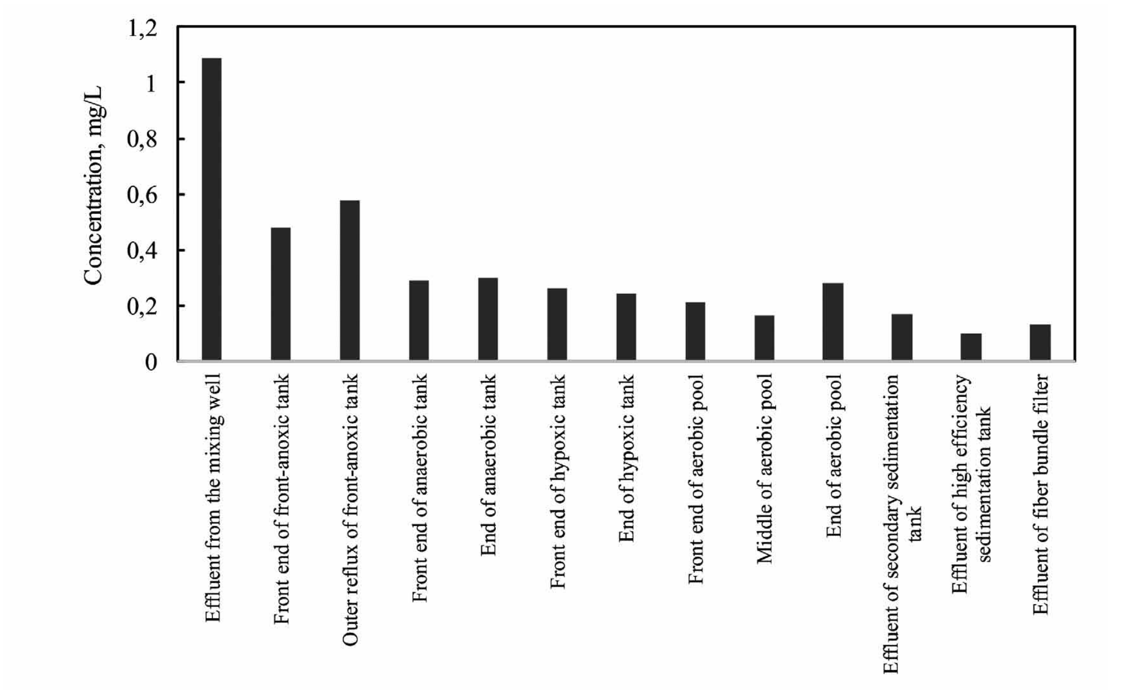

Fig. 7. Phosphorus change along the process of wastewater treatment

are 0.289 mg/L and 0.298 mg/L, respectively. There is no obvious anaerobic phosphorus release phenomenon, which may be related to the large amount of sludge at the bottom of the anaerobic tank. The capacity of tank and the hydraulic retention time are seriously compressed, which results in the aging and death of the sludge. A large amount of the floating sludge appears on the surface of the tank.

Constructive comments on the whole process. According to the above analysis, some existing problems can be found in ZXSTP. Correspondingly, the suggestions and improvement methods are proposed as follows.

Firstly, the concentration of ammonia nitrogen at the end of the aerobic tank is 0.268 mg/L, which is basically converted into nitrate nitrogen. It indicates that excessive aeration exists at the end of the aerobic tank. Thus, reducing the aeration at the end of the aerobic tank is suggested in order to decrease the concentration of DO in the internal-external reflux, which can promote the recovery of the anoxic environment of the anoxic tank and bring down the operation cost.

The concentration of COD in the pharmaceutical wastewater and municipal wastewater ranges from 102 to 574 mg/L, which is mainly SOCD. The removal effect of COD in each pretreatment unit is unsatisfied, so the toxic and harmful substances in the influent may impact the biochemical system. It is recommended to optimize the pretreatment unit. The COD concentration in the influent is 49 mg/L, which can meet the Grade A standard, but it needs to be further optimized due to the risk of exceeding the standard.

The TP and TN concentrations can achieve the Grade A standard of GB 18918-2002.

Furthermore, it is recommended to clean up the sludge at the bottom of the biochemical system, and to overall inspect, maintenance and replacement of each impeller. Meanwhile, the water impeller should be installed at an appropriate location to improve the mixing of the sludge and water in the anaerobic tank and the anoxic tank, so that to reduce the occurrence of the floating sludge caused by sludge aging.

Conclusion

The overall operation of the ZXSTP is stable, the removal efficiency of contaminants is high, and the control measures are reasonable, which reflects a high level of comprehensive management. According to the analysis of the water quality and the whole process of the historical inlet and outlet water data, the operation measures need to be optimized, the source control should be strengthened, the industrial wastewater monitoring and the official website investigation must be conducted, so as to avoid the impact of toxic and harmful wastewater on the activated sludge system under the current influent water quality conditions. For the actual operation of the ZXSTP at present, it is suggested to optimize the pretreatment unit, strengthen the removal effect of SS in the chemical park wastewater, improve the operation state of the aerobic tank, and enhance the removal efficiency of refractory toxic substances. Further optimization of the advanced treatment unit, the daily maintenance and an overhaul of the equipment should be strengthened, which can ensure the efficient and orderly treatment of the target waste water at the ZXSTP.

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