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Research on Upgrading and Reconstruction in Low Concentration Urban Sewage Treatment Plants

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Carrousel oxidation ditch treatment technology with front-facing anaerobic tank is adopted in sewage treatment plant of a southern city in China. Based on A standard of *urban sewage treatment plant pollutant discharge standards (GB18918-2002)*, TN and TP concentrations of the actual effluent are beyond the standard. Analyzing the process flow, inlet and outlet water quality, the main reason of the low removal rate of TN and TP was the lower inflow organic concentration compared to the design value. It's difficult to form aerobic/anaerobic alternating operation environment as design for nitrogen and phosphorus removal in oxidation ditch. The corresponding reconstruction was carried out. The results showed that stable up-to-standard of effluent quality was achieved by changing vertical surface aerator to microporous aeration, on-demand aeration controlling nitrogen, reducing or closing internal reflux, adding the carbon source, completing the sewage collection system and so on. The average removal rate of tested TN and TP in 2017 can reach 50% and 88% respectively.

1. Introduction

In southern China, the actual inflow organic concentration is often lower than the designed value in the operation of sewage treatment plant. In fact, it can't save operation cost of the low concentration inflow (He, et al. 2016, Wang, et al. 2014, Zhang, et al. 2016). On the contrary, it may bring a series of problems, such as abnormal growth of activated sludge in biochemical system, too small of the sludge floc to precipitate, declining of the activated sludge volume, influence of TN and TP removal rate, reducing the investment benefit of sewage plant and increasing the burden of operation (Sun, et al. 2016, Zhang, et al. 2014). So the sewage treatment system may be hard to operate properly. Therefore, it's a hot research topic that how to make the outlet water quality reach A standard of *urban sewage treatment plant pollutant discharge standards (GB 18918-2002)* stably in sewage treatment plants with lower concentration inflow(Larry B. Barber, et al. 2015). Zhang, et al (2011) integrated a field survey, batch tests and microbial community identification to improve the effectiveness of the enhanced biological phosphorus removal (EBPR) process for WWTPs and the anaerobic P-release rate was found to be an effective indicator of EBPR. Liu, et al (2012) developed an innovative adsorption /nitrification /denitrification /sludge-hydrolysis wastewater treatment process (ENRS) characterized by carbon source manipulation with a biological adsorption unit and a sludge hydrolysis unit to enhance nitrogen removal and reduce sludge production for municipal wastewater treatment. Wang, et al (2015) had concluded that anammox bacteria were widespread in diverse treatment units of municipal WWTPs, regardless of the oxygen content (even DO>2 mg/L), substrate loadings (low to 2.1-51.0 mg N/L), seasonal condition (winter and summer) or operating process (AAO, OD, SBR, and MBR), with the abundance of 105-107 hzs gene copies/g (Figueroa, et al. 2012, Wang, et al. 2013). Jin, et al (2015) compared two aeration modes, step aeration and point aeration, in a full-scale Carrousel oxidation ditch with microporous aeration. The result was that step aeration had an overall higher TN removal efficiency (Guo, et al. 2013 and 2014).

The above literature may discuss the removal of pollutants in different sewage treatment plants. For low concentration inflow, there's almost no reports. In this paper, it's discussed of the operation in sewage treatment plants with lower concentration inflow and the problems in the operation process. As to the existing problems, the corresponding reconstruction measures were carried out for the stable water quality standards of the effluent.

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2. Profile of sewage treatment plant

2.1 Profile and design standards

L sewage treatment plant (L-STP) is located in southern China. It was built in 2009, with the service area of 30.1km^2 and the design disposal capacity of 120000 m^3/d. Carrousel oxidation ditch treatment technology was adopted with front-facing anaerobic tank. The designed effluent quality can meet B standard of *urban sewage treatment plant pollutant discharge standards (GB 18918-2002)*. The designed parameters of raw sewage and effluent water quality are shown in Table 1.

Table 1: Designed quality of raw sewage and effluent water

Water quality indicator	BOD_5	CODcr	SS	$TN(NH_3\text{-}N)$	TP
Designed water quality of raw sewage (mg/l)	100	200	140	35(25)	3
Designed water quality of effluent (mg/l)	20	60	20	20(8)	1

2.2 Technological Process

Carrousel oxidation ditch treatment technology was adopted with front-facing anaerobic tank in L-STP. And the vertical surface aerator was used for aeration. Urban sewage was sent to the plant after the collection of pipe network and the elevation of outside pump station. Urban sewage drifted into inlet pump station through coarse bar screen removing large floats. There're four centrifugal submersible sewage pumps in pumping station to elevate sewage to vortex grit chamber through one pipe of 1.6 meters in diameter. There're three rotating-drum fine screen before vortex grit chamber to further remove the suspended solids, especially the filamentous and banded suspended solids. After sand water separation, sewage entered into the anaerobic tank and stayed some time before entering the carrousel oxidation ditch. The chemical removing phosphorus technology was used and the dosing spot of liquid polymer aluminum located at water distribution weir of the secondary clarifier in integrated well. Treated by oxidation ditch, sewage flowed to secondary clarifier evenly by integrated well. After separating, the supernatant was disinfected by sodium hypochlorite and then flowed into Yangtze river. A part of sludge from the secondary clarifier was pumped back into oxidation ditch, the other part as excess sludge was sent into sludge dewatering process by centrifugal concentrating dehydration. The specific process was shown in Figure 1.

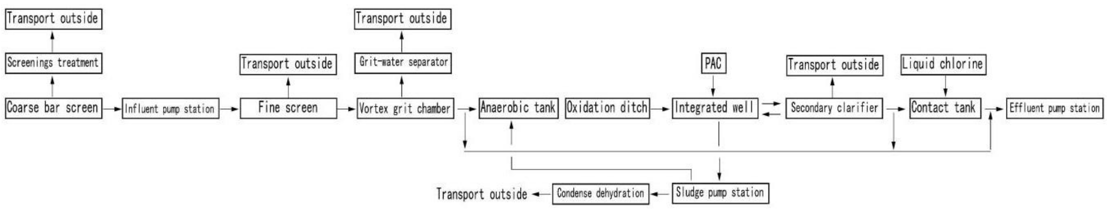

Figure 1: Process flow chart

2.3 The main structures and process parameters

The main structures include coarse bar screen, water pump station, vortex grit chamber, anaerobic tank, oxidation ditch, secondary clarifier and so on. The parameters of main structures are shown in Table 2.

Table 2: Main structures

No	Item	Specifications	Amount	Remarks
1	Coarse bar screen room	L*B*H=16.8*8.6*11.2	1	co-construct underground
2	Water pump station	L*B*H=15.8*8.6*11.2	1	reinforced concrete structure, H=10m
3	Fine screen room	L*B*H=12.8*7.6*4.4	1	reinforced concrete structure
4	Vortex grit chamber	D=5m,H=4.65m	2	Round reinforced concrete structure
5	Anaerobic tank	L*B*H=112*9*5.2	2	Annular reinforced concrete structure, HRT=1.5h
6	Carrousel oxidation ditch	L*B*H=112*37*5	2	Annular reinforced concrete structure, HRT=7.7h $F_W=0.078kgBOD_5/kgMLSS\cdot d$, $MLSS=4000mg/l$
7	Integrated well	D=13m,H=7.8m	1	half-underground reinforced concrete structure
8	Secondary clarifier	D=40m ,H=4.62m	4	Round reinforced concrete structure T=2.5h, R=100%, q_{max}=1.17$m^3/m^2\cdot h$
9	Contact tank	L*B=40*21.2	1	Underground reinforced concrete rectangular tank
10	Sludge pumping station	L*B=12.7*10.4	1	half-underground reinforced concrete structure
11	Sludge thickening and dewatering station	L*B=24*10	1	Double construction of masonry-concrete structure

3. Analysis of operation and existing problems

3.1 Operation analysis

Statistical analysis on the monitoring results of inlet water quality in L-STP, the inlet water quality indicators of the maximum, minimum, average and 85% reliability value can be obtained in 2016 as shown in Table 3. It can be seen from Table 3 that certain difference was existed between the average inlet water quality and the original design value, especially the actual values of COD, BOD and SS were smaller than the original design value. The actual value of TP exceeded quota sometimes. Table 4 showed the average water quality of inflow and effluent in January, 2017.

Table 3: Inflow quality and original design value of L-STP in 2016 (Unit: mg/L)

Water quality indicator	COD	BOD_5	SS	NH_3-N	TN	TP
Maximum inflow	186.97	64.12	79	18.64	30.5	3.7
Minimum inflow	107.27	33.24	53.26	10.97	16.00	1.54
Average inflow	146.71	47.45	64.91	14.9	21.22	2.28
85% reliability inflow	170	85	119	21.25	29.75	2.55
Original design inflow	200	100	140	25	35	3
Average effluent	21.14	1.52	4.16	0.38	12.5	0.38
Original design effluent	60	20	20	8	20	1

Table 4: Quality of inflow and effluent in January, 2017 (Unit: mg/L)

Water quality indicator	COD	BOD_5	SS	NH_3-N	TN	TP
Inflow	169.10	64.12	69.74	18.64	25.10	2.17
Effluent	29.25	2.02	4.81	0.72	17.62	0.98

Analyzed on Table 3 and Table 4, the main evaluation indexes can meet B standard of *urban sewage treatment plant pollutant discharge standards (GB18918-2002)*. As to A standard, TN/TP can't meet standard in most time of the year. Compared to the design standards, water pollutant concentration is seriously low. It's in the low load running for a long time with the phosphorus removal rate of only 54.8% (including chemical phosphorus removal) and the nitrogen removal rate of 29.8%. The nitrogen and phosphorus removal effect is poorer. At present, TN/TP of the effluent can meet standard is due to the low pollutants concentration in water.

3.2 Analysis of existing problems

3.2.1 Analysis of TN out of limits in effluent

(1) The biological denitrification of oxidation ditch achieved alternation of anoxic and aerobic in the "circular runway type" tank. There exited synchronous nitrification and denitrification in the same tank for the nitrification of NH_3-N and the removal of TN. There're 74% NH_3-N in the TN of inflow, but only 4% NH_3-N in the TN of effluent. It showed that nitrification effect is better and denitrification effect is lower. It can be explained by adequate oxygen and complete nitrification in carrousel oxidation ditch. NH_3-N can be converted to nitrate nitrogen in time. Without independent anoxic zone, denitrification effect is low in the alternation of anoxic and aerobic. At the same time, the dissolved oxygen concentration is too high (>0.5 mg/L) to inhibit denitrification because of the low organic matter concentration of inflow and less consumption of oxygen. It can meet the demand of nitrogen removal by nitration as generally considered DO within 0.8-1.1mg/L in aerobic zone of oxidation ditch. It makes little sense to improve DO again for the nitrification effect. So substandard TN in effluent may be caused by poor denitrification effect.

(2) The carbon source is serious shortage. The limited denitrification carbon source in raw water may be aerobic consumed partly and the denitrification is affected. The value of C/N in raw water is low to only 2.5. Flowed through anaerobic zone, the value may be further reduced. It's generally considered that biological denitrification effect may be good as C/N>4-6. Actually the needed C/N can be as high as 8. So the unsatisfactory denitrification effect may due to the low C/N in raw water.

(3) The construction scale and inflow water quality of L-STP have relatively large difference to the actual values in operation because of incomplete sewage collection system. It may directly cause low total inflow. Part of combined sewer system and groundwater infiltration in southern China may make the low concentration of inflow and it is far lower than designed value. This is the main reason of not normally running in L-STP.

3.2.2 Analysis of TP out of limits in effluent

The method of biological phosphorus removal supplemented by chemical phosphorus removal is used in L-STP. The reasons of TP out of limits in effluent may be as follows.

(1) Not enough carbon source in raw water, there is no guarantee of enough matrix for Phosphorus Accumulating Organisms (PAOs). The low C/N caused nitrate nitrogen back into the anaerobic zone. It can't work well for biological phosphorus removal of phosphorus release in anaerobic zone and phosphorus uptake in aerobic zone. Resulting in unsatisfactory biological phosphorus removal effect.

(2) The removal of phosphorus was mainly by eliminating excess sludge. So excess sludge production has the most direct impact on phosphorus removal effect. The designed excess sludge production is 10200kg/d. Because of low influent organic concentration, excessive sludge autoxidation may be caused in aeration process. The sludge concentration is low to 2500mg/L, which is below the appropriate concentration for removing phosphorus. Less sludge production caused low removal rate of TP.

(3) Because of low influent concentration and less oxygen consumption, the value of DO is above 0.5 mg/L in anaerobic zone influencing phosphorus releasing of PAOs. The DO environment in oxidation ditch is affected by the fluctuation of quantity and quality of raw water significantly. In the period of low low load, the area of DO high is too large to form a steady alternating aerobic and anoxic environment in oxidation ditch. It may directly affect the growth, phosphorus release ability and synthetizing PHB with organic matrix of PAOs, which would result in poor effect of biological phosphorus removal.

(4) Liquid polymer aluminum is used for designed chemical phosphorus removing in L-STP. The dosing spot of liquid polymer aluminum located at water distribution weir of the secondary clarifier in integrated well. Then through mixing in vertical mixer and reacting in folded plate, distributed sewage flowed to secondary clarifier. But the flocculating time in this process is too short to form big alum flowers and achieve good precipitation effect in the secondary clarifier.

4. Adjustment of process operation

4.1 Reconstruction measures

4.1.1 Control nitrogen by on-demand aeration

The designed value of DO is 2 mg/L in oxidation ditch. The actual TN concentration is out of limits in effluent, mainly for nitrate. It showed that the nitrification effect is good in oxidation ditch and the denitrification effect is poor. So the aerator in oxidation ditch should be adjusted. The vertical surface aerator was used for aeration in the original technology, with oxygenating and pushing flow of mud mixture, as shown in Figure 2. It's difficult to coordinate the two. It's often seen that DO is just right with not enough impetus or impetus is enough with excessive DO. This may seriously affect the processing efficiency of oxidation ditch.

So the vertical surface aerator is replaced by microporous aerator of controlled aeration volume, as shown in Figure 3. The adjustable section is set between the anoxic zone and the aerobic zone in oxidation ditch. Based on the current pool, the degassing section is set in the end of the aerobic zone, with internal reflux pump of nitrification liquor in the end. The sewage flowed from anaerobic tank into the front of reconstructed anoxic zone directly, mixing with refluent nitrification liquor through degassing section. It's realized the maximum use of the volume of anoxic zone and carbon source of inflow theoretically. The adjustable section is set to ensure the residence time of nitrification and denitrification in oxidation ditch and to deal with obvious variation of inflow sewage quality. Two aeration units are reserved for adjustable aerobic section in the end of anoxic zone, supplementing for not sufficient aeration. The effluent from aerobic zone flows into degassing zone. Underwater blenders are set up to prevent sludge sedimentation, reduce DO in effluent and internal reflux and strengthen denitrification.

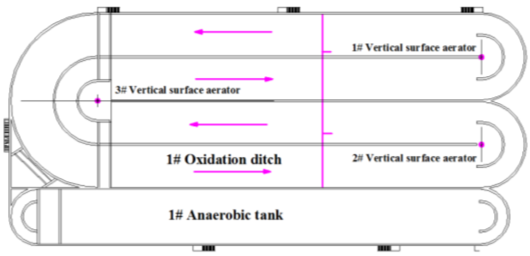

Figure 2: Layout of oxidation ditch before reconstruction

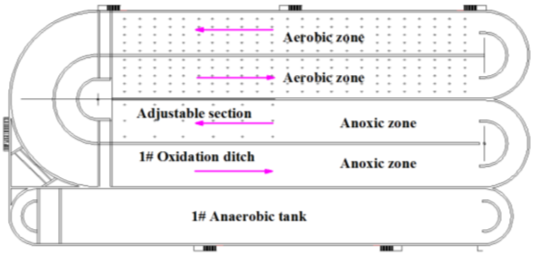

Figure 3: Layout of oxidation ditch after reconstruction

4.1.2 Adjust sludge reflux ratio (SRR)

External reflux is to ensure sludge concentration and supplement biomass in biochemical tank. Because of too small solid load and too long retention time in secondary clarifier, anaerobic and excessive denitrification is occurred with phosphorus releasing. Internal reflux is to ensure sufficient denitrification to obtain a favourable effect by returning nitrification liquor of NO_3-N to anoxic zone. Back mixing of too much DO may affect denitrification.

Reflux ratio(R) has an effect on denitrification rate. In theory the bigger the reflux ratio, the more refluent NO_x-N and the more thorough denitrification. It's not higher denitrification rate with biger R. Too big R may cause the lack of carbon source and the increase of DO concentration to affect denitrification. At the same time excessive R may ask for bigger volume to keep enough HRT in reactor.

So the denitrification ability can be strengthened by reducing internal reflux ratio. Meanwhile phosphorus removal influenced by NO_x-N can be avoided effectively. Then phosphorus releasing of PAOs and excessive phosphorous uptake may go on sufficiently. To a certain extent it can improve the ability of biological phosphorus removal.

4.1.3 Other measures

The built rainwater and sewage pipe network may be general investigated, error recovery and dredged for completing the sewage collection system. As to the newly-built drainage pipeline networks, it should be strictly controlled on design and construction. Then the ground water infiltration capacity of drainage pipeline networks may reduce to the minimum and the influent quality and quantity may meet the design requirements.

4.2 Effect analysis

Taking measures of changing aeration mode in oxidation ditch, adjusting internal reflux ratio and so on, the operation monitoring results showed that it had little impact on the removal efficiency of COD, BOD5, SS, NH3-N. Indicators of effluent can meet A standard. When the designed TN of influent is below 35 mg/L, TN of effluent can be stable under 15mg/L with the average removal rate of 50%, as shown in Figure 4. The removal rate of biological phosphorus is 50%-60% and the TP of effluent in oxidation ditch is 1.5-2 mg/L in 2017. Supplemented by chemical phosphorus removal, the final effluent TP can be stable under 0.5 mg/L with the average removal rate of 88%, as shown in Figure 5. Then the effluent can meet the water quality standards stably.

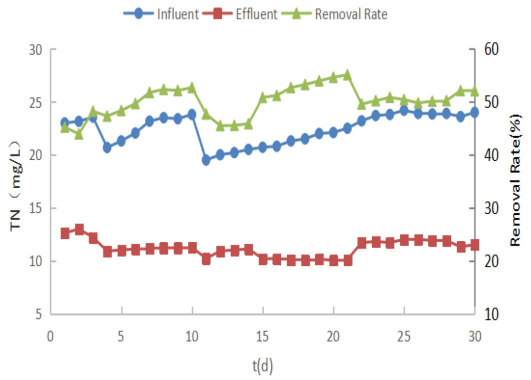

Figure 4: Removal of TN after reconstruction

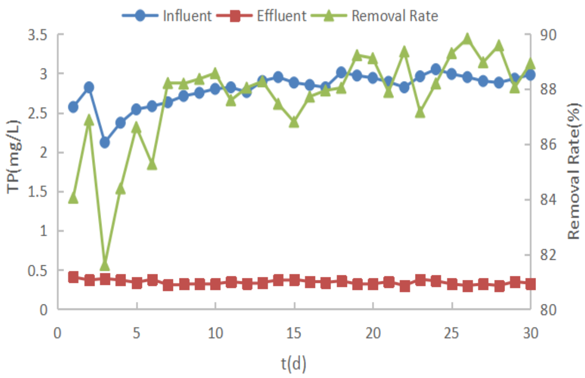

Figure 5: Removal of TP after Reconstruction

5. Conclusion

(1) The improvement and normal operation of sewage pipe network is the necessary premise for treating effectively. The construction of drainage pipe network and sewage treatment plant should be carried out simultaneously for synchronous development in capacity of collection and treatment, so as to give full play to the efficiency of sewage treatment plant.

(2) Under the condition of low organic concentration of influent, aeration should be controlled in stages or reduced to lower excessive self-oxidation in sludge. The anaerobic conditions should be strictly controlled in anaerobic zone for the biological removal effect of nitrogen and phosphorus.

(3) The addition of organic matter can improve the carbon source of influent in denitrification zone of oxidation ditch. This can insure the effect of denitrification while reducing the influence of NO_x-N on PAOs.

(4) By reducing internal reflux, the removal efficiency of nitrogen and phosphorus can be improved efficiently with lower energy consumption.

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