Application of Flow Field Analysis in the Process Design of Modified Microporous Aeration Oxidation Ditch

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Abstract: According to the environment and water quality factors of the project location, an improved microporous aeration oxidation ditch process is designed, which has the characteristics of biochemical reaction of space division, microporous aeration, infinite water circulation in the ditch, and multiple water inlets; under simplified boundary conditions, based on the CFD method, the SSTK-W model is used to close the RANS equation to simulate the flow field in the hypoxic and aerobic areas. With the optimal equipment configuration and the lowest energy consumption, the flow velocity in the trench is more than 0.3m/s, to ensure high buffering capacity of the process; study the flow field state and the unfavorable flow velocity under the optimized operation state of the flow thruster; the rationality of the design is verified through the commissioning and operation of the sewage treatment plant.

1. Introduction
In September 2018, Zhaotong City was successfully listed as one of the first batch of 20 national demonstration cities for the treatment of black and odorous water bodies in the country. The construction content consists of 26 projects, of which the new Zhaotong City Second Sewage Treatment Plant is an important component in the improvement of infrastructure part, and need to have demonstration and leading role. Elevation of project location is about 2000m, the water temperature in winter is 10℃, the sewage concentration is BOD5/COD=0.27~0.5, BOD5/N=1.8~4; improved design of microporous aeration and oxidation ditch for biochemical reaction tank in sewage treatment plant; use large-scale finite element analysis software ANSYS, CFD analysis method to simulate the flow field in the ditch, and optimize the design of the flow thruster; the commissioning operation of the plant verifies the treatment effect.

2. Design points of improved microporous aeration oxidation ditch
The wastewater treatment plant will build two groups of reaction tanks in the short term, with a single group scale of 20000 m³/d, two groups scale of 40000 m³/d, and long-term 80000 m³/d; the pre-anoxic tank retention time is 0.5h, and the anaerobic tank retention time is 1.5h. The residence time of the anoxic tank is 3.36h, the residence time of the aerobic tank is 16.08h, and the effective water depth of the reaction tank is 5m; pre-hypoxia, anaerobic, hypoxia, and aerobic space segmentation are beneficial to improve the stability of nitrogen and phosphorus removal, Liu Xiaotian et al.[1], Xie Zhuocheng et al.[2] conducted related research; microporous aeration and oxygen supply at the bottom of the tank increase the efficiency of dissolved oxygen; the aeration area accounts for about 70% of
the total biological reaction area, and the separation of anoxic and aerobic spaces can reduce the adverse effects of denitrification of anoxic and aerobic alternates in the traditional oxidation ditch, Ren Xiangfeng et al. [3] conducted related research; 30% of the sewage enters the pre-anoxic tank and 70% of the sewage enters the anoxic tank to achieve multi-point water inflow; the mixed liquid return pump realizes the return of nitrification liquid, and the sludge return first enters the pre-anoxic tank to further consume dissolved oxygen; the pre-anoxic and anaerobic zone is in a completely mixed state, and the hypoxic and aerobic zone is in a plug flow and completely mixed state; the center of the diversion wall is eccentric by 1.0m to the side where the water flows into the curve, and the diversion wall extends 1.5m in the direction of the water flowing out of the curve; the water outlet is close to the downstream of the aeration zone to avoid sludge floating in the secondary settling tank; Figure 1 show the main reaction tank design.

3. Thruster design and flow field simulation

3.1. Thruster design
According specification [4], the anaerobic and anoxic stirring power should be 2~8W/m³, the oxygen supply volume power of the oxidation ditch should not be less than 15W/m³, and the average flow velocity in the ditch should be greater than 0.3m/s; pre-anoxic and anaerobic zone design small diameter high-speed underwater mixer 1.5kW (1 unit) and 4kW (2 units) respectively; the hypoxic and aerobic zones design large-diameter low-speed thrusters (D=1.5m, N=2.2kW), 4 and 22 thrusters in anoxic and aerobic zones respectively. Figure 2 show the effective length and width of a single inference device at different propulsion speeds, when the propulsion speed is 0.3 m/s, the effective width and length of the device are 6m and 55m respectively.

3.2. Simulation of flow field in hypoxic and aerobic zone
Use general large-scale finite element analysis software ANSYS, UC to establish physical model, CFX software based on CFD method, SSTK-W model closed RANS equation for flow field simulation. Under the condition of flow velocity> 0.3m/s in the ditch, rationally optimize the number of pushers, save energy, and analyze the state of the flow field, Cao Gang et al. [5], Liang Yanpeng et al. [6], Zhang Zhizheng et al. [7] conducted related research.

3.2.1. Boundary conditions and section selection
Push streaming device is large-diameter low-speed thrusters with D=1.5m and N=2.2kW; the model analysis ignores the influence of import and export, and analyzes with a closed circular corridor; the mixed liquid reflux does not participate in the analysis; assuming that the water surface in the ditch is a free surface; the wall has no slip and the velocity is zero, only the overall flow characteristics in the corridor are analyzed, and the wall roughness only affects the flow in the boundary layer of the wall; ignore the influence of microporous aeration on water flow; the model is gridded, the flow velocity in the corridor is only obtained by the flow pusher, and the curve of the corridor is not encrypted. Three
sections are selected for analysis, the section near the bottom characterizes the flow characteristics of the bottom layer; the section near the center axis of the thruster characterizes the flow characteristics of the middle layer; the section close to the water surface characterizes the flow characteristics of the water surface.

3.2.2. Simulation result
Figure 3～11 show the flow field simulation conclusion of corridor bottom, central axis of the thruster and corridor water surface. The water flow in the corridor flows counterclockwise under the action of the thruster; the average flow velocity in the entire section is 0.302m/s; the average velocity of the middle section is 0.35m/s, and the velocity in front of the thruster reaches 1.0m/s; the average flow velocity at the cross section of the surface layer is 0.32m/s, with the order of \( V_{\text{middle}} > V_{\text{surface}} > V_{\text{bottom}} \), this feature is consistent with the study by Liang Yanpeng et al.\[6\].

Affected by the effective widening of the equipment, two thrusters are installed in the 10m wide corridor. The parallel thrusters reduce the flow velocity in the middle area. The mutual influence of the thrusters is different in the three sections, and the influence of the middle layer is minimal, there is no vortex, and the velocity in the unfavorable area is about 0.25m/s; the vortex and low velocity area of the surface layer are the most obvious, which is consistent with the study of Zhang Zhizheng et al.\[7\], followed by the bottom layer. The unfavorable area of the corridor flow velocity is not concentrated at the curve, but appears at the downstream exit of the curve; the eccentric treatment of the diversion wall and the downstream extension design have a certain reduction in the disadvantageous flow velocity inside and outside the diversion wall, but it has not been eliminated, the inner and outer sides of the diversion wall have the characteristics of flow velocity gradients with decreasing outward and inward velocity respectively.
When operating 8 thrusters in the aerobic zone, except for a few areas where the flow velocity is lower than 0.1 m/s, the integrated flow velocity in the corridor can reach 0.311 m/s, and the flow lines in the corridor are evenly distributed counterclockwise, and there is no large vortex and stagnant water on the whole area. Affected by the curve, vortex and stagnant water appear in the middle layer on the straight section where the thruster is not operated; the surface and bottom streamlines are denser and more collisions at the curve, indicating greater water loss in the curve. When the thruster is not operated in the hypoxic zone, the flow velocity in the ditch is less than 0.1 m/s, which is consistent with the theoretical flow velocity of the inflow, return sludge and return mixture flow through the gallery section, in order to achieve the flow velocity > 0.3m/s, the anoxic corridor needs to run 2 thrusters.

4. Sewage plant commissioning and operation
In January 2021, the second sewage treatment plant in Zhaotong City entered the commissioning stage. The commissioned water volume in January was 7200 m$^3$/d, the commissioned water volume in February was 15000 m$^3$/d, and it entered normal operation since March, with a water intake of 37000~46000 m$^3$/d; Table 1 show the quality of incoming and outgoing water.
Tab. 1 Designed water quality of sewage treatment plant (mg/L)

| project | BOD5  | CODcr  | SS    | TN    | TP    | NH3-N |
|---------|-------|--------|-------|-------|-------|-------|
| Inlet   | 81.6~115.8 | 169.4~237.4 | 104.7~134.9 | 26.5~29.8 | 3.1~4.2 | 22.9~27.2 |
| Outlet  | 1.8~4.8 | 19.6~26.4 | 6.6~6.8 | 10.9~11.0 | 0.5~0.9 | 0.7~1.8 |

The water inflow of the two sewage plants in Zhaotong City can be adjusted to each other. Since March, the second sewage plant has basically operated at full capacity; the influent concentration in March was higher than that in April, which was mainly due to the large release of pollutants accumulated in the urban drainage pipe network after the construction period was over. BOD5/COD=0.48 and BOD5/N=3.08 indicating that the sewage can be biochemically better, but the influent concentration is not high, and the mixed flow of clean water in the urban drainage pipe network still exists. Turn on the thruster according to the flow field simulation, the effluent quality of the sewage biochemical reaction tank was significantly better than the first A standard, the TP exceeded the standard in some periods mainly because the sludge dewatering section operated abnormally and the remaining sludge discharge was limited.

5. Conclusion

(1) According to the altitude, temperature, and water quality of the influent water, the modified microporous aeration oxidation ditch is designed to divide pools into pre-anoxic, anaerobic, anoxic and aerobic spaces, microporous aeration oxygen supply, large-diameter low-speed flow thruster keeps the water flow in the ditch>0.3m/s, and realizes multi-point water inflow.

(2) The flow velocity of the biochemical reaction tank corridor is a key design parameter. According to the specifications and the effective propulsion width and length of a single plug flow device, the equipment has high power and high energy consumption. Under simplified boundary conditions, based on the CFD method and using the SSTK-W model to close the RANS equation to simulate the flow field in the hypoxic and aerobic zones, when operating 8 thrusters in the aerobic zone and 2 thrusters in the hypoxic zone, the comprehensive flow velocity is kept above 0.3m/s, effectively reducing the number of equipment running and saving energy consumption.

(3) The simulation results show that the flow velocity in the corridor section is in the vertical gradient relationship of \( V_{\text{middle}} > V_{\text{surface}} > V_{\text{bottom}} \), and the overall flow velocity of the intermediate layer reaches 0.35m/s; the unfavorable flow velocity area does not appear in the curve, the eccentric and downstream extension design of the diversion wall can alleviate the problem of unfavorable flow velocity in the curve and downstream of the curve; microporous aeration at the bottom of the tank can avoid sludge settling in areas with unfavorable flow rates; there is an area with unfavorable flow velocity between two parallel flow thrusters, and the width of the corridor should be reasonably optimized according to the effective widening of the flow thruster equipment.

(4) The commissioning and operating data show that the treatment scale and the quality of the incoming and outgoing water of the sewage treatment plant meet and exceed the design requirements.

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