Jilin city central wastewater treatment plant renovation design scheme

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Abstract. Jilin City is one of the top ten famous Chinese cities worth introducing to the world. To further improve the construction of urban infrastructure and meet the needs of the economic and social development of Jilin City, the Jilin City Government Joint Development and Reform Commission and the Ecological Environment Bureau decided to expand and renovate the former Jilin City wastewater treatment plant. This study designs a wastewater treatment plant by comprehensively considering the policy needs and the local basic background characteristics of Jilin to solve the wastewater overflow problem. The design modified the anaerobic tank and Carroussel oxidation ditch processes, which have more advantages than traditional treatment processes, mainly including better BOD, nitrogen and phosphorus removal efficiency, less power consumption, and lower operating costs. This treatment plant design contains two special characteristics: the design considers the overall plan and pipeline layout of the wastewater treatment plant, and the size data of each module are calculated through theoretical study conforming to the real case.

Keywords: Wastewater Treatment Plant, Carroussel oxidation ditch, Jilin City.

1. Introduction

Water resources play a vital role in the survival and development of human beings and even the whole species [1]. With the rapid development of urbanization and the economy worldwide and the high frequency of extreme weather conditions, water resources have become particularly precious. Additionally, serious problems such as water waste and water pollution have not been well controlled, even though there is a worsening trend in some areas. On the one hand, people's demand for water is increasing day by day with the development of the city. On the other hand, there is a greater need in the direction of water resources management, of which wastewater treatment is a significant link.

Jilin City is an important city located in the northeast of China, which is also the first batch of national comprehensive pilot areas for new urbanization. To further improve the construction of urban infrastructure and meet the needs of economic and social development of Jilin City, the Jilin City Development and Reform Commission passed the approval of the feasibility study report on the adjustment of the Phase III project of the Jilin City Wastewater Treatment Plant in February 2022. Implementing the project will further improve the urban infrastructure of Jilin City, ensure the safe and reliable operation of the Jilin City wastewater treatment plant, and have good environmental and social benefits. Due to a lack of funds and limited space encountered in the process of project promotion, the

designed wastewater plant treatment scale is 26,200 m^3/day with a maximum of 38,200 m^3/day. In this study, a wastewater treatment plant is designed to comprehensively consider the policy needs and the local basic background characteristics of Jilin, to solve the wastewater overflow problem [2].

2. Background

2.1. Jilin City

2.1.1. Location boundary. Jilin City is located in the center of Jilin Province, the northeast hinterland of Changbai Mountains, Changbai Mountains to Songnen plain transition zone by the Songhua River. It borders Yanbian Korean Autonomous Prefecture in the east, Changchun City and Siping City in the west, Harbin City in Heilongjiang Province in the north, and Baishan City, Tonghua City, and Liaoyuan City in the south, with a total area of 27120 square kilometers [3].

2.1.2. Geographic conditions. Jilin City is located in the transition zone from the Changbai Mountain area to Songnen Plain, with a superior natural environment and complex landform types (Fig. 1). The terrain gradually decreases from southeast to northwest, forming four major landforms: Zhongshan mountain area, low hill area, canyon lake area, and valley plain area. The water system through Jilin City is mainly Songhua River, accounting for 84% of the city's total area [3]. Changyi District is an administrative region belonging to Jilin City, located in the Changbai Mountain range to the Songliao Plain transition zone [4].
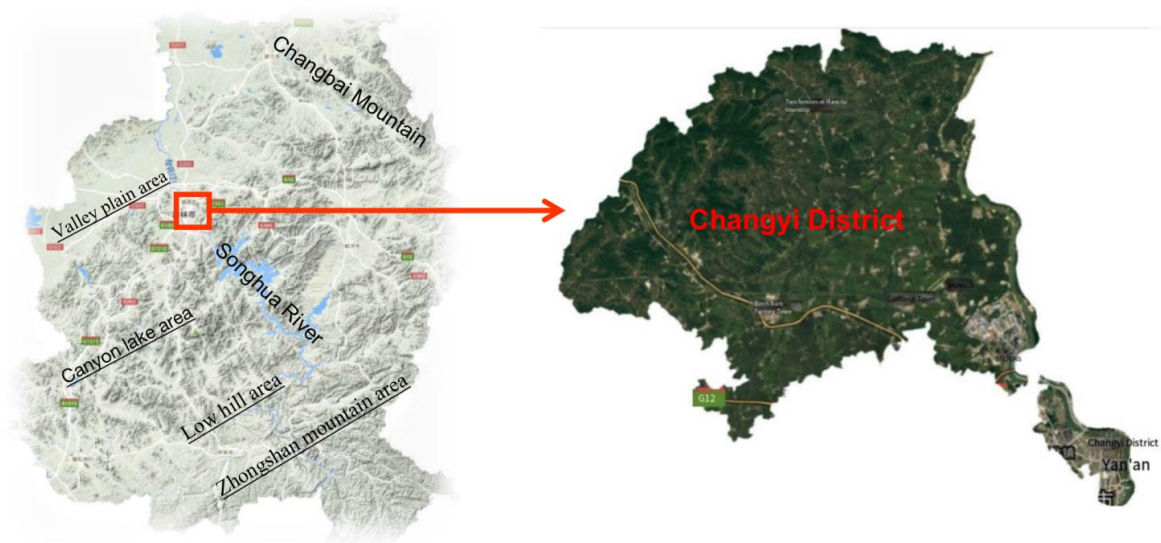

Figure 1. Topographic map of Jilin City and Changyi District.

2.2. Wastewater treatment plant

2.2.1. Location. The project is located at the former site of the Jilin City wastewater treatment plant, which is located in the second industrial water area of Songhua River, Jilin City, 200 meters upstream of Xiushui Bridge on the left bank of Songhua River (Fig. 2). The first phase of the existing wastewater treatment plant enters downstream of the river discharge outlet, and the second phase enters upstream of the river discharge outlet [5].
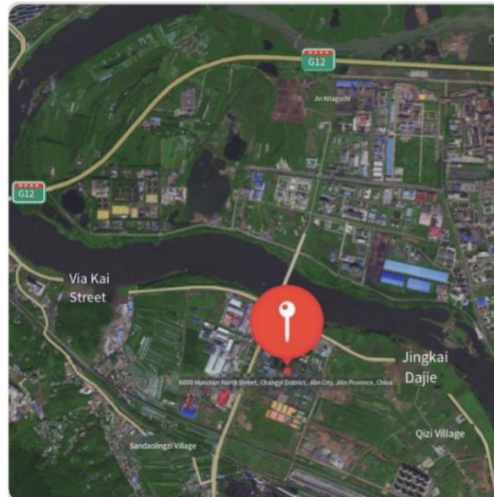
Figure 2. Location of the wastewater treatment plant.

2.2.2. Wastewater treatment process. The process of wastewater treatment is mainly divided into three parts, primary treatment, secondary treatment, and tertiary treatment parts. The most crucial part and the main difference between different wastewater treatment plants is the secondary treatment part, which mainly includes A^2O, oxidation ditch, and membrane treatment process [6]. Each process has its advantages and disadvantages. In the design and practice of wastewater treatment plants, it is necessary to consider the geographical location, hydrological factors, economic conditions, and other factors.

3. Wastewater treatment plant design

3.1. Design of urban wastewater and rainwater pipe network system

3.1.1. Design of urban wastewater network. The municipal wastewater treatment plant is located in the southeast corner of Changyi District, which is in the lower reaches of the Songhua River flowing through Changyi District. Considering the West-East terrain distribution, the direction of urban wastewater trunk pipe is determined from west to east. Because of the reasonable layout of the units in the Jiuzhan development zone, the water pipes can be laid along the larger main road. Each block takes the adjacent municipal wastewater pipe section (municipal wastewater branch pipe) to discharge, and then the municipal wastewater branch pipe is fed into the corresponding main pipe. For individual blocks with large block areas, the multi-slice method is adopted, that is, a single large block is divided into several smaller drainage areas, to meet the requirements of drainage. For the wastewater discharge of factories and enterprises, the sum of domestic wastewater, industrial and living wastewater, and industrial production wastewater of industrial enterprises will be collected into the main pipe as a centralized flow. The wastewater flow of the railway station was also calculated as the central flow using the reference value [7, 8].

3.1.2. Design of urban stormwater pipe network. The rain pipe is arranged from north to south, which can also make good use of the terrain advantages of Changyi District. The catchment area of the rainwater pipe section should be evenly distributed and roughly equal, which should be well reflected in the design. In addition, for individual blocks or industrial enterprises (far away from the city), in order to prevent the pipe section from being laid too long, and increase the cost and burial depth, it is discharged into the lake and the outflow river nearby. The regulation function of the lake water is used to store and treat rainwater, and finally, the rainwater is discharged into the Songhua River by the discharge pipe section [9].

3.2. Determination of construction scale of the wastewater treatment plant

3.2.1. Determination of the amount of water treated. According to the overall planning requirements of the Environmental Protection Bureau of Jilin City, Jilin Province, the final scale of this wastewater treatment plant is determined to be 26.2 thousand m^3/day of wastewater treatment, and the maximum day flow is 38.2 thousand m^3/ day. Jilin City has a population of 413,000. The per capita domestic water quota in this district is 150L/ (cap·d), and the per capita domestic wastewater quota is 120L/ (cap·d) according to the value of 80%.

3.2.2. Determination of wastewater quality and treatment degree. According to the overall urban planning of Jilin City, combined with the actual measurement results of the wastewater quality of the living area in the diversion system in recent years and the investigation of the wastewater quality of the urban wastewater treatment plant, and considering the influence of the water quality of the living area and the industrial area, the following wastewater quality is obtained (Table 1). The effluent requirements of the wastewater treatment plant are designed in strict accordance with the national first-class discharge standards.

Table 1. Wastewater quality and treatment standard of Jilin City.

Water quality standards	BOD_5 (mg/L)	CODcr (mg/L)	SS (mg/L)	NH_3-N (mg/L)	TP (mg/L)	TN (mg/L)
Inlet water quality	200	400	200	40	5	45
Outlet water quality	10	50	10	5	0.5	15
Removal efficiency	95.0%	87.5%	95.0%	87.5%	90%	66.67%

3.3. Determination of construction scale of wastewater treatment plant
The flow charts of anaerobic tank + oxidation ditch processes are as follows (Fig. 3):
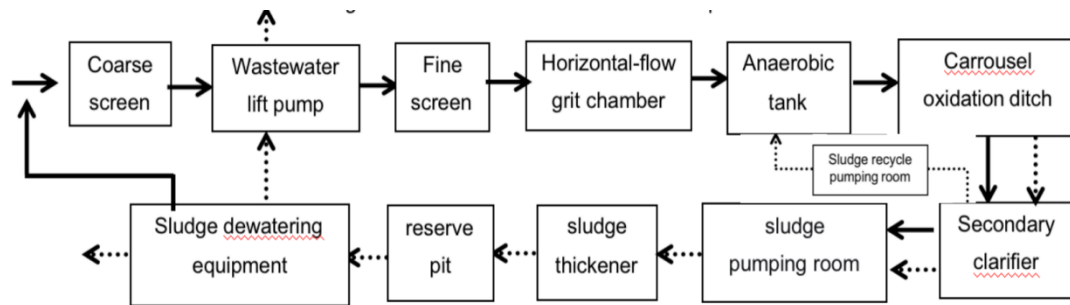

Figure 3. Modified anaerobic tank + oxidation ditch processes. Note: · · ·> Fixed wire Line; →liquid.

After the urban wastewater is collected through the sewage and stormwater network, it first enters the coarse screens through the water inlet for pretreatment to intercept large suspended particles and debris such as branches and stones. Then, the wastewater is raised from the lift pump to the roof about 6 meters from the ground to ensure that the wastewater flow in the wastewater treatment plant mainly relies on gravitational potential energy, reducing energy consumption. On the roof, there are fine screens and a horizontal-flow grit chamber to intercept smaller particles or dissolved substances.

The wastewater treated in the first stage enters the anaerobic tank and Carrousel oxidation ditches for the second stage of treatment. In order to obtain better phosphorus and nitrogen removal fruit, an anaerobic tank was added in front of the Carrousel oxidation ditch. All the returned sludge and

wastewater enter the anaerobic zone, and the residual nitric nitrogen in the returned sludge can be denitrified under the condition of anoxia and carbon source. The wastewater is further removed from BOD, nitrogen, and phosphorus in the Carrousel oxidation ditch system. The treated wastewater enters the secondary sedimentation tank, and the solid particles are settled by gravity to form sludge. Part of the sludge is returned to the anaerobic tank by the sludge return unit for further reaction. The other part of the sludge enters the sludge thickening tank through the sludge lifting pump house. Common treatment methods include sludge concentration, dehydration, digestion, and incineration. The treated sludge can be used as fertilizer, landfill, or for energy recovery.

4. Design theories and results

4.1. Design theories

4.1.1. Urban wastewater pipe network. First is to determine the specific discharge of municipal wastewater. The specific flow rate of the residential area (q0):

$$q0 = \frac{864 \times q'}{86400} = \frac{r \times wq}{100} \tag{1}$$

Where: r, The domestic water consumption quota (average daily) of residents, 150L/cap·d; wq, The wastewater quota, 80%.

The calculated specific flow rate of the residential area is 1.20 (L/s).

Second is to determine each centralized flow rate. Total coefficient of change: $K_Z = \frac{2.7}{Q^{0.11}}$,

Where: Q - the average daily average wastewater flow, L/s; the flow rate (Q) for Jilin oil refinery, Jilin City Water Works, Jilin No. 1 Middle School, Jilin train station are 15.624, 9.69, 15.68, 6.0 (L/s), respectively (Table 2).

Table 2. The relationship between Q and K_Z.

Q, L/s	<5	15	40	70	100	500	>1000
K_Z	2.3	2.0	1.8	1.7	1.6	1.4	1.3

4.1.2. Urban stormwater pipe network. The design flow of storm pipe (q_{Jilin}) can be calcuated based on design rainstorm intensity formula and flow formula:

$$qJilin = \psi \times q = \psi \times \frac{167A_1(1 + clgP)}{(t_1 + mt_2 + b)^n} \tag{2}$$

Where: q - storm intensity (L/(s·ha)); P - recurrence interval (a), 1; t_1 – surface water collection time (min), 10min; M - reduction factor; t2 - flow time of stormwater in pipes and canals (min), 5min; Ψ - runoff coefficient, 0.68; A_1, b, c, m, n - local coefficient, are 23.473, 7, 0.68, 2, 0.86, respectively.

The regulating water volume of the collecting well entering the drainage pipe section of the rain lake (V_{lake}) is:

$$Vlake = \frac{V_{pool}}{t}\left(\frac{L}{s}\right) \tag{3}$$

Where: Vpool - the area of the Rain Lake (m^3), 110000m^3; t - the regulating pool is drained once in 24 hours (h), 86400s.

Totally, the rainstorm intensity formula of Jilin city is $q_{Jilin} = \frac{2665.6}{(27 + 2\sum t_2)^{0.86}}$; the regulating water volume of the collecting well entering the drainage pipe section of the rain lake is 12.73 (L/s).

4.2. Calculation of each step

4.2.1. Coarse screen. The height of screens:

$$H = h + h1 = \frac{1}{2}B1 + h1 = \frac{1}{2}\left(\frac{2Q_{max}}{v_1}\right)^{\frac{1}{2}} + h1 \qquad (4)$$

Where: Q_{max} - maximum designed flow of wastewater treatment plant optimal hydraulic section (m^3/d), 3.82 m^3/d; $v1$ - velocity of flow (m^2/d), 0.6m^2/d.

The total width of screens:

$$B = 2B_2 = S(n\text{-}1) + e \times n \qquad (5)$$

Where: S, n – local coefficient, are 0.01, 23, respectively; e - the space between coarse screens (m), 0.02m.

The total length of screens:

$$L = L_1 + L_2 + 1.0 + 0.5 + \frac{H_1}{\propto} = \frac{3}{2}\ L_1 + 1.0 + 0.5 + \frac{h + h_2}{tg\alpha} = \frac{3}{2}\frac{B - B_1}{tg\propto_1} + 1.0 + 0.5 + \frac{\frac{1}{2}B_1 + h_2}{tg\alpha} \qquad (6)$$

Where: B - the total width of screens (m), 1.36m; α - the installation angle of coarse screens (°), 60°; α_1, 20°; h_2, 0.3 m.

The number of gaps for screen:

$$n = \frac{Q_{max} \times sina^{0.5}}{ehv} = \frac{0.382 \times sin60°^{0.5}}{0.02 \times 0.56 \times 0.7} \qquad (7)$$

Where: v - the flow velocity pass the screen (m/s), 0.7m/s.

The total width of screens: B = 1.36m; the total length of screens: L = 2.48 m; the height of screens: H = 1.06 m and the number of gaps for screen: n = 45.3 ≈ 46.

4.2.2. Intake lift pump house. The area of catchment pool:

$$S = \frac{W}{H} \qquad (8)$$

Where: W - the volume of catchment pool (m^3), 68.74 (m^3); H - the effective water depth (m), 2.0m.
Total head estimation before pump selection:

$$H = (H_a - (H_{inlet} - D \times b - H_{through} - H)) + H_{in} + H_{free} + \frac{H_h + (H_a - H_{average} + H_d)\ 1000i \times p}{1000} \qquad (9)$$

Where: H_a - the water level that after the outlet pipe is raised (m), 38.8 m; H_{inlet} - the inlet pipe bottom elevation (m), 31.624 m; D - the diameter of pipe (m), 0.900 m; $H_{through}$ - the head loss through the screen (m), 0.1 m; H_{in} - the pipe head loss in the pump house (m), 1.5 m; H_{free} - the free head loss (m), 1.0 m; H_d - the buried depth of the center of the total outlet pipe (m), 1.0 m; 1000i, b, H, H_h, p - local coefficient, are 9.88, 0.37, 2, 320, 1.3.

The Total head estimation after pump selection:

$$H = (H_{frictionl\ s} + H_{local\ s}) + (H_{total} + H_1 + H_2 + H_3 + H_4) + H_{difference} + H_{free} \qquad (10)$$

$$Ho = H_{frictional\ o} + H_{local\ o} \quad (o = 1\text{-}4) \qquad (11)$$

$$H_{frictional\ o} = \frac{L_o \times 1000i_o}{1000} \qquad (12)$$

$$H_{local\ o} = \frac{\S_o \times v_o^2}{2g} \qquad (13)$$

Where: L_s - the length of the part of straight pipe (m), 1.2 m; $\S_{s\ 1}$ - a bellmouthing, 0.1; $\S_{s\ 2}$ - a 90º elbow, 0.67; $\S_{s\ 3}$ - a gate, 0.1; $\S_{s\ 4}$ - a reducing pipe, 0.21; H_{total}, 4.128 m; L_1 - the length of the part of straight pipe (m), 0 m; $\S_{1\ 1}$ - a one-way valve, 1.4; $\S_{1\ 2}$ - a 90º elbow, 0.6; $\S_{1\ 3}$ - a gate, 0.1; $\S_{1\ 4}$ - a drawdown tube, 0.3; $\S_2$ - a T-tube, 1.5; $\S_3$ - a T-tube, 0.1; $\S_{4\ 1}$ - a T-tubea, 0.1; $\S_{4\ 2}$ - a 90º elbow, 0.64; $\S_1$

$_3$ - a 90° elbow, 0.64; $v_{s\,1}$, $v_{s\,2}$, $v_{s\,3}$, $v_{s\,4}$, $v_{1\,1}$, $v_{1\,2}$, $v_{1\,3}$, $v_{1\,4}$, v_2, v_3, v_4 - water velocities (m/s), are 1.21, 1.21, 1.21, 6.5, 1.53, 1.43, 1.53, 1.53, 6.5, 1.53, 1.94m/s; L_2 - the length of the part of straight pipe (m), 2.6 m; L_3 - the length of the part of straight pipe (m), 0.7 m; L_4 - the length of the part of straight pipe (m), 5 m; $1000i_s$, $1000i_2$, $1000i_3$, $1000i_4$ - local coefficient, 4.41, 2.60, 9.88, 9.88.

The total head estimation before pump selection: H = 16.239m, the area of catchment pool: S = 34.37 m^2, the total head estimation of pump selection: H = 16.688 m.

4.2.3. Fine screen. According to equations (4-7), the input parameters for fine screen are: S, n - local coefficient, are 0.01, 80, respectively; e - the space between coarse screens (m), 0.01 m; B - the total width of screens (m), 1.59 m; α - the installation angle of coarse screens (°), 60°; $α_1$, 20°; h_2, 0.3 m; v - the flow velocity pass the screen (m/s), 0.8 m/s.

The fine screen is divided into two grids, each with a net width of 0.56 m. The total width of screens: B = 1.36 m; the total length of screens: L = 2.97 m; the height of screens: H = 1.07 m and the number of gaps for screen: n = 79.3 ≈ 80.

4.2.4. Horizontal-flow grit chamber. The volume of horizontal-flow grit chamber :

$$V = \frac{V_{total}}{2 \times 2} = \frac{Q_{max} \times 86400 \times T \times X}{10k} \times \frac{1}{2 \times 2} \tag{14}$$

Where: T - the days between sludge discharge (day), 2 days; k, X - local coefficient, are 1.4, $\frac{3}{10}$.

The total height of horizontal-flow grit chamber:

$$H = h_1 + h_2 + h_3 = h_1 + \frac{A}{B} + h + \delta \times L_1 = h_1 + \frac{Q_{max}}{v \times n' \times b} + h + \delta \frac{v \times t - 2a}{2} \tag{15}$$

$$a = \frac{2h'}{tg\partial^\circ} + a_1 \tag{16}$$

Where: v - designed flow velocity of horizontal-flow grit chamber (m/s), 0.25 m/s; t - residence time (s), 40s; n' - cell number of total width of pool, 2; b - width of each cell (m), a - the width of top of sand settling bucket (m); ∂ - angle between the wall and the horizontal plane (°), 55°; h1 - the maximum added height of the sand sink (m), 0.3m; h' - the height of sand settling bucket (m), 0.5m; a_1 - the width of bottom of sand settling bucket (m), 0.5m; δ - bottom slop of horizontal-flow grit chamber (°), 0.06°.

The volume for each grit chamberV is 0.35 m^3 and the total height of horizontal-flow grit chamber H is 1.67 m.

4.2.5. Anaerobic tank. The volume of anaerobic tank:

$$V_{an} = Q_{an} \times T = \frac{Q_{max}}{K_Z} \times T \tag{17}$$

Where: K_Z - local coefficient, 1.46; Q_{an} - the designed water quantity (m^3/s); T - the hydraulic retention time (h), 2.5h.

The diameter of anaerobic tank:

$$D = \left(\frac{4A_{an}}{\pi}\right)^{\frac{1}{2}} = \left(\frac{4\frac{Q' \times T}{h_{water}}}{\pi}\right)^{\frac{1}{2}} \tag{18}$$

Where: Q' - the half of desigedn water quantity (m^3/s), 0.13 m^3/s; h_{water} - the depth of water (m), 5 m.

The area of anaerobic tank: A is 234 m^2; the diameter of anaerobic tank D is 18 m.

4.2.6. Carroussel oxidation ditch. The oxidation ditch is a six-ditch oxidation ditch with a plane size of 79.39 m·36 m. The sludge age of oxidation ditch was set to 22 d. The concentration of dissolved BOD5 in outlet water is 6.4 mg/L and the designed sludge age is 12.5 d.

The nitrification rate is 0.045 L/d and its volume is 4925.42 m^3. The denitrification rate is 0.017 kg NO$_3$-N/(kg MLVSS·d) and its volume is 4294.59 m^3. Total volume of pool is 9220.01m^3.

In addition, the total length and width of carrousel oxidation ditch are 79.39 and 36 m.

Oxygen demand of carrousel oxidation ditch is 133.97kg/h and the oxygen content of deoxidized water is 248.9kg/h. Sludge reflux amount and sludge residual amount is 51.7% and 1102.997kg/d.

4.2.7. Secondary clarifier. Two amplitude-flow secondary clarifiers are set, which the way of inlet and outlet water are from peripheral water.

The volume of sludge storage:

$$VW = \frac{2\,T_w \times (1+R)Q_{designed} \times X}{X + X_r} \tag{20}$$

Where: T_w - mud storage time of the mud storage area (h), 2h; R, X, X_r - local coefficient, are 0.67, 4000, 10000; $Q_{designed}$ - the designed flow for each secondary clarifier (m^3/d), 11232 m^3/d.

The area of secondary clarifier

$$A_{sec} = \frac{Q_{disugned}}{24 \times q_b} \tag{21}$$

The total height of secondary clarifier:

$$H_{sec} = q_b \times tsed + \frac{\frac{1}{2}VW}{\frac{Q_{disugned}}{24 \times q_b}} + 0.4VM + H_4 + \frac{t_{total} - t_{sed}}{2I} + H_6 \tag{22}$$

Where: q_b - surface load (m^3/(m^2·h)), 0.8 m^3/(m^2·h); t_{total} - the total time (h), 28 h; t_{sed} - the sedimentation time (h), 2.5 h; VM - the volume of sludge storage (m^3), 1786.4 m^3; H_4 - the maximum added height (m), 0.5 m; I - bottom slope of secondary sedimentation tank (°), 0.010°; H_6 - depth of sludge hopper in the center of tank (m), 1 m.

The area of secondary clarifier A_{sec} is 585 m^3 and the total height of secondary clarifier H_{sec} is 5.6 m.

4.2.8. Contact tank. The process adopts diaphragm type contact reaction tank.

The volume of contact tank V is 470m^3; the velocity of water flow: v is 0.08m/s; the surface area of contact tank: S_{con} is 196m^2; the total corridor width: B is 12.6m and the length of contact tank L is 15.5m.

5. Discussion

My wastewater treatment plant design has some advantages as follows: Due to the constant water level and continuous discharge, the weir overflow rate is reduced, eliminating the periodic surge of effluent that is common in other bioprocesses such as SBRs. A good ability to withstand the impact load of water volume and water quality; A high efficiency of BOD removal, which can reach 99% under good operating conditions. The oxidation furrow has the characteristic of pushing flow, so there is a gradient of dissolved oxygen along the long direction of the tank, forming aerobic, hypoxic and anaerobic zones for nitrification and denitrification, respectively. The N and P can be well removed by reasonable design and control.

The oxidation ditch has a strong adaptability to changes in water temperature, water quality, and water quantity. Reduce and simplify the scale of sludge treatment facilities. The oxidation ditch process system can omit the primary sedimentation tank, and reduce and simplify the scale of sludge treatment facilities, greatly reduce the construction cost. Its unique circular winding design can also reduce the occupation of sewage treatment plant land. Greatly reduce the construction cost and less power consumption and lower operating costs based on energy efficient operations compared with other biological treatment processes [10].

6. Conclusion

In this study, a wastewater treatment plant is designed to comprehensively consider the policy needs and the local basic background characteristics of Jilin. The wastewater of Jilin City is collected through the sewage and stormwater pipe network and then enters the wastewater treatment plant. The final scale of

this wastewater treatment plant is determined to be 26.2 thousand m^3/day of wastewater treatment, and the maximum day flow is 38.2 thousand m^3/ day.

In the first stage of treatment, large suspended particles, big debris, smaller particles, and dissolved substances can be well intercepted. In addition, suspended matter and sludge were successfully separated from the water under the action of the horizontal-flow grit chamber. Moreover, modified anaerobic tank and carroussel oxidation ditch processes are combined in the second treatment stage, which have many advantages over traditional treatment processes, including better BOD, nitrogen and phosphorus removal efficiency, less power consumption, and lower operating cost. [10] Since there is no special requirement for the sanitary conditions of the receiving water body, liquid chlorine is used as a disinfectant in the third treatment stage, which is effective and cheap.

This treatment plant design contains two primary advantages. Firstly, the design considers the overall plan and pipeline layout of the wastewater treatment plant through the field investigation of the wastewater treatment plant, the study of policy popularization, and the comparative analysis of technology. Secondly, the size data of each module conforming to the Phase III project of the Jilin City wastewater Treatment Plant are calculated through theoretical study. The effluent requirements of the wastewater are designed in strict accordance with the national first-class discharge standards.

During the operation of the wastewater treatment plant, it is necessary to make full use of the mobility and flexibility of the overall process, combined with technology such as information big data and automatic control, to achieve energy saving and emission reduction based on achieving high standard nitrogen and phosphorus removal requirements.

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