J. COMBIN. MATH. COMBIN. COMPUT. 127a (2025) 2675--2694

Journal of Combinatorial Mathematics and Combinatorial Computing
www.combinatorialpress.com/jcmcc

Research on system Dynamics Model of Efficient Urban Sewage Treatment Plant Design

Wanfen Wang[1, ✉]

[1] *School of Architecture and Civil Engineering, West Anhui University, Lu'an, Anhui, 237000, China*

ABSTRACT

In today's increasingly stringent sewage discharge standards, the construction of a new generation of wastewater treatment plants more and more urgent. This paper adopts MBBR as the main process to treat wastewater, the pretreatment process of wastewater treatment plant adopts coarse and fine grating + cyclone sand sedimentation tank, and the secondary treatment process selects AAO process. Through the reasonable calculation of water volume and hydraulics, and then calculate the size of each structure. Based on the ASM2 model, combined with the conversion rate equation of the AOO reaction tank, the kinetic model of the wastewater treatment system was constructed. Analyzing the inlet and outlet water quality monitoring data of the high-efficiency wastewater treatment plant for one year of operation, it was found that the average values of inlet and outlet water COD concentration in one year of operation were 255.437 and 10.556 mg/L, respectively, and the annual average removal rate was 94.37%. The average values of ammonia nitrogen in and out of the water for the whole year were 32.085 and 1.107mg/L, and the average ammonia nitrogen removal rate was 96.98%. All the effluent indicators have reached the “urban sewage treatment plant pollutant discharge standards” level A discharge standards and environmental protection departments on the effluent indicators, indicating that the overall operational efficiency of the research-designed high-efficiency wastewater treatment plant is good, and has reached the expected goals, with significant environmental and social benefits.

Keywords: MBBR process; structures, high efficiency, wastewater treatment plant, COD concentration

1. Introduction

With the continuous advancement of urbanization and the development of industrial production, the urban population is expanding, industrial enterprises are booming progress, and the ensuing problems of domestic sewage and industrial sewage are also troubling the health of urban residents, and the impact on the whole ecological environment is also increasing, and sewage treatment has become imminent [1-4]. China is also gradually emphasizing the protection and management of the

✉ Corresponding author.
E-mail address: 1458504405@qq.com (W. Wang).
Received 05 January 2024; Revised 15 March 2024; Accepted 10 November 2024; Published Online 15 April 2025.
DOI: 10.61091/jcmcc127a-151

environment, and has formulated many laws and regulations to restrain the corresponding pollution. Sewage treatment enterprises are responsible for the operation and management of urban sewage treatment plants and ancillary facilities, and play a crucial role in controlling water pollution and ensuring the quality of the water environment [5-8]. The market demand, profitability, and sustainable development level of wastewater treatment enterprises are issues of concern in the development process of wastewater treatment enterprises, but also by the influence of multiple factors constraints of a dynamic process, managers are often difficult to scientific and effective decision-making, and system dynamics is one of the decision-making [9-12].

System dynamics is a method to study the changes and interrelationships of systems, which can simulate and evaluate the behavior of dynamic systems. In wastewater treatment projects, there are numerous and complex factors affecting economic efficiency, such as investment costs, operation and maintenance costs, and environmental benefits [13-16]. Traditional economic evaluation methods are difficult to take into account the interactions and change trends among these factors, while system dynamics can evaluate the economic benefits of wastewater treatment projects more comprehensively by establishing a system dynamic model, revealing the correlation between system structure and behavior, and searching for key factors [17-20].

The innovation of the research lies in the construction of a high-efficiency municipal wastewater treatment plant, and its system dynamics model, using the upgraded MBBR process in combination with the AAO reaction tank model. Based on the MBBR process and the requirements of the internal and external environment of the station area, design calculations are carried out to determine the design parameters of the sewage treatment station on the premise of ensuring that the effluent water quality meets the standards, with the direction of saving investment and the purpose of reducing the operating costs. Finally, the COD, BOD_5, TP, TN, NH3-N, SS and pH value and other related indicators of the incoming and outgoing water of the sewage treatment plant are selected for testing and analysis after one full year of uninterrupted and stable operation. The operational efficiency and pollution removal rate of the innovative process design are explored.

2. Design of high-efficiency wastewater treatment plants

2.1. MBBR process design

2.1.1. MBBR process. Membrane treatment solutions, as a new technology born on top of the membrane separation material, the relevant works were applied to the desalination of seawater in the 1960s [21]. Subsequently, along with the birth of various types of new membranes, membrane technology has also developed to drinking water, sewage disposal and other scenarios. Accompanied by the membrane material production to achieve the scale, processing, etc. to achieve the expected equipment, integration and other effects, coupled with the popularization of the relevant technology and the public, membrane technology slowly evolved from the latent technology into a practical value of the technology. It can be utilized in large-scale projects, and can achieve ideal competition with traditional technologies.

Membrane - bioreactor (MBBR) process, as a membrane separation and traditional wastewater process between the effective integration of treatment and reuse programs, international water treatment in recent years, has gained a lot of attention in various aspects [22]. Reclaimed water treatment, but also to achieve a more ideal promotion and use.

Membrane bioreactor (MBBR) process sketch shown in Figure 1, one-piece program has a more ideal water quality, smaller footprint and other characteristics [23]. Relying on the discrete mechanism of the membrane module, the treatment efficiency is greatly improved, and at the same time, the reaction rate is greatly improved because of the increase in sludge concentration and the birth of dominant bacteria. Membrane bioreactor, combined with the needs of biological treatment, to build three major reaction zones (pools). Membrane modules are submerged in the aerobic zone, and each zone relies on submersible propellers to realize the effect of circulation. The mixing of sewage and return sludge, and the release of phosphorus from the anaerobic environment by the phosphorus-collecting bacteria, also result in an increase in the concentration of phosphorus in the sewage.

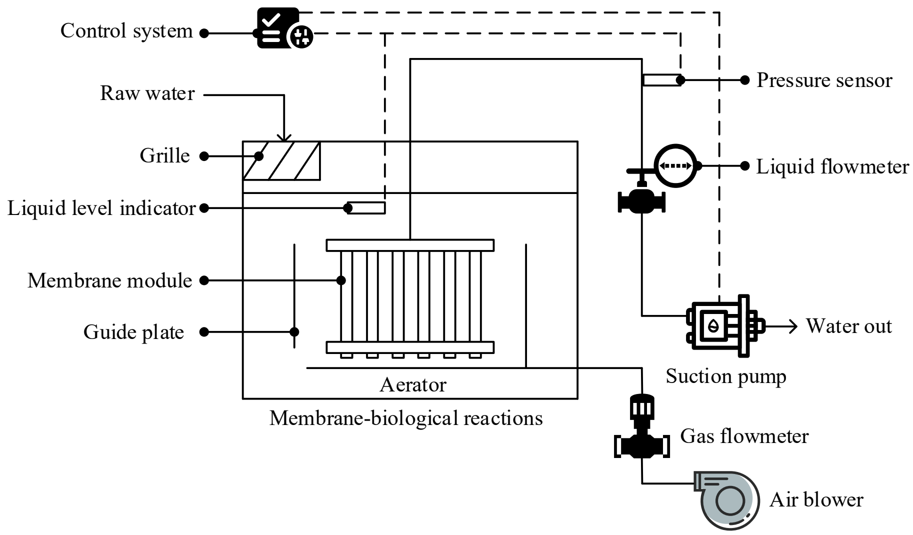

Fig. 1. Process diagram of membrane bioreactor

MBBR process has the following characteristics:

1) Membrane bioreactor mainly using PVDF membrane, surface pore size of the specific information for the 0.1 ~ 0.5 μm, can be more efficient solid-liquid separation process. And the standard data is relatively high, the quality also has more stable characteristics, suspended solids and turbidity is more similar to zero, can meet the demand for reuse.

2) Efficient interception effect, will cause microorganisms completely intercepted into the reactor, through the way to reach the hydraulic retention (HRT) and sludge age (SRT) between the effective separation, and then realize the control more flexible.

3) In response to the traditional active precipitation, the maximum concentration limitations, the concentration index in the reactor is relatively high, which is also 2 to 4 times the traditional program, the actual data for 5000 ~ 10000mg / L, for the change of water quality and quantity of water has a more ideal adaptability, shock load resistance index is relatively strong.

4) is beneficial to strengthen the bacterial interception, growth and reproduction phenomena, and nitrification efficiency, COD_{Cr} removal rate and other indicators have been effectively improved, the reaction time has also been significantly reduced. The relatively large organic matter is effectively retained, thus ensuring its continuous degradation.

5) The system design utilizes the PLC control program, which can achieve the ideal automation control, and the operation is also more convenient.

6) The membrane material adopts the corresponding program of polyvinylidene fluoride, which has good anti-pollution effect, and can be convenient for subsequent cleaning treatment, suitable for sewage treatment. Chemical indicators are more stable, strong antioxidant function, can use ordinary oxidizing agents to carry out the corresponding cleaning treatment.

7) The sludge age is long, and the membrane separation mechanism will allow more macromolecules to be retained. Under the environment of high volume and low sludge load, the specific emission index of residual sludge is less than 50% of the traditional program.

8) The loading index of the volume is relatively high, and the occupation range is relatively small. The start-up is more rapid, and the influence posed by sludge expansion can be avoided.

2.1.2. Process flow. This design is based on a wastewater treatment plant as a prototype, the proposed construction of a wastewater treatment plant with the same daily treatment capacity and the treatment process of Membrane Bio-reactor (MBBR) process, this design is based on a reasonable calculation of the water volume and hydraulics, which in turn calculates the size of each structure. Under the premise of saving economic estimates, the compact layout of the sewage treatment plant structures, improve its process flow as shown in Figure 2. Finally, the investment estimation of the wastewater treatment plant is completed by calculating the civil construction investment and installation investment of this design.

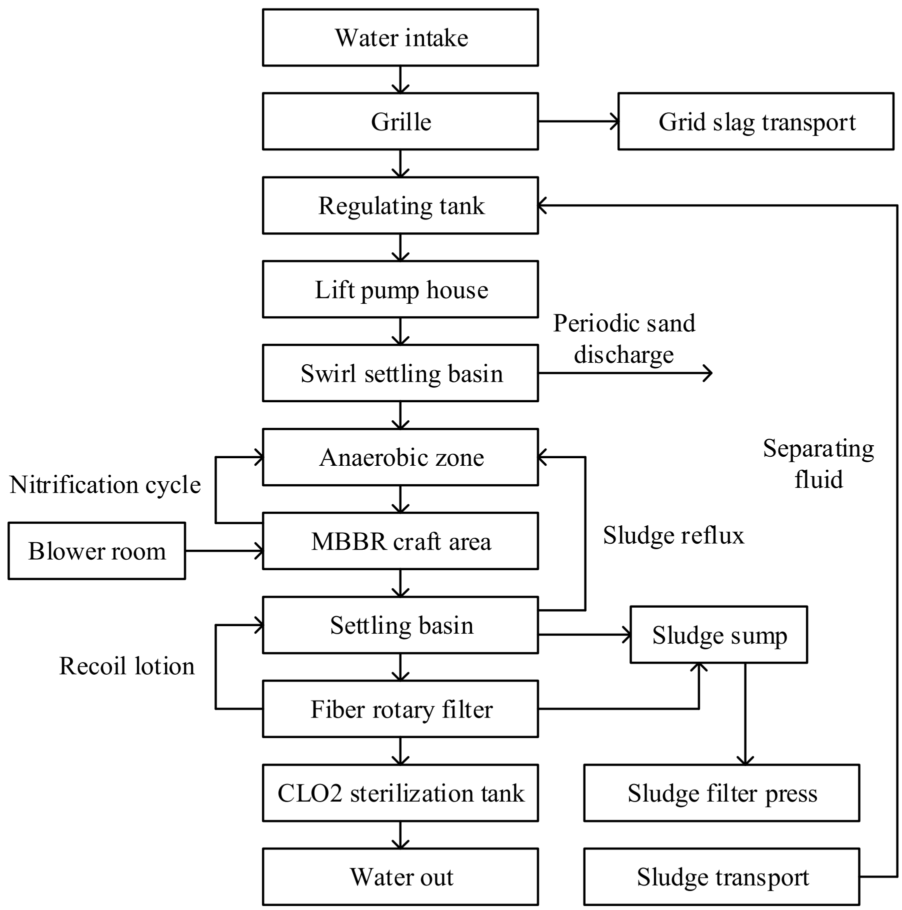

Fig. 2. High efficiency wastewater treatment plant process flow

2.2. Design of sewage treatment plant structures

2.2.1. Center grid design:

1) Design parameters. Maximum flow rate $Q_{\max} = 0.015\mathrm{m}^3/\mathrm{s}$, over-grate flow rate $v_1 = 0.5\mathrm{m}$, grating installation angle $\alpha = 30°$, grating gap width $e = 20$ mm, grating bar width $s = 10$ mm.

2) The calculation schematic of the grating design is shown in Figure 3.

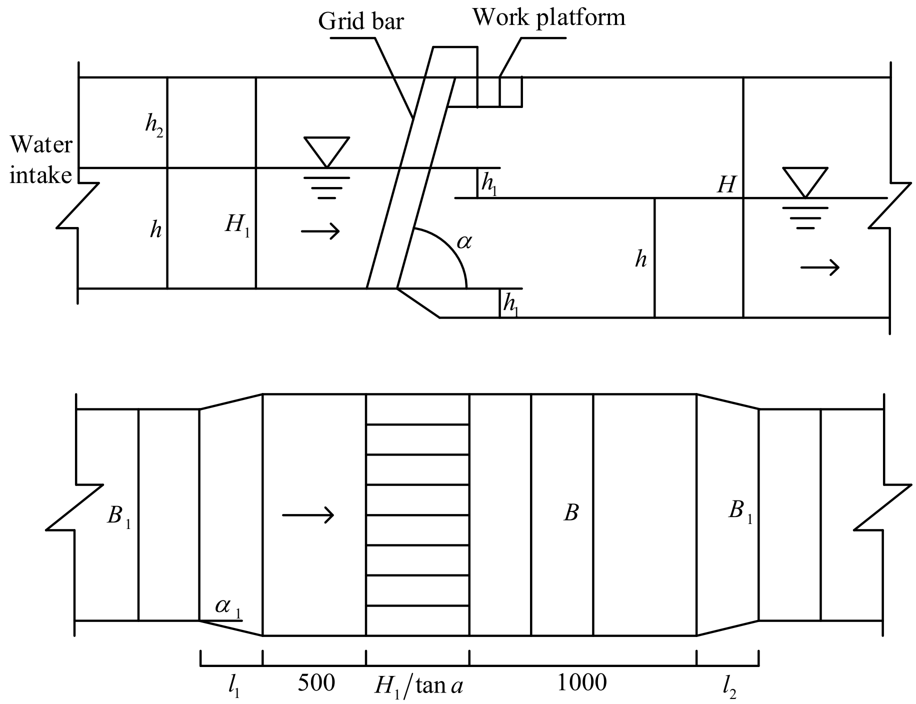

Fig. 3. Grid calculation diagram

3) Calculation of the center grid design:

(1) Grid before the water depth h

From the formula $Q_{\max} = B_1^2 v_1 / 2$, the width of the inlet pool is:

$$B_1 = \left(\frac{2Q_{\max}}{v_1}\right)^{0.5} = \left(\frac{2\times 0.031}{0.5}\right)^{0.5} = 0.352\text{m} \tag{1}$$

So the depth of water in front of the grill $h = B_1 / 2 = 0.176\text{m}$.

(2) Number of grating gaps, is:

$$n = \frac{Q\sqrt{\sin\alpha}_{max}}{bhv_2} \tag{2}$$

Where, n is the number of gaps in the grating, pcs. Q_{max} for the maximum design flow rate, m^3/s. a for the inclination angle of the grating, b for the net clearance of the grating bars, coarse grating b = 50~100mm, medium grating b = 16~50mm, fine grating b = 2~10mm. v_2 for the flow rate over the grating, m/s. h for the water depth in front of the grating, m.

4) Calculation of slot width B. Calculation formula for slot width B:

$$B = S(n-1) + bn \tag{3}$$

Where, B is the width of the grid groove, m. S is the width of the grid bar, m, take 0.05m. n is the number of gaps in the grid bar, one. b is the net clearance of the bars.

Substitute the value into the above equation:

$$B = S(n-1) + bn = 0.01\times(5-1) + 0.02\times 5 = 0.14\text{m} \tag{4}$$

5) Length of the tapering part of the water channel L_1. Width of inlet pool $B_1 = 0.3m$, angle of expansion of tapering part $\alpha_1 = 20^{\circ}$

Then the length of the tapering part of the inlet channel:

$$L_1 = \frac{B - B_1}{2\tan\alpha_1} = \frac{0.6 - 0.2}{2 \times \tan 20^\circ} = 0.36\text{m} \tag{5}$$

6) Resistance coefficient. Calculated by the formula:

$$\xi = \beta\left(\frac{S}{e}\right)^{4/3} \tag{6}$$

Where, ξ is the resistance coefficient, its value is related to the shape of the bar section. e for the net spacing of the grating, β for the shape coefficient, the grating for the rectangular section $\beta=2.45$, circular section $\beta=1.78$. The water surface for the semi-circular rectangular section $\beta=1.83$, s for the width of the grating, 10mm, that is:

$$\xi = \beta\left(\frac{s}{e}\right)^{4/3} = 1.78\left(\frac{10}{30}\right)^{4/3} = 0.40 \tag{7}$$

2.2.2. MBBR main process design:

1) Design parameters

Adopt A/O mode, A:O=1:3.

Filling ratio of aerobic tank filler is 30%.

Residence time, HRT=5h.

BOD_5 Sludge load L_S, take $0.15\text{KgBOD}_5/\text{kgMLSS}\cdot\text{d}$.

Sludge concentration X_a, 16g/L=16000mg/L.

Sludge age θ_c, 45d.

Gas-water ratio of biochemical tank is 6:1.

Sludge yield Y, 0.5KgVSS/kgBOD_5.

2) A/O tank volume calculation. According to the sludge load calculation, there are:

$$V_{good} = \frac{24Q(S_0 - S_e)}{1000 L_V \eta} \tag{8}$$

$$L_V = Ls \times Xa \tag{9}$$

Where, V_{good} for the aeration pool volume, m^3. S_o for the aeration pool into the water BOD_5 value, mg / L. S_e for the aeration pool out of water BOD_5 value, mg / L. Q for the design flow rate of the aeration pool (m^3/h). L_V is the BOD_5 volumetric loading of the aeration tank, kgBOD5/(m^3 filler-d). η is the fill ratio of the aeration tank, 50%.

Calculations were obtained:

$$L_V = Ls \times Xa = 0.13 \times 15 = 1.95\text{kgBOD}_5/(\text{m}^3\text{filler}\cdot\text{d}) \tag{10}$$

$$V_{good} = \frac{24Q(S_O - S_e)}{1000 L_V \eta} = \frac{1000(150 - 10)}{1000 \times 1.54 \times 30\%} = 303.03\text{m}^3\text{,take } 303\text{m}^3 \tag{11}$$

Set up 2 groups, each with a volume of, $303 \div 2 = 151.5\text{m}^3$.

3) A/O pool hydraulic retention time. Calculated by the formula:

$$t = \frac{V_{good}}{Q} = \frac{303}{1000} = 0.303\text{d} = 7.08\text{h take 8h} \tag{12}$$

According to the design specification, there exists a certain ratio relationship between anaerobic and aerobic retention time and volume, i.e., anaerobic: aerobic = 1:3. It can be seen that the hydraulic retention time of anaerobic tank is $t_{\text{anaerobic}} = \frac{8}{4} = 2\text{h}$, and the capacity of the tank is $V_{\text{anaerobic}} = \frac{303}{4} = 76\text{m}^3$, i.e., each tank volume is 42.6m^3.

4) Sludge return ratio R. The formula is:

$$X_R = \frac{10^6}{SVI} \times r \tag{13}$$

Where, r for the sludge re-settlement tank in the residence time, pool depth, sludge thickness and other factors related to the general take the value of 1.2. SVI for the reaction of the activated sludge cracking coagulation settlement performance, generally between 50 ~ 100, this design take 50, then:

$$X_R = \frac{10^6}{SVI} \times r = \frac{10^6}{50} \times 1.2 = 24000\,(\text{mg/L}) \tag{14}$$

Then, according to the known mixture of suspended solids concentration X (MLSS) = 14000mg / L, the return sludge concentration of 12000mg / L, according to the design specifications of the A/O process, it can be known that the sludge return ratio of 50% -100%, this design to determine the sludge return ratio R = 100%.

5) Calculate the amount of residual sludge excluded every day. Calculation of apparent sludge yield:

$$Y_{\text{obs}} = \frac{Y}{1 + k_d \theta_c} = \frac{0.5}{1 + 0.04 \times 10} = 0.3571 \tag{15}$$

$$\begin{aligned} \Delta X &= Y_{obs} Q_{max}(S_o - S_e) - KdVX_v + fQ_{max}(SS_o - SS_e) \\ &= 0.3571 \times 1200(0.15 - 0.01) - 0.04 \times 455 + 0.7 \times 1200(0.16 - 0.02) \\ &= 4.05\text{kg/d} \end{aligned} \tag{16}$$

Where ΔX is the remaining sludge volume (kgSS/d), V is the volume of the reaction tank (m^3). X is the average concentration of suspended solids in the reaction tank mixture (gMLSS/L), generally 8~10gMLSS/L for MBBR. θ_C is the sludge sludge age (d), Y is the sludge yield coefficient (kgVSS/kgBOD_5) of 0.5~1.0 at 20°C. $Q_{\max}$ is the maximum amount of sewage in the design average day (m^3/d), S_o is the influent $BOD_5(kg/m^3)$. S_e is the effluent $BOD_5(kg/m^3)$, k_d is the attenuation coefficient (d^{-1}), the value of $20°C$ is 0.05~0.075. f is the sludge conversion rate of SS, SS_o is the suspended solids concentration in the influent of the bioreactor (kg/m^3), and SS_e is the suspended solids concentration in the effluent of the bioreactor (kg/m^3).

6) Aeration system design. Oxygen demand AOR = removal of BOD_5 oxygen demand a remaining sludge in BOD_U oxygen equivalent $+NH_3 - N$ nitrification oxygen demand a remaining sludge in $NH_3 - N$ oxygen equivalent a denitrification denitrification oxygen production. That is:

$$\begin{aligned} O_2 &= aKQ(S_0 - S_e) + b[Q \times K(TN_0 - TN_e) - 0.12\Delta X] \\ &- C[Q \times K(TN_0 - TN_e - MH_3 - N) - 0.12\Delta X] - d\Delta X \end{aligned} \tag{17}$$

Where, a for the oxygen rate, take the value of 1. K for the coefficient of variation, take the value of 1.5. Q for the daily treatment of sewage 1000 m^3/d. S_0 for the treatment of BOD_5 concentration, 150mg / L. S_e for the effluent BOD_5 concentration, 10mg / L. b for the coefficient, take 4.5. TN_0, take 40mg / L. TN_e, take 10mg / L.

7) air volume calculation. The use of blower aeration, the effective water depth of the aeration pool is 3.5m, the aeration diffuser installed from the bottom of the pool 0.1m. Then the diffuser on the static water pressure is 3.5m, using HC260 disk type microporous aerator, $E_A = 30\%$.

Aeration pool gas supply is:

$$G_S = \frac{O_2}{0.21\rho E_A} = \frac{348.23}{0.22\times 0.25\times 30\%} = 2.11\times 10^4\,\mathrm{m}^3/\mathrm{d} \tag{18}$$

Where O_2 is the net oxygen demand, kg/d. p is the air density at room temperature, $0.25\mathrm{kg/m}^3$. Ea Oxygen utilization coefficient, 0.25.

2.2.3. Coarse grating and lift pump house design:

1) Coarse grating. Function: Remove the larger floating matter in the sewage, and intercept the debris with a diameter larger than 20mm, cut down the SS content in the water partially, and intercept the larger solid pollutants in the sewage in a suspended or floating state, in order to ensure the normal operation of the submersible pump.

Type: underground reinforced concrete channel.

Quantity: 1 with lifting pump room.

The rough grating and lift pump room workshop has a footprint of $96.35\ \mathrm{m}^3$ and a height of 6.0m.

Part of the calculation is as follows:

Set the grating before the water depth of 1.0m, over the grating flow $v = 0.8$ m / s, grating gap width of 0.015m, grating installation inclination angle of 60°.

Grid slot width:

$$n = \frac{Q_{\max}\sqrt{\sin\alpha}}{bhv} = \frac{0.25\times 0.98}{0.010\times 1\times 0.9} \approx 27 \tag{19}$$

$$\begin{aligned} B &= S(n-1)+bn \\ &= 0.01(27-1)+0.015\times 27 \\ &= 0.665m \text{ take } 0.7\mathrm{m} \end{aligned} \tag{20}$$

Where, n for the number of bars, a for the installation of the grille inclination, h for the grille before the water depth (m), v - over the grille flow rate (m / s), S for the width of a single grille (m), b for the gap between the grille (m).

Over-grate loss:

$$\begin{aligned} h &= \beta\left(\frac{S}{b}\right)^{\frac{4}{3}}\frac{v^2}{2g}\sin\alpha K \\ &= 2.45\left(\frac{0.01}{0.015}\right)^{\frac{4}{3}}\frac{0.9^2}{18.2}\sin 60^\circ\times 3 \\ &\approx 0.25\mathrm{m} \end{aligned} \tag{21}$$

Where, h for the head loss through the grille (m), β for the shape of the coefficient is generally 2.45, K for the grille by the dirt clogging head loss increase times, g for the acceleration of gravity ($\mathrm{m/s}^2$).

2) Lifting pumping station. Function: To elevate the sewage at one time, so that the sewage flows through the treatment structure by gravity in order to ensure the normal operation of the sewage plant.

Type: Underground reinforced concrete rectangular structure.

Quantity: 1 seat, built together with grating canal.

Main equipment:

A. Submersible Pump

Equipment type: submersible sewage pump.

Quantity: 5 sets in total, (3 with 2 standby, frequency conversion).

Design parameters: flow rate 450 m^3/h.

Lift: 20m.

Power: 45KW.

Control mode: according to the level of the catchment basin, automatically controlled by PLC, the pumps run in sequence in turn, also can be manually controlled on site.

B. Electric hoist

Design parameters: lifting capacity 2.0t, power 4.5KW.

Quantity: 1 set.

Control mode: electric hoist using on-site control.

2.2.4. AAO reactor design. Function: Under the condition of providing enough oxygen and creating anoxic and aerobic environment in the biological reaction pool, the activated sludge, which multiplies in large quantities in the biological reaction pool, is utilized to degrade the pollutants in the water, so as to achieve the purpose of purifying the water quality.

Structure form: semi-underground reinforced concrete structure.

Processing scale: 15,000 m^3/d.

Quantity: 2. The total design size of single pool structure is 54.2×18.0×8.5m, effective water depth is 8.0 m. The workshop covers an area of 2245.73 m^3. The building height is 4.5 m^3, and the model of AAO treatment tank is shown in Fig. 4, which is divided into four areas: anaerobic area, anoxic area, aerobic area and sedimentation area.

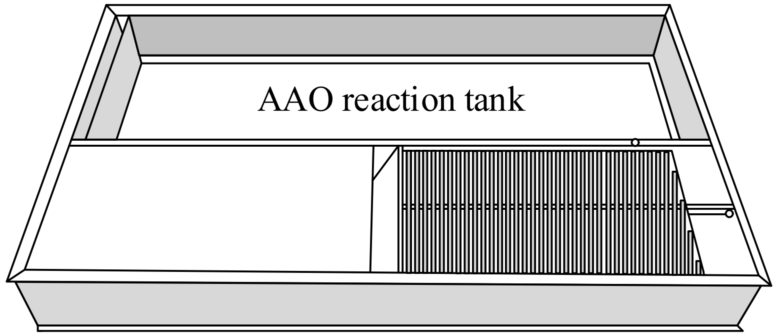

Fig. 4. Schematic diagram of AAO pool

Some of the calculations are as follows:

1) Calculation of aerobic zone. Calculate the maximum specific growth rate of nitrifying bacteria under low water temperature conditions μ, and the typical value of the half-rate constant K_n for nitrogen in nitrification is 1.0 mg/L, specifically:

$$\mu = 0.45 \frac{N_a}{K_n + N_a} e^{0.098(T\text{-}15)} = 0.275 \tag{22}$$

Calculate the sludge age of the design sludge in the aerobic zone θ_{co}, taking a safety factor of $F = 3.0$, θ_{co} as:

$$\theta_{co} = F \frac{1}{\mu} = 3.0 \times \frac{1}{275} = 0.10909 \approx 11\text{d} \tag{23}$$

Where θ_{co} is the design sludge age in the aerobic zone and F is the safety factor.

Calculate the volume of aerobic zone

The total sludge yield coefficient Y_t is 1.0kgMLSS/kgBOD_5 and the average concentration of suspended solids in the mixture is $X = 5.0\text{gMLSS/L}$, specifically:

$$\begin{aligned} V_0 &= \frac{Q(S_o - S_e)\theta_{co} Y_t}{1000X} \\ &= \frac{13000 \times (200-5) \times 7.5 \times 1.0}{1000 \times 5} \\ &= 3803\text{m}^3 \end{aligned} \tag{24}$$

Where V_0 is the volume of aerobic zone (m^3), S_0 is the influent BOD_5 concentration (mg/L), Se is the effluent BOD_5 concentration (mg/L), Q is the design flow rate (m^3), X is the average concentration of suspended solids in the mixed liquor, and Y_t is the coefficient of total sludge yield (kgMLSS/kgBOD_5).

2) Calculation of residual sludge volume. alculate the attenuation coefficient Kd at the design low water temperature, $20°C$ when the attenuation coefficient K_{d20} is $0.060d^{-1}$ temperature coefficient θ_r is 1.05.

Then:

$$\begin{cases} K_{dT} = K_{d20} \times (\theta_T)^{T-20} \\ K_{d15} = 0.05 \times (1.05)^{15-20} = 0.046d^{-1} \end{cases} \tag{25}$$

The amount of residual sludge ΔX is calculated

Take the sludge yield coefficient $Y = 0.6\text{kgVSS/kgBOD}_5$, SS the sludge conversion rate $f = 0.5$ gMLVSS/gSS. The proportion of MLVSS in MLSS is $\nu = 0.6$ and the average concentration of volatile suspended solids $X_v = 0.6 \times X = 2.4\text{gMLVSS/L}$ in the mixed liquor in the bioreactor.

ΔX The calculation formula is:

$$\begin{aligned} \Delta X &= YQ(S_O - S_e) - K_d V X_V + fQ(SS_O - SS_e) \\ &= 2851 kg/d \end{aligned} \tag{26}$$

3) Volume calculation of anaerobic zone. Take the anaerobic zone hydraulic retention time $t_p = 1.84$ h, V_p for:

$$V_p = \frac{t_p Q}{24} = \frac{1.84 \times 13000}{24} = 1008\text{m}^3 \tag{27}$$

Where, V_p for the anaerobic area volume (m^3), t_p for the anaerobic area hydraulic retention time (h), Q for the design of sewage flow (m^3/d).

2.3. *Reflector system dynamics model*

The composition and activity of microbial community structure are critical for reflecting the performance of wastewater treatment systems. However, the period of microbial community structure measurement is long and costly, and the obtained microbial community structure characteristics are difficult to be quantitatively characterized by simple methods for modeling applications. Compared with the microbial community structure, microbial activity indicators have the characteristics of fast and convenient detection, and can reflect the characteristics of microorganisms to a certain extent. Considering the modeling of wastewater treatment system dynamics, it has simplicity and practicality. Therefore, this paper adopts the system dynamics model of AOO reflecting pool, which is used to reflect the trend of microbial activity indicators, is a more reasonable idea.

The reactor model in this study is based on the ASM2 model, so the determination of kinetic parameters or stoichiometric parameters of the model is also based on the ASM2 model. Users can adjust the parameters according to their actual model. The total kinetic equations for each component can be introduced by combining the conversion rate equations of the reaction cell and the solution and estimation of the relevant unknown stoichiometric coefficients.

The wastewater treatment system contains 19 sub-reaction processes, and each component (except the inert component) is involved in at least one of these sub-reaction processes. Therefore, the reaction rate of the component in the whole system is the sum of its reaction rate in each subreaction equation. For example, the fermentation product SA is consumed in the aerobic growth process of the parthenogenetic heterotrophic bacterium (process 3), consumed in the anoxic growth process (process 8), generated in the fermentation process (process 10), consumed in the storage process of the polyphosphate bacterium XPHA (process 7), and grown in the decomposition process of XPHA (process 5). Therefore, the total reaction kinetic equation for the fermentation product SA should be the sum of the reaction rates in these processes. From this it follows:

$$\left(\frac{dSA}{dt}\right) = \left(\frac{dSA}{dt}\right)_3 + \left(\frac{dSA}{dt}\right)_8 + \left(\frac{dSA}{dt}\right)_{10} + \left(\frac{dSA}{dt}\right)_7 + \left(\frac{dSA}{dt}\right)_5 \tag{28}$$

Through this expression, you can find out the amount of concentration change of a certain component at any moment, combined with the single reaction cell model, you can calculate the concentration of a certain component at any moment. In the actual operation of the sewage treatment plant, people are only concerned about the quality of water in and out, so the model can be calculated by controlling the moment of water discharge t to get the component of water discharge.

3. Analysis of the operational effectiveness of sewage treatment plants

In order to investigate the treatment elasticity and treatment effect of a high-efficiency wastewater treatment plant under unstable water quality as proposed in this paper, the relevant indicators of the wastewater treatment plant after a full year of uninterrupted and stable operation were selected for analysis. A high-efficiency wastewater treatment plant in the daily process, the inlet and outlet water operating parameters are recorded and monitored. The COD (Chemical Oxygen Demand), BOD_5 (Five-day Biochemical Oxygen Demand), TP (Total Phosphorus), TN (Total Nitrogen), NH3-N (Ammonia Nitrogen), SS (Suspended Substances Concentration), and pH values of the incoming and outgoing water of the wastewater treatment plant were tested and analyzed. In order to ensure the accuracy and scientificity of the data and analysis, analytical calculations to explore the operational efficiency and pollution removal rate are important feedback and assurance to maintain and keep the wastewater treatment plant running efficiently.

3.1. Effectiveness of pre-treatment at wastewater treatment plants

COD, BOD_5 removal is mainly through the biological process treatment of A/O reaction tank and MBBR membrane tank for removal. The results of the analysis of the treatment effect of each unit are shown in Table 1, and it can be seen that relative to the traditional wastewater treatment program (grid + sand sedimentation tank + regulating tank + hydrolysis acidification tank), the removal rate of high-efficiency (A/O reaction tank + MBBR membrane tank + clear water tank) wastewater treatment program are higher than the traditional program. The removal rates of COD (Chemical Oxygen Demand), BOD_5 (Five-Day Biochemical Oxygen Demand), SS (Suspended Solids Concentration), NH3-N (Ammonia Nitrogen Content) and TP (Total Phosphorus Content) of the high-efficiency wastewater treatment program are higher than 81.90%, 89.29%, 90.91%, 96% and 83.87% respectively. Grids, sedimentation tanks, conditioning tanks and acidification tank processes played a lesser role in their removal. The removal of suspended solids could be more than 50% under the grid, sedimentation tank, conditioning tank and acidification tank processes, which proves that the removal of suspended solids can be achieved by a combination of physical and biological actions. Ammonia nitrogen can only be removed by the A/O reaction tank and MBBR membrane tank, and the overall removal rate is more than 88% under these two processes.

Table 1. Processing effect analysis table of each unit

Processing unit		Traditional sewage treatment scheme	High efficiency wastewater treatment scheme
COD (mg/L)	Water intake	300	210
	Out of water	⩽217	⩽38
	Removal rate	⩾27.67%	⩾81.90%
BOD_5 (mg/L)	Water intake	150	140
	Out of water	⩽110	⩽15
	Removal rate	⩾26.67%	⩾89.29%
SS (mg/L)	Water intake	210	110
	Out of water	⩽75	⩽10
	Removal rate	⩾64.29%	⩾90.91%
NH3-N (mg/L)	Water intake	-	-
	Out of water	40	⩽5
	Removal rate	-	⩾96%
TP (mg/L)	Water intake	4	3.1
	Out of water	⩽3.0	⩽0.5

	Removal rate	⩾25.00%	⩾83.87%

3.1.1. Analysis of COD treatment effect. The annual inlet and outlet water COD operation data of a high-efficiency wastewater treatment plant is shown in Figure 5, which shows that the inlet water COD concentration of the wastewater treatment plant is in the range of 213.08~271.59 mg/L. According to the requirement of COD content in the effluent quality of the sludge treatment plant, the effluent water meets the standard when the COD is ⩽45 mg/L. The 365 water samples obtained throughout the year were tested and the COD concentration values of the inlet and outlet water were recorded. The average values of COD in and out of the water throughout the year were 255.437mg/L and 10.556mg/L, respectively, which meet the design treatment requirements of high-efficiency wastewater treatment plant.

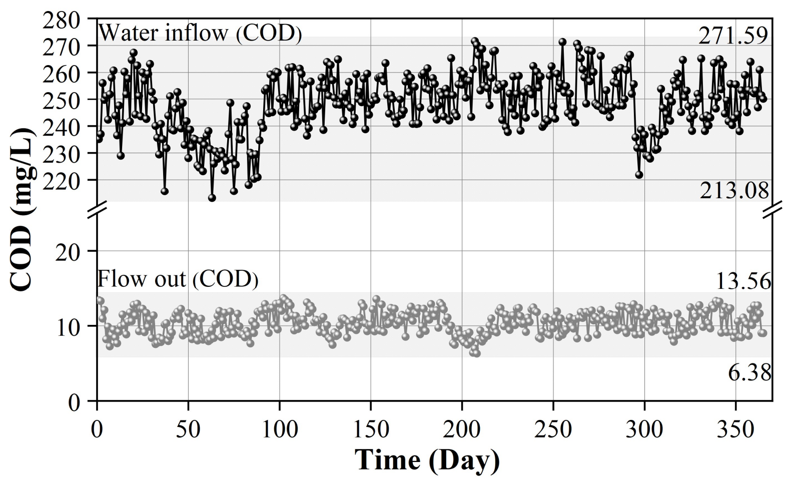

Fig. 5. Annual COD operation data of inlet and outlet water

The results of COD removal rate analysis for the whole year are shown in Figure 6, it can be seen that the average COD removal rate for the whole year is 94.37%, and the COD removal rate for every day in the whole year is more than 93.5%, which is much higher than the COD removal rate required by the design of the wastewater treatment plant, and the efficient and uniform COD removal rate represents that the operation of this high-performance wastewater treatment plant is in good condition.

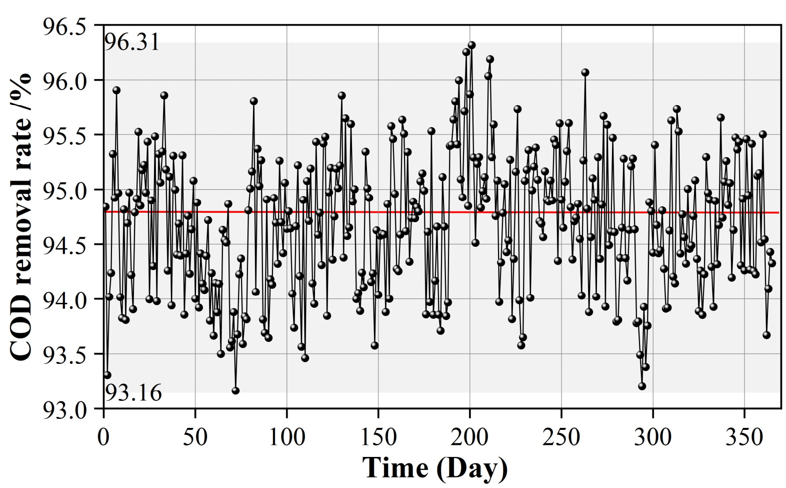

Fig. 6. Annual COD removal rate analysis diagram

3.1.2. Analysis of NH3-N treatment effect. Annual inlet and outlet water NH_3-N operation data shown in Figure 7, you can see that the wastewater treatment plant influent ammonia nitrogen range of 21.5 ~ 46.5mg / L, the design of ammonia nitrogen in the effluent ⩽ 2mg / L, the average value of the annual inlet and outlet water ammonia nitrogen were 32.085mg / L and 1.107mg / L, effluent quality to achieve the provisions of the first-class standard of sewage discharge to meet the requirements of high-performance wastewater treatment plant design and treatment. At the same time, the first half of the ammonia nitrogen influent water quality fluctuations, into the second half of the influent ammonia nitrogen with the increase in operating date and increase. However, the ammonia nitrogen content of the effluent water quality is more stable, which highlights the stability of the operation of the new wastewater treatment plant.

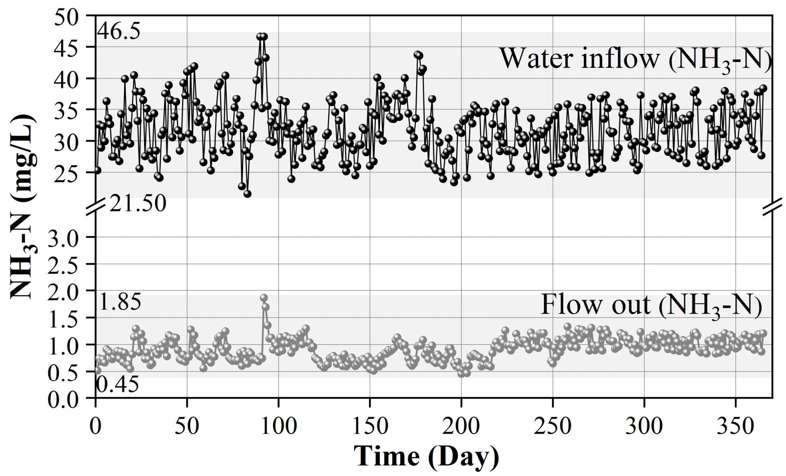

Fig. 7. Annual NH3-N operation data of water inlet and outlet

The removal rate of ammonia nitrogen throughout the year is shown in Fig. 8, and there are relatively large fluctuations in the ammonia nitrogen removal rate due to the large volatility of ammonia nitrogen influent water quality. The average ammonia nitrogen removal rate for the whole year was 96.98%, which was higher than the removal rate required by the design, which reflected the high efficiency of the operation of the wastewater treatment plant and the timeliness of the control system regulation.

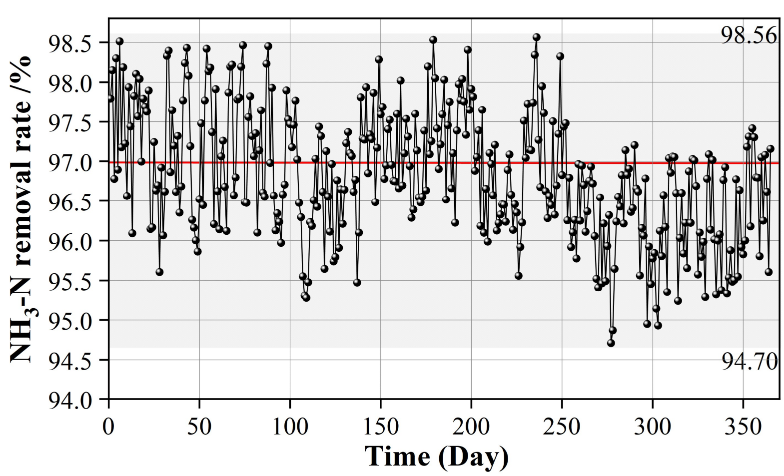

Fig. 8. Annual NH3-N removal rate analysis diagram

3.1.3. pH change analysis. Wastewater plant design process for pH influent water quality testing for 6 to 9, and treated effluent water quality to the same pH requirements.

The annual pH value of the incoming and outgoing water is shown in Figure 9, it can be seen that the pH value fluctuates from January to March, the highest is greater than 9, the lowest is less than or equal to 7, the fluctuation range of the treated water quality is also relatively large, but also in the range of 6-7.5. And after March pH value changes are smaller, water quality stabilized between 8 ∼ 8.4, the pH of the effluent water between 6.8 ∼ 7.2. According to this treatment before and after the fluctuation range of data can be seen, sewage treatment operation process pH value of the water parameters are affected by the influent water quality, so according to the nature of the influent water quality and the operation of the effect of the comparison, the calculation of the optimal set of operating parameters on the operation of the sewage treatment plant and other related parameters of the control is to improve the effect of sewage treatment and sewage treatment plant operation of the top priority of the economy and efficiency.

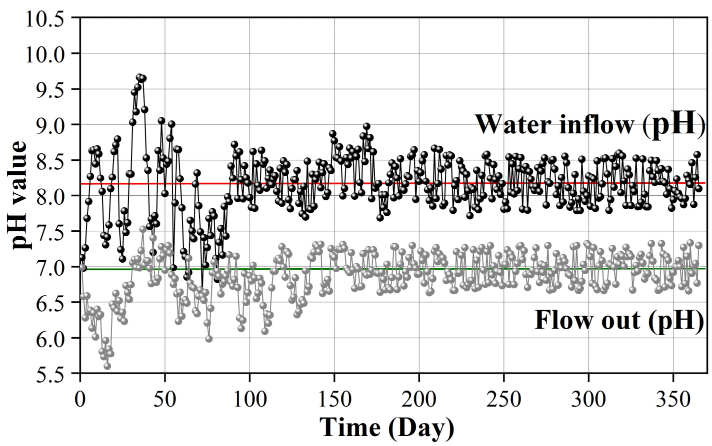

Fig. 9. Annual pH operation data of water inlet and outlet

3.2. Analysis of microbial community structure in wastewater treatment

In this paper, the kinetic model of the reflecting cell system was used to calculate the concentration of the microbial community in the reacting cell of the wastewater treatment plant at any moment. The experimental high-efficiency wastewater treatment plant (A/O reactor + MBBR process) was named AM, where the pre-denitrification zone was named AM1, the anaerobic zone was named AM2, the anoxic zone was named AM3, and the aerobic zone was named AM4.

3.2.1. OTU Analysis. Qiime software was used to cd-hit all Effective Tags to remove redundant sequences, cluster sequences into OUT (Operational Taxonomic Units) with sequence difference level at 0.05 (i.e., 95% similarity) level, and at the same time select the representative sequences with the highest frequency of occurrence in the OTUs, remove the sequences containing only one OTUs containing only one sequence (Singleton) were removed, and the representative sequences of OTUs were subjected to species annotation (Greengenes). The data from each sample in the OTU table were homogenized using the least amount of data among the samples as the criterion, and the homogenized data were further used for subsequent Alpha and Beta diversity analyses.

Comparison of the number of OTUs for the high performance wastewater treatment facilities was carried out and the results are shown in Fig. 10.The number of OTUs for AR-1, AR-2, AR-3, and AR-4 were 2674, 2734, 2751, and 2704, respectively, and there was a difference of 77, or about 2.80%, between the highest number of OTUs, AR-3, and the lowest number of OTUs, total number of OTUs, AR-1. The number of common OTUs is 1863 and the number of common OTUs is more than 69.67% of the total OTUs. The analysis shows that for the same wastewater treatment facility, there is a slight difference in the number of OTUs in different process sections. However, the overall difference is not significant, and the number of common OTUs can account for more than 60% of the total number of

OTUs, indicating that there is little overall difference in the biological community structure of each treatment unit of the same wastewater treatment system.

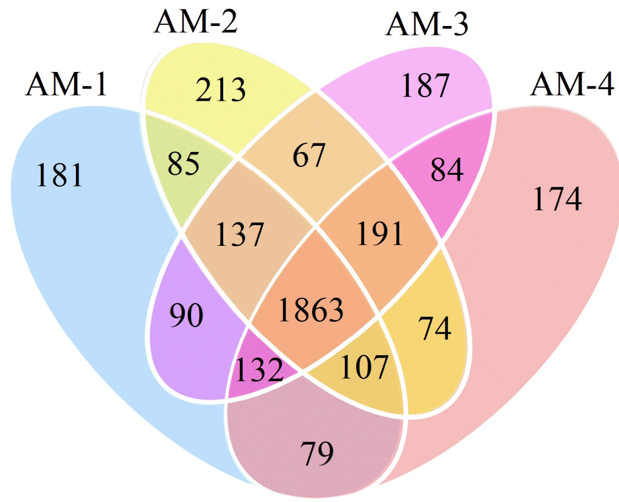

Fig. 10. Number of OTU of WWTPs (longitudinal comparison)

In order to further explore the differences in the number of OTUs between different wastewater treatment facilities, the aerobic zones (AM4-1 to AM4-5) of each wastewater treatment system were compared, and the results of the number of OTUs of the high-efficiency wastewater treatment facilities (side-by-side comparison) are shown in Fig. 11. As can be seen from the figure, the number of OTUs in each section of the aerobic zone of AM4 is 1599, 2734, 2084, 1657 and 1983, respectively, and the difference between the total number of OTUs in AM4-2, which has the highest number of OTUs, and AM4-1, which has the lowest number of OTUs, is 1135, or about 41.51%. The number of common OTUs was 633, and the number of common OTUs accounted for less than 39.59% of the total number of OTUs.

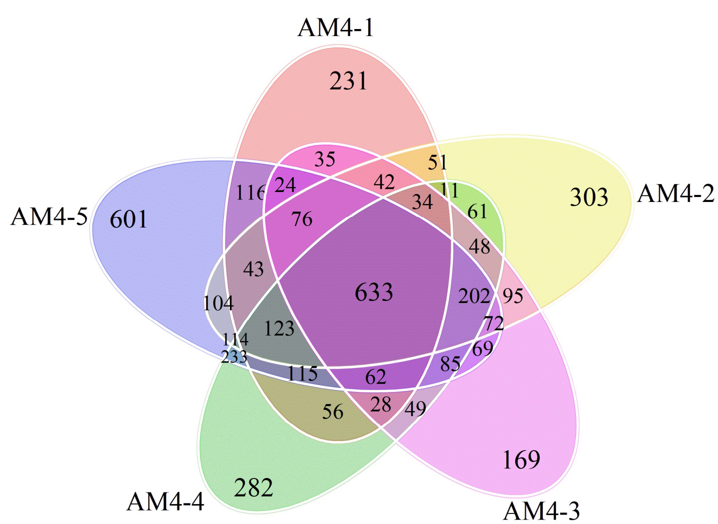

Fig. 11. Number of OTU of WWTPs (Horizontal comparison)

The analysis shows that the number of OTUs in different wastewater treatment facilities has a large difference and the number of common OTUs is small, indicating that there is a large difference in the microbial community structure of different wastewater treatment processes. For the same process, the number of OTUs may also have a large difference (e.g., AG, AR) or a small difference (e.g., CS, CP), suggesting that the wastewater treatment process may not be the determining factor for the differences in microbial community structure. Considering that the wastewater from each wastewater treatment facility, with different reception ranges and different geographical locations, the quality of the influent water from the wastewater treatment facility, on the other hand, is likely to be a potentially critical factor causing the differences in microbial community structure.

3.2.2. SOUR correlation analysis. In this study, we investigated the intrinsic correlation between microbial activity indexes (SOUR) in the aerobic section of the wastewater treatment facility, inlet and outlet water quality parameters (COD, NH_3-N, TN, TP), as well as wastewater treatment process parameters (DO, MLSS), and the performance of the wastewater biological treatment process. It was also analyzed in conjunction with the changes in microbial community structure, which is of great significance for further revealing the internal process mechanism of wastewater biological treatment unit, realizing the efficient, stable and low-consumption operation of wastewater biological treatment, as well as monitoring and early warning of the water body environment. At the same time, it can also provide a theoretical basis for the optimization of wastewater treatment facilities. Normal operation of sewage treatment system SOUR value is usually 8-20 $mgO_2/(gMLSS \cdot h)$, if the oxygen consumption rate of activated sludge is much higher than the normal value, indicating that the load of activated sludge is too high, when the water quality of the effluent is poor, the residual organic matter is more. If the oxygen consumption rate of activated sludge is lower than the normal value, it indicates that the number of residual organic matter in the effluent is less, and the effluent water quality is better.

The SOUR online monitoring of the influent and effluent water of the high efficiency wastewater treatment plant for the whole year is shown in Figure 12, which shows that most of the SOUR values of the wastewater treatment facilities during this period were below 20 $mgO_2/(gMLSS \cdot h)$, indicating that the wastewater treatment system as a whole operated normally, which was also well confirmed by the monitored effluent water quality. Further investigation of the distribution of SOUR values in the less than 20 $mgO_2/(gMLSS \cdot h)$ cases reveals that for nearly half of the days, the measured SOUR values were less than 10.5 $mgO_2/(gMLSS \cdot h)$.

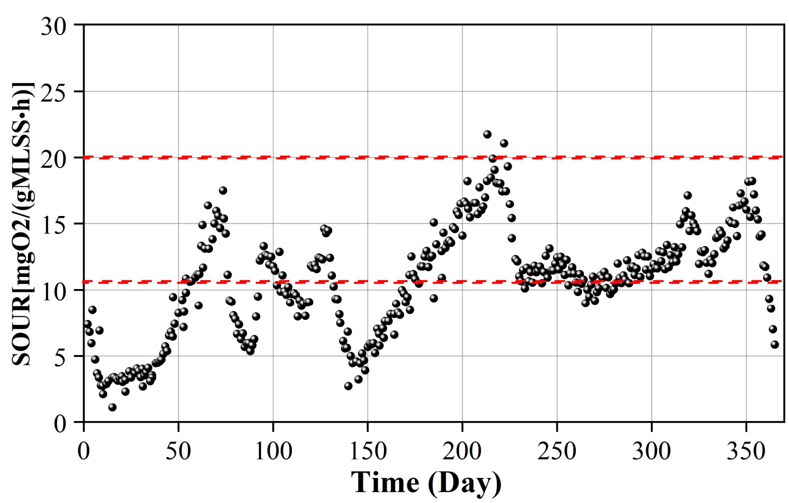

Fig. 12. Online monitoring data of SOUR

SOUR is an important indicator for evaluating the metabolic activity of sludge microorganisms, which may be affected by factors such as environmental conditions, water quality indicators and process parameters. The correlation analysis of SOUR, water quality indicators (pH, COD, NH3-N, TN, TP) in aerobic section of wastewater treatment system, process parameters (DO) and ambient temperature was done as shown in Figure 13. As can be seen from the figure, SOUR showed negative correlation with temperature T ($P \leq 0.1$), and significant negative correlation with MLSS and COD

($P \leq 0.05$). The factors that have a greater influence on SOUR are pH, temperature and organic matter concentration (in terms of COD).

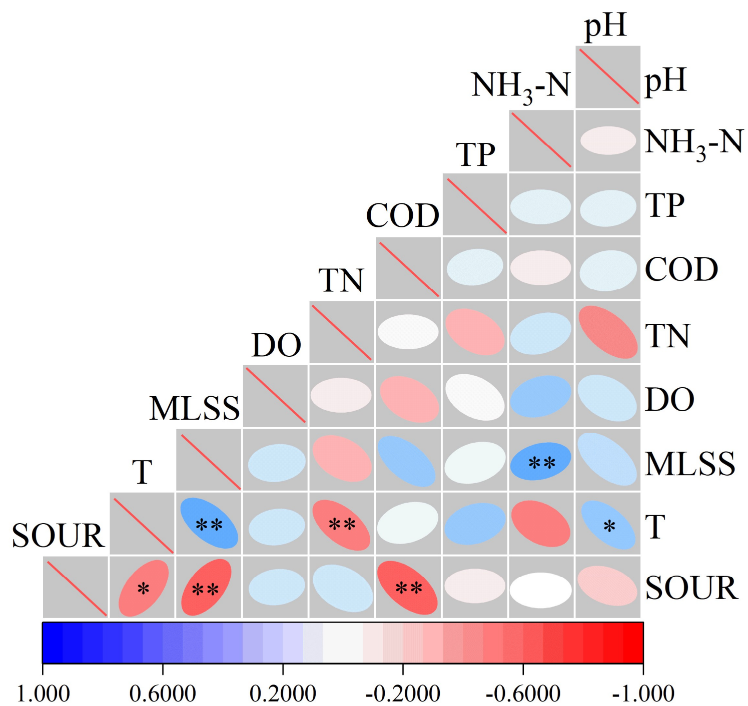

Fig. 13. Correlation analysis

Comparing the results of this study, it can be found that COD and temperature do present a more significant correlation on SOUR, while pH is not reflected. The probable reason for this is that pH only has an effect on sludge respiration rate when it is outside of a certain range (pH 6.5-8.0), whereas the wastewater treatment system is relatively stable, with measured pH basically around 7, and therefore does not have a more practical effect on sludge respiration.

4. Conclusion

The urban wastewater treatment plant related treatment process selection, accounting for the relevant parameters, as well as later on the completion of the wastewater treatment plant operation effect records and system dynamics analysis, clear wastewater treatment plant operation effect and later on the optimization of the operation mode. The following conclusions can be obtained:

1) Processes such as AAO reaction tank and MBBR membrane tank are introduced. Among them, the mixing reflux ratio of AAO reaction tank is 300%, and the MBBR membrane tank is selected as curtain membrane module. And the operation results are predicted, the expected COD removal rate of AAO reaction tank + MBBR membrane tank + clear water tank is ⩾94.37%, NH3-N removal rate is ⩾ 96.98%, the pH value of effluent is stabilized between 6.8 and 7.2, and the removal effect of each parameter meets the design treatment requirements of wastewater treatment plant.

2) The SOUR values of the influent and effluent of the high-efficiency wastewater treatment plant for the whole year are distributed in the case of less than 20 $mgO_2/(gMLSS \cdot h)$, and about nearly half of the days, the SOUR values are less than 10.5 $mgO_2/(gMLSS \cdot h)$. Fully consider the intrinsic connection between influent water quality, operating parameters and wastewater treatment system performance.

In summary, the design and operation parameters of AAO process should be set in strict accordance with the influent parameters and water quality and quantity, and the later operation should be flexibly adjusted according to the operation experience and data background.MBBR membrane method and physical treatment method, which runs stably in the process of sewage treatment, is suitable for the treatment of municipal wastewater. Record monitoring and analysis of influent water quality, so as to set the optimal operating parameters is to ensure that the optimization of sewage treatment plant operating efficiency and economy of the best choice.

References

[1] Fuxia, Y. , Mian, Y. , & Jiangchuan, X. . (2018). The productivity dynamics of china???s environmentally friendly production technologies in terms of wastewater treatment techniques. BioMed Research International, 2018, 1-10

[2] Duan, B. , Zhang, W. , Zheng, H. , Wu, C. , & Bu, Y. . (2017). Disposal situation of sewage sludge from municipal wastewater treatment plants (wwtps) and assessment of the ecological risk of heavy metals for its land use in shanxi, china. International Journal of Environmental Research and Public Health, 14(7), 823.

[3] Gu, D. , Song, Z. , Kang, H. , Mao, Y. , & Feng, Q. . (2021). Occurrence, profiles and ecological risk of bisphenol analogues in a municipal sewage treatment plant. Bulletin of Environmental Contamination and Toxicology, 1-6.

[4] Koo, D. , Park, N. S. , Oh, J. I. , & Yoon, S. . (2020). A study on the rational requirement area estimation of municipal sewage treatment facilities using statistical techniques. Journal of Korean Society of Environmental Engineers(3).

[5] Ding, A. , Wang, J. , Lin, D. , Tang, X. , Cheng, X. , & Li, G. , et al. (2017). In situ coagulation versus pre-coagulation for gravity-driven membrane bioreactor during decentralized sewage treatment: permeability stabilization, fouling layer formation and biological activity. Water Research, 126(dec.1), 197-207.

[6] Polus, M. , & Anielak, A. M. . (2021). The occurrence of archaea in municipal sewage sludge and their importance in the process of biological treatment of sewage. Przemysl Chemiczny, 100(10), 977-980.

[7] Semyachkov, A. I. , & Pochechun, V. A. . (2018). Sewage treatment technology for mining-and-smelting enterprise. IOP Publishing (Vol.451, pp.012232). IOP Publishing.

[8] Wang, X. . (2020). Research on enterprise sewage treatment based on infiltration technology. IOP Conference Series Earth and Environmental Science, 514, 032040.

[9] Eiselt, H. A. , Sandblom, C. L. , & Jain, N. . (2017). A spatial criterion as decision aid for capital projects: locating a sewage treatment plant in halifax, nova scotia. Journal of the Operational Research Society.

[10] Zhao, S. , Duan, W. , & Cui, N. . (2023). Characterizing vocs emissions of coal chemical enterprise in china: a case study in five coal chemical enterprises. Environmental Science and Pollution Research(59), 30.

[11] Bogomolova, E. Y. , & Kochetova, K. A. . (2019). Correlation of the payment for excess environmental pollution with costs of sewage treatment at oil refining. Economic Consultant, 25.

[12] Ya-Jing, Y. , Xue-Qiang, L. U. , Xiao-Long, S. , Hong-Lei, L. , Hui, L. I. , & Cui-Ling, T. . (2017). Evaluation of wastewater treatment technologies of enterprises in an industrial park based on optimization of the whole wastewater treatment process. Zhongguo Huanjing Kexue/China Environmental Science, 37(8), 3183-3189.

[13] Sadino-Riquelme, M. C. , Donoso-Bravo, A. , Zorrilla, F. , Valdebenito-Rolack, E. , D. Gómez, & Hansen, F. . (2023). Computational fluid dynamics (cfd) modeling applied to biological wastewater treatment systems: an overview of strategies for the kinetics integration. Chemical Engineering Journal.

[14] Chen, Y. , Lan, S. , Wang, L. , Dong, S. , Zhou, H. , & Tan, Z. , et al. (2017). A review: driving factors and

regulation strategies of microbial community structure and dynamics in wastewater treatment systems. Chemosphere, 174(may), 173-182.

[15] Haihan, Z. , Ji, F. , Shengnan, C. , Baoqin, L. , Raju, S. , & Zhenfang, Z. , et al. (2018). Disentangling the drivers of diversity and distribution of fungal community composition in wastewater treatment plants across spatial scales. Frontiers in Microbiology, 9, 1291.

[16] Zhang, S. , Jin, Y. , & Ren, W. H. . (2023). Artificial intelligence in wastewater treatment: a data-driven analysis of status and trends. Chemosphere, 336(Sep.), 139163.1-139163.8.

[17] Videira, N. , Antunes, P. , & Santos, R. . (2017). Engaging stakeholders in environmental and sustainability decisions with participatory system dynamics modeling. Springer International Publishing.

[18] Zhang, X. , Liang, Y. , & Liu, W. . (2017). Pricing model for the charging of electric vehicles based on system dynamics in beijing. Energy, 119(JAN.15), 218-234.

[19] Tobias, K. , Matthias, N. , Alexander, R. , Rodríguez Mirta, & Yaroslav, Z. . (2018). Efficient calculation of open quantum system dynamics and time-resolved spectroscopy with distributed memory heom (dm-heom). Journal of Computational Chemistry.

[20] Chen, L. , Zhang, H. , Wu, Q. , & Terzija, V. . (2017). A numerical approach for hybrid simulation of power system dynamics considering extreme icing events. IEEE Transactions on Smart Grid, PP(99), 1-1.

[21] Alharthi Mamdouh S.,Bamaga Omar,Abulkhair Hani,Organji Husam,Shaiban Amer,Macedonio Francesca... & Albeirutty Mohammed. (2022). Evaluation of a Hybrid Moving Bed Biofilm Membrane Bioreactor and a Direct Contact Membrane Distillation System for Purification of Industrial Wastewater. Membranes(1),16-16.

[22] Miaojie Li,Yonghong Liu,Xiaode Zhou,Ning Wang & Bo Yuan. (2023). A Study on The Carriers Compound Multi-Stage MBBR Biological Treatment Process for Domestic Sewage. Sustainability(10).

[23] Zhu Xiaoming,Shu Mengzhao,Ge Jun,Wang Xiao & Huang Shenglin. (2021). Experimental study on the treatment of rural domestic sewage by modified MBBR sludge and bio-membrane coupling integrated process. IOP Conference Series: Earth and Environmental Science(4).