Application of Magnetic Coagulation High-Efficiency Precipitation Process in the Advanced Treatment Section of Sewage Treatment Plants

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Abstract: The magnetic coagulation high-efficiency sedimentation technology organically combines flocculation and magnetic separation, fully utilizing the magnetic cohesion and the bridging effect of flocculants to form magnetic flocs for accelerated sedimentation. Taking the second phase of Chengnan Wastewater Treatment Plant as an example, the application of magnetic coagulation high-efficiency sedimentation process in the project is studied. Hydraulic models and hydraulic velocity vector models of the mixing agitator and coagulation reaction agitator are established. The impeller type and speed of the agitator are calculated based on the tank type and chemical properties. CFD simulation is used to study the effect of adding magnetic powder to wastewater.

1 Introduction

The environmental protection policies successively introduced by the national and local governments, coupled with the general public's aspirations for a better life, have raised higher requirements for environmental protection and governance. To meet the increasingly stringent sewage discharge standards, which impose higher requirements on indicators such as P, conventional advanced treatment processes have become inadequate.

Magnetic coagulation and sedimentation technology is an upgraded version of traditional sedimentation tank processes. By adding highly efficient and recoverable magnetic particles, it further enhances the flocculation effect and sedimentation speed of the system[1]. It is an organic combination of magnetic separation technology and flocculation technology, fully leveraging the magnetic coagulation force and the bridging effect of flocculants to increase the surface load of the unit.

Taking the second phase of Chengnan Sewage Treatment Plant as an example, this article studies the performance parameters of agitators and their impellers from system design and agitator equipment sizing to ensure mixing effectiveness. Combined with actual operating data, it discusses the applicability of magnetic coagulation sedimentation technology in advanced sewage treatment.

2. Project Overview

In the advanced treatment of the second phase project of Chengnan Sewage Treatment Plant, a new magnetic coagulation high-efficiency sedimentation tank system (divided into 2 groups) is built to stably and reliably reduce the SS concentration and TP. The sludge is the precipitated sludge after flocculation reaction with chemicals added. The sedimentation tank adopts a bottom-up water inflow method, and the inflow water is the mixed sewage after flocculation. Inclined pipes are installed in the upper part of the sedimentation area for mud-water separation, and the clear water is collected by the upper outlet tank and discharged. Considering the need for emergency response in the sewage treatment plant, a mixing tank is reserved in the magnetic coagulation high-efficiency sedimentation tank for emergency addition of powdered activated carbon in case of accidents[2][3].

2.1. Design Water Quality

The water to be treated by the high-efficiency sedimentation tank system comes from the effluent of the secondary sedimentation tank. The designed treatment capacity is 100,000 m³/d, with a variation coefficient of 1.3. The normal flow rate is 4,166.67 m³/h, and the peak flow rate is 5,416.67 m³/h. The main inlet and outlet water quality requirements are shown in Table 1.

Table 1 Main Inlet and Outlet Water Quality Requirement

Indicator	Inlet	Outlet
SS	≤60	≤3.0
TP	**≤10**	**≤0.3**

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2.2. Design Conditions

The main design parameters of the magnetic coagulation high-efficiency sedimentation tank in this project (per group) are as follows:

Design flow rate (peak flow rate): 5417m^3/h

Surface load of sedimentation area (peak flow rate): 18.20m^3/m^2·h

Mixing time: 2.36min

Coagulation time: 1.36min

Magnetic powder mixing time: 1.34min

Flocculation time: 2.29min

Total area of inclined pipe sedimentation tank: 290m^2

Length of inclined pipe: 1.1m

Installation angle of inclined pipe: 60°

Magnetic powder supplement amount: 5.0mg/l

Dosage of 10% PAC solution: 233.2mg/l

Dosage of PAM (anionic):0.5mg/l

3. System Design

3.1. Structures and Design Parameters (In Table 2)

Table 2 Structures and Design Parameters

Mixing Agitation Tank		
Quantity	Unit	2
Effective size	m	4.2×4.2×6 Total height: 7.4
Average residence time	min	3.05
Peak residence time	min	2.36
Rapid Mixing Tank		
Quantity	Unit	2
Effective size	m	3.2×3.2×6 Total height: 7.4
Average residence time	min	1.77
Peak residence time	min	1.36
Magnetic Powder Mixing Tank		
Quantity	Unit	2
Effective size	m	3.2×3.2×5.9 Total height: 7.4
Average residence time	min	1.74
Peak residence time	min	1.34
Flocculation Reaction Tank		
Quantity	Unit	2
Effective size	m	4.2×4.2×5.9 Total height: 7.4
Average residence time	min	3.00
Peak residence time	min	2.29
High-Efficiency Sedimentation Tank		
Quantity	Unit	2
Diameter	m	14
Inclined pipe area	m^2	151
Inclined length of inclined pipe	m	1.1
Spacing of inclined pipe	mm	80
Inclination angle	°	60
Average effective surface load	$m^3/(m^2·h)$	13.80
Peak surface load	$m^3/(m^2·h)$	18.20

3.2. Calculation of System Agitator Equipment

3.2.1 Calculation of uniformity

As the core equipment of the sedimentation tank, the agitator affects the sedimentation efficiency and treatment effect of the sedimentation system through input power and residence time, given certain conditions of tank type and medium.

The sedimentation tank system adopts a graded mechanical agitation design, and the relationship between gradient velocity and tank type, input power, and chemical properties is shown in (1):

$$G = \sqrt{\frac{P}{\mu V}} \quad (1)$$

In the equation, P stands for the input power of the agitator (W); μ represents the dynamic viscosity of the medium (Pa·s); and V indicates the effective volume of the mixing vessel (m^3).

1) Mixing tank

The impeller rotation speed and impeller type of the mixing agitator are determined by calculation according to the tank type and chemical properties. The agitator performs mixing and agitation through the rapid rotation of the impeller, so that the suspended solids in the sewage form flocs under the mixing action of the coagulant aid, which is beneficial to the subsequent precipitation treatment.

The uniformity calculation sheet is is shown in Table 3.

Table 3 Mixing Pool Uniformity Calculation Report

Tank1		
Volume (Rectangular)	m^3	106.72
Impeller Dia	inches	68.9
S.G.	min	1.02
Blending Time (Single)	min	1.84
Degree of Agitation		Strong
Tank2		
Volume (Rectangular)	m^3	61.44
Impeller Dia	inches	68.89
S.G.	min	1.02
Blending Time (Single)	min	1.01
Degree of Agitation		Violent

2) Flocculation tank

The agitator of the flocculation reaction tank promotes the collision and adsorption of colloidal particles in the water at a low speed and gradually forms flocs of a certain size[4], and mixes the polymer with the sewage to improve the solid-liquid separation effect of the sedimentation tank.

The uniformity calculation sheet is shown in Table 4.

Table 4 Calculation of Uniformity of Flocculation Tank

Tank3		
Volume (Rectangular)	m^3	60.93
Impeller Dia	inches	70.866
S.G.	min	1.1
Blending Time (Single)	min	1.01
Degree of Agitation		Violent
Tank4		
Volume (Rectangular)	m^3	104.08

Impeller Dia	inches	104.33
S.G.	min	1.1
Blending Time (Single)	min	1.47
Degree of Agitation		Violent

After calculations, it has been confirmed that the G-value control in this system adheres to the standards outlined in the "DB32T-Technical Specification for Magnetic Coagulation Sedimentation Water Treatment" (coagulation zone: 300-1000s^{-1}, magnetic powder mixing zone: 100-500s^{-1}, flocculation zone: 70-200s^{-1}). The appropriateness of the mixing intensity and uniformity has been validated, ensuring thorough reactions between chemicals and sewage in each tank.

3.2.2 Hydraulic Model Diagram

Using each sedimentation tank as the research subject, we employ the computational fluid dynamics (CFD) modeling approach to simulate the water flow patterns and velocity vectors within the tank. By modifying the shape and dimensions of the paddle, we aim to identify the most suitable agitator equipment. The model diagram is presented as follows:

(1) The mixing and agitation process is rapid mixing, and inclined blade paddles are used to generate a comprehensive axial and radial flow, the Flow Field Diagram is shown in Figure 1, the Computer Velocity Vector Model Diagram is shown in Figure 2.

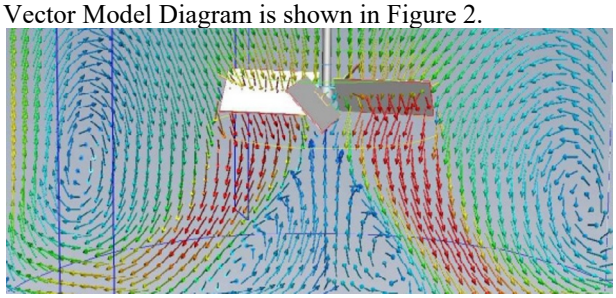

Figure 1 Flow Field Diagram of Computer Hydraulic Modell Diagram of the Mixing Blender

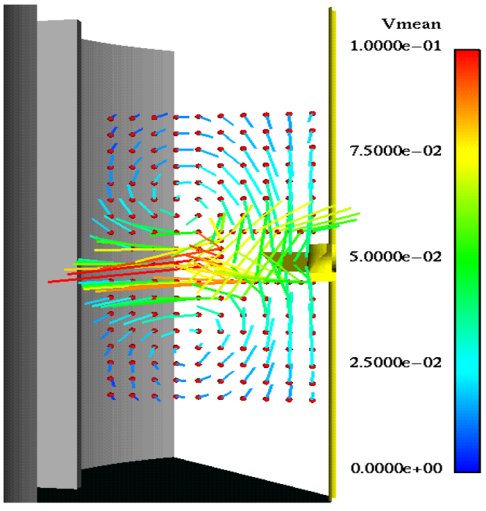

Figure 2 Computer Velocity Vector Model Diagram of the Mixing Blender

(2) The coagulation reaction process is coagulation. PAC coagulant is added for chemical and flocculation reactions, and narrow-edge hydrofoil paddles are used, which can produce a better up-down circulation mixing effect and save more than 50% energy compared with ordinary ones., the Flow Field Diagram is shown in Figure 3, the Computer Velocity Vector Model Diagram is shown in Figure 4.

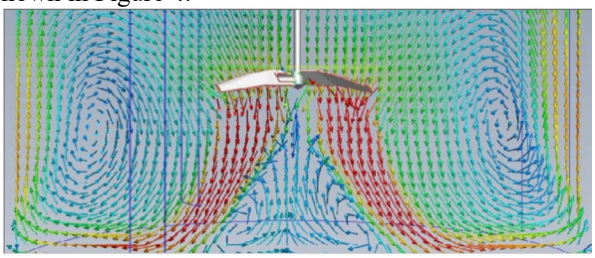

Figure 3 Flow Field Diagram of Computer Hydraulic Model Diagram of the Coagulation Reaction Mixer

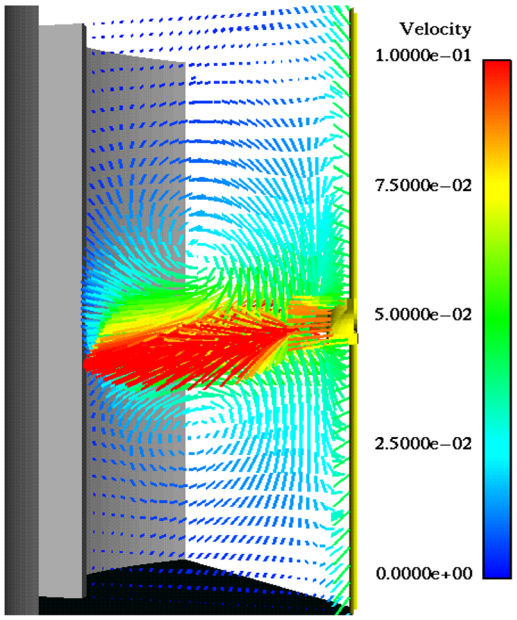

Figure 4 Computer Velocity Vector Model Diagram of the Coagulation Reaction Mixer

(3) The loading and mixing process involves complete mixing of suspended solids. Magnetic particles are added for loading reactions and further reactions of reflux sludge. The use of narrow-edge hydrofoil blades produces a better mixing effect of up-and-down circulating flow, ensuring that the magnetic medium does not settle in this area. the Flow Field Diagram is shown in Figure 5, the Computer Velocity Vector Model Diagram is shown in Figure 6..

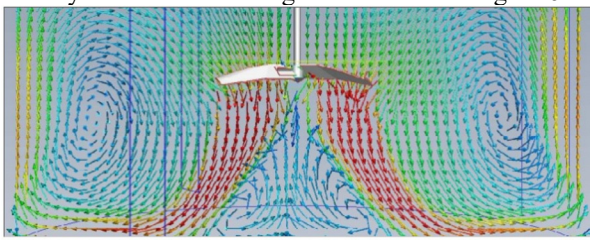

Figure 5 Flow Field Diagram of Computer Hydraulic Model of the Load Mixer (Note: The figure is a CFD simulation of adding 5g/L magnetic powder into sewage)

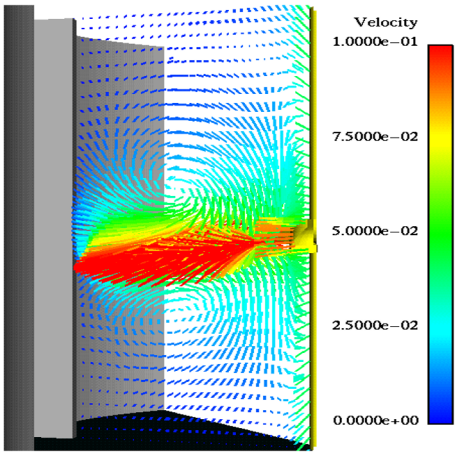

Figure 6 Computer Velocity Vector Model Diagram of the Load Mixer

(4) The flocculation and agitation process is rapid mixing, complete mixing of solid suspension and also needs to take into account flocculation. Polymer PAM is added to enable the effective combination of flocs and magnetic powder to form large and dense flocs, ensuring the effective sedimentation of flocs in the high-efficiency clarification tank. The flocculation agitator is the core equipment to ensure the effluent effect. A large wide paddle specially customized for magnetic flocculation is used, which can generate large-displacement rapid mixing and suspension without breaking the flocs., the Flow Field Diagram is shown in Figure 7, the Computer Velocity Vector Model Diagram is shown in Figure 8..

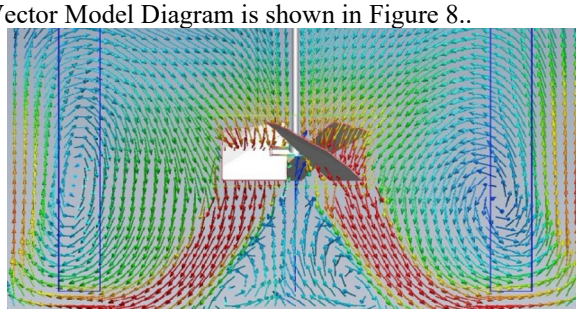

Figure 7 Flow Field Diagram of Computer Hydraulic Model of the Flocculation Mixer (Note: The figure is a CFD simulation of adding 5g/L magnetic powder into sewage)

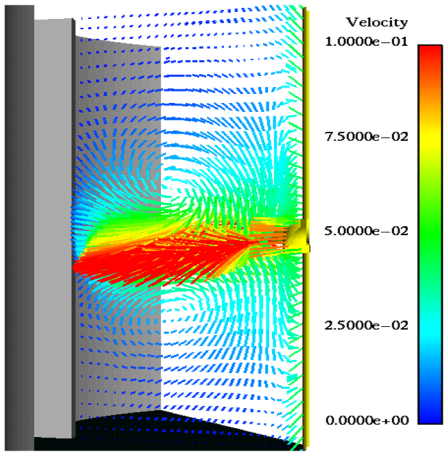

Figure 8 Computer Velocity Vector Model Diagram of the Flocculation Mixer

Through analyzing the model diagrams of the mixing tank, flocculation tank, and sedimentation tank in relation to the paddle blades, and conducting multiple verifications and calculations, we designed and optimized the paddle blades. The specially manufactured agitators can thoroughly mix chemicals with the water, as well as the magnetic medium with the water, through the rotation of the paddle blades. The materials used are corrosion-resistant to the added chemicals, possess sufficient mechanical strength and wear resistance, and help reduce energy consumption during agitation, the specially developed blade shape is shown in Figure 9.

Figure 9 Special Paddle for Magnetic Coagulation

3.3. System Supporting Equipment

3.3.1 Magnetic Powder Recovery and Return System

An external slurry pump is used to pump the sludge at the bottom of the clarification tank into the magnetic powder recovery system and the loading reaction tank.

The sludge passes through the magnetic powder shearer to separate the combined sludge and magnetic powder, so that the magnetic powder and sludge are completely separated, and then enters the magnetic separator to recover the magnetic powder through magnetic force.

The system is equipped with a magnetic powder recovery flowmeter and a sludge return flowmeter, ensuring smooth operation of the water pump through frequency modulation by setting the flow rate

3.3.2 Others

The excess sludge generated by the magnetic coagulation precipitation system is discharged into the original sludge treatment unit of the plant through the sludge transfer pump. The capacity and quantity of the sludge transfer pump shall ensure the timely discharge of the sludge in the sludge temporary storage tank in the system[5]. To avoid algae growth and biofilm adhesion, an automatic flushing device is installed.

4. System Economic Analysis

The second phase of Chengnan Sewage Treatment Plant was put into operation in March 2021. Up to now, the sewage treatment plant has been in normal operation for more than four years, with a production load of 100%, and all indicators of the effluent stably meet the first-class A discharge standard.

The operation cost of this system process section is as follows: Power consumption: 970kWh; PAC consumption: 12t/d, Unit price: 650yuan/t (Al_2O_3, concentration 10%); Anionic PAM consumption: 0.05t/d, Unit price: 15,000yuan/t (dry powder); Magnetic powder consumption: 0.3 t/d, Unit price: 2,000 yuan/t; Water consumption: 50 t/d, Unit price: 5yuan/t. The total operation cost is 0.100794 yuan/t, which is relatively low.

5. Conclusion

The actual operation of the project demonstrates that the magnetic coagulation sedimentation technology employed in this project yields good application results, exhibits high shock load resistance, and operates stably. The effluent TP and SS indicators can consistently meet standards over the long term, with a magnetic powder recovery rate reaching 99%. Compared to traditional high-efficiency sedimentation tanks, the dosage of PAC and PAM is reduced by 50%, significantly reducing the operating costs of the wastewater treatment plant.

The magnetic coagulation high-efficiency sedimentation process exhibits significant advantages in the advanced treatment section of wastewater plants, with low operating costs and broad prospects for promotion and application. In the context of stringent emission standards, the magnetic coagulation technology stands out even more due to its high surface load, making it highly suitable as a process unit for advanced treatment, upgrading, and reclaimed water reuse in wastewater plants.

References

1. Sun Zhitao, Li Jun, Wang Xiujie, Zhang Yang, Wu Yaodong, Pei Hanbo. Research and Application Progress of Magnetic Coagulation Technology in the Field of Water Treatment. Technology of Water Treatment, 2023, 07 (002).
2. Xie Chenghao, Qian Can, Tan Yingyu, Xu Jiajia. Application of AO-MBBR-Magnetic Coagulation Precipitation-Denitrification Filter Process in the Upgrading and Expansion of Sewage Treatment Plants. Water Supply and Drainage, 2024, 50 (Supplementary Issue): 29-32.
3. Zhou Aijun, Wang Xiaomin, Mei Rongwu. Study on the Upgrading and Reconstruction Process of Urban Sewage Treatment Plants under Zhejiang Standards. Environmental Pollution and Control, 2021, 43 (10): 1316-1320.
4. Fang Hua, Yang Shun, Zhao Jinyu, Li Wubo, Yu Jianghua. Removal Characteristics of Pollutants by Magnetic Coagulation in Black and Odorous Water Bodies. China Water & Wastewater, 2023, 15 (010).
5. Zeng Lei, Liu Chang, Ruan Chao, Huang Kai, Li Jin, Xiong Zhen. Analysis on the Stable Operation Efficiency of the "A/RPIR + Magnetic Coagulation Precipitation" Combined Process in Urban Wastewater Treatment. Technology of Water Treatment, 2024, 50 (1): 138-142, 146.