Research on Water Treatment of Kongmu-Lake based on Micro Vortex Flocculation Technology with the combination of vortex reactor

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Abstract. Aiming to solve the problems of greater blindness and randomness in selecting design and operating parameters of micro vortex clarifier, this experiment used the Kongmu-Lake water as the research object to investigate the effects of flocculation time and coagulant dosage on flocs performance and flocculation efficiency under different working conditions, and the best parameter of vortex reactor dosage ratio and operational limits of the micro-vortex flocculation tank are optimized. The raw water flows through the type of HJTM-2 vortex reactor firstly, and the ratio of flocculation time that water flow through the type of HJTM-2 and HJTM-1 vortex reactor is 1:2. Under the best optimal working condition, the best coagulant dosage is 22mg/L and the flocculation time is 14.3min. At this time, the removal rate of turbidity, CODMn, UV254 reached 96.81%, 64.12%, 55.56%, respectively. The maximum floc equivalent diameter is 1.39mm, and the fractal dimension is 1.73.

1. Introduction
With the development of our country's economy and the improvement of people's living standard, people pay more and more attention to the water quality problems related to life closely. However, the rapid development of industrial enterprises has brought environmental pollution, leading to the raw water quality deteriorated year by year. How to strengthen the protection of source water and improve the water treatment process in order to meet the requirements of drinking water is an important issue in the field of water treatment [1,2].

In view of the bottleneck problems such as high consumption and low efficiency in the operation of the traditional clarifier, the research team of East China Jiaotong University has developed a micro-vortex clarification tank [3] which is based on the vortex reactor. The equipment has been widely used in recent years and has achieved better social and economic benefits [4,6]. In the case of micro vortex flocculating water purification technology [7,8], our research on its mechanism and key technology is still incomprehensive and unthorough. Therefore, in the practical engineering application, the design and operation parameters are chosen blindly and randomly, which has caused serious obstructions during the further popularization of this technology in water treatment engineering. In this experiment, the effects of flocculation time and coagulant dosage on flocs performance and flocculation efficiency were investigated under different working conditions about different dosage ratio of vortex reactor, and the
best parameter of vortex reactor dosage ratio and operational limits of the micro-vortex flocculation tank are optimized to provide data reference for practical engineering application.

2. Equipment and methods

2.1. Equipment

The experimental device mainly includes micro-vortex flocculation tank, sedimentation tank and machine vision system.

The design parameters of micro-vortex flocculation tank are as follows: the length, width and height of the device are 1m, 0.75m, and 2.3m respectively. And its cross section are 12(3×4) squares that length is 0.25 m. The squares are communicated by holes arranged in the upper and lower levels.

The design parameters of sedimentation tank are as follows: the length, width and height of the device are 1.75 m, 1.0m, and 2.3m respectively. The ramp pipe is installed with a honeycomb inclined tube which length is 900 mm, diameter is 30 mm and installation angle is 60 degrees. The effluent of the micro-vortex flocculation tank passed through a connecting pipe that diameter is 150 mm and width of transition section is 250 mm. After passing through the inclined pipe area, the clean water and floc are separated, and the separated water rises to the outlet weir and then passes through the effluent tank, while the separated flocs are deposited in the cemented area at the bottom of the inclined pipe sedimentation apparatus and discharged through three rows of 65 mm parallel perforated pipes.

The HJTM1 and HJTM2 type vortex reactors are 200 mm hollow spheres made of ABS plastic. The design parameters of reactors are as follows. The opening diameter of HJTM1 and HJTM2 type vortex reactors are 35mm and 25mm, and the aperture ratio of them are 65% and 50% respectively.

Machine vision system mainly includes image acquisition system, image processing system and data processing software. Image acquisition system is mainly composed of gigabit network industrial digital camera, power supply and gigabit cable and computer.

2.2. Methods

In this experiment, the micro-vortex flocculation technology with independent intellectual property rights was used to optimize the coagulant and determine the optimal dosage by the coagulation sedimentation beaker test. The effects of flocculation time and coagulant dosage on flocs performance and flocculation efficiency were investigated under different working conditions about different dosage ratio of vortex reactor, the best parameter of vortex reactor dosage ratio and operational limits of the micro-vortex flocculation tank were optimized. The combined conditions of different vortex reactors in flocculation devices are shown in Table 1.

| Working conditions | 1   | 2   | 3   | 4   | 5   |
|-------------------|-----|-----|-----|-----|-----|
| Shaft number      | 1-12| 1-12| 1-12| 1-8 | 1-4 |
| Type of vortex reactors | -  | HJTM-1 | HJTM-2 | HJTM-2 | HJTM-1 | HJTM-2 | HJTM-1 |

3. Test results and discussion

3.1. Effect of influent flow rate on the water treatment of Kongmu-Lake

In this experiment, when the dosage of PAC was 18 mg/L, the influence of different influent flow rate (flocculation time) on the water treatment of Kongmu-Lake was studied. Here are the five working conditions: The influent flow rate is 2, 4, 6, 8 and 10m³/h, while the flocculation time is 42.8, 21.4, 14.3, 10.7 and 8.6 min, respectively.

The influence of different influent flow rate on flocculation efficiency of raw water in Kongmu-Lake is shown in Fig. 1, 2 and 3.
From Fig. 1, 2, 3, it can be seen that the removal rate of turbidity, potassium permanganate index (COD$_{Mn}$) and UV$_{254}$ gradually increase with the increase of influent flow rate, and then show a downward trend under the five working conditions. When the inlet flow rate is $6\,m^3/h$, the removal rate of turbidity, COD$_{Mn}$ and UV$_{254}$ reaches the maximum value, and the flocculation effect is the best under the working condition two, three, four and five. In the $8m^3/h$, under the condition one, the removal rate of turbidity, COD$_{Mn}$ and UV$_{254}$ reaches the highest value. The experimental phenomena shows that under the same dosage condition, when the inlet flow quantity is low which means long flocculation time, and flow rate is low, the velocity difference and shear force between the layers of water flow become smaller accordingly, and the collision probability between colloidal particles is reduced. Therefore, it is not
favorable for the relative motion between colloidal particles in laminar flow. At the same time, the number of micro-vortex formed in the reaction zone of micro-vortex flocculation tank is less and the vortex scale is low, which leads to less chance of collision aggregation between colloidal particles in water. The colloidal particles formed by the coagulant hydrolysis cannot adsorb all the colloidal particles in water, and some of the colloidal particles in micro-vortex flocculation device are not involved in the reaction. Therefore, the turbidity, COD$_{\text{Mn}}$ and UV$_{254}$ removal rate of raw water in Kongmu-Lake were reduced by micro-vortex flocculation tank; when the inlet flow increases to a certain extent, the shear flow between the laminar flow is too large, resulting in the disintegration of the floc, and the settling property of the flocs is not conducive to the subsequent precipitation separation. Therefore, the flocculation effect shows a downward trend.

Compared with the 5 conditions, the water treatment of Kongmu-Lake with the vortex reactor is better than that without the vortex reactor. Among them, condition five has the best flocculation effect. When the influent flow rate is 6m$^3$/h, the removal rate of turbidity, COD$_{\text{Mn}}$, UV$_{254}$ reaches maximum and are 96.26%, 51.58%, 48.39% respectively. Under condition five, the HJTM-2 vortex reactor with a small aperture has a large flow and a large velocity difference between the flow layers, resulting in a large number of micro vortex, so that it is beneficial to floc collision and flocculation; However, when the water flows through the HJTM-1 vortex reactor with large aperture diameter, the resistance is reduced and the vortex scale is increased, which reduces the shear failure of the water and effectively avoids the destabilizing floc being re-broken, this situation is conducive to floc subsequent settlement separation, therefore, the flocculation effect is the best at this time. Floc property under different flow rate is shown in Fig. 4, 5.

![Figure 4](image-url)  
**Figure. 4** Floc equivalent diameter under different flow rate

![Figure 5](image-url)  
**Figure. 5** Floc fractal dimension under different flow rate
From Fig. 4, 5, when the flow rate is low, the equivalent particle size of the flocs is small, and the fractal dimension is also small, and the compactness and settability are general. With the increase of inlet flow rate, the equivalent particle size and fractal dimension of flocs will increase. When the inlet flow rate is $6\text{m}^3/\text{h}$, the equivalent particle size and the fractal dimension of the floc are the highest under working condition two, three, four and five. When the inlet flow rate is $8\text{m}^3/\text{h}$, the equivalent particle size and fractal dimension of flocs reaches the maximum under the working condition one. When the flow rate continues to increase, it is broken under the shear force of water flow, and the equivalent particle size and fractal dimension decrease.

Under the condition five, the flocculation effect is the best. When the inlet flow rate is $6\text{m}^3/\text{h}$, the equivalent particle size and fractal dimension of flocs reach the maximum and are $1.17\text{mm}$ and $1.77\text{mm}$ respectively, at this time, floc density and settling performance are the best.

3.2. Effect of dosage on the water treatment of Kongmu-Lake

Test at this stage is under the following condition: the dosage of coagulant increase from $10\text{mg/L}$ to $26\text{mg/L}$ and inlet flow rate is $6\text{m}^3/\text{h}$ which means flocculation time is $14.3\text{min}$.

The influence of different PAC dosage on the flocculation effect of raw water in Kongmu-Lake is shown in fig. 6, 7 and 8.

![Figure 6](image1.png)

**Figure. 6** Removal rate of Turbidity under different PAC dosage

![Figure 7](image2.png)

**Figure. 7** Removal rate of COD$_\text{Mn}$ under different PAC dosage
From Fig. 6, 7, 8, the removal rate of turbidity, COD$_{\text{Mn}}$ and UV$_{254}$ increase firstly and then decrease with the dosage increasing under 5 kinds of working conditions. When the dosage of coagulant is insufficient, only a part of the colloid particles in water collide with the colloidal particles produced by hydrolysis of coagulant, and the flocculation effect is common at this time; as the dosage of coagulant increases gradually, the colloidal particles produced by hydrolysis of coagulant can collide with the colloid particles in the water and form larger and denser flocs; when the dosage of coagulant exceeds the optimum dosage and continues to increase, some of the colloidal particles formed by the coagulant hydrolysis collide with the colloidal particles in the water. Some positively charged colloids increase the positive charge in the water and cover colloidal particles of the adsorption surface, so that the same-sex repulsion between colloidal particles increased. Thus, colloidal particles cannot occur aggregation, which is called "colloidal protection". This phenomenon is not conducive to the accumulation of dispersed colloidal particles in water.

When the coagulant dosage is 22mg/L, the removal rate of turbidity, COD$_{\text{Mn}}$, UV$_{254}$ reaches 96.81%, 64.12%, 55.56% respectively and are the largest.

The influence of different PAC dosage on the floc property of raw water in Kongmu-Lake is shown in fig. 9 and 10.

**Figure. 8** Removal rate of UV$_{254}$ under different PAC dosage

**Figure. 9** Floc equivalent diameter under different PAC dosage
As is shown in Fig. 9, 10, when the dosage is 22 mg/L, the equivalent diameter and fractal dimension of flocs under condition five are 1.39 mm and 1.73 respectively. Furthermore, the two values are the largest.

4. Conclusion
The flocculation effect of the vortex reactor in the flocculation tank is better than that without the vortex reactor. The best parameter of vortex reactor dosage ratio and operational limits of the micro-vortex flocculation tank are optimized, that is, the raw water flows through the type of HJTM-2 vortex reactor firstly, the ratio of flocculation time about flowing through the type of HJTM-2 and the type of HJTM-1 vortex reactor is 1:2.

Under the condition of the optimal working condition. When the dosage is 18 mg/L, the removal rate of turbidity, COD$_{Mn}$ and UV$_{254}$ as well as floc size and fractal dimension will first increase and then decrease gradually with the raise of influent flow rate. When influent flow rate is $6m^3/h$ (i.e. flocculation time is 14.3 min), the removal rate of turbidity, COD$_{Mn}$, UV$_{254}$ reaches 96.26%, 51.58% and 48.39%, respectively, and flocculation effect is the best. At this time, the floc equivalent diameter is 1.17 mm, and the fractal dimension is 1.77.

Under the condition of the optimal working condition. When the influent flow rate is $6m^3/h$, with the increase of coagulant dosage, the removal rate of turbidity, COD$_{Mn}$ and UV$_{254}$ as well as floc size and fractal dimension will gradually increase and then decrease. When the coagulant dosage is 22 mg/L, the removal rate of turbidity, COD$_{Mn}$, UV$_{254}$ reaches 96.81, 64.12%, 55.56%, respectively, at this time, the floc equivalent diameter is 1.39 mm, and the fractal dimension is 1.73.

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