Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2019.23854

149 (2019) 329–334
May

The treatment of micro-polluted source waters by micro-vortex clarification

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Received 22 October 2018; Accepted 15 January 2019

ABSTRACT

The integrated micro-vortex clarifier is used for intensive conventional treatment of raw water from micro-polluted water source as well as from water plants with common water quality problems. The results showed that when the influent flow of integrated micro-vortex clarifier is 8 $m^3 h^{-1}$, the influent turbidity was 21.7 NTU, and when the dosage was 10 mg L^{-1}, then the effluent turbidity of clarification tank maintained stable below 3 NTU. The removal rates of ultraviolet UV_{254} and chemical oxygen demand Mn (COD_{Mn}) were 25% and 41%, respectively. When the working conditions remained unchanged, the dosage was increased to 16 mg L^{-1}. The effluent turbidity of clarifier was stable at 0.5 NTU, and the removal rates of UV_{254} and COD_{Mn} increased to 40% and 60%. As the dosage was increased within a certain range, Zeta potential rose gradually and equivalent diameter of floc became larger, and then effluent turbidity decreased, while the removal rates of UV_{254} and COD_{Mn} increased, which were measured by the flocculation control device and the Zeta potential instrument. This study compares other clarification technologies; the micro-vortex clarification process deserves wide application for its various advantages, such as a higher coagulation efficiency, a shorter reactivity time, a better quality of finished water, and a stronger adaptive capability.

Keywords: Micro-vortex clarification; Vortex reactor; Micro-polluted water; Water quality

1. Introduction

The supply of high-quality tap water for the general residents has embodied our government's desire to carry out the scientific outlook on development to comprehensively safeguard the security of drinking water and to improve its quality. China's city water supply industry is facing the dual stresses of combating water source contamination and enhancing water quality standards. Based on a study, enhanced conventional treatment technology (such as enhanced coagulation) is one of the empirical technical means for water plants to enhance water yield and improve effluent quality [1].

In the 1970s and 1980s, a lot of waterworks in China built clarification tanks, which were integrated water purification structures including mix, flocculation, and precipitation. Today, they are old and facing problems including low water production, high-energy consumption, and poor water quality. According to a scholar, this led to a fall of water supply, which added to the shortage of supply for growing consumer demand and quality [2]. Actiflo® high-speed sedimentation tank by OTV-Kruger, a subsidiary company of French Veolia, and high-density clarification tank (DENSADEG) by French Degremont Corporation are patented products widely used all over Europe [3]. Nevertheless, they are exposed to some shortcomings in China especially with their high investment costs [4].

According to a research, improvement must be on the performance of clarification tank, development for its applicable scope, enhance the efficiency of flocculation process, ability of anti-impact and the effect of movement, save investment, and decline water operation cost [5–10]. Therefore, it is necessary to develop a kind of an optimal economically efficient clarification technology taking into account structural styles, constructing conditions, and operational management conditions [11]. Study showed that theory and practice show

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that the technology of micro-vortex clarification based on the vortex coagulation, which was designed by East China Jiaotong University, has good economic benefits, social results, and a good application prospective [12–14].

2. Experimental materials and methods

2.1. Experimental materials

2.1.1. Testing apparatus

The integrated micro-vortex clarification process, with an overall consideration of structural styles, constructing conditions, and operation management conditions, is proposed on the basis of micro-vortex coagulation and Hazen theory [15]. It mainly involves technologies including micro-vortex coagulation, inclined-tube sedimentation separation, and sludge thickening. The structure of clarification tank is shown in Fig. 1 (the scale is 8 $m^3 h^{-1}$). The main characteristics of integrated micro-vortex clarification processes are as follows:

First, the vortex reactor (as shown in Fig. 2) which is developed from the integrated application of vortex theory and the small grid flocculation technology is made of a net hollow sphere-shaped by arc-shaped solid ropes with a certain roughness [16–18]. They are installed in the flocculation units referring to the inside room of the first and the second vortex reaction zones.

Second, inclined-tube settlers are installed in clarification chambers with high surface hydraulic load. They strengthen sedimentation of small particles and ensure precipitation effect and perfect clarification efficiency of the clarification tanks.

Third, sludge thickening units are added, which can complete sludge thickening effectively, and the density of discharge sludge is high. They can also decrease the pressure of sludge treatment facilities and reduce sludge disposal costs.

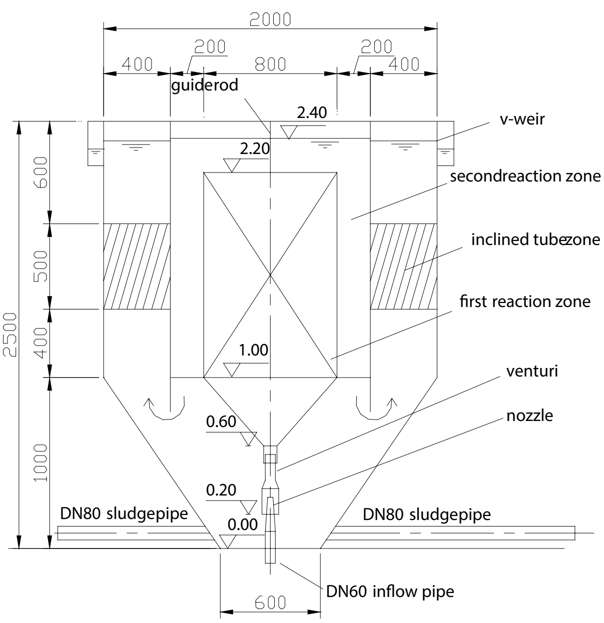

Fig. 1. Structure diagram of micro-vortex clarifier.

Fig. 2. The vortex reactor.

2.1.2. The vortex reactor

The vortex reactor whose flocculation mechanism mainly includes the micro-vortex coagulation and the three-dimensional contact flocculation has the following characteristics:

(1) The flow velocity and orientation changes in through-hole water flow and the friction of both inside and outside the wall resistance produce a micro-flow vortex flow; (2) Easy construction without fixation, no direction required, and it can be put into the pool directly; (3) Materials have good strength, nontoxic, corrosive resistant, anti-aging, and with a service life of several decades; (4) Simple structure, management convenience, easy operation and maintenance, floats in the stream and rotates up to the water, and cannot be easily blocked while floating.

The vortex reactor can create better hydraulic conditions, which respond to each kind of intrinsic hydraulic factor and attain a better coagulation-flocculation effect. It can create more opportunity for colloid in eddies, and there are a lot of massive floccule particles that accumulate and suspend in vortex reactor, while the tiny floccule is adsorbed [19]. Therefore, the vortex reactor's coagulation efficiency is very high.

2.1.3. Testing equipment

- Regulating reservoir.
- Coagulant dissolving container, size: $D \times H$ = 65 cm × 75 cm, V = 250 L.
- Vortex reactor. The HJTM-1vortex reactor-tapping diameter is 35 mm and diameter is 20 cm.
- QDX10-12-0.55 submersible pump.
- BB50-PVP4 metering pump produced by NIKKISO EIKO.

2.1.4. Experimental reagents

PAC: industrial liquid medicine, produced by Ganjiang Water Purification Agent Ltd. in Nanchang.

2.2. Experimental method

Experimental equipments were first put at the designated position. Then vortex reactors with diameter of 200 mm and pore diameter of 35 mm were added into the first and second reaction chambers [20]. The test started formally after adjustment to run stably. The influent water during experiment was micro-polluted raw water. The influent quality is shown as Table 1.

After controlling the dosage of flocculent by measuring the change of turbidity using chemical oxygen demand Mn (COD_{Mn}), ultraviolet UV_{254}, and Zeta potential of effluent, the effect of micro-vortex clarifier for treating micro-polluted raw water was analyzed.

The detecting indicators or methods in the test are shown in Table 2.

3. Results and discussion

3.1. Effect of dosage on removal rate of effluent turbidity, Zeta potential, $UV_{254,}$ and COD_{Mn}

- Under the working condition of temperature at 28°C, influent flow of 8 $m^3\ h^{-1,}$ and influent turbidity of 21.7 NTU, flocculent PAC of 10 mg L^{-1} was added into the micro-vortex clarifier. Turbidity, COD_{Mn}, UV_{254}, and Zeta potential of effluent were measured after micro-vortex clarifier was in a stable process. All the changes are shown as the Figs. 3 and 4.
- Under the unchanged working condition, the dosage of flocculent PAC was increased to 12 mg L^{-1}. Turbidity, COD_{Mn}, $UV_{254,}$ and Zeta potential of effluent were measured after micro-vortex clarifier was in a stable process once again. All the changes are shown as Figs. 5 and 6.
- Under the unchanged working condition, the dosage of flocculent PAC was increased to 16 mg L^{-1}. Turbidity, COD_{Mn}, $UV_{254,}$ and Zeta potential of effluent were measured after micro-vortex clarifier was in a stable process after the third time. All the changes were shown as Figs. 7 and 8.

Table 1
Influent quality

Influent flow, $m^3\ h^{-1}$	8
Influent turbidity, NTU	21.7
Zeta potential, mV	–26.68
UV_{254}, cm^{-1}	0.0703
COD_{Mn}, mg L^{-1}	8.16
Water temperature, °C	about 28

Table 2
Water quality monitoring projects and analysis methods

Testing item	Analysis method
Turbidity, NTU	TDT—2 turbidimeter
UV_{254}, mg L^{-1}	Ultraviolet spectrophotometer
COD_{Mn}	acidic titration method of $KMnO_4$
Zeta potential	90 plus Zeta particle size analyzer
Floc morphology	Flocculation control device analyzer

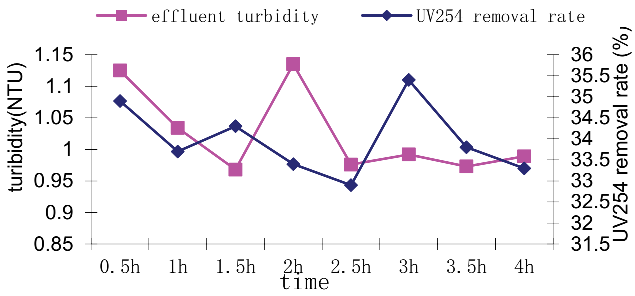

Fig. 3. The effluent turbidity and UV_{254} removal rate.

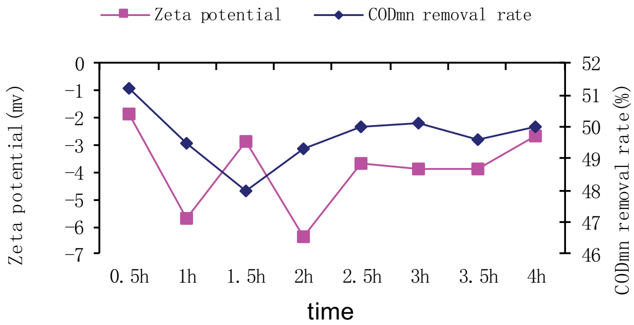

Fig. 4. The effluent Zeta potential and COD_{Mn} removal rate.

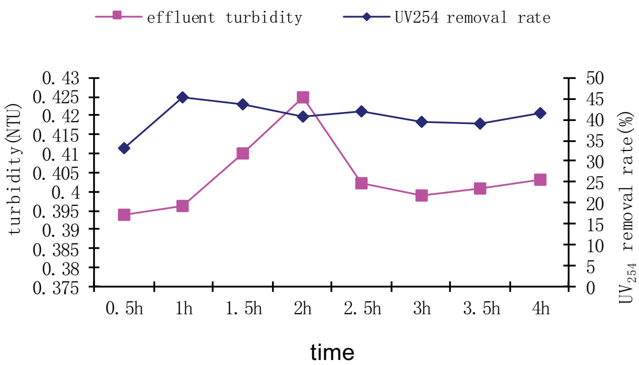

Fig. 5. The effluent turbidity and UV_{254} removal rate.

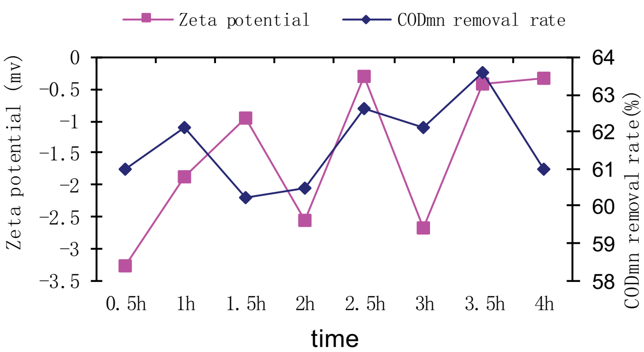

Fig. 6. The effluent Zeta potential and COD_{Mn} removal rate.

3.2. The effect of floc on dosage of flocculent

There is a large effect of floc on dosage of flocculent (Wen Po Cheng et al. 2011). It is found by monitoring flocculation control device analyzer for a long time. Figs. 9–11 show the changes of floc morphology on the dosages of 10, 12, and 16 mg $L^{-1,}$ respectively.

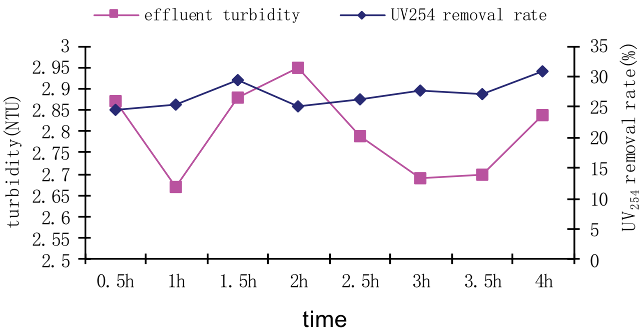

Fig. 7. The effluent turbidity and UV_{254} removal rate.

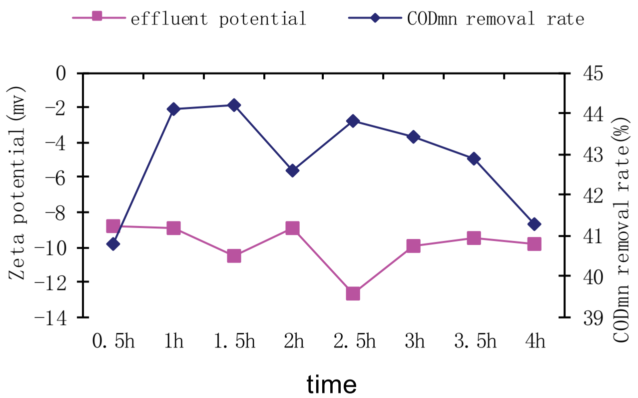

Fig. 8. The effluent Zeta potential and COD_{Mn} removal rate.

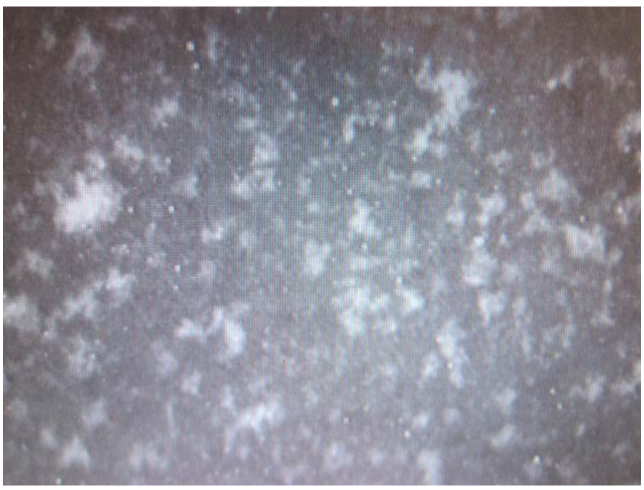

Fig. 9. Picture of floc morphology (10 mg L^{-1}).

Fig. 10. Picture of floc morphology (12 mg L^{-1}).

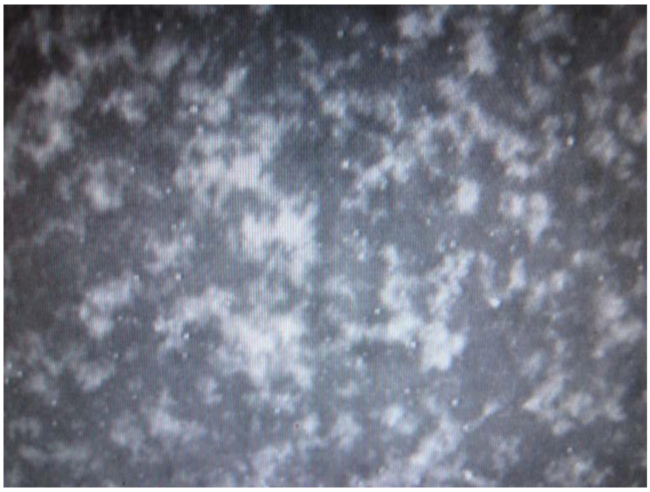

Fig. 11. Picture of floc morphology (16 mg L^{-1}).

As shown from above figure, floc became solid and dense when dosage of flocculent was added from 10 up to 16 mg L^{-1}.

3.3. Results and analysis

Under the working condition of temperature at 28°C, influent flow of 8 m^3 $h^{-1,}$ and influent turbidity of 21.7 NTU, flocculent PAC of 10, 12, and 16 mg L^{-1} were added into the micro-vortex clarifier successively. The removal rate of turbidity, COD_{Mn}, and UV_{254} were measured after micro-vortex clarifier was in a stable process. All the changes are shown in Table 3.

As shown in Table 3, when flocculent of 10 mg L^{-1} was added, the turbidity of effluent could be controlled below 3 NTU. The removal rate of UV_{254} was close to 30%, and the removal rate of COD_{Mn} was up to 43%. When the dosage of flocculent was increased to 12 mg L^{-1}, the turbidity of raw water declined from 21.7 to 1 NTU. The removal rate of UV_{254} was close to 30%, and the removal rate of COD_{Mn} was near 50%. When the dosage of flocculent was increased to 16 mg L^{-1} again, the turbidity of raw water stayed below

Table 3
Experiment result

Dosage of PAC/(mg L^{-1})	Removal rate of effluent turbidity/(NTU)	Removal rate of effluent UV_{254}/(%)	Removal rate of effluent COD_{Mn}/(%)	Equivalent diameter of floc/(mm)
16	0.5	40	60	0.487
12	1	33.5	50	0.451
10	3	25	41	0.399

0.5 NTU. The removal rate of UV_{254} was close to 40%, and the removal rate of COD_{Mn} was up to 60%.

As known from the results of treatment, when the dosage of flocculent increased from 10 to 16 mg L^{-1}, the Zeta potential also increased from –12 to –2 mV. The stability of colloid changed from destabilization to fast aggregation. The floc morphology became denser, and equivalent diameter of floc became larger. So, the turbidity of effluent kept on reducing, and the removal rates of UV_{254} and COD_{Mn} kept on increasing.

4. Conclusion

- From the above technical analysis, we could conclude that the main method of increasing flocculation efficiency was by controlling mechanical agitation abroad. While some domestic experts, mainly working on water treatment, prefer to attain the goal of enhancing coagulation by controlling its' hydraulic conditions such as eddy current scale. The technology of vortex-enhanced coagulation in this experiment was already utilized in many actual productions for reconstruction and expansion of waterworks. For example, an author introduced such vortex coagulation technology in the reconstruction of a waterwork in LiLing. The result of reconstruction indicated that micro-vortex clarifier had numerous advantages such as easy operation, good adaptability, low investment, low operation expense, and quick effect.
- This experiment further proved that the technology of vortex-enhanced coagulation could remove organic pollutants efficiently in micro-polluted source water and reduce the effect of disinfection by-products. In addition, the mutual relation of internal coagulation factors is researched by measuring the changes of Zeta potential and floc morphology in experiment. It can also provide reference for later controlling parameters of optimizing coagulation. The experiment provides scientific advice and guidance, especially for the reconstruction or expansion of the old plants, which possesses a high practical value offering better water quality and social benefits. In order to make good use of the micro-vortex technology, further studies should be carried out regarding the mechanism of the micro-vortex clarification.

Acknowledgement

This work was supported by the National Natural Sciences Foundation of China (No. 51268012). The author wishes to thank International Science Editing for their expert help in editing the manuscript.

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