

Practical Paper

Study on the technology of vortex coagulation and its application in water plant of DongFeng motor corporation

Tong Zhengong

ABSTRACT

After a brief introduction to the core parts of vortex coagulation technology, such as the characteristics of the vortex reactor, and its working mechanism with contact-flocculation, this paper emphasizes that the critical point of this technology lies in the determination of the opening diameter on different surfaces and the control of the opening rate. Through the following illustration of its application on accelerator in a water supply plant in Shiyan in which the treatment scale of the accelerator is increased from 1,280 to 2,500 m³/h, the effluent turbidity of the accelerator is lower than 3 NTU and the effluent turbidity of finished water is lower than 1 NTU, the investment of per ton water is lower – 30 yuan RMB. The paper argues that in comparison to other coagulation reactors, the vortex reactor deserves wider application for its various advantages, such as its higher coagulation efficiency, shorter reactivity time, better quality of finished water, stronger adaptive capability, convenience in construction and so on.

Key words | flocculation, vortex clarification, vortex coagulation, vortex reactor

Tong Zhengong
School of Civil Engineering of East China,
Jiaotong University,
Nanchang 330013
China
E-mail: zzggtt@126.com

INTRODUCTION

The process of water treatment includes two stages, coagulation and flocculation, these being one of the most important and difficult parts to handle. The effect of flocculation could directly determine the running state of the subsequent courses, the cost of the process and the finished water quality. Practice has proved that the reasonable design of coagulation can not only improve the quality of the effluent, but also achieve the purpose of saving energy, reducing dosage and lowering operational costs. The coagulate efficiency can be improved sharply by the use of a vortex reactor, a patented product of East China Jiaotong University (the number of the patent: CN00249081 and ZL.200920141662.5). The author of this paper has been much involved in this project, including transforming the reaction zone of the clarifier to the vortex reaction zone, and installing the skew plates in the precipitate

zone. After technical renovation, the capacity of water treatment has doubled, and the turbidity of the effluent has been getting lower and steadier.

THE VORTEX REACTOR

The characteristics of the vortex reactor

The technical features of the vortex reactor, the core of the micro-eddy coagulation–flocculation process, are as follows. (1) The shape of the vortex reactor looks like a hollow sphere. The diameter of the sphere is designed based on the need of the process and the surfaces, both inside and outside, are roughened. (2) There are some openings on the surface. The diameter and opening rate are also designed based on the need of the process. (3) The vortex reactor is

doi: 10.2166/aqua.2012.095

made up of ABS plastic material, of which the bulk density is a little higher than that of water. The wall thickness is designed according to the intensity of the structure (Tong & Fang 2004).

The vortex reactor has some characteristics determined by its structure. These characteristics are as follows. (1) Construction can be simplified to a great extent due to the fact that the reactor does not need to be fixed during installed, and that it can be put into the clarifier without any directional requirements. (2) The vortex reactor is easy to produce and transport because of its simple structure. (3) The micro-eddy currents are generated by the changes of the rate and direction of water flowing through the openings, and the frictional drag between the inside and outside walls. (4) The material the reactor uses is high-intensity, non-toxic, corrosion-resistant, and aging-resistant, therefore the service life is able to amount to several decades. (5) The vortex reactor is easy to manage and maintain. The machine only needs to be taken from the water first and then washed. There is no need to worry about it being full with floating materials as that the reactor keeps floating and rotating in an upward flow rather than staying afloat at the water's surface (Tong & Fang 2004; Tong *et al.* 2009).

The working principle of the vortex reactor

Attaining a better coagulation–flocculation effect, the vortex reactor can create better hydraulic conditions which respond to each kind of intrinsic hydraulic factor. Figure 1 shows the vortex reactor's flocculation and its flocculation mechanism mainly includes the vortex coagulation and the three-dimensional contact flocculation.

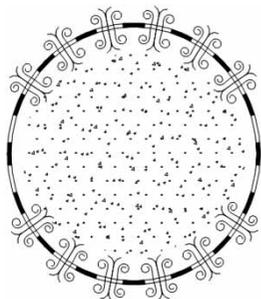


Figure 1 | The vortex reactor's flocculation.

The vortex coagulation

Multiple micro-eddies are formed when the water passes through the massive holes on the surface of the vortex reactor. The vortex reactor forms a grid effect with the openings on the hollow balls. Unlike the traditional grid craft, the grids formed in this way are at the surface of the sphere and are thus characterized by their multi-positions and multi-angles. The effective micro-eddy quantity of the vortex reactor is greater than that of the traditional grid craft because the grids of the vortex reactor in a unit volume outnumber the traditional grids (Yan 1999). According to Kolmogoroff's theory of turbulence, there exist many eddies with different sizes in a turbulent flow. Energy is transferred from the large eddies to the small eddies and then to the smaller ones. Particles in large eddies tend to move without mutual collisions, while the turbulence in small eddies is not so powerful as to push particles, and the collisions of particles occur when the eddy's size is similar to the particles (Carlson *et al.* 2000).

There are two reasons for the diffusion and collision of particles in eddies. First, the velocity differences in different flow layers of the eddies result in the relative motion of particles among these flow layers, which thus adds to the probability of particles to collide. Second, the centrifugal inertia force driven by the revolving function of the turbulent flow leads particles to move along the whirlpool radial, which also increases the particle collision frequency. Therefore, the coagulation efficiency is very high since there is more opportunity for colloids in eddies.

The three-dimensional contact flocculation. The vortex reactor has a hollow shell, and the interior velocity of the flow is slow. The massive floccule particles, or the so-called alum floc, accumulate and suspend in water. The alum floc has the adsorption on the tiny floccule. The process is called contact flocculation. The vortex reactor has a better flocculation effect than the traditional contact flocculation clarifier. There are two reasons for this: first, there is only one layer of suspend floccule in the traditional clarifier, while in the new craft where the water flows vertically through vortex reactor, every micro-eddy has the suspended floccule which forms the three-dimensional contact flocculation with the large bulk; second, it provides better

conditions for the formation of floccule in the vortex reactor. The oversized floccule can be crushed to small fragments by the hefty micro-whirling action, so the flocculation capability remains. The oversized floccule lessens the adsorptive capacity due to a decrease in the total surface. Such floccules with lower compactness can be crushed by the micro-eddy current, and this then recomposes new floccules with high compactness, which is helpful for separating precipitation (Tong *et al.* 2009).

The vortex clarification process

The vortex clarification process is proposed on the basis of micro-vortex coagulation and Hazen theory, which mainly involves technologies including micro-vortex coagulation, inclined tube sedimentation separation, with an overall consideration of structural styles, constructing conditions and operation management conditions. It includes mainly two parts. First, vortex-grid flocculation reactors, which are developed from the integrated application of vortex theory and the small grid flocculation technology, are installed in the flocculation units. Second, inclined-tube settlers are installed in clarification/separation chambers, which has strengthened sedimentation of small particles, ensured precipitation effect and perfected clarification efficiency of the clarification tanks (Huang *et al.* 2009; Tong & Hu 2010).

ENGINEERING APPLICATION

Engineering background and technology reformation

The water factory in Shiyang city currently consists of four water workshops with a water supply scale of $30 \times 10^4 \text{ m}^3/\text{d}$. Through decades of development and continuous technology reforms, the water plant has been playing an important role in the local production and living as well as providing the water supply for fire control. However, most of the water supply equipment is aging and needs to be upgraded, and the water supply's quantity and quality also need continuous improvement. In order to change the status quo, the water plant should focus on the choice of the suitable technology, the maximization of

profits with the minimal investment, and the gradual improvement of the existing water supply system.

The second water workshop of the water plant was built in 1971 with a water purification capability of $6 \times 10^4 \text{ m}^3/\text{d}$. The water treatment process is adopted by the use of two sets of mechanical accelerating clarifiers and siphon filters. The diameter of each clarifier is 23,880 mm, the depth is 6,500 mm, and the water purification capability is $1,280 \text{ m}^3/\text{h}$. After the expansion of another conventional rapid filter and the transformation of the deposition section of the existing clarifiers during the 1990s, the water purification capability of the water plant has been improved to $7 \times 10^4 \text{ m}^3/\text{d}$.

The raw water turbidity remains low for most of the time, and can be as high as about 200 NTU, with a maximal turbidity of 800 NTU within a short time. The raw water quality (annual average, the data are provided by the water workshop) is shown in Table 1.

The technological transformation must be carried out under the conditions of appropriate investment, without any increase in land use or new buildings. One clarifier has been chosen to launch a pilot project on the technological transformation, which is designed to meet the following detailed objectives:

1. The water treatment capability should be extended from 1,280 to $2,500 \text{ m}^3/\text{h}$.
2. The turbidity of the effluent water of the clarifier should be lower than 3 NTU, and continuously lessened to 1 NTU as a result of the reconstruction of the filter, thus being able to meet the new national water quality standard.
3. The chemical dosing system and the sludge control system should realize automation which would improve the finished water quality.

After comparing and contrasting the coagulation–flocculation process in China and abroad, we finally decided to adopt the vortex coagulation–flocculation process for the

Table 1 | The raw water quality

Turbidity (NTU)	Zeta potential (mV)	TOC (mg/L)	NH ₃ -N (mg/L)	COD _{Mn} (mg/L)	pH
36.49	-19.70	3.42	0.41	2.74	7.24

technical reform of the clarifier in the second workshop (known as vortex clarification). The main goal of this technical innovation is the melioration of water production and quality of the clarifier, achieved by the improved coagulation efficiency with the full use of the vortex reactor, and the enhanced sedimentation effect with the use of inclined pipes.

The main points of the design for reconstruction

The design for reconstruction

Reconstruction of the clarifier in the second workshop was carried on without destroying its framework. The designed parameters are as detailed below:

1. capability of water purification: $2,500 \text{ m}^3/\text{h}$ or $6 \times 10^4 \text{ m}^3/\text{d}$;
2. micro-whirlpool reaction volume: 250 m^3 ;
3. micro-whirlpool reaction time: 6 min;
4. area of the sedimentation zone: 370 m^2 ;
5. upflow velocity in the sedimentation zone: 2.0 mm/s.

The stages of reconstruction

The stages of reconstruction include several steps.

1. Remove from the clarifier the machinery chamber, the mixer, the umbrella plate, the partition between the first and the second reactive room, triangle slot and some other barriers. Keep the existing reactive room, headrace, pool outer wall, knighthed, etc. untouched.
2. Heighten both the exterior wall and catchment system by 0.35 m so that hydraulic pressure is high enough to guarantee more water flowing into the filter and thus the improvement of the capability of accumulating water.
3. Reconstruct the first reactive room by extending the partition between the existing reactive room and headrace room to the bottom of the pool, and the second reactive room by lengthening the exterior wall of the headrace. Reshape the pool bottom to a slope for the use of sludge removal, install the vortex reactor bracket, and throw into the clarifier a vortex reactor with its diameter of 200 mm. The high efficiency reaction core has therefore come into being.

4. Lengthen the seamless steel pipe of the inflow pipeline to the pool center. Rotate it down 90° , then insert it into the bottom of the first reactive room, and treat the outlet properly. Maintain enough room for sludge storage in the center of the bottom of the clarifier.
5. Rearrange three sludge discharge pipelines in a circle with a diameter of 12.8 m so as to guarantee the high efficiency of sludge discharge. Set a hydraulic sludge discharge valve. Connect the sludge discharge pipeline with the pressure pipe outside the clarifier for water back-washing when needed.
6. Add oblique tubes made of nontoxic polyvinyl chloride in the sedimentation zone for the melioration of the sedimentation effect. The diameter of these tubes is 30 mm, the thickness 0.6 mm and the length 1,000 mm.
7. Adopt the automatic operation of the chemical dosing system instead of the old manual operation. Add a flowmeter and nephelometer for the sake of saving coagulants and maintaining the stability of water quality.
8. Change the sludge discharge valve into a fast open valve with automatic control for the purpose of the timely removal of the sludge and water saving in discharging sludge. The automatic control of sludge discharge should be implemented without requiring more meters.

Figures 2 and 3 show the sectional views of the clarifier before and after technical innovation.

Automatic control

Intelligent control of the coagulant dosage system. Two conditions, the chemical condition and the hydraulic condition, must be met for the assurance of coagulation effect. The hydraulic condition can be improved by the vortex reactor technology and the chemical condition can be guaranteed by reasonable and automatic control for the dosage of the coagulant. Since the raw water turbidity in this project changes little, it is quite appropriate to use the intelligent control with such advantages as less instrument requirement, less manual intervention, and high reliability.

The instruments which need to be installed in this method include a raw water flowmeter, a raw water turbiditor, and a sedimentation effluent turbiditor. Under normal conditions, the dosage is determined primarily by the

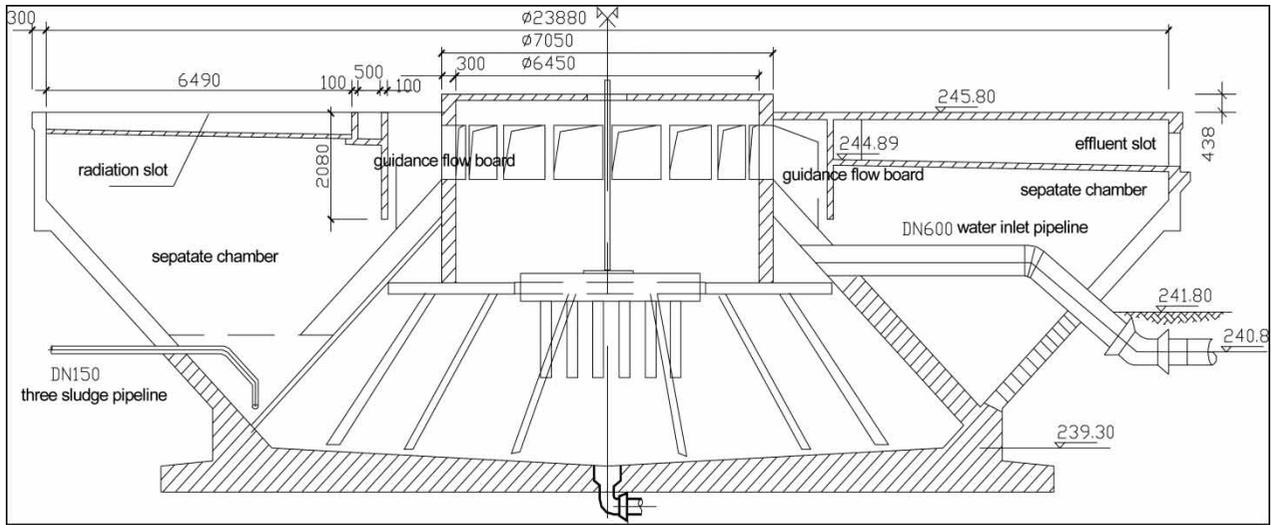


Figure 2 | The sectional view of the clarifier before technical innovation.

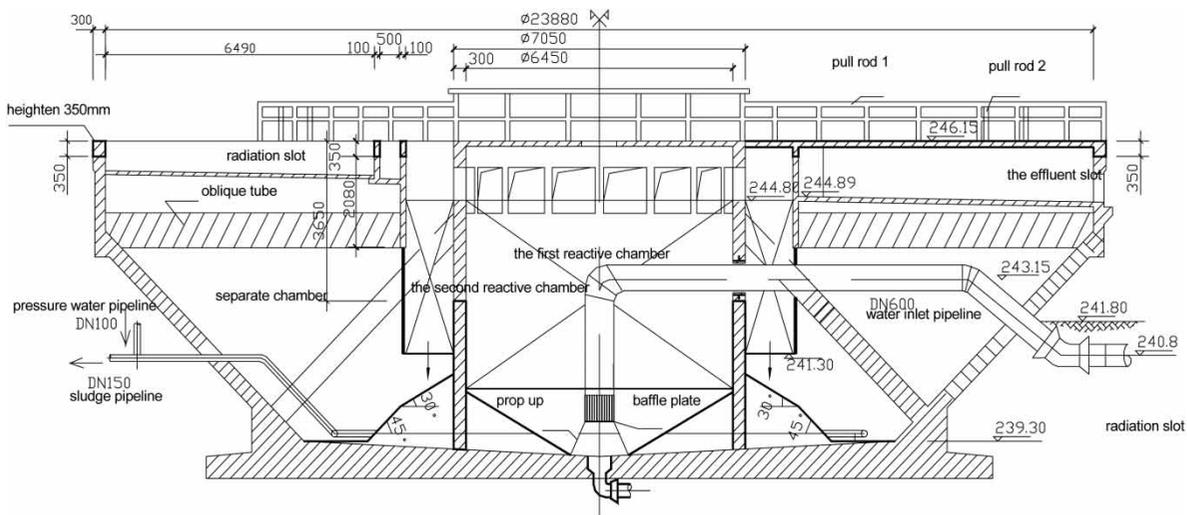


Figure 3 | The sectional view of the clarifier after technical innovation.

controller according to the raw water flow. The dose ratio coefficient, namely the amount of dose per unit water, is determined by a fuzzy control algorithm in the controller, which has the function of automatic learning and optimization based on the relationship between the raw water turbidity, the effluent water turbidity and the actual dosage.

Automatic control of sludge disposal. The key to stable operation of the craft is to make sure that sludge can be drawn out appropriately. The craft can also play a role in saving

the water consumption by reasonably and automatically controlling the sludge disposal cycle and the lasting time.

The sludge discharge is controlled by the method of estimating the sludge accumulation, that is, estimating the volume of sludge from the clarifier by multiplying the raw water flow and the turbidity difference between the raw water and the clear water. In this way both the sludge disposal cycle and the lasting time are under control without needing extra equipment. Since sludge disposal is timely and accurately controlled, the clarifier can keep working in good condition.

DEBUGGING AND OPERATION

The entire project of renovation is simple and convenient, with a short construction period of less than 3 months. The results of the trial operation had been satisfactory during the 6 months after reconstruction; the water quality before and after the vortex clarification is shown in Table 2. Since then, the system has operated properly, stably and effectively. The annual average water quality of the water plant is shown in Tables 3 and 4 shows some parameters of the clarifier before and after vortex clarification technical innovation (all the data are provided by the waterworks supervisory center).

On the whole, with the use of the vortex reactor, the raw water has been fully activated, and the water quality has obviously been improved. First, water flows in the first reaction chamber of the clarifier without reflux, the alum and

Table 2 | The water quality before and after the vortex clarification

Date	Water volume (m ³ /h)	Raw water quality (NTU) (the water inlet turbidity of the vortex clarification)	Coagulation water quality (NTU) (the effluent turbidity of the vortex clarification)
5.8	2,495	49	1.4
5.15	2,510	45	1.3
5.24	2,460	43	1.5
4.2	2,480	30	1.6
4.14	2,470	25	1.3
4.22	2,470	23	1.1
3.15	2,460	40	1.4
3.30	2,480	30	1.7
2.15	2,480	50	2.5
2.28	2,480	50	1.5
1.15	2,480	40	2.5
1.24	2,510	40	1.8

Table 3 | The water quality after the reconstruction

	Turbidity (NTU)	Zeta potential (mV)	TOC (mg/L)	NH ₃ -N (mg/L)	COD _{Mn} (mg/L)	pH
Raw water	36.49	-19.70	3.42	0.41	2.74	7.24
Coagulated water (the effluent water quality of the vortex clarification)	2.16	-2.50	1.88	0.28	1.59	7.08
Finished water	0.68	-2.10	1.80	0.29	1.56	7.07

Table 4 | Some parameters of the clarifier before and after technical innovation

Comparison of project	Before innovation	After innovation
Water volume (m ³ /h)	1,280	2,500
The coagulant dosage (PAC)	15 mg/L	11 mg/L
Flocculation time	~15 min	~10 min
Sediment time	80 min	42 min
Floc.	Not clear	Clear
Effluent water quality of the vortex clarification	≤10 NTU	≤3 NTU
Finished water turbidity	1 NTU	0.5 NTU

particles are distinct and the precipitation performance is good, all of which show high efficiency of the vortex reactor. Second, the quantity of the finished water has improved significantly. As long as the chemical dosing system is controlled well, the water turbidity before filtration can be maintained stably under 3 NTU and the finished water turbidity under 1 NTU.

The workers on duty can timely adjust the dosage after becoming familiar with the new process. Especially after the operation of the automatic control system of chemical dosing, the turbidity of the finished water has been kept below 0.5 NTU, which reaches the new national water quality standard (GB5749 – 2006). Thanks to the renovation, both the turbidity of the precipitation effluent water and the consumption of filter backwash water have been decreased significantly.

CONCLUSION

The key technical factors for the application of the vortex reactor are to achieve good coagulation–flocculation

efficiency by selecting opening diameters on different surfaces, controlling the opening rate of vortex reactor, selecting different kinds of the vortex reactors and integrating opening diameters. The efficiency of the coagulation–flocculation process has been improved greatly in the second workshop due to the adoption of the vortex coagulation–flocculation technology. The treatment scale of the clarifier has been extended from 1,280 to 2,500 m³/h, the effluent turbidity has been kept lower than 3 NTU, the effluent turbidity of finished water has been maintained under 1 NTU, and the cost per ton of water has been under 30 yuan, all of which has reached the expected objectives.

The innovation points of this project can mainly be demonstrated in the following three points:

1. The vortex coagulation–flocculation technology has upgraded the traditional process with the overall coagulation efficiency doubled. The capacity of producing water of the clarifier has therefore been increased by 50–100% in comparison with that of the traditional clarifier under the same conditions.
2. The unique design of the vortex reactor has overcome the shortcomings of the grid reactor process, which include difficulty of production and installation, being easily jammed, and having low life expectation. The vortex reactor makes possible the application of the vortex coagulation–flocculation process.
3. Adopting this new process can improve the capacity of purification and the quality of effluent water without the requirement of constructing new buildings or destroying the main structure of the original ones. It has offered an effective means for technical innovation of the traditional purification process to attain the objectives of meliorating water purification as well as the effluent quality.

In recent years, the micro-vortex coagulation and the vortex clarification technology are included in more and more engineering projects. For example, the treatment scale of former hydraulic circulating clarifier in the water supply plant of Jimo Water Supply Company in Shandong Province is 10,000 m³/d (actual water yield is 7,000 m³/d). After the reform of the vortex clarification technology, the water production increases to 15,000 m³/d, and the turbidity of clarified effluent remains below 3 NTU (Zhang *et al.* 2006). Hengyang Thermoelectricity Corporation of Zhejiang

Province has been using the integrated water purification handling equipment for water supply, the processing scale of which is 8,000 m³/d. Now, due to the vortex clarification process, the water supply scale is enhanced to 1.2×10^4 m³/d and the pre-filter (vortex clarification effluent) water turbidity is less than 2.5 NTU (Tong *et al.* 2009). Also, in the rebuilding of the Liling Railway Water Plant of Hunan Province and in the Luoqing Project for the relocation of Shanghai Pudong Iron & Steel Co Ltd the vortex clarification technology has proved to be beneficial (Huang *et al.* 2009; Tong & Hu 2010; Tong & Lu 2012).

The wide application of this technology can explore the potential of the existing water supply facilities to the greatest extent and make the minimum investment for the maximum benefit, which proves one of the most economical and effective technologies for current water supply industries to increase the water yield and improve effluent water quality. Most importantly, it provides scientific advice and guidance, especially for the reconstruction or expansion of the old plants, which possesses a high practical value and offers better water quality and social benefits.

In order to make good use the vortex technology, further studies should be carried out regarding the mechanism of the micro-vortex coagulation and the vortex clarification.

ACKNOWLEDGEMENTS

This work was supported by the National Natural Sciences Foundation of China (No. 50868005). The author wishes to thank International Science Editing for their expert help in editing the manuscript.

REFERENCES

- Carlson, K., Via, S., Ballamy, B. & Carlson, M. 2000 Secondary effects of enhanced coagulation and softening. *J. AWWA* **92** (6), 63–75.
- Huang, J. H., Fang, Y. H., Chen, X., Fang, Y. Z. & Xi, Z. X. 2009 Micro-vortex flocculation/inclined-tube settling technology for reconstruction of mechanical clarifier. *China Water Wastewater* **25** (20), 77–78.

- Tong, Z. G. & Fang, Y. Z. 2004 Application of micro-whirling coagulation in Xiqiao waterworks. *Water Wastewater Eng.* **30** (6), 19–21.
- Tong, Z. G. & Hu, F. P. 2010 Study on the integrated vortex-grid clarification technique and its application. *China Water Wastewater* **26** (6), 98–100.
- Tong, Z. G., Hu, F. P. & Fang, Y. Z. 2009 Application of the vortex flocculation clarification technology in a water treatment plant in Jiaxing. *Water Wastewater* **35** (10), 15–17.
- Tong, Z. G. & Lu, P. P. 2012 Application of micro-vortex coagulation process in rebuilding engineering of Liling Railway Water Plant. *China Water Wastewater* **28** (4), 79–81.
- Yan, X. S. 1999 *Water Supply Engineering*. 4th edition. China architecture Industry Press, Beijing.
- Zhang, P. T., Hu, F. P. & Zhang, Q. 2006 Micro-whirling reactor and its applications in South City water supply plant of Jimo Water Supply Company. *J. East China Jiaotong Univ.* **23** (5), 9–11.

First received 7 December 2011; accepted in revised form 28 March 2012