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Original Research Paper

Study on the Technology of Vortex Clarification and its Application in Wastewater Treatment

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ABSTRACT

After a brief introduction to the core parts of vortex coagulation technology, like the characteristics of vortex reactor, and its working mechanism with contact-flocculation and vortex coagulation, this paper emphasizes that the critical point of the vortex clarification technology is the micro vortex coagulation. Also it tells us the application of clarification tank in wastewater reuse plant. After alteration of the standard clarification tank in which the micro vortex reactor has been put into the first and second flocculation areas and the inclined pipes into the sedimentation area, the treatment scale of the vortex clarification tank is increased, and the effluent turbidity of the tank is lower than 3 NTU, the effluent turbidity of finished water is lower than 1 NTU and the investment of per ton micro-vortex water is lower than 50 Yuan RMB. The paper argues that in comparison to other coagulation reactors, micro vortex reactor deserves wide application for its various advantages, such as its higher coagulation efficiency, shorter reactivity time, better quality of finished water, stronger adaptive capability, and more conveniences in construction and the like.

INTRODUCTION

In the processes of water treatment, the coagulation-flocculation, which includes two stages, i.e. coagulation and flocculation, is one of the most important and difficult parts to handle (Zhou 2011). The theoretical analysis and a large number of engineering practices show that in the aspect of coagulation process the use of patented product design of East China Jiaotong University-vortex reactor (Patent Number: CN00249081 and ZL.200920141662.5), can greatly improve the efficiency of the coagulation tank to improve water quality. The purpose is to conserve energy and reducing operating costs. I have presided over and participated in a number of projects, to transform the reaction zone of the clarifier into a pool of micro-eddy current response, adding inclined-tube to precipitation zone. After technical renovation, the capacity of water treatment has been doubled, and the turbidity of the effluent has been lower and steadier.

MICRO VORTEX REACTOR

The characteristics of vortex reactor: The core of micro-eddy current coagulation is vortex reactor, which is the porous hollow sphere made up of ABS plastic-based material. Inside and outside of the sphere surface is made of rough surface having small holes and aperture, and the opening rate is in accordance with the determination of water treatment. Fig. 1 is the vortex reactor coagulation schematic diagram. It has the following characteristics (Tong 2004): (1) the flow velocity and orientation changes in through-hole water flow and in addition, the friction of both inside and outside the wall resistance, and has a micro-flow vortex flow; (2) Easy construction, without the installation of fixed, no direction required, and it can be put into the pool directly; (3) Materials have good strength, non toxic, corrosion-resistant, anti-aging, service life of several decades; (4) Simple structure, management convenience, easy operation and maintenance, up to the water in the stream will float and rotate, and can not easily be blocked.

Principle of eddy current reactor: Attaining the better coagulation-flocculation effect, the micro-vortex reactor can create a better hydraulic condition which respond to each kind of intrinsic hydraulic factors. Its flocculation mechanism mainly includes the micro-vortex coagulation and the three-dimensional contact flocculation.

***Micro-eddy current cohesion*:** When water flows through a large number of holes of the vortex reactor's wall, it forms many small vortices at the same time. According to Kolmogoroff's theory of local isotropic turbulence, we can see that turbulence exists in a variety of vortex that has different scales. Large vortex delivers energy to the small vortex, and energy will be transmitted to the smaller vortex. Large vortex often tends to have particles moving as a whole without colliding with each other. Too small-scale vortex is often not enough stronger to tend the particles colliding with each other. Only vortex' scale and particle size be similar to those vortex will be caused by collisions between particles. Compared to the traditional grid process, vortex reactors are formed into grid at the ball surface, which have multi-directional, multi-angle characteristics, and unit volume much bigger than the traditional net grid technology. They cause greater velocity between the flow layers because of vortex, and layer flow caused by the relative movement of the bring particles. They cause the centrifugal force by rotating, which cause the particles to move along the vortex radial, have no stable colloidal particles in the water, have more collision opportunity by the role of micro-eddy current, and have higher cohesion efficiency (Yan 1999).

In sum, 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 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 more chance of collision is available for the colloids in eddies.

***Three-dimensional contact flocculation*:** Because of micro-eddy current, reactor is the hollow shell, when the water flow through the vortex reactor, the external flow velocity is greater than the internal, this will enable the internal accumulation of substantial flower-fan floccus body, form the mud layer residue that can cause the role of adsorption and flocculation to the non-stable colloids in the water flow. Vortex clarifiers have a higher flocculation effect compared to traditional contact flocculation clarifiers. First, only one layer suspended flocs in the traditional clarifiers, but all vortex reactors have suspended flocs in the reaction zone of vortex clarifiers, which causes the total size big and the formation of three-dimensional contact flocculation. Second, there is higher-quality growth of flocs in vortex reactor; excessive growth of the flocs will be broken into smaller flocs maintaining flocculation ability under the role of micro-eddy current. Lower density flocs will be broken down and re-flocculation will occur into a higher density floc under the role of micro-eddy current, in favour of precipitation.

THE VORTEX CLARIFICATION

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 plate/tube sedimentation, separation and sludge thickening, with an overall consideration of structural styles, constructing conditions and operation management conditions (Tong 2008).

The structure of clarification tank is shown in Fig. 2. It includes three units.

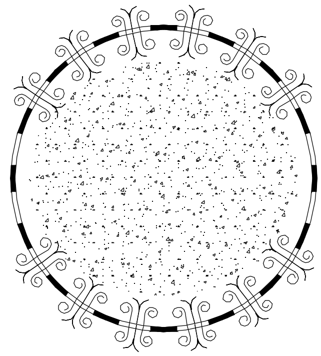

Fig.1: The vortex reactor coagulation schematic diagram.

1. 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 referring to the inside room of the first and the second vortex reaction chambers.
2. Inclined-tube settlers are installed in clarification chambers, which have strengthened sedimentation of small particles, ensured precipitation effect and perfected clarification efficiency of the clarification tank, with high surface hydraulic load.
3. Sludge thickening units are added, which can complete sludge thickening effectively, and the density of discharge sludge is high. It can also decrease the pressure of sludge treatment facilities, and reduce sludge disposal costs.

The raw water with coagulant enters vortex clarifier from inflow pipe. Then it goes into the first reaction zone through nozzle and venturi. After that, it flows down into the second reaction zone through transition area. And then it flows out from the bottom of the second reaction zone. The flocs with good settling ability will be deposited into sludge concentration area through solid-liquid separation by inclined tube. The clear water collected by the annular sink through V-weir, then flow out of the vortex clarifier. The concentrated sludge can be withdrawn by the sludge pipe.

ENGINEERING APPLICATION

Engineering background: After the treatment of sewage by chemical or biological methods in a workshop of Baosteel, first class pollutants have reached the discharge standard. To save water, the company has taken a decision to carry out the production and reuse of sewage. Influent water quality and water quality requirements are as given in Table 1.

Treatment process: The company guidelines to the wastewater reuse system engineering include to select

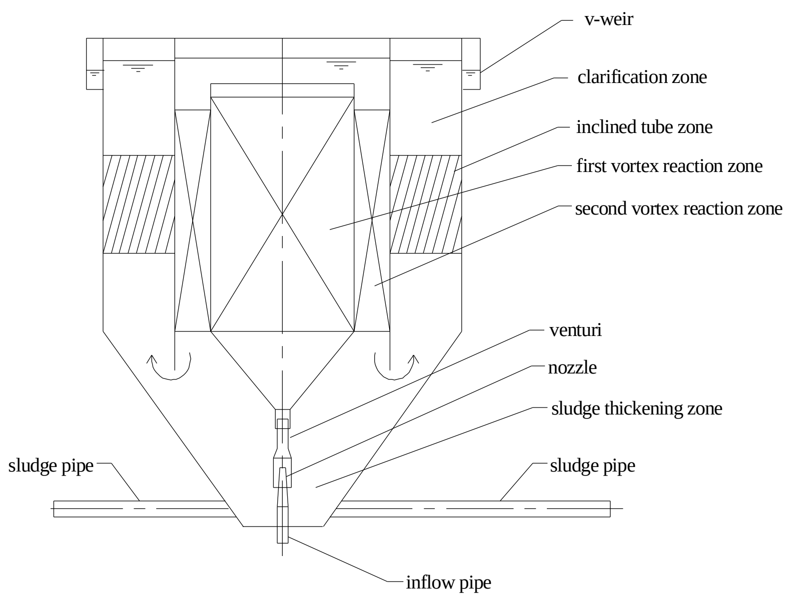

Fig. 2: The schematic diagram of the vortex clarification.

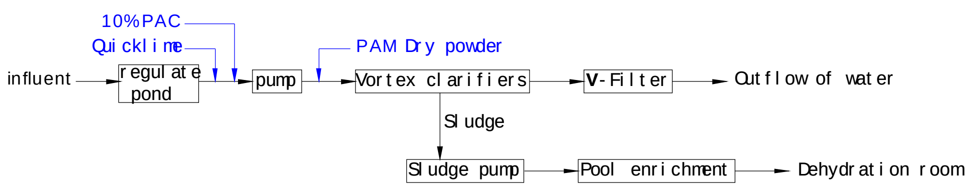

Fig. 3: Wastewater treatment process flow diagram.

reasonable technology with minimal capital investment, to create the greatest benefits, requiring the shortest period, the smallest area and the water turbidity before filter stability at the 3NTU all the year round.

We can see from Table 1 that the sewage of this treatment plant after treatment by chemical and biological means, has only suspended solids (SS) larger than the water quality requirements, so the main issue of the treatment process is considered the removal of turbidity. The company after the repeated demonstration and comparison, eventually decided to adopt the vortex clarifiers that use micro-eddy current coagulation made by East China Jiaotong University. The company thought of making full use of eddy current reactor to enhance the effect of coagulation and precipitation and use of the inclined tube, so as to achieve the purpose of enhanced clarifiers's capacity of water and improve water quality. The main flow process is shown in Fig. 3.

***Vortex clarifiers*:** Water treatment volume is 14000m^3/d, the core of the entire treatment process is vortex clarifiers. We designed two parallel vortex clarifiers. Each clarifier's diameter is 12.0m, the total depth is 7.5m, volume is about 550 m^3 when maximum flow is 420 m^3/h (when a pool maintenance, another pool should have 70% of the total treatment capacity, so each pool according to the largest flow of 420m^3/h has been designed) and residence time of about 1.31 hours.

Vortex clarifier (Fig. 4), set in a mixed unit, has coagulation, flocculation, liquid/solid separation, automatic sludge removal and sludge recycling and other functions. The project used for eddy current clarifiers is upflow solid contact and separation of cell cycle. Major components for the two reaction chambers are: For first current flocculation reaction chamber, the region around 2.4 meter in diameter; and for the second vortex flocculation chamber, outer ring of the

Table 1: The characteristics of influent and outflow of water.

Number	Pollutants	Influent quality (mg/L)	Outflow quality (mg/L)
1	pH	6-9	6-9
2	Suspended solids (SS)	200	10
3	Biochemical Oxygen Demand (BOD_5)	30	20
4	Chemical Oxygen Demand (COD_{Cr})	120	80
5	Total Hardness ($CaCO_3$)	400	350

Table 2: The main design parameters for vortex clarification.

Number	Design parameters	Design parameter	Maintenance of single-cell parameter
1	Water treatment quantity	300 m^3/h	420 m^3/h
2	Inlet pipe diameter	DN350	
3	Inlet pipe velocity	0.87 m/s	1.21 m/s
4	Outlet pipe diameter	DN400	
5	Outlet velocity	0.66 m/s	0.93 m/s
6	Micro-vortex reaction time	7.4 min	5.3 min
7	Micro-vortex reaction velocity	37~96 m/h	52~134 m/h
8	Inclined tube aperture	φ 80	
9	Sediment surface area	95.7 m^2	
10	Surface load	3.13 $m^3/m^2{\cdot}h$	4.39 $m^3/m^2{\cdot}hr$
11	Reserve time	1.83 h	1.31 h
12	Triangular weir length	38.64 m	
13	Load on the triangular weir	230 $m^3/m{\cdot}d$	281 $m^3/m{\cdot}d$
14	Triangular weir high	6 cm	
15	Triangular weir head	2.4 cm	2.8 cm

Table 3: The dosage of coagulant.

Coagulant type	PAC	Quicklime	PAM dry powder
Dosage	12576 L/d	1000 kg/d	25 kg/d

first reaction chamber, the region is about 3.6 meters in diameter. In area of external reaction zone of the precipitation, there are inclined tubes to enhance control of sludge retention time and to increase the sludge concentration. At the bottom of reactor there are regions of sludge storage and concentration. Storage of precipitated sludge is temporary in the region with a certain degree of enrichment. There is continuous operation of the rake to scrap the mud mixed sludge to facilitate its removal by the sludge pump.

Outflow-water from biological and chemical treatment enters into the vortex clarifier's lower part of the first reaction chamber by DN350 water pipe, and outflows by the lower part of the second reaction chamber into the precipitation zone. The completion of coagulation and flocculation process takes about eight minutes effective time.

Water enters into inclined tube in sedimentation area for water separation after full coagulation and flocculation. The process of separation is finished in the inclined pipe, and the isolated sludge slide down to the bottom pool along the inclined wall, into the sludge concentration zone. The mud scraper is set up at the bottom of the pool with a protection device with torque. Sludge is transported to the centre of bottom pool by the sludge scraper. Sludge pump work according to information collected from the sludge interface devices and torque switch on mud scraper regularly to emit the mud. Mud scraper is regulated by the gear installed above the water surface above joined by a casing-pipe. It will alarm when mud scraper torque exceeds the set torque to remind the emergency sludge. The water isolated from the water tank inflows into the V-filter by the outlet pipe. In order to prevent deposition of sludge in reaction zone, a DN 200 manual sludge hoist is set up at the bottom of the first reaction zone. Sludge is periodically discharged by the operator (Zhang 2006). The main design parameters of the vortex clarifier are given in Table 2.

***Dosing and discharge system*:** Coagulant (PAC) and the stone mortar are added to water before the regulation of pool pump, and pool is adjusted in order to complete the mixing reaction. In order to improve flocculation, static mixer is used for mixing. Stone mortar and coagulant are added mainly in order to remove the hardness and suspended solids (Tzoupanos 2010). Polymer flocculants can help in efficient

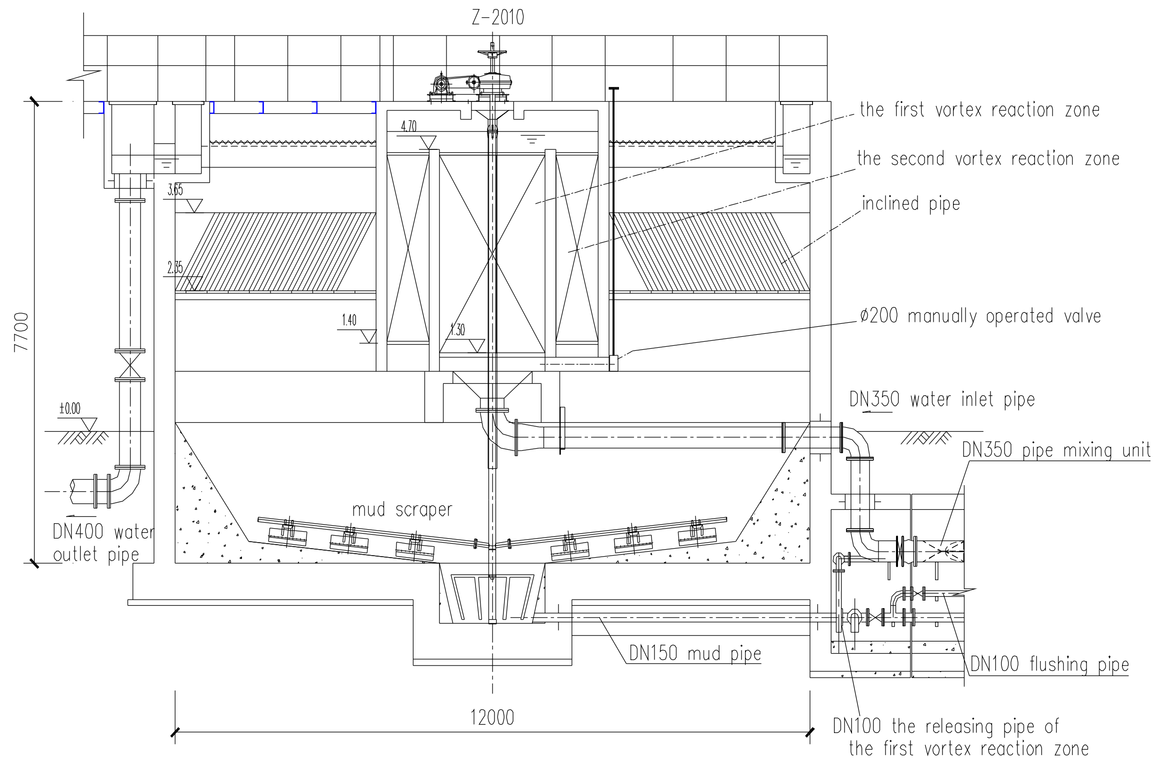

Fig. 4: The vortex clarification tank process flow diagram.

removal of the suspended solids from wastewater by coagulation and flocculation reactions. In the process of wastewater upward flow, downward precipitation of solids form a layer of sludge, which plays the role of a filter bed for smaller particles. It further promote the precipitation of solids to carry out the reaction completely. Dosage of stone mortar and coagulant were controlled on the basis of pH of water before the micro-eddy flocculation reactor and the outlet pipe. When the water pH rose to 10, Ca^{2+} with stone mortar complete response to generate $CaCO_3$ sludge. Flocculant dosage according to the influent flow amount are controlled by the main control room in order to ensure the efficient removal of suspended particles (Wang 2012). When quantity of influent is 14000m^3/d, various dosage used are as given in Table 3.

Ensuring discharge in time, is the key of stable operation of the process. The rational control discharge cycle can play the role of savings in self-consumption of water by dual-use of one backup equipment, which can be manual on/off in the field or in the main control room, and automatic control through interface instrument of the sludge in the vortex clarify pool to control the sludge pump opening, and the implementation of the automatic switching between pumps into the sludge storage tank and then proceed to dehydration. The mud coming out from vortex-clarifier with relatively a high rate of solids about 3% is easy to dehydrate. Sludge scraper in the vortex-clarifier tank can be manually switched on/off in the field or through the main control panel. Discharge tube connected to the pressure water pipes outside the pool, if necessary, can be used in order to wash sludge at the bottom.

DEBUGGING RUN SITUATION

After more than a year of running, the pool water quality after clarifying is given in Table 4. It can be seen that the vortex clarifying process reached the Company's outlet water quality requirements. As the running influent water SS in most cases are at about 500 mg/L, they cause more deposition in the first reaction room, and it will affect the outlet water quality if discharged delayed. The whole process of water clarification is easy with convenient and shorter construction period. After more than a year of satisfactorily running the plant with water quantity at the time of 420m^3/h with reasonable control and discharge of sludge timely, the pool water turbidity was stabilized to maintain below 3NTU which after filter by the V-filter further reduced to 1NTU. Because of the outlet water in the clarify pool has low turbidity, the consumption of the anti-filter water chemicals is

Table 4: Effluent water quality after vortex clarification.

Serial Number	Pollutants	Clarifier's outlet water quality (mg/L)	Filter outlet water quality (mg/L)
1	pH	7.5	7.5
2	Suspended solids	8	1
3	Biochemical Oxygen Demand (BOD_5)	20	18
4	Chemical Oxygen Demand (COD_{Cr})	80	76
5	Total hardness ($CaCO_3$)	350	350

also significantly reduced with extension of the work cycle.

CONCLUSIONS

The key technical factors for the application of 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. At present, vortex clarifiers have been in operation for nearly three years in sewage water treatment works at Baosteel where the pool water turbidity has been stable at below 3NTU, and after filtration the water turbidity is less than 1NTU. Vortex investment per ton of water is below 50 Yuan to achieve the desired objectives of water quality. Practice shows that vortex reactor with high coagulation efficiency shorten the reaction time with excellent outlet water quality, ability to adapt to change, construction convenience, easy maintenance and management, and with a certain promotion value.

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