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Research on Swirling Cavitation Degradation and Its Application in Wastewater Treatment

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Abstract. By means of computer simulation for the flow field, the condition of swirling cavitation formation and the shape of cavitation distribution were analyzed with CFD software. The accuracy of simulation results and the validity of wastewater treatment device were verified according to the testing results of device's working parameters and degradation for Rhodamine B. The criterion to judge cavitation formation or degradation efficiency has been established. The industrialized enlargement for mini wastewater treatment device has been analyzed by means of simulation. It is useful to establish industrial application foundation of this kind of wastewater treatment device.

Introduction

Wastewater in industry is usually composed of some organic component because active additive, emulsifier or other additive used in producing process sometimes. Photo activation-oxidation is used to degrade organic compound in wastewater generally. Pollutant produced in wastewater treatment process will result in new pollution again. So, a lot of researchers have been paying attention to look for new method and equipment to degrade organic wastewater discharged in manufacturing industry.

Cavitation is the phenomenon that slight bubbles (caused by liquid evaporation) appear and grow up explosively because local pressure in the fluid system is lower than the liquid's saturated vapour tension, and then the bubbles are cracked suddenly [1]. It results in temperature sharply raised and pressure rapidly increased in the tiny scale of zone. Meanwhile, strong impact-wave and high-speed ejection appear. Since the cavitation phenomenon discovered, the theory and the content of cavitation phenomenon have been deep development. In the past, the cavitation, considered as the extremely destructive hydraulics phenomenon, is harmful for not only small-scale hydraulic machinery but also large-scale hydraulic engineering. With the progress of technology, cavitation is involved in more and more new domain. Recently, the high binding energy when the bubbles cracked has been used to break the long molecular chain of organic to achieve the goal of degradation. Research results about ultrasonic cavitation for organic degradation can be easily found, but the industrialized application of ultrasonic cavitation has encountered the insurmountable difficulty. The hydrodynamic cavitation is a very good substitution method. Compared with ultrasonic cavitation, the equipment of hydrodynamic cavitation is simple, the energy used factor is higher, industrialized operation is easily realized [2-6].

In order to get hydrodynamic cavitation, the zone in which pressure is lower than the saturated vapor tension at corresponding temperature has to be obtained through the flow field change. According to domestic and international references, hydrodynamic cavitation can be formed by means of either jet or swirling. The energy consumption and the degradation efficiency considered, Kalumuck and Chahine[7,8] found the swirling cavitation need less energy and get higher efficiency than the jet cavitation by p-nitrophenol's degradation experiment. J. G. Wang et al. [9,10] succeed carrying on the Rhodamine B degradation experiment by swirling cavitation. We have developed mini model of the swirling cavitation device for wastewater degradation based on the principle of cavitation. Numerical simulation and experimental verification have been done.

Swirling Cavitation Degradation and Simulation Analysis

There are many types of structure for swirling formation in theory. If simple structure and easy manufacturing are taken into account, the practical and applied structure for swirling can be abstracted as shown in Fig. 1 and its transformation. The device of swirling cavitation degradation as shown in Fig. 1 consists of combined chamber, swirling chamber and baffle plate. There are four rectangular tangential slits distributed uniformly in cylindrical swirling chamber. Liquid pumped into combined chamber flows through slits into swirling chamber. Fluid forced through slits with high tangential velocity will revolute in the swirling chamber. The swirling flow makes low pressure zone appear along revolution axis. The zone with pressure lower than saturated vapour tension can be formed if condition is suitable. Cavitation bubbles can be generated continuously in low pressure zone. Cavitation bubbles rushing out swirling chamber with fluid to impact baffle surface results in pressure increasing sharply to make bubbles cracked. That means hydrodynamic cavitation done. An orifice designed in the top of swirling chamber allows a small stream down to force fluid flow out from swirling chamber more quickly [11].

3D geometric model of fluid domain corresponding to the device shown in Fig. 1 can be created firstly. Then, use CFD (Computational Fluid Dynamics) software to create its mesh model by finite volume method. The swirling chamber's flow field condition and the pressure distribution are simulated finally. Simulation conditions are as following: four slits in the swirling chamber are of 0.1mm wide and 150mm long, diameter of swirling chamber is 10mm, diameter of orifice in the top of swirling chamber is 2mm, inlet pressure is 0.7MPa, and temperature of fluid is 40 degrees Centigrade (test's thermal equilibrium temperature in laboratory). And initial conditions in simulation are set up as: ideal air and water set as two phase fluid model (the ideal air is dispersed phase and water is continuous phase), standard   model set as the simulation turbulent model.

From the simulation results shown in Fig. 2, the cone-shape distributed low pressure zone is formed in swirling chamber center. When the low pressure is lower than 7376Pa (the saturated vapour tension at 40 degrees Centigrade), cavitation bubbles can be formed. Simulation result shows that the zone with pressure lower than saturated vapor tension can be formed, and simulation flow rate is 0.671173L/s. As shown in Table 1, simulation impulse forces   exerting on the baffle plate vary with the change of distance   between swirling chamber outlet and baffle plate.

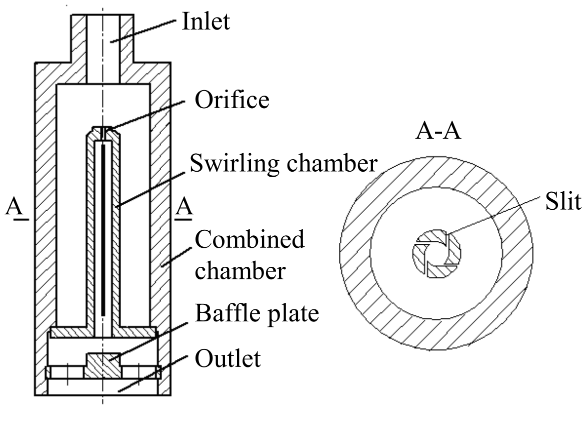

Fig. 1 Device of swirling cavitation degradation

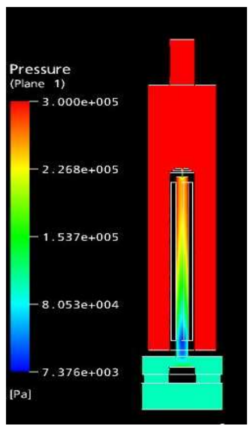

Fig. 2 Simulation pressure nephogram

Experimental Verification

In order to verify the accuracy of simulation results, flow rate and impulse force of swirling flow exerting on the baffle plate are measured as inlet pressure is set to 0.7MPa. Test unit shown in Fig. 3 consists of piezoelectric dynamometer (Kistler9257B), signal amplifier and signal gathering processor (DEWE-BOOK-FW-NI-16) and personal computer (with vibration and dynamic signal analysis system DEWESoft650). The flow rate measured with glass rotameter is 0.7L/s corresponding to inlet pressure 0.7Mpa. It is very close to the simulation flow rate (0.671173L/s) with small deviation (4.118%). According to data of Table 1, it is known that measured impulse forces are close to simulation impulse forces correspondingly with deviation less than 17.63%. They will decrease with the increase of distance D in similar changing regulation.

Table 1 Comparison of test results and simulation data

D /mm	F′ /N	F /N	Deviation /%
70	14.0685	17.08	17.63
80	13.9732	16.67	16.18
90	13.8907	16.62	16.42

The validity which the swirling cavitation device can degrade organic wastewater was confirmed by experiment. The experiment conditions involve the initial concentration is 5mg/L of rhodamine B aqueous solution (product of Shanghai Chemical Co.), the solution pH value is 3.8, the solution total quantity is 12L, the temperature was controlled with the help of condenser in the water tank, the concentration of rhodamin B in aqueous was tested with 722E spectrometer (product of Shanghai Spectroscope Equipment Co.) based on the absorption at the wavelength of 554nm. The swirling method deal with liquid quantity ($1.2\times10^{-2}m^3$) corresponding to inlet pressure 0.7Mpa and temperature 40 degrees Centigrade is bigger than that of ultrasonic method ($1.0\times10^{-3}m^3$) as ultrasonic reactor with an emission power of 150W, a frequency of 20kHz and temperature 40 degrees Centigrade to degrade Rhodamine B aqueous solution. The swirling cavitation degradation efficiency is higher. The swirling cavitation energy efficiency (2.5mg/MJ) is much higher than the ultrasonic cavitation energy efficiency (0.15mg/MJ).

Through simulation confirmation experiment and Rhodamine B degradation experiment, it has verified that swirling cavitation will exist so long as pressure within the zone being lower than the saturated vapor tension at this temperature, and the device can degrade organic matter in wastewater.

Industrial Enlargement Analysis

It follows from simulation and experimental results mentioned above that the swirling cavitation wastewater treatment device can degrade the organic wastewater and the simulation results are the credibility. In order to meet the needs of dimension design for large flow rate device in industrial application, CFD software is still used to verify that the structure of mini-device mentioned above is valid for large flow rate device because the great dimensional scaled model experiment is very difficult to be carried on under the current experiment condition limited in laboratory. Path-cross-area is used as a basic parameter in the process of device proportional amplification. That is, the cross-area of inlet, outlet, slit, swirling chamber and the flow rate of device will increase in the same amplifying time. Simulation results of device amplified 10 times is illustrated in Fig. 4. There exists a zone with pressure lower than saturated vapor tension. That means the amplified device is valid for wastewater degradation.

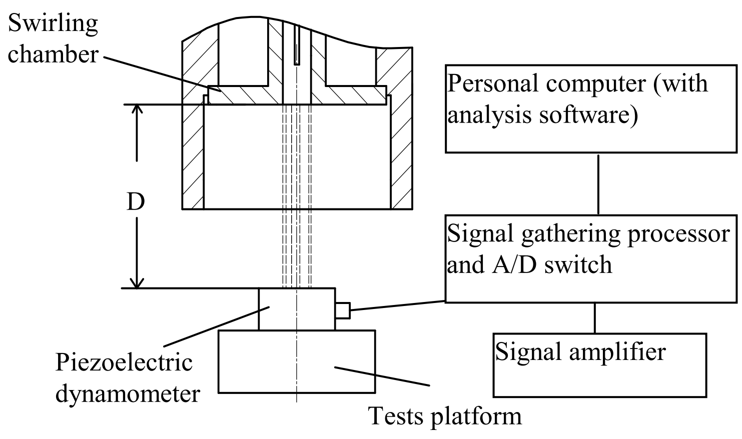

Fig. 3 Sketch of test unit

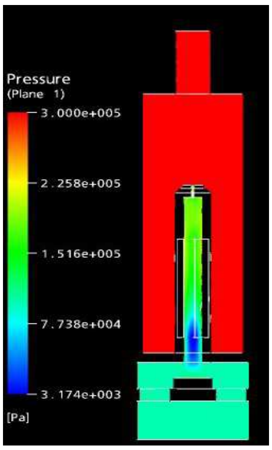

Fig. 4 Simulation pressure of large-scale model

Conclusion

Based on the principle of swirling hydrodynamic cavitation, the model of wastewater treatment device with simple structure and manufacturability has been created. By means of computer simulation for the flow field, the condition for cavitation and the shape of cavitation distribution were analyzed with computer software. The accuracy of simulation results and the validity of wastewater treatment device were verified according to the testing results of device's working parameters and degradation for Rhodamine B. Through the theoretical analysis and the experimental verification, the only criterion conclusion was obtained. The lowest region pressure is lower than the saturated vapor tension region shape and the size to appraise the cavitation whether to produce with the cavitation degradation effect in this temperature. The industrialized enlargement for wastewater treatment mini device was studied by simulation analysis. The foundation for the industrialized application of swirling cavitation wastewater treatment device was established.

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