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Investigation on Oxygenation Performance and Numerical Simulation of Swirling Aerator

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Abstract. The oxygenation performance of the swirling aerator was evaluated by an air-water system oxygenation experiment. The flow pattern analysis on the oxygenation process of the swirling aerator was carried by PIV measurement and numerical simulation. The test results showed that the oxygen transfer coefficient (K_{La}) increased with the increase of intake air volume, and the maximum value of K_{La} (20ºC) was 0.721L/min under 8m^3/h condition. PIV measurement results showed that the number of tiny bubbles in the water increased with the increase of intake air volume and the bubbles form vortex in the pool with the water flow, which enhanced the mass transfer effect. The maximum number of tiny bubbles appeared at 8m^3/h. The results of numerical simulation showed that due to the difference in speed, obvious vortex phenomenon occurs. With the increase of intake air volume, the intensity and quantity of vortex increase, the air-water mixing was more sufficient, and the air volume fraction was higher.So the oxygenation performance was stronger, which was consistent with the PIV measurement and oxygenation test results.

1. Introduction

At present, most of China's sewage treatment plants use activated sludge process. Aeration and oxygenation is the main energy consumption of the activated sludge process, and about 50%-60% of the electricity cost of the sewage treatment plant is blasted. In the activated sludge process, the main functions of aeration are oxygenation, agitation and mixing. The oxygenation performance of the aerator affects the removal of organic matter in the biological treatment of sewage and the stable operation of the biochemical system [1], which is crucial in the activated sludge process. Generally, high quality aerators should have low resistance loss and high oxygen transfer efficiency under normal service life [2, 3].

Most urban sewage treatment plants in China use disk aerators for biochemical aeration and oxygenation. Disk aerators are used earlier and have mature technology. They have low-pressure loss and high oxygen transfer efficiency. However, there is an aeration dead zone during aeration, and the stirring performance is weak. When aerating, the sludge deposits on the surface of the disk and consumes a lot of energy when it is started up. The swirling aerator is a new type of aerator that includes an intake tube, a screw with a spiral blade, and a cylindrical body of staggered mushroom head cutters. Compared with the disk aerator, the swirling aerator has the advantages of no sludge blockage, intermittent operation, no sludge accumulation in the bottom tank, and low power consumption. It can be more energy-saving and environmentally friendly in the activated sludge process. In this paper, the oxygenation test was carried to study the change law of oxygenation performance of swirling aerator

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under different aeration flow rates. The fluid analysis of the oxygenation process of the swirling aerator was carried by means of PIV measurement and numerical simulation.

2. Materials and methods

2.1. Materials

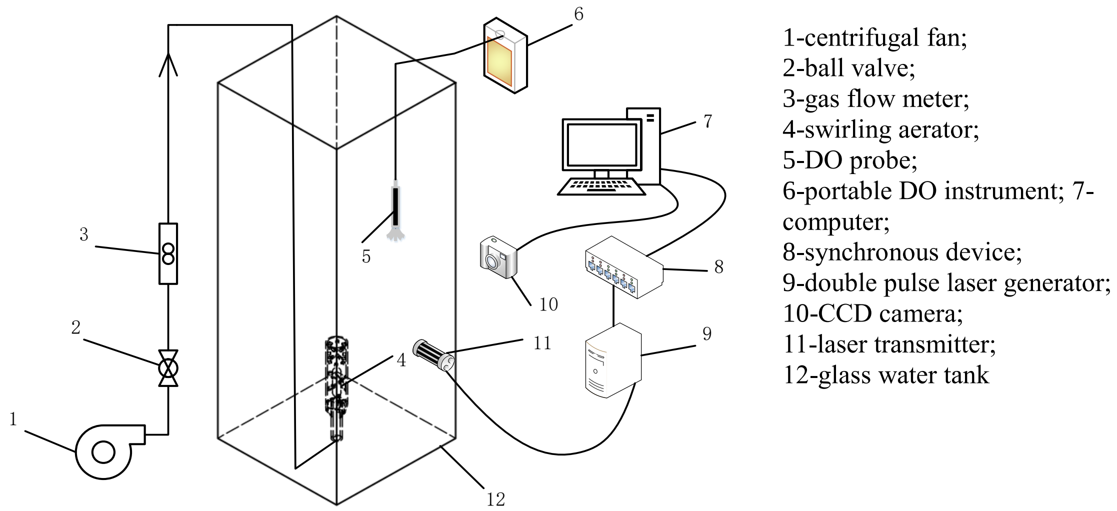

Figure 1. Device diagram of oxygenation experiment of swirl aerator

The experimental water is tap water, the deoxidizer used is Na_2SO_3, and the catalyst is $CoCl_2 \cdot 6H_2O$. The experimental device is shown in Figure 1. It mainly includes a water tank, a PIV test system, a portable DO meter, a centrifugal fan, and a swirling aerator. The water tank is made of transparent tempered glass with a size of 300×300×1000mm, and the test water depth is 800mm. The swirling aerator is installed at the bottom of the water tank, and the portable DO instrument probe is placed 300mm deep under the water, placed on the side of the pool wall and 30mm away from the pool wall; the upper limit of the CCD camera installation shooting height in the PIV test system is 50mm below the water surface; In order to prevent the central bubble from blocking the laser from penetrating the entire section, the laser emitter was mounted 50mm off center.

2.2. Methods

Before the oxygenation test, tap water is poured into the water tank, and then Na_2SO_3 and $CoCl_2$ were added to remove dissolved oxygen in the water to zero. The water temperature is measured, and then the fan is activated to perform aeration and oxygenation. The dissolved oxygen concentration was recorded every 10 s in the first 3 min of the test, and then the dissolved oxygen concentration was measured every 0.5 min until the dissolved oxygen reached saturation. The PIV test system was turned on after the dissolved oxygen was saturated, and the microbubbles are used as tracer particles. The images taken by the camera are input to the computer through the capture card, and the image processing is performed using Insight software. The experiment investigated the oxygenation effect of the inlet flow rate under the conditions of $4m^3/h$, $6m^3/h$ and $8m^3/h$, and measured the oxygenation performance by calculating the oxygen transfer coefficient and the PIV test image analysis. According to the double membrane theory proposed by Whitman in 1923 [4], the mass transfer process of oxygen can be expressed by Eq. (1). If the temperature is not 20°C, K_{La} can be corrected by Eq. (2).

$$\text{In}(C_s-C_t)= -K_{La}t + C \quad (1)$$

$$K_{La}(20°C)= K_{La}(T) \times \theta^{(20-T)} \quad (2)$$

Where K_{La} is the oxygen transfer coefficient, C_s is the dissolved oxygen saturation concentration of water at the experimental temperature and pressure, *t is a certain time in the experiment*, C_t is the dissolved oxygen concentration at a certain time t, C is a constant, and θ is the empirical temperature correction coefficient, which is taken as 1.024.

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3. Results and discussion

3.1. Oxygenation capacity

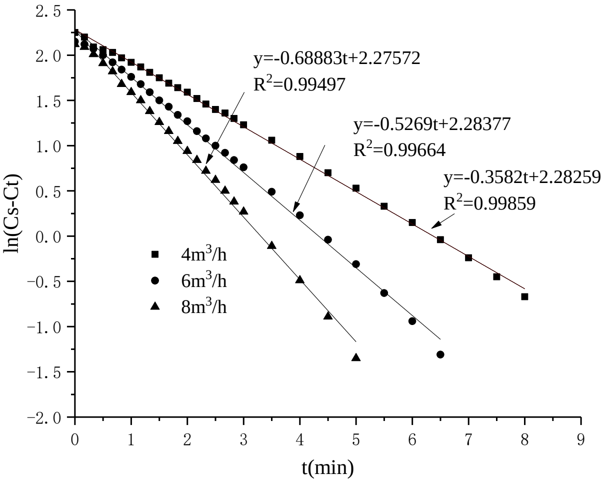

Figure 2. Relationship curve of In(C_s-C_t)-t under different working conditions

It can be seen from the Eq. (1) that if the relationship curve between In(C_s-C_t) and t is made, the inverse of the slope is K_{La}. The experimental water temperature is 18ºC, and the Cs is 9.46 mg/L. It can be seen from Figure 2 that K_{La} (18ºC) is about 0.358 L/min and R^2 = 0.99859 under the condition of 4 m^3/h, the fitting effect is good. Calculated from Eq. (2), K_{La} (20ºC) is 0.375 L / min. Under the condition of 6m^3/h, K_{La} (18ºC) is about 0.527L/min and R^2=0.99664, the fitting effect is good. Calculated from Eq. (2), K_{La} (20ºC) is 0.553 L/min. Under the condition of 8m^3/h, K_{La} (18ºC) 0.688L/min and R^2=0.99497, the fitting effect is good. Calculated from Eq. (2), K_{La} (20ºC) is 0.721 L/min. It can be seen that K_{La} increases with the increase of intake air volume.

3.2. PIV measurement

The flow field and velocity field information of gas-liquid two-phase flow during aeration process were obtained by PIV measurement, and the flow velocity under different working conditions was analyzed.

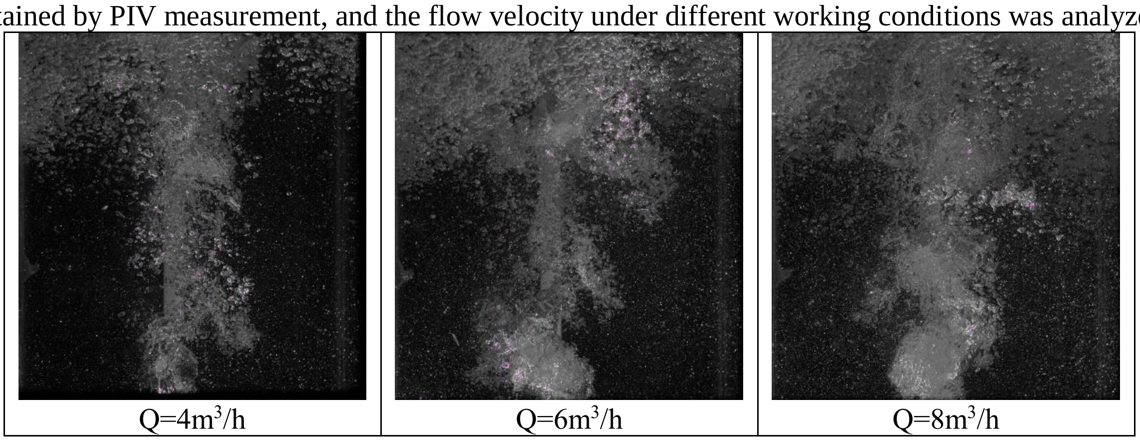

Figure 3. Photographs taken by CCD camera under different working conditions

The intake air is cut into tiny bubbles under the action of the swirling aerator. The larger the air volume flowed in, the larger the flow rate of air was, and the more microbubbles generated by the cutting collision. It can be seen from Figure 3 that as the intake air volume increases, the number of tiny bubbles in the water increases, and when Q=8m^3/h, the microbubbles are the most. Microbubbles can increase the residence time of air in water, increase the mass transfer rate and utilization efficiency of oxygen, which is consistent with the experimental results of oxygenation capacity in Figure 2.

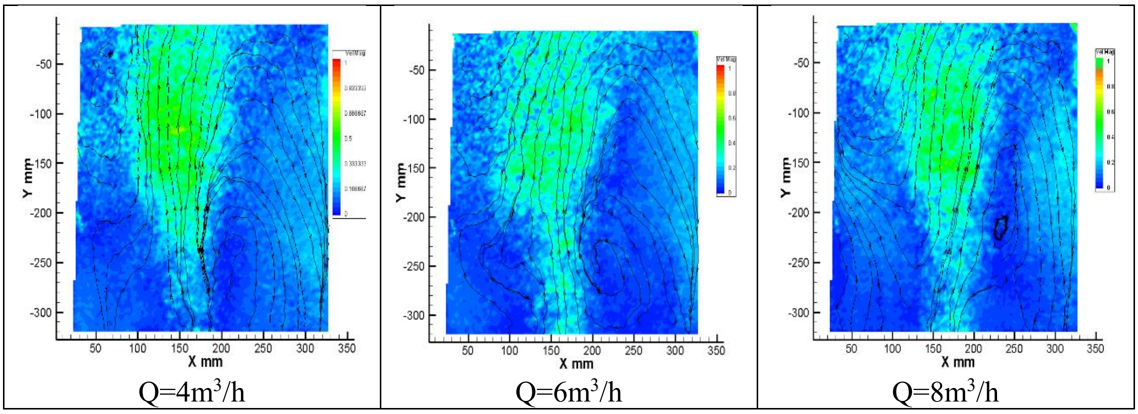

Figure 4. Velocity field and cloud chart under different working conditions

Figure 4 shows the velocity field and cloud image obtained by PIV test. The bubbles move with the water in the pool. The velocity of the center bubbles is relatively large, and the two sides are relatively small. Due to the difference of speed, the bubbles on the left and right sides move downward to form a circulation. The vortex appears, strengthens the mixing effect of air and water, and enhances the mass transfer effect. It can be seen that as the intake air volume increases, the vortex intensity increases and the number of vortex increases, which is more conducive to air-water mixing and enhanced mass transfer effect.

3.3. Numerical simulation

The simulation was performed with Fluent software, and the Euler-EulerModel and the standard k-ε turbulence model were selected[5-8].

It can be seen from the velocity streamline diagram in Figure 5 that due to the speed difference, the water in the reactor moves from the center of the swirling aerator to the periphery at high speed, and the surrounding water flows back to the center, generating multiple vortexes, and the turbulence intensity is large. Air and water can be mixed well. The position of the red dotted frame in the figure 5 is the position taken during the PIV measurement. Comparing Figure 4 and Figure 5, it can be seen that the velocity streamline distribution in the simulation results is basically the same as the velocity streamline obtained by the PIV test analysis, that is, the middle region is moving upward at high speed, the two sides form multiple circulations. Moreover, as the intake air volume increases, the intensity and the number of vortex increases, and the air-water mixing is more sufficient, which is beneficial to enhance the oxygen transfer efficiency, and is consistent with the oxygenation test results.

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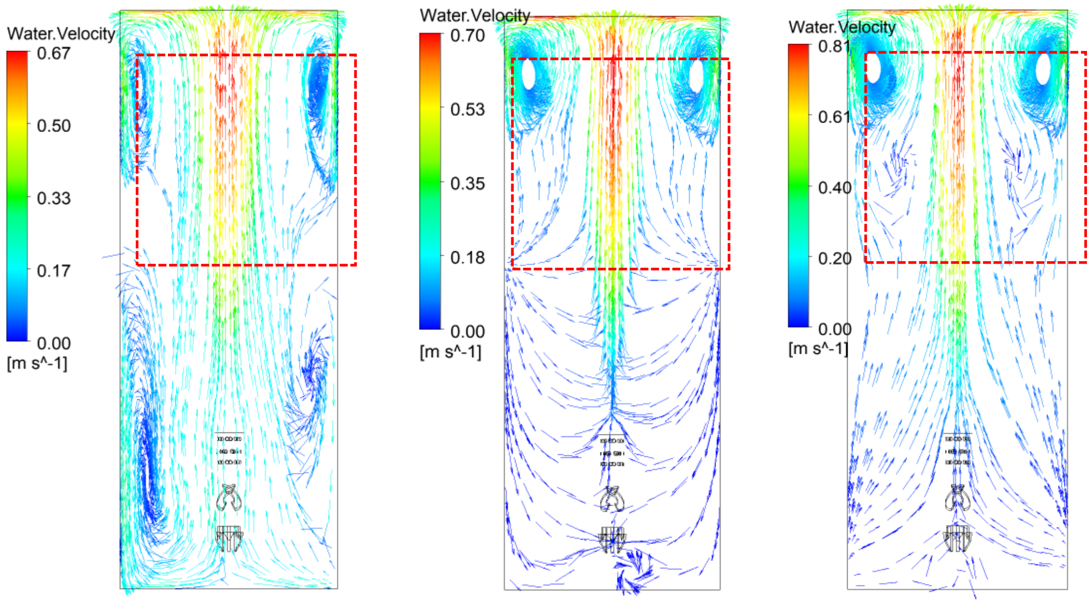


Q=4m^3/h Q=6m^3/h Q=8m^3/h

Figure 5. Velocity streamline diagram under different working conditions

After the air passes through the aerator, it moves upwards at a high speed. The outlet of the aerator has a large diameter, and the resistance is small, which is not easy to block. It can be seen from the air volume fraction in Figure 6 that the air volume distribution is basically the same under different working conditions. But the larger the air volume flowed in, the higher the air volume fraction was. The high air volume fraction indicates that the air content is high, and the oxygenation capacity of the aerator is strong, which is consistent with the oxygenation test results.

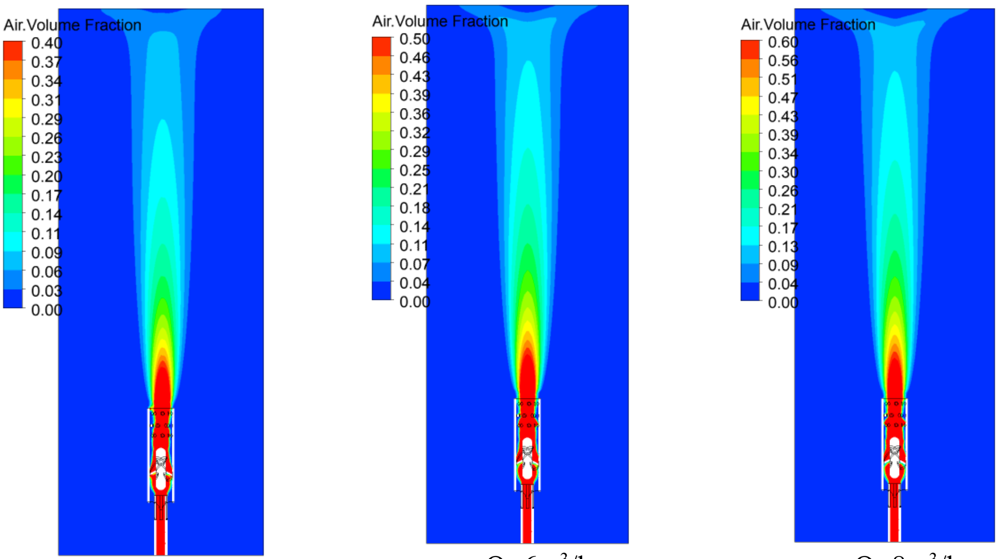
4. Conclusion

The following conclusions can be obtained by oxygenation test, PIV measurement and numerical simulation:

(1) When the water temperature is constant, the oxygen transfer coefficient (K_{La}) of the swirling aerator increases with the increase of the intake air volume, and the maximum K_{La} (20 ºC) is 0.721 L/min under the condition of 8 m^3/h.

(2) With the increase of the intake air volume, the number of tiny bubbles in the water increases, and the bubbles move with the water in the pool to form vortexes, which is conducive to the mixing of air and water and enhances the oxygen transfer efficiency.

(3) In the numerical simulation results, as the intake air volume increases, the intensity and quantity of vortex increase, and the air volume fraction is higher. This indicates that the oxygenation capacity is enhanced, which is consistent with the PIV measurement and oxygenation test results.



Q=4m^3/h Q=6m^3/h Q=8m^3/h

Figure 6. Air volume fraction under different working conditions

Acknowledgments
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