Numerical simulation of micro-nano bubble central intake aeration

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Abstract. In this paper, ANSYS FLUENT was used to simulate the gas-liquid two-phase flow in the process of micro-nano bubble central air intake aeration and optimized the central air intake aeration conditions. The particle size of microbubbles was 2 μm, the Eulerian model was used in multiphase flow model, and the standard k-ε model was used in turbulence model. The gas-liquid two-phase flow field with different aeration velocity was simulated. The effects of aeration time on gas holdup were studied. The results showed that the aeration effect was better with the increase of aeration speed, stronger turbulence, two-phase mixing and oxygen mass transfer.

Key words: micro-nano bubbles; central intake aeration; numerical simulation.

1. Introduction
Compared with ordinary bubbles, micro-nano bubbles have the characteristics of large specific surface area [1], high zeta potential at the interface [2, 3] and free radical ions [4, 5]. They have unique technical advantages and wide application prospects in fishery, mineral flotation, water treatment and other fields [6, 7, 8]. The application of micro-nano bubble technology in the field of aeration and the improvement of aeration technology have an excellent application prospect. However, there is still room for further study on the foaming mechanism and practical application of microbubble technology [9].

Computational fluid dynamics (CFD) is an analytical method based on computer mathematical simulation to solve the problems of flow, heat transfer and other physical and chemical phenomena. It is widely used in aircraft and ship aerodynamics, hydraulics, hydromechanics and other fields. It has a lot of application results for the numerical simulation of biological filter, oxidation ditch and other hydraulic reactors in the field of environmental engineering.

In this paper, ANSYS FLUENT was used to simulate the gas-liquid two-phase flow in the process of micro-nano bubble central air intake aeration. The effects of gas holdup, liquid velocity and pressure on the operation efficiency of aeration process were investigated, in order to provide guidance and reference for optimizing aeration conditions.

2. Aeration model
Euler model was used to describe the interaction of gas-liquid two-phase flow. The equations of conservation of momentum and mass were established for the control volume, and then the instantaneous local differential equation and interface discontinuity relation of each phase were derived...
from the existing equations, and then the Euler model was obtained. The two phases were regarded as incompressible fluid, so the density of liquid and gas was constant. The heat transfer between gas and liquid phases was ignored in the calculation.

2.1. Control volume equation

In the process of aeration reaction, the liquid phase was continuous phase and the gas phase was dispersed phase. The control volume equations in the coordinates of Euler-Euler system were listed [10]:

Conservation of mass equation:

\[
\frac{\partial a_i}{\partial t} + \nabla g(a_iu_i) = 0
\]  

Conservation equation of momentum:

\[
\frac{\partial a_i \rho_i u_i}{\partial t} + \nabla (a_i \rho_i u_i u_j) = -a_i \nabla p_i + \nabla (a_i \tau_{ij}) + F_i + a_i \rho_i g
\]  

\( a \)-volume fraction, %; \( i \)-liquid or gas; \( t \)-time, s; \( g \)-gravitational acceleration, m/s²; \( u \)-current speed, m/s; \( \rho \)-density, kg/m³; \( j \)-vector of \( x, y, z \); \( p \)-pressure, Pa; \( \tau \)-viscous stress tensor, Pa; \( F \)-interphase force in micro element, N/m³.

The interphase force only considers the influence of traction force in this simulation, and the expression was:

\[
F = -0.75a_g(1-a_g)\rho_i \frac{c_p}{d_g} | u_g - u_i | (u_g - u_i)
\]  

S-N traction model was adopted, and the traction coefficient was:

\[
C_D = \begin{cases} 
\frac{24(1+0.15Re^{0.667})}{Re} & \text{Re } \leq 1000 \\
0.44 & \text{Re } > 1000 
\end{cases}
\]

\[
Re = \frac{\rho_i u_i d_g}{\mu_g}
\]

The liquid phase adopted the standard k-ε model in this numerical simulation, whose equation was as follows [11]:

K-transfer equation:

\[
\frac{\partial}{\partial t} (\rho k) + \frac{\partial}{\partial x_i} (\rho k u_i) = \frac{\partial}{\partial x_j} \left( \mu + \frac{\mu_k}{\sigma_k} \frac{\partial k}{\partial x_j} \right) + G_k + G_b - \rho \varepsilon
\]

ε-transfer equation:

\[
\frac{\partial}{\partial t} (\rho \varepsilon) + \frac{\partial}{\partial x_i} (\rho \varepsilon u_i) = \frac{\partial}{\partial x_j} \left( \mu + \frac{\mu_k}{\sigma_\varepsilon} \frac{\partial \varepsilon}{\partial x_j} \right) + C_{1\varepsilon} \frac{\varepsilon}{k} (G_k + C_{3\varepsilon} G_b) - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k}
\]  

2.2. Model construction and equation solution

The conceptual model was cube aeration tank, as shown in Fig.1(a). Xiao [10] carried out numerical simulation of two-phase flow in the aeration process, the simulation results are consistent with the experimental results, with good accuracy and reliability. As a reference, the height of liquid level was 70cm, the length is 20 cm, the width was 5 cm, and the top of the lower left corner was the coordinate origin. The temperature of continuous phase and dispersed phase were both 25 °C. The aerated distributor was a porous distributor with a diameter of 25 mm and a central air intake. The grid was divided into tetrahedral structure grids, and the grid structure was shown in Fig.1(b). The number of nodes was 34650, and the number of grid cells was 34202.In the simulation, the wall of the model was a slip free boundary condition, and the velocity inlet and pressure outlet boundary conditions were used at the bottom and the top respectively. The spatial derivative adopted quick scheme, the time derivative adopted first-order upwind scheme, the pressure velocity coupling adopted phase coupled simple
scheme, the relaxation factor of momentum equation took 0.3, the pressure relaxation factor took 0.7, and the other parameters adopted default values [12].

![Fig. 1 (a) Aeration model; (b)Mesh of aeration model](image)

3. Simulation results and analysis

In this paper, two-dimensional transient numerical simulation of gas-liquid two-phase flow in micro-nano bubble aeration technology was carried out. Referring to the main technical parameters of the micro bubble generation device (model XZCP-K) of Yunnan xiazichun Environmental Protection Technology Co., Ltd., the bubble size was selected as 2 μm, and the air content was selected as 85%. When the output of steam water mixture was 0.5m3/h, 1.0m3/h, 2.5m3/h, 3.5m3/h, the simulated aeration speed was 0.07m/s, 0.14m/s, 0.35m/s, 0.49m/s. When the aeration speed was 0.49m/s, the contour map of gas holdup in different aeration process of central air intake distribution was shown in Fig.2.

As shown in Fig. 2, under certain aeration conditions, the bubbles gradually moved upward in the initial stage of aeration process, and diffused from near the air inlet to the surrounding. The upward trajectory of the bubble group was a straight line. In the process of rising, the liquid block moved to both sides to form a circulation. The trajectory of the bubble group was mushroom like. After the aeration process lasted for a period of time, the bubble group oscillated, and the amplitude of oscillation gradually expanded. The movement of the bubble group in the vertical direction deviated from the central axis gradually, and the upward trajectory bent to a certain extent, finally forming a more obvious wave shape. The simulation results were in accordance with the PIV experimental results of Luo [11] for gas-liquid two-phase flow in aeration tank, which verified the reliability and effectiveness of the numerical simulation. With the increase of aeration speed, the transverse distribution of bubble group became wider, and the maximum gas holdup gradually deviated from the central axis of the intake. The rising speed of bubble group was accelerated, the radial width was increased, the swing amplitude was larger, and the gas holdup of each point was also increased, so as to increase the contact area between gas and liquid, increased the oxygen transfer efficiency, increased the dissolved oxygen content in liquid phase, and achieved better aeration effect. However, the aeration speed should not be too high, otherwise, it is easy to make bubbles coalesce and increase, and escape from the liquid phase, which is not conducive to the dissolution of oxygen. The collision and coalescence of bubbles will also widen the main body of the bubble group.
Fig. 2 Contours of gas volume fraction in central gas aerated process

Fig. 3 showed the horizontal distribution of gas holdup at three horizontal positions with the aeration speed of 0.49 m/s and the height from the bottom of 15 cm, 35 cm and 55 cm. The coordinate axis took the top of the lower left corner of the model as the origin, and studied the change of dissolved oxygen content through gas holdup distribution. After the aeration process lasted for a period of time (3.75 s), the peak value of gas holdup gradually deviated from the central axis of the air inlet. At a height of 15 cm from the bottom, it deviated about 45 mm in the negative direction, and the transverse distribution range of gas holdup was mainly 20-160 mm. At a height of 35 cm from the bottom, it deviated about 20 mm to the negative direction, and the transverse distribution range of gas holdup was mainly 40-110 mm. At the height of 55 cm from the bottom, it deviated about 30 mm to the negative direction, and the transverse distribution range of gas holdup was mainly 30-120 mm. It was similar to the aeration rate of 0.35 m/s, but the curve changes more sharply, the bubble group swung more violently.

With the increase of aeration rate, the transverse distribution range of gas holdup and the distance between the peak value and the central axis at the intake were increased. In addition, the aeration time to reach the same gas distribution was reduced, and the maximum gas holdup and the gas holdup at each position in the flow field were also gradually increased. After the aeration process lasted for a period of time, the bubble group oscillated to a certain extent. In the flow field, momentum transfer occurred between the gas phase and the gas-liquid phase at the same time. The circulation process also promoted the mass transfer between the gas-liquid phase and realizes the dissolution of oxygen. At a small aeration speed, the transverse distribution of gas holdup showed a single peak. With the increase of aeration speed, there were multiple peaks of gas holdup. There was not only a peak at the bubble group, but also a peak in the circulation area on both sides of the bubble group.

In the process of aeration, the movement, coalescence and rupture of bubble group increased the turbulence intensity of liquid phase. It made the gas-liquid contact area increased, and enhanced the diffusion and mass transfer of gas phase in the liquid phase, promoted the dissolution of oxygen in water, and increased the content of dissolved oxygen. The full utilization of oxygen was realized, the operation cost was saved, and the economic and efficient aeration effect was realized. However, when the aeration speed is too high, bubbles tend to coalesce, break and escape, reducing the time of dissolution and mass transfer, and reducing the aeration effect.
Fig. 3 The transversal distribution of gas hold-up ration in central gas aerated process (The gas velocity is 0.49m/s; (a)1.5s, (b)2.35s, (c)3.1s, (d)3.75s)

4. Conclusion
(1) In the central air intake aeration, the bubble group moved vertically upward in the initial stage of the aeration process, and diffused from the vicinity of the air inlet to the surrounding. The rising track of the bubble group was a straight line. In the process of rising, the bubble group moved to both sides due to the blocking effect of liquid, and finally forming a circulation.

(2) After the aeration process lasted for a period of time, the bubble group oscillated, the movement in the vertical direction gradually deviated from the central axis, and the rising track appeared a certain degree of bending, and finally formed a more obvious wave shape.

(3) With the increase of aeration rate, the oscillation amplitude of bubble group increased, the gas holdup deviated, and the multi peak phenomenon occurred. The gas holdup of each point in the flow field increased, which made the dissolved oxygen content increase and improved the aeration effect.

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