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Experimental and Simulation Study on the Pool Fire of Low Pressure Atomizing Nozzle

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Abstract. Bubble atomization technology, originated in the 1990s, has the advantages of simple structure, good atomization effect, low influence of liquid viscosity on atomization effect and low energy consumption. At present, it is widely used in the fields of combustion, spraying and fire fighting. In order to further expand the application field of bubble atomization, the possibility of applying bubble atomization to cooling and cooling is studied in this paper. In this paper, six types of bubble atomization nozzles with different structures are designed and a special experimental platform is built to measure the data of six types of nozzle. The flow characteristics, droplet size distribution, droplet velocity distribution and other parameters of six kinds of bubble atomizing nozzles were studied, and the experimental results were compared and analyzed. On this basis, Fluent simulation software was used in this paper to simulate the gas-liquid two-phase distribution, velocity distribution and spray velocity distribution at the nozzle outlet of the mixing chamber structure, so as to supplement and verify the experimental results. Different nozzle structures have great influence on the atomization effect of the bubble atomization nozzle. This conclusion will play a certain role in the design of the bubble atomization nozzle in the future.

1. Introduction

The research of the bubble atomizer is inspired by the flash atomization [1]. The flash atomization refers to the process of dissolving carbon dioxide and other gases that can be dissolved in water under a certain pressure and reaching a saturated state. After the liquid is ejected from the nozzle, due to the reduction of the ambient pressure, the gas will be separated, expanded and even exploded, thus forming the atomization. However, a large expansion chamber is needed for the slow formation of flash atomized bubbles. A. H Lefebvre and others first proposed a new atomization method, that is, bubble atomization method. A series of researches have been carried out on bubble atomization technology [2], grant g, Jones A and others have carried out extensive researches on water mist fire extinguishing, and the research results show that water mist can put out different types of fires [3-5]. Ge Jian and Li Xiaokang carried out a simulation study on the fire extinguishing performance of the pulsed water mist in the confined space, and thought that the water mist was more suitable for extinguishing liquid fires [6-8]; Xu Yuequn and others simulated the fire extinguishing performance of the bubble water mist, and the results showed that the bubble water mist had a better cooling effect [9,10]; In order to make it better used in cooling and cooling, this paper designs the air pressure ratio, whether there are holes in the



middle of the nozzle and the number of injection holes on the mixing cavity, and studies the influence of three factors on the characteristics of the fog field.

2. Test System and Nozzle

The test was carried out in a confined space of $5.0\text{ M} \times 5.0\text{ M} \times 3.1\text{ M}$. a door with a size of $1\text{ m} \times 2\text{ m}$ was set on the wall; a square smoke vent with a length of 30 cm was set on the side, and the height from the smoke vent to the ground was 2.5 M. a gas monitoring device was set in the main center. The fire source is a round oil pool fire with a diameter of 30 cm. The fuel is diesel oil. The fire source is set in the center of the room. The wall material is glass and the ground is concrete. The fine water mist nozzle is located directly above the oil pan, with a height of 2.7m from the ground. Thermocouples are arranged directly above the oil pan. Three thermocouples are arranged every 10 cm along the center line of the oil pan surface. The number between the third and the fourth thermocouples is 1-4 from bottom to top, and the number 1 thermocouple is close to the oil pan surface. The ambient temperature is set as $20\text{ }^{\circ}\text{C}$ and the humidity is 40%. According to the actual situation, the fire source is in the center of the combustion chamber, which is a disc with a diameter of 30 cm and a height of about 0.1 M. the fire source is shown in Figure 1.



Figure 1. Fire Source Layout

2.1. Design of Bubble Atomizer

The former design of the bubble atomizer is mainly used in the fields of pharmacy, spraying and so on. Now it is applied in the research of fire-fighting and used to carry on the transformation design. So that its atomization characteristics are better conducive to fire fighting. In this paper, the nozzle is of internal gas and external liquid type,

In order to facilitate the study of the transformation process of the two-phase flow pattern inside the nozzle, transparent plexiglass tube is used to make the outer wall and mixing chamber of the nozzle. The inner diameter of the outer plexiglass pipe is 20 mm, the wall thickness is 3 mm, and the total length of the nozzle is about 20 cm. According to the number of injection holes, gas-liquid ratio and whether there are holes in the middle of the mixing chamber, the diameter of the test oil pan is 30 cm, and the oil volume is 400 ml. various working conditions are shown in Table 1.

Table 1. Test conditions

Number of holes	Gas liquid ratio/Mpa	With or without holes	Experimental fire extinguishing time/s	Smoke exhaust mode
Two Lines	0.3:0.8	With/Without	198/315	Mechanical smoke exhaust
	0.4:0.8	With/Without	93/305	
	0.5:0.8	With/Without	78/342	
	0.6:0.8	With/Without	127/389	
	0.8:0.8	With/Without	112/190	
	0.9:0.8	With/Without	206/215	
	1.0:0.8	With/Without	197/232	
Four Lines	0.3:0.8	With With Without Without Without With/Without With	116	Mechanical smoke exhaust
	0.4:0.8		56	
	0.5:0.8		70	
	0.8:0.8		231	
	0.9:0.8		171	
	1.0:0.8		134/181	
	1.1:0.8		180	

Through reference [11-12], we get the calculation formula of GLR as follows:

$$\beta = \frac{Q_a}{Q_a + Q_l} \quad (1)$$

$$GLR = \frac{W_a}{W_l} = \frac{\rho_a}{\rho_l} \frac{\beta}{1 - \beta} \quad (2)$$

Where: Q_A is the volume flow of gas and Q_L is the volume flow of liquid.

According to the experimental fire-extinguishing time, under the same pressure hydraulic ratio, the middle hole has less time than the non hole, so the nozzle with hole has better fire-extinguishing effect. When there is a hole, the air pressure is less than the water pressure, and the air pressure water pressure ratio is less than 0.3-0.4mpa, the fire extinguishing effect is better. When there is no hole, the air pressure is greater than the water pressure, and the air pressure water pressure ratio is greater than 0.1MPa, the fire extinguishing effect is better. When the number of rows is a single variable, the fire-fighting effect of four rows is slightly better than that of two rows. The reason for this situation is that the density ratio of air and water used in the experiment is less than 0.005. According to formulas 3.1 and 3.2, when GLR is less than 0.1, a slight increase of GLR will cause a sharp change of gas volume flow and liquid volume

flow; when GLR is more than 0.1, with The trend of GLR changes is much smoother, and the corresponding changes of gas volume flow and liquid volume flow will also become smoother.



Figure. 2. Bubble Atomization Spray Diagram

The angle of atomization cone is an important parameter to show the atomization effect. It is the angle of the night fog torch after liquid atomization. Because the liquid mist jet has a certain entrainment effect on the surrounding air, which makes the gas pressure in the center of the liquid mist drop slightly, the liquid mist torch is not a positive cone, but a certain contraction phenomenon. The angle between the two tangents is the angle of atomization cone. The angle of atomization cone is an important parameter of nozzle, which can describe the spatial distribution of liquid mist to a certain extent. The size of the atomized cone angle has a considerable effect on the spray. When the atomization angle is large, the penetration depth of the spray is shorter, and the penetration depth of the spray is longer if the atomization cone angle is small. The measurement of Figure 2 shows that the spray cone angle of the nozzle is about 80 degrees, which indicates that the direct injection bubble atomizer has a longer penetration depth and the spray has a larger longitudinal velocity. Experimental observation shows that the atomization of the bubble atomizer is not symmetrical in the radial direction, slightly tilted, and the spray state has a certain periodicity. The instability of spray is related to the working state of air compressor. Because the working state of the air compressor is related to the gas pressure in the nitrogen cylinder, when the nitrogen pressure reaches the lower limit, the air compressor starts to operate. When the nitrogen pressure reaches the upper limit, the air compressor stops running, resulting in instability of the gas parameters, resulting in a certain periodicity of the spray state.

3. Reflection of Thermocouple on Atomization Quality of Nozzle Under Different Gas-liquid Pressure Ratio

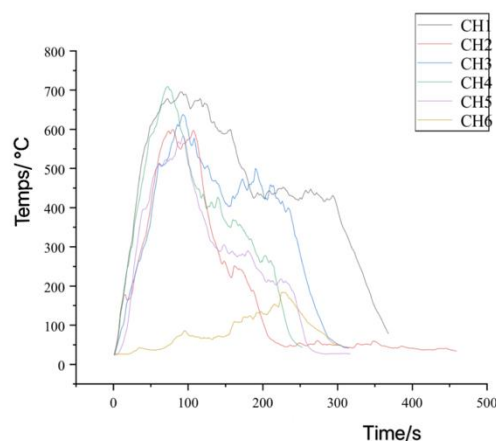


Figure. 3. Two rows without holes

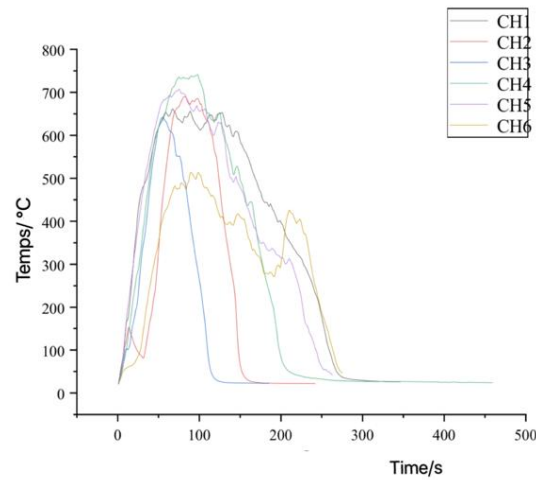


Figure. 4. Two rows of holes

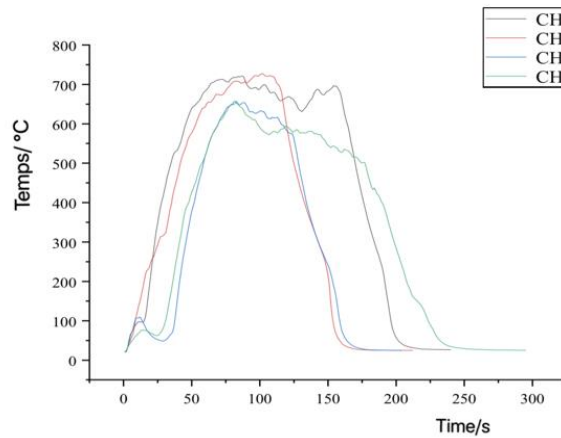


Figure. 5. Four rows without holes

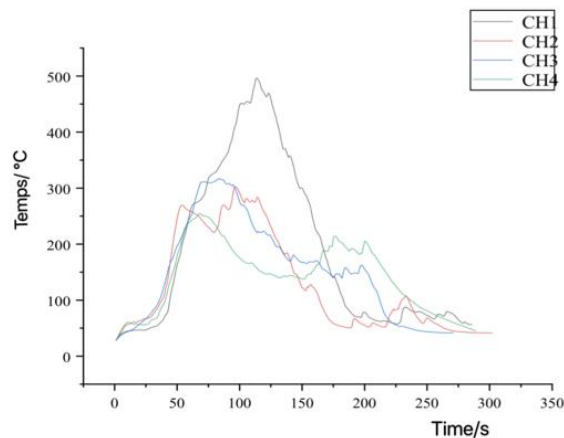


Figure. 6. Four rows of holes

From figures 3 and 4, it can be seen that at low gas-liquid ratio, with the increase of gas-liquid pressure ratio, the fire extinguishing time gradually decreases. It can be seen from figures 4, 6, 4 and 5

that the flow rate has a great influence on the atomization effect. For nozzles with the same structure and size, different flow rates not only have a great influence on the shape of the outlet torch, but also on the distribution characteristics of the liquid particles. The general rule of the above figures is: under the same gas-liquid pressure ratio, the fire extinguishing time of four rows of nozzles is shorter than that of two rows of nozzles, which shows that when the gas-liquid injection pressure is stable, reducing the flow rate of the nozzle will lead to the deterioration of the atomization effect of the nozzle; when the gas-liquid ratio is small, the flow rate has a greater impact on the atomization effect. The two-phase flow in the mixing chamber and the outlet part of the nozzle is a kind of nearly uniform bubble flow pattern when it operates at a large flow rate. There is no stratification between the gas and liquid, so it has a better atomization effect.

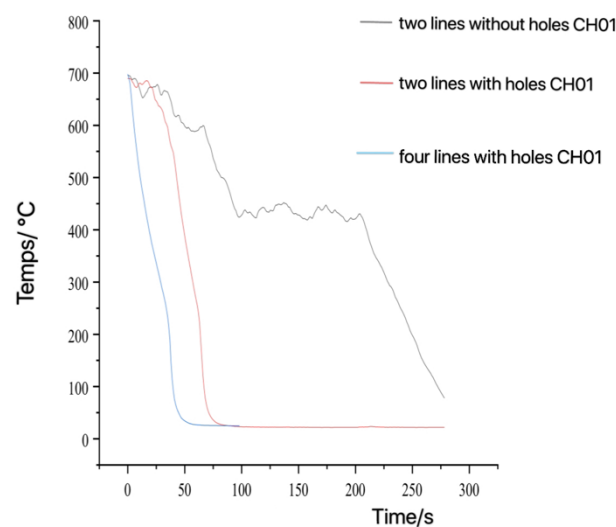


Figure. 7. Type Comparison of Air Pressure 0.4MPa and Water Pressure 0.8MPa

Figure 7 shows the typical flow characteristics of the bubble atomizer. The curve in the comparison chart shows:

(1) When the gas-liquid pressure ratio is fixed, the temperature of oil pool fire corresponding to two rows of perforated nozzles and four rows of perforated nozzles decreases rapidly, while the temperature of two rows of non perforated nozzles decreases slowly.

(2) When the gas-liquid pressure ratio is fixed, the time needed for the temperature of four rows of perforated nozzles to drop to the minimum value is the shortest, the time needed for two rows of perforated nozzles is longer, and the time needed for two rows of non perforated nozzles is the longest. It can be concluded that the number of air holes and whether there are holes in the middle of the nozzle will affect the atomization effect of the air bubbles.

4. Fluent Simulation

4.1. Grid Division

Based on the selection of nozzle parameters, the geometric modeling of the internal flow field of the bubble atomizer is carried out by using gambit. Due to the difficulty of mesh generation in the nozzle, the method of combining unstructured mesh and structural mesh is adopted to mesh generation. Figure 8 shows the modeling and meshing results of the bubble atomizer. The hexahedral mesh is used in the calculation area, and the total mesh number is 69167.

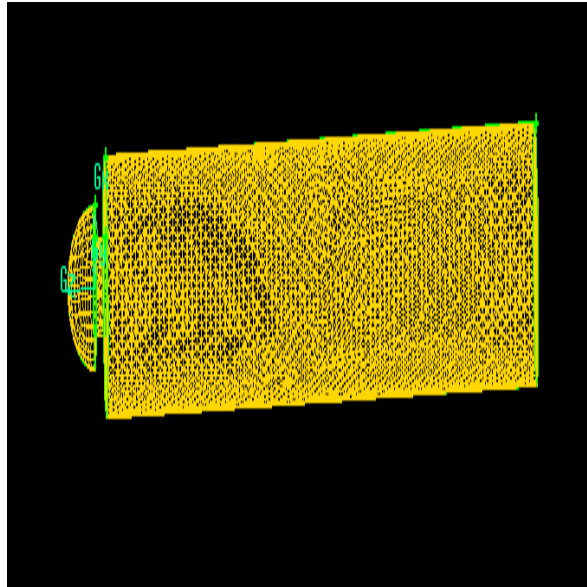


Figure 8. Bubble Atomizer Modeling and Grid Division

On the basis of modeling with Gambit, based on the data obtained from the experiment, the simulation of the best spray working condition is carried out. The simulated working condition is the gas pressure 0.4MPa water pressure 0.8MPa. The simulation diagram of velocity distribution and component distribution of the inner flow field of the nozzle is given in this paper, and the internal flow field of the bubble atomization nozzle is analyzed.

According to the above criteria, this paper selects the realizable model to simulate the internal flow field of the bubble atomizer. Simple method is used to couple pressure and velocity. The boundary conditions are calculated as follows:

(1) Entrance boundary conditions

Gas inlet speed:

$$v = \frac{Q_a}{S_{ain}} \quad (3)$$

Where Q_A is the volume flow under the standard condition and S_{ain} is the cross-sectional area at the gas inlet. V is the liquid inlet speed.

$$v = \frac{Q_w}{\rho S_{win}} \quad (4)$$

Where Q_w is the mass flow of the liquid, ρ is the density of the liquid, and S_{win} is the cross-sectional area of the liquid inlet.

The hydraulic diameter h on the inlet boundary is calculated as follows:

$$H = \frac{4A}{x} = 4R_h \quad (5)$$

Where x is the perimeter of the contact surface and R_h is the hydraulic radius.

The turbulence intensity I is calculated as follows:

$$I \cong 0.16(\text{Re}_{DH})^{-1/8} \quad (6)$$

Where re is the inlet Reynolds number and the temperature is room temperature.

(2) Exit boundary conditions

Because the environment at the nozzle exit is complex, the simulation is simplified. Outlet boundary positioning nozzle

The outlet section of is set as a pressure type outlet, and the outlet pressure is one atmospheric pressure.

(3) Wall boundary conditions

The solid wall adopts the conditions of no velocity slip and no mass penetration. In order to ensure the accuracy of calculation and avoid too fine mesh division near the wall, the mature wall function is used to simulate the influence of the wall on the flow field. The bottom boundary layer of the cylinder in the mixing chamber is defined as the pressure inlet, and the bottom boundary layer of the cylinder near the nozzle is defined as the pressure outlet.

4.2. Pressure Distribution (unit: MPa)

Through the numerical simulation method, the pressure distribution in the mixing chamber is studied, and the simulation results of the pressure distribution in the mixing chamber are selected, which are 0.8MPa for water pressure and 0.4MPa for air pressure.

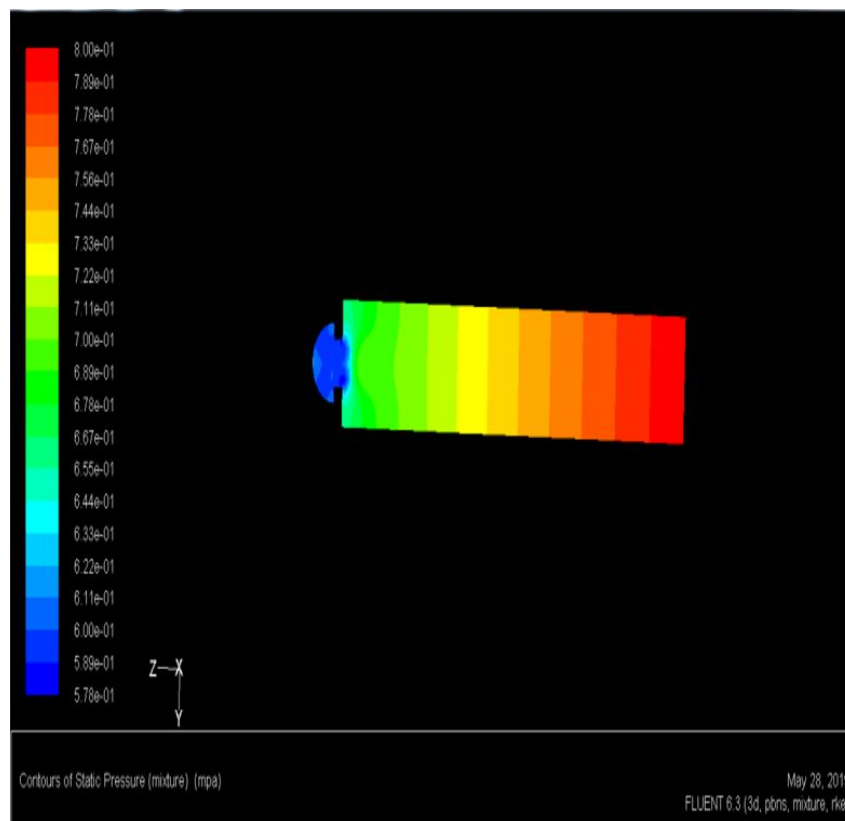


Figure 9. Pressure Distribution of $x = 0$ section

From the figure, we can see that the pressure in most areas of the mixing chamber is very close to 0.8MPa, and there will be a gradual decrease from 0.8MPa at the connection between the mixing chamber and the nozzle outlet, which is consistent with Bernoulli's law in hydrodynamics.

4.2.1. Two Phase Flow Distribution. The bubble atomizer is a typical two-phase flow nozzle. The mixing of two-phase flow in the mixing chamber has a great influence on the atomization characteristics of the nozzle. However, it is very difficult to observe the two-phase distribution in the mixing chamber of the nozzle during the experiment. Therefore, it is necessary to study the distribution of two-phase flow in the mixing chamber of the bubble atomizer by using the numerical simulation method And feasible research methods. Fig. 3.3 and Fig. 3.4 are the simulation results of the two-phase flow distribution of $x = 0$ section in the mixing chamber

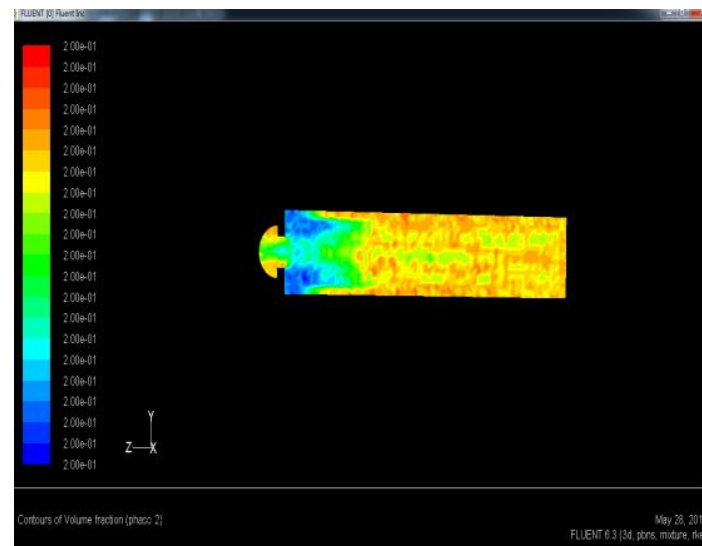


Figure 10. Nitrogen volume distribution

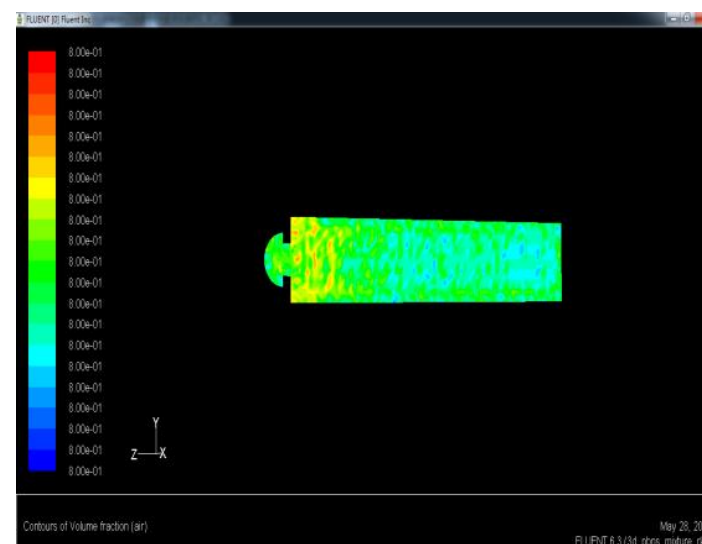


Figure 11. Water volume distribution

From the figure, we can see that in the mixing chamber of the nozzle, water is mainly concentrated in the center, while gas is surrounded, which is also consistent with the test situation. The volume fraction of indoor water varies from 9.29% to 10.77%. From this, we can get that the mixing condition of the two-phase fluid in the mixing chamber is relatively uniform, and the difference between the minimum liquid content and the maximum liquid content ranges from 1.43% to 1.59%. Due to the gravity effect, the liquid content at the bottom of the mixing chamber is more than that at the upper part; because the two-phase flow enters the mixing chamber in the form of swirl injection, the gas content at

the center of the mixing chamber is more than that around the mixing chamber due to the influence of swirl. The relatively uniform two-phase flow distribution in the mixing chamber is very helpful to improve the atomization quality of the nozzle. In addition, the two phase flow in the mixing chamber is symmetrically distributed along the central axis. The uniform distribution of the symmetry can improve the uniformity of the spray particle size, concentration and velocity distribution in the external flow field of the nozzle.

4.2.2. Velocity Distribution. It is very important for us to study the velocity distribution of two-phase flow in the mixing chamber of bubble atomizer by numerical simulation. At the same time, the velocity at the nozzle outlet can be obtained by simulation, and then compared with the experimental results in the previous chapter. Figures 12 and 13 show the simulation results of two-phase flow velocity distribution in the mixing chamber.

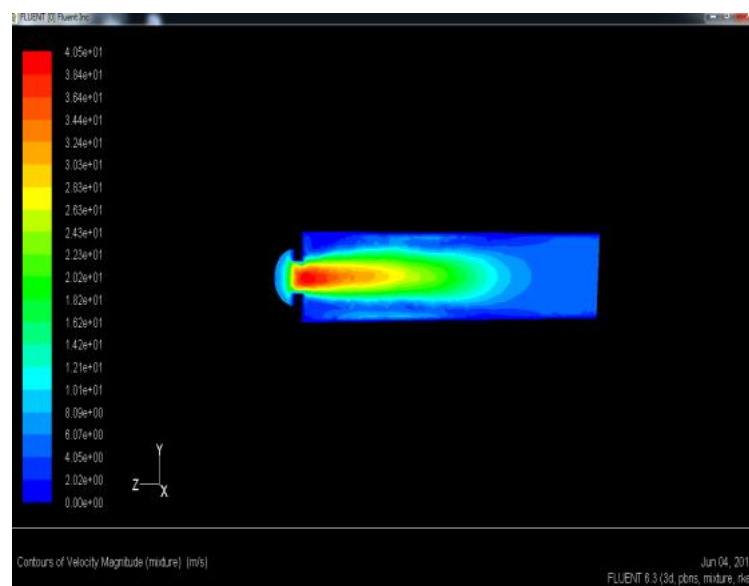


Figure 12. X = 0 section velocity distribution

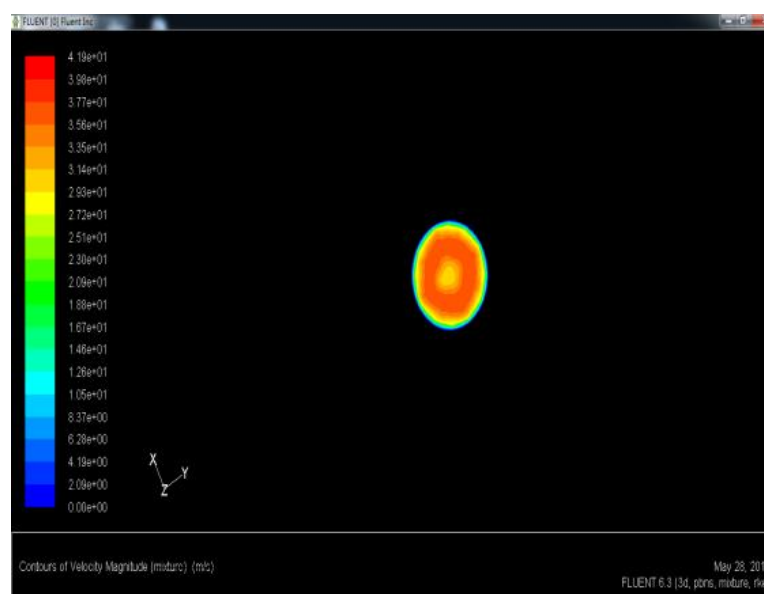


Figure 13. Z = 0 section velocity distribution

It can be seen from Fig. 3.5 that the speed change range of two-phase flow in the mixing chamber is 0-41.9m/s, and the minimum value of two-phase flow speed in the mixing chamber is concentrated in the central area of the mixing chamber, which is determined by the way of two-phase flow entering the mixing chamber. Since the way of two-phase flow entering the mixing chamber is swirl, a region with smaller speed will be formed in the center of the mixing chamber. In order to express the effect of swirl injection mode on the velocity distribution in the mixing chamber more intuitively, the velocity distribution on the cross section $x = 0$ of the mixing chamber model is intercepted in this paper. From figure 13, we can see that the liquid phase velocity at the center of the same section in the hemisphere is the highest, and the velocity value decreases gradually with the increase of radial distance. The velocity vector distribution curve along the X axis in Fig. 3.5: it can be seen that the maximum velocity of two-phase flow in the mixing chamber both appears at the nozzle and is very close to the measured velocity of the spray center at the 20mm exit of the nozzle, and the error is within the range of 5%, which further verifies the accuracy of the experiment. It can be seen that the trend of droplet velocity dis

tribution is consistent with the experimental results. Therefore, the correctness of the experimental results is further verified and the reliability of the experimental results is increased.

5. Conclusion

Through the analysis of the simulation results, it is found that:

1. Under the same air pressure hydraulic ratio, the effect of extinguishing fire with holes in the middle of nozzle is better than that without holes.
2. When there is a hole in the middle of the nozzle, the air pressure is less than the water pressure, and the air pressure water pressure ratio is less than 0.3-0.4mpa, the fire extinguishing effect is better.
3. When there is no hole in the middle of the nozzle, the air pressure is greater than the water pressure, and the air pressure water pressure ratio is greater than 0.1MPa, the fire extinguishing effect is better.
4. When the number of air inlet rows is a single variable, the fire extinguishing effect of four rows is slightly better than that of two rows.
5. Different nozzle structures have a great influence on the atomization effect of the bubble atomizer.

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