Optimal Design and Flow-field Simulation of a Dual Fluid Atomizer

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Abstract. Two-dimensional turbulent flow-field properties of two types of dual fluid atomizers which are currently popular in the market were numerically simulated and studied by using the commercial fluid dynamics software FLUENT. The present paper summarized their atomization characteristics respectively after studying the distribution rules of internal pressure, streamline and turbulent kinetic energy of the two kinds of dual fluid atomizers at different air flow rates. Finally, the conclusion was reached that the water absorption of the Type B atomizer is better than that of the Type A atomizer, but the secondary atomization effect of the Type B atomizer is not as good as the Type A’s.

1. Introduction

Atomizer is used in modern life and industry widely [1, 2]. There are two kinds of atomization processes in dual fluid atomizers, one is primary atomization where the liquid becomes droplet or irregularly shaped liquid through the porous medium; the other is secondary atomization where droplets are further broken into smaller ones by the high-speed gas [3, 4]. It should be noted that there is less detailed research for inside flow of the dual-fluid atomizer.

The numerical simulations of the two kinds of dual fluid atomizers were carried out in this paper to figure out their distribution laws of pressure, streamline and turbulent kinetic energy respectively. Their own atomization characteristics were also compared and summarized.

2. Working principle and physical model of dual-fluid atomizer

The model of the two dual-fluid atomizers are shown in Figure 1. The structure mainly includes five parts: inlet pipe, orifice (throttle unit), porous medium, water-receiving casing and outlet pipe. The working principle is that compressed air enters from the inlet pipe and passes through the orifice, then it forms negative pressure in the porous medium, and generates pressure difference using the external atmospheric pressure, thereby inhaling water generates primary atomization through the porous medium. Then the secondary atomization occurs when droplet is separated from the porous medium and crushed by high-speed air, and the pulverization effect is better thanks to the vortex.

This paper simulates a simplified model of the dual fluid atomizers using ICEM. The hybrid mesh which is mainly quadrilateral mesh is adopted, and the total number of grids is 3273 and 2705 respectively. The computational fluid domain and the mesh of the two-type atomizers are shown in Fig.2.
3. Mathematical model

Regardless of heat exchange this paper assumes that the fluid is incompressible, then two kinds of three conservation laws, namely mass conservation and momentum conservation can be written as following:

Mass conservation equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$  \hspace{1cm} (1)

Where: $u$, $v$, $w$ is the speed component in the direction of the $\vec{u}$ velocity component, $m/s$.

Momentum conservation equation:

$$\frac{\partial (\rho u)}{\partial t} + \text{div}(\rho u U) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} \frac{\partial \tau_{zx}}{\partial z} + F_x$$  \hspace{1cm} (2)

$$\frac{\partial (\rho v)}{\partial t} + \text{div}(\rho v U) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} \frac{\partial \tau_{zy}}{\partial z} + F_y$$  \hspace{1cm} (3)

$$\frac{\partial (\rho w)}{\partial t} + \text{div}(\rho w U) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{zx}}{\partial x} \frac{\partial \tau_{zy}}{\partial y} \frac{\partial \tau_{zz}}{\partial z} + F_z$$  \hspace{1cm} (4)

where $p$ is the fluid pressure, $\tau_{xx}$, $\tau_{xy}$, $\tau_{yx}$, $\tau_{yy}$, $\tau_{zx}$, $\tau_{zy}$, $\tau_{zz}$ is the stress component of the viscous stress, $\rho$; $F_x$, $F_y$, $F_z$ is physical strength, if all the physical forces in the micro-body are only gravity, and the $z$-axis is vertical, then there is $F_x = F_y = 0$, $F_z = -\rho g$. 

Figure 1. Physical structure of double fluid atomizer (half cut)

Figure 2. Computational domain and mesh
4. Simulation results and discussion

4.1. Type A atomizer

4.1.1. Pressure distribution of the Type A atomizer. The atomization effect can be adjusted by changing the air flow rate for a dual fluid atomizer. The pressure cloud diagrams inside the Type A atomizer are presented as shown in Fig. 3. It can be found that the pressure drops significantly after the orifice and the negative pressure value increases significantly as the air flow rate increases as shown in Fig. 3(a), Fig. 3(b), Fig. 3(c) and Fig. 3(d). The negative pressure is almost evenly distributed in the outlet pipe with the air flow rate is 10 m/s, 40 m/s and 70 m/s in Fig. 3(a), Fig. 3(b) and Fig. 3(c), but the lower negative pressure is almost distributed in the outlet in Fig. 3(d) with the air flow rate is 100 m/s.

![Pressure diagrams of the Type A atomizer under different air flow rates](image)

**Figure 3.** Pressure diagram of the Type A atomizer under different air flow rates

4.1.2. Internal streamline and turbulent kinetic energy of the Type A atomizer. The dual fluid atomizer generates vortex at the outlet pipe due to the orifice. The vortex makes the distance of the droplet moving in the outlet pipe longer, so the droplet is easily broken into smaller droplets, so that the atomization quality gets better. It can be seen that the vortex increases with the increase of air flow rate 10 m/s and 40 m/s by comparing Fig. 4(a) and Fig. 4(b). The vortex area does not change much at air flow rates of 40 m/s, 70 m/s and 100 m/s by comparing Fig. 4(b), Fig. 4(c), and Fig. 4(d), while the vortex intensity becomes significantly stronger. It means an increase in the quality of the atomization.
Figure 4. Streamline of the Type A atomizer under different air flow rates

The magnitude of vortex strength can also be represented by turbulent kinetic energy. It can be seen that the vortex is mainly concentrated at the wall of the outlet pipe, and the turbulence intensity and area increase with the increases of the air flow rate by comparing Fig. 5(a), Fig. 5(b), Fig. 5(c) and Fig. 5(d).

Figure 5. Turbulent kinetic energy diagram of the Type A atomizer under different air flow rates

4.2. Type B atomizer

4.2.1. Pressure distribution of the Type B atomizer. The pressure cloud diagrams inside the Type B atomizer is shown in Fig. 6 when the air flow rate is 10m/s, 40m/s, 70m/s, 100m/s. It can be found that the negative pressure of the Type B atomizer is almost concentrated on the pipe wall, and the negative
pressure area hardly changes as the air flow rate increases by comparing Fig. 6(a), Fig. 6(b), Fig. 6(c) and Fig. 6(d).

![Pressure diagram of the Type B atomizer under different air flow rates](image)

**Figure 6.** Pressure diagram of the Type B atomizer under different air flow rates

4.2.2. *Internal streamline and turbulent kinetic energy of the Type B atomizer.* It can be seen that the vortex area of the Type B atomizer is mainly concentrated near the central axis of the outlet pipe, and the vortex area does not change much as the air flow rate increases by comparing Fig. 7(a) and Fig. 7(b), Fig. 7(c) and Fig. 7(d).

![Streamline of the Type B atomizer under different air flow rates](image)

**Figure 7.** Streamline of the Type B atomizer under different air flow rates

It can be seen that the vortex is mainly concentrated at the axis of the outlet pipe. And the turbulent flow area becomes smaller as the air flow rate increases, and the secondary atomization effect becomes worse by comparing Fig. 8(a), Fig. 8(b), Fig. 8(c) and Fig. 8(d).
Figure 8. Turbulent kinetic energy diagram of the Type B atomizer under different air flow rates

5. Conclusion
Firstly the Type B atomizer has better water absorption than the Type A atomizer. The negative pressure area of the Type B atomizer is concentrated on the pipe wall, while the negative pressure of the Type A atomizer is almost evenly distributed in the outlet pipe. Secondly the Type A atomizer is superior to the Type B atomizer in the secondary atomization. Water is mainly concentrated near the wall of the outlet pipe when it is absorbed into the porous medium. The vortex area of the Type A atomizer is almost near the wall of the outlet pipe, while Type B’s is near the center line of outlet pipe. Therefore, this paper suggests that Type A atomizers can be adopted for the senior need of secondary atomization; Type B atomizers can be adopted for the senior need of water absorption.

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