Numerical Study on the Effects of Ambient Air Pressure on Water Mist Characteristics

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Abstract

The effects of ambient air pressure on water mist characteristics were investigated with CFD code FDS6.0. The cases with ambient air pressures of 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, 2.5 and 3.0 atm, and water mist operating pressure of 1.5 MPa were considered in the numerical simulation, while the validation experiments were conducted with a single orifice nozzle at normal ambient pressure by using a LaVision Particle-Master Shadow system. The results show that the Sauter mean diameter ($D_{32}$) of water mist decreased and the droplet velocity increased with the decrease of the ambient air pressure in the same location within the spray. Spray contraction phenomenon occurred where the contraction locations were different under different ambient pressures. Some of the results should be helpful for optimising the water mist fire suppression system.

Keywords: CFD; Two phase flow; Water mist characteristic; Ambient pressure

1. Introduction

Water mist as a clean and efficient fire extinguishing agents has been received considerable attention and widely used in practical applications. The mechanisms of fire extinguishment have been widely studied through the experiments and the numerical simulation in the past years [1-4]. They found that the water mist characteristics, such as droplet size, droplet velocity, spray cone angle, mist momentum and flux are the key factors which affects the fire extinguishing efficiency. The applications of water mist system are not limited to normal atmospheric pressures, such as under low ambient pressure in the high altitude areas, while the water mist characteristics may be influenced by ambient pressure. Most of the previous studies [6-8] had been focused on the fuel spray behavior and atomization characteristics affected by ambient pressure. However, little work has been performed focusing on the effects of ambient pressure on water mist. Cai et al. [9] experimentally investigated the effects of low ambient pressures on spray cone angle, spray flux density and flow coefficients, but did not include droplet size and velocity.

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In present study, we don’t consider the atomization process of the spray, but only focus on spray characteristics of the far-nozzle region affected by ambient pressure. A number of studies [2-5] had been used CFD code, known as FDS to model water mist systems. The above studies indicated that the new version of FDS had been improved for predicting water mist. So the effects of ambient air pressure on water mist characteristics were investigated with FDS6.0 due to the limit of experimental conditions.

2. Model Description

The FDS code (svn revision 17534) was used in this study. The governing equations and solution methods for the gas phase are described in the FDS Technical Reference Manual [10] and will not be repeated here. FDS uses Large Eddy Simulation to describe the turbulent motion of the gas phase and Lagrangian description of the dispersed phase. It is a typical two phase flow process for water mist from a nozzle injecting into quiescent gas phase. The turbulent model of Dynamic Smagorinsky model was used in the current simulation, but didn’t consider the Secondary breakup model. Particle Transport model in the Gas Phase, the evaporation model, and the Drag Reduction model had been described in the FDS Technical Reference Manual [10] and will also not be described here.

3. Single orifice nozzle experiment and simulation parameters

Characterization experiments of a single orifice nozzle by a LaVision Particle-Master Shadow system were conducted at normal ambient pressure, as shown in Fig.1. The measurement points were located at 0.5 m below the nozzle, and the results were shown in Table 1. Fig. 2 shows the computational domain with $0.5 \times 0.5 \times 2.0$ m, whose sides are open. The nozzle was placed at the center and 1.5 m high, the measurements were taken along the radial locations 0.5 m and 1.0 m below the nozzle. Ambient temperature was 20°C. The final FDS simulation parameters including mesh size $\Delta x$ of 0.01m, droplets per second inserted to domain of $1.5 \times 10^5$, offset parameter $R$ of 0.05m were obtain through a series of sensitivity study. A user defined cumulative number fraction (CNF) based on experiment data was used to describe the droplet size distribution. Fig. 3 shows droplet CNF distributions and droplet axis velocity. Then the cases with ambient pressure of 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, 2.5,3.0 atm, and operating pressure of 1.5 MPa were numerically simulated.

<table>
<thead>
<tr>
<th>Test codes</th>
<th>Operating pressure (MPa)</th>
<th>$D_{50}$ ($\mu$m)</th>
<th>$D_{32}$ ($\mu$m)</th>
<th>Spray angle (Degree)</th>
<th>Flow number (L/min/MPa$^{0.5}$)</th>
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</thead>
<tbody>
<tr>
<td>Case1</td>
<td>0.5</td>
<td>114</td>
<td>88</td>
<td>22</td>
<td>0.33</td>
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<tr>
<td>Case2</td>
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<td>87</td>
<td>65</td>
<td>21</td>
<td>0.31</td>
</tr>
<tr>
<td>Case3</td>
<td>2.5</td>
<td>58</td>
<td>53</td>
<td>20</td>
<td>0.316</td>
</tr>
</tbody>
</table>

Table 1. Nozzle characterization at normal ambient pressure

Fig. 1. Experiment facility

Fig. 2. Physical model

Fig. 3. Droplets CNF distributions and droplet axis velocity by FDS and Experiment
4. Results and discussion

4.1 The effects of ambient pressure on droplet velocity

Fig. 4 shows the distribution of time-averaged droplet velocity per cell at the plane of Y=0. It can be seen that with the increase of ambient pressure, the droplet velocity will obviously decrease as a whole. In addition, with the increase of ambient pressure, more droplets concentrate near the nozzle and the velocity of the droplet far from the nozzle is relatively small. Fig. 5 (a) and (b) show the radial distribution of droplet velocity 0.5 m and 1.0 m below the nozzle. Fig. 5 (c) shows the variation of droplet velocity in the center of the spray 0.5 m and 1.0 m below the nozzle under different ambient pressures. It can be found that the droplet velocity decreases rapidly under the relative small ambient pressures, such as lower than 1.5 atm, but with further increase of ambient pressure, this reduction trend becomes not obvious. The interpretation about these is that with increase of ambient pressure, the air density will increase, such as from 0.236 kg/m³ of 0.2 atm to 3.595 kg/m³ of 3.0 atm, and which will lead the increase of aerodynamic force between gas phase and liquid phase.

4.2 The effects of ambient pressure on droplet size

Fig. 6 shows the distribution of the time-average droplet size (D_{32}) per cell within the plane of Y=0, and Fig. 7 gives the radial distribution of D_{32} and its variation under different ambient pressures. From Fig. 6 and Fig. 7, it can be seen that the droplet size obviously decreases with the decrease of ambient pressure, and there is an obvious contraction phenomenon under different ambient pressures. The position of contraction point varies with the increase of ambient pressure. It can also be found that D_{32} was large near the contraction point but it will first increase and then decrease for relative large ambient pressures in radial. The reason is that with the increase of ambient pressure, the droplet velocity will decrease due to
the effects of Drag force, which is relative large for large droplet. For different ambient pressures, the droplet velocity reached the balance value at different position. So the droplets will first gather at different position which will lead the contraction of spray, and the large droplets will concentrate near these positions.

Fig. 7. The radial distribution of $D_{32}$ (a)0.5 m, (b)1.0 m below nozzle and (c) variation of $D_{32}$ with ambient pressure

5. Conclusions
A numerical simulation approach based on FDS code has been used to investigate the effects of ambient pressure on water mist characteristic. Following conclusions can be drawn:
(1) The experimental results of a single orifice nozzle at normal ambient pressure were in good agreement with the simulated results.
(2) The simulated results under different ambient pressures showed that the Sauter mean diameter ($D_{32}$) decreased and the droplet velocity increased with the decrease of ambient pressure. There was a spray contraction phenomenon under different ambient pressures, while the contraction point will move toward to the nozzle with the increase of ambient pressure.

The future work will focus on the effects of ambient pressure on mist droplet number density and mist flux and some experimental investigations.

References