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NOZZLE DIAMETER INFLUENCE ON SPRAYCHARACTERISTICS IN A CONSTANT VOLUME COMBUSTION CHAMBER

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ABSTRACT

The effect of nozzle diameter on spray characteristics including spray penetrations, core angle (far field) and Sauter mean diameter (SMD) were investigated in a constant volume combustion chamber. The nozzle diameter at the time of fuel injection were set to 0.20mm, 0.18mm, 0.14mm. Results indicate that penetration length reduces with the decrease of the nozzle diameter from 0.20mm to 0.14mm. However, they have little effect on core angle and the variation of core angle is less decreased at three conditions. In the process of spray development, spray penetrations show a linear growth before they keep a relatively stability value. The far-field spray cone angle shows a first suddenly enlarging and later maintains a constant value, but the results are affected by measurement mode. SMD suddenly decrease and later keep a constant value.

Keywords: Nozzle diameter, Penetration length, SMD, Core angle.

1. INTRODUCTION

Researches on spray and combustion in diesel engines are recently receiving more attention due to China attaches importance on environment protection and energy strategies, and takes more and more rigorous requirements on energy conservation and emission reduction. It has carried on a lot of researches including experiment, computer simulation and control. Nozzle diameters affect directly spray and cavitation effect, and attract more attention. Spray characteristics and the air–fuel mixing process influent combustion and emission processes of diesel engines. High injection pressure and little nozzle diameters are the inevitable trend of diesel engines development, and there are less investigations at the condition of high injection pressure and little nozzle diameters. For this reason, numerical study on the effect of different diameters on spray penetrations, core angle and SMD.

Under very little nozzle diameters, the change of nozzle diameters effect on the spray characteristics. With the increase of nozzle diameter, spray penetrations show a linear growth. The effect of nozzle diameter on the far-field spray cone angle is larger than on the near-field spray cone angle [1]. Woon Phui Law al studied a computational fluid dynamics (CFD) simulation of a partial combustion lance (PCL) aiming to evaluate the effect of nozzle design on its performance. The findings from this work may be useful for design retrofits of a PCL [2]. The influence of structure factor of pressurized-swirl injector nozzle on hollow cone spray was studied. When the nozzle diameter increases from 0.5 mm to 1 mm, the factors such as ratio of injector nozzle length to diameter, coordination of shape of nozzle and needle at the nozzle entrance, nozzle shape at nozzle exit are the important factors that influence the spray characteristic of pressurized-swirl injector [3].

The paper applied diesel as a raw, used ICEM to build a constant volume combustion chamber model, calculated spray penetrations, core angle and SMD at different nozzle diameters, then compared and analysed the results.

2. MODEL ESTABLISHMENT AND VERIFICATION

2.1 Establish geometric model

The paper uses a constant volume combustion chamber model to simulate. Fig 1 presents the geometry which is employed in this work has a cylindrical shape with 100 mm diameter and 100 mm length, so the volume of chamber is 785000mm^3. And only one orifice for focusing on spray characteristics which locates on the center of cylinder top. The length of nozzle in the chamber is 0.5mm. Fig 2 presents meshing model of the research field which is divided by ICEM. Mesh is hooks and the 40mm×40mm center region is encrypted, the sum of mesh is 300000.

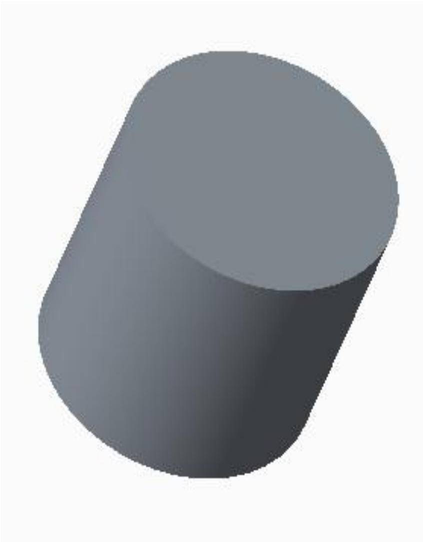

Figure 1. Combustion chamber structure

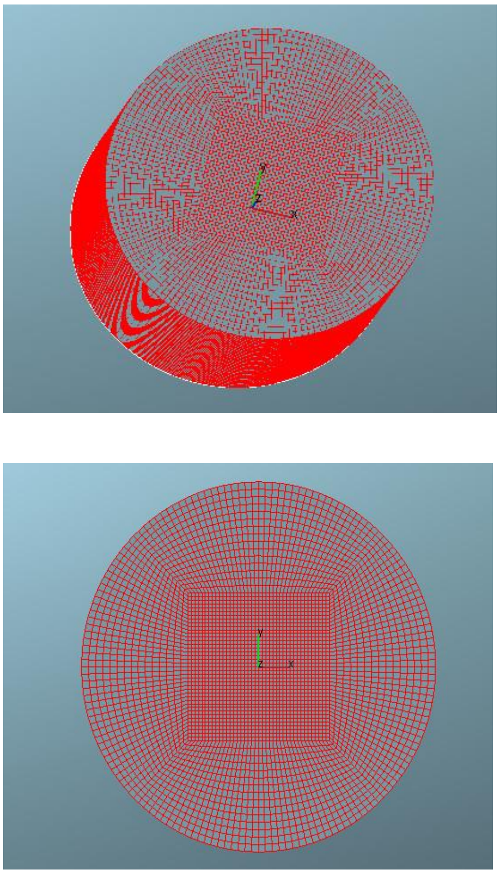

Figure 2. Combustion chamber mesh

2.2 Boundary conditions

Main parameters: fuel diesel, ambient pressure 5MPa, ambient temperature of constant combustion chamber 683K, ambient density 25.51kg/m^3, fuel temperature 293K, injection pressure 120MPa, injection timing in engine 2.5ms, calculation time 5ms[4]. Three diameters used are 0.14mm, 0.18mm and 0.20mm. The calculation equation of pressure difference △p and injection velocity U_{jet} is given by[5]

$$U_{jet} = \frac{4Q_f}{\pi N_{noz}\rho_f \Delta t_{inj} d_0^2} \quad (1)$$

$$\Delta \mathrm{p} = \frac{\rho_f U_{jet}^2}{2C_d} \quad (2)$$

Where Q_f is fuel quantity supplied each circle, d_0 is nozzle diameter, N_{noz} is the number of nozzle, ρ_f is fuel temperature, $\triangle t_{inj}$ is injection timing in engine, C_d is flow coefficient which is related to the parameter of nozzle and selected from 0.6~0.8.

In the paper, the number of nozzle N_{noz} is one, fuel density is 852kg/m^3, injection timing in engine is 2.5ms, flow coefficient can select 0.7. According to two equations, receiving U_{jet} 363.7m/s and fuel quantity supplied 1.19×10^{-5}kg, 1.97×10^{-5}kg and 2.24×10^{-5}kg.

2.3 Mathematical model and model validation

The turbulence model adopts K-epsilon which is commonly used, but will take much time. Wave is used to calculate the process of spray break-up of droplets which is the most common model for secondary break-up, analyzing unstable growth along the axial direction of spray on the field of air and liquid intersection. When the unstable amplitude is more than critical value, droplets start to break. O'Rourke model simulates the process of droplets coalescence, which not only can reduce the timesteps of spray calculation, but also ensure the new droplets' location and velocity whose distribution is given by Gauss formula:

$$\sigma_{u'}^2 = \sigma^2 \frac{1-e^{-D_p t_{turb}}}{1+e^{-D_p t_{turb}}}\left[1-e^{-2D_p \delta t}\right] \quad (3)$$

$$\sigma_{x'}^2 = \frac{\sigma_{u'}^2}{D_p^2} + \sigma^2\left[t_{turb}.\Delta t - \frac{2t_{turb}}{D_p}\left(1-e^{-D_p \delta t}\right)\right] \quad (4)$$

If this model can not reduce the timesteps, but it can shorten calculation time validly when turbulence time tturb is very small. Evaporation model is Splading model which ignores the internal temperature and concentration gradient, and ratio of thermal diffusion and mass diffusion coefficient Lewis is 1. After setting by FIRE, the result shows as Fig 3 and makes a compare with the result of spray shape shown as Fig 4 [5].

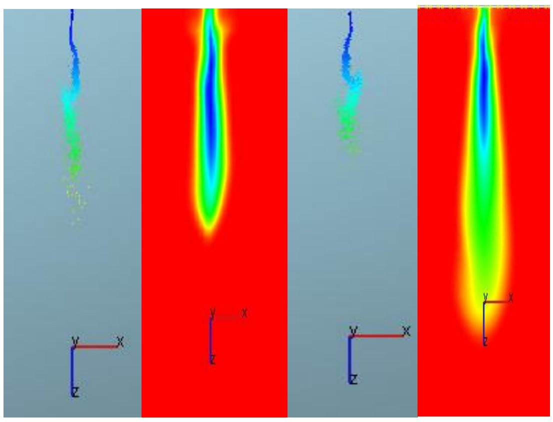

Figure 3. Spray shape from simulation

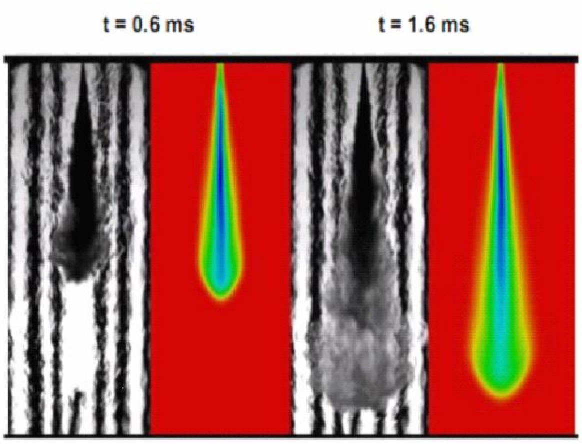

Figure 4. Spray shape from reference

Figure 3 shows the spray shape at the time 0.6ms and 1.6ms, and the second and forth represent temperature distribution in the constant combustion chamber, which is similar with reference and the model established is appropriate.

3. RESULTS AND DISCUSSIONS

The parameters of spray characteristics was received by the file of FIRE. The penetration length and core angle are refined as Fig 5[6]. Distance between nozzle hole and spray front is refined penetration length that is represented by S. The far-field spray cone angle is the angle between two lines enveloping spray leaded from nozzle hole.

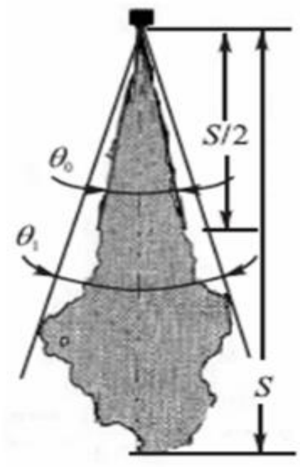

Figure 5. The refinement of spray geometric parameters

3.1 The nozzle diameters effect on penetration length

Fig 6 shows penetration length according to nozzle diameters. Obviously, in a period of time after starting injection, penetration length shows a linear growth and leads to maximum value, then experiencing a little decrease and keep a relatively stability value. The result can be explained that each time of injecting fuel, penetration has a maximum value under the certain pressure. When putting pressure suddenly, penetration length will increase and get maximum. It can also be observed that the larger diameter has larger length at the same energizing time. The length receives maximum at same time after injection. At the larger nozzle diameter, it is poor to make droplet break, flow distance keeping higher droplet density increases. At the other hand, spray kinetic energy and penetration length enlarge when SMD of droplets increase at the beginning of injection.

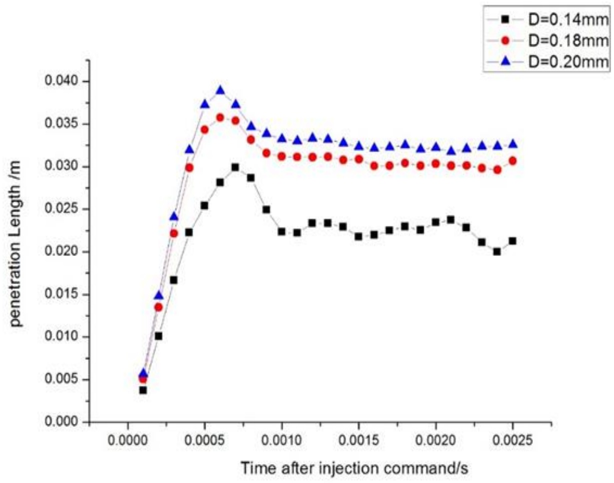

Figure 6. Spray penetration length

3.2 The nozzle diameters effect on SMD

The SMD according to the nozzle diameters are presented in Fig7. It was observed that with fuel injection, SMD decrease suddenly and later keep a constant value. At the beginning of spray, nozzle diameter, ambient pressure and injection pressure affect fuel evaporation characteristics. Then fuel forms small droplets and SMD decrease with existence of droplet break-up, atomization, evaporation. When it decreases a certain value, the velocity of droplet break-up reaches equilibrium with evaporation velocity, then SMD keep a constant value. SMD increase with the increase of nozzle diameters. At the larger nozzle diameter, SMD have larger value before generating break-up and atomization.

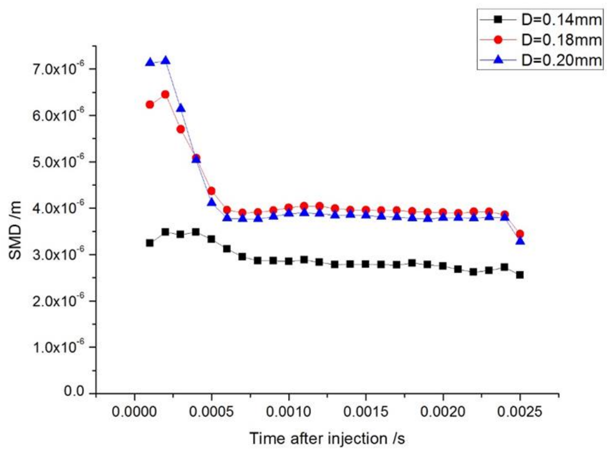

Figure 7. Variety of SMD with injection time

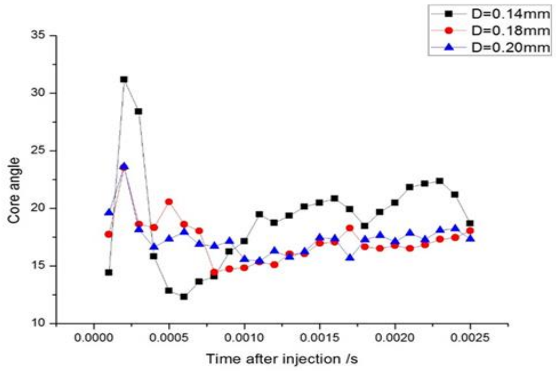

Figure 8. Variety of core angle with injection time

3.3 The nozzle diameters effect on core angle

Spray core angle increases sharply as the energizing time early on, then decreases gradually to a constant value and keep it until the end of injection, as shown in Fig8. Penetration length is lower at the beginning of injection, primary break-up leads to larger radial length which results in larger core angle. With the continuation of fuel injection, penetration length and spray radial length produced by break-up keep a constant value, core angle waves in a narrow range. It was observed that core angle varies among a certain value at different diameters. So nozzle diameters have a lower effect on far-field spray cone angle.

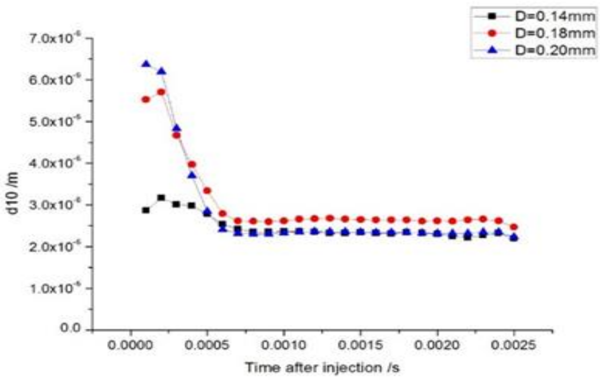

Figure 9. Variety of d10 with injection time

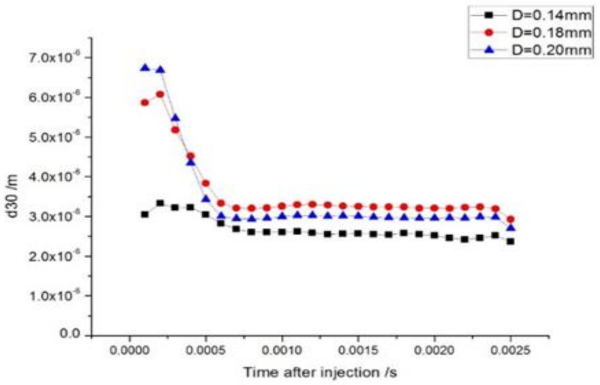

Figure 10. Variety of d30 with injection time

3.4 The nozzle diameters effect on d10 and d30

Fig 9 and 10 shows the d10 and d30 decrease with the increase of injection time and later tend to a constant value. The d10 is defined as arithmetic mean diameter and d30 as volume mean diameter. At the beginning of fuel injection, droplets diameter are decided by boundary conditions, initial conditions and fluid properties. When break-up, atomization and evaporation occur, droplets diameter decrease, and producing much little droplets.

4. CONCLUSION

(1) With the continuation of fuel injection, penetration length increases sharply, then leads to a certain value and keep invariant. When nozzle diameter enlarges, penetration length increases.
(2) The increased nozzle diameters have a relatively little influence on far-field spray cone angle.
(3) For microscopic spray characteristics like SMD, d10 and d30, they appear similarly regular changes, nozzle diameter have larger impact on them originally.

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