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Study on Diesel-Methanol-Water Emulsion Spray in High-Pressure Bomb

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The spray characteristics of diesel-methanol-water emulsion in a constant volume chamber were studied through high-speed photography experiment and the spray penetration and spray cone angle of emulsion in different ambient pressures and injection pressures were measured. The results showed that the spray penetration of diesel-methanol-water emulsion decreased with the increasing ambient pressure, but increased with the increasing nozzle pressure. The spray cone angle increased with the increasing the ambient pressure and the nozzle pressure. Under the same condition, the spray penetration of diesel-methanol-water emulsion was greater than that of diesel, while the spray cone angle was less than that of diesel. Because the viscosity and surface tension of diesel-methanol-water emulsion was greater than that of diesel, emulsion had worse atomization than diesel.

Keywords: High-speed photography, Emulsion, Spray characteristics, Spray penetration, Spray cone angle.

INTRODUCTION

With energy and environmental problem highlight increasingly in recent years, the alternative fuel has widely attracted. This is due to the fact that micro-explosion phenomenon, also termed as secondary-atomization, will happen during emulsion combustion, which could promote combustion and reduce emissions, so it is a kind of ideal alternative fuel with good characteristics and prospect future for the internal combustion engine[1,2]. Diesel-methanol-water (DMW) emulsion is a new kind of oxygenated emulsion fuel which has more advantages of fewer emulsifiers, longer stable phase and higher calorific value than other two-phase oil/water emulsion because of the adding methanol. Therefore, diesel-methanol-water emulsion has come to receive a great deal of attention[3-5]. The application of such emulsion is particularly suitable for regions which are rich in coal but deficient in petroleum because methanol can be made from coal.

Liquid fuel burn only after been atomized, spray characteristics of liquid fuel including spray penetration, spray cone angle and droplet size distribution have an important influence on the combustion and emissions. Many researchers have done a large amount of fruitful work on the spray characteristics of different fuels. Gao *et al*.[6] studied the spray characteristics of biodiesel with different blend ratios using experimental and simulation methods, it is found that the spray penetration and spray speed increase with the decrease of diesel. Lee *et al*.[7] observed the differences of the spray characteristics between alternative fuel LPG, DME and *n*-dodecane in a constant volume chamber under high temperature and high pressure and compared with the spray characteristics of different fuels respectively. Suh *et al*.[8] studied the spray characteristics of DME form macroscopic and microscopic aspect and they get the conclusion that DME has better atomization than conventional diesel under the same conditions. However, in the recent years, the studies of emulsion mainly focus on properties of emulsions, micro-explosion and combustion in the diesel engine, *etc*.[9-12]. There are few reports about the spray characteristics of emulsion. As a kind of emulsion fuel, there must be some differences between diesel-methanol-water and diesel in spray characteristics. Therefore, it is really necessary to study the spray characteristics of diesel-methanol-water emulsion.

In this paper the high-speed photography experiment is conducted to observe the spray process of diesel-methanol-water in a constant volume chamber. The influences of ambient pressure, injection pressure were analyzed and the difference between emulsion and diesel is also compared. So the studies have important theory and application value for diesel-methanol-water emulsion.

EXPERIMENTAL

The experiment uses a high-speed digital video camera to shoot the spray development process of diesel-methanol-water emulsion in a constant volume chamber (CVC) with a diameter of 120 mm quartz glass window. The whole experiment system consists of the injection system, the constant volume chamber, the control system, the high-speed digital video camera and the data acquisition and processing system. The injection system consists of the fuel supply system, speed regulation motor, high-pressure oil pump and fuel injector, *etc*. The rotational speed of the speed regulation motor is set at 550 rpm, a diesel nozzle with a single orifice 0.34 mm in diameter ordered from the manufacturer and the pressure of fuel injector is set to 20 MPa and 13 MPa. The CVC is filled with nitrogen, with the highest pressure at 6 MPa. Because this experiment was conducted at the room temperature (293 K), the influence on spray evaporation of the spray penetration and spray cone angle were negligible. During the experiment, it is needed to implement synchronization of the high-speed CCD camera, single injection pump and data acquisition system. The entire experimental system is controlled by a TP801B type single board computer. The high-speed data acquisition system is the MCDL (The Multi-Channel Data Link) which is the synchronous acquisition with high-speed digital camera system and the sampling frequency and shooting frequency are the same.

In the experiment, diesel-methanol-water emulsion with numbered D70M10W20 was compounded through the ultrasonic emulsification technology. The letters D, M and W represent diesel, methanol and water, respectively and the numbers after letters represent mass fractions of the components. Therefore, D70M10W20 emulsion means that the mass fractions of diesel, methanol and water are 70, 10 and 20 %, respectively. In addition, the emulsifier is compounded prepared by Span 80 and Tween 60.

RESULTS AND DISCUSSION

The pictures of spray process were got at different ambient pressures (0.1, 1.1, 2.1, 3.1 MPa) when the pump speed is 550 rpm and injection pressure is 20 MPa. Due to space limitations in this article only the 4 pictures after injection under different ambient pressure. The influence of ambient pressure on the spray penetration and spray cone angle of D70M10W20 emulsion is analyzed respectively as follow.

As can be seen from the pictures, at the initial time the ambient pressure has little effect on the spray penetration. The reason is that the spray doesn't begin to atomize in the short time after injection and the mixture rate of spray-air is relative low. Therefore, at this moment the spray penetration is mainly influenced by injection pressure. As shown in Fig. 1, the spray penetration of the first picture under different ambient pressure is approximate. With the development of emulsion spray, ambient pressure has more and more influences on the spray penetration. When the ambient pressure is 0.1 MPa, the spray penetration of the second picture (0.5 ms) almost pass the quartz glass window vision. However, when the ambient pressure is 3.1 MPa, the spray pass the quartz glass window vision at the forth picture (1.5 ms).

Fig. 2 shows the spray penetration of D70M10W20 emulsion decreases with the increase of ambient pressure at 0.5 ms after injection and Fig. 3 shows the change of emulsion spray penetration with time under the condition of 3.1 MPa ambient pressure. Through comparison of these two figures we can find that ambient pressure has significant effect on D70M10W20 emulsion spray penetration. The main reason is that, with increase of ambient pressure, ambient gas is denser and creates more drag on spray. This will influence the spray penetration in two ways. Firstly, the momentum transfer between spray and gas is strengthened, thus the dissipation of kinetic energy increases and the spray penetration decreases. Secondly, the entrainment ability of spray is strengthened, which increases the radial development of spray, as a result, spray penetration decreases and spray cone angle increases.

The measured values of D70M10W20 emulsion spray cone angle under different ambient pressures is shown in Fig. 4. It is found that the spray cone angle of D70M10W20 emulsion increases with the increasing ambient pressure. This is mainly because that high ambient pressure makes the surrounding is more dense and creates more drag on the emulsion spray with the increase of ambient pressure and the more drag strengthens the axial expansion of the spray.

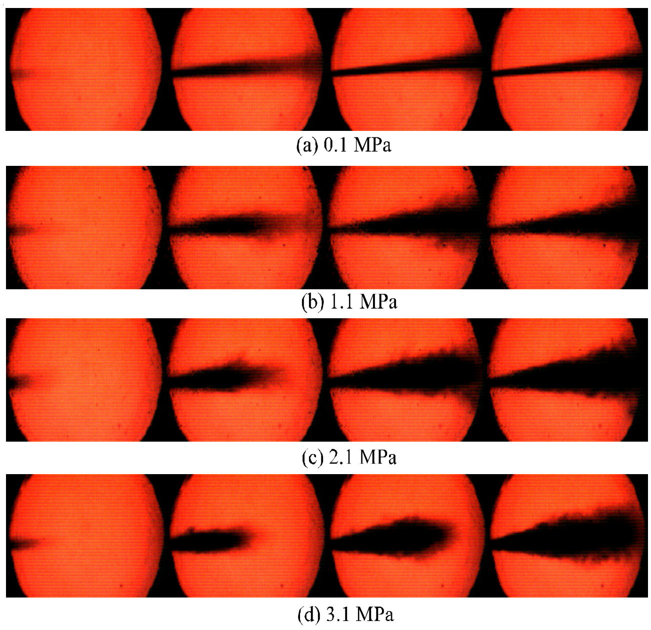


Fig. 1. Spray of D70M10W20 emulsion under different ambient pressures

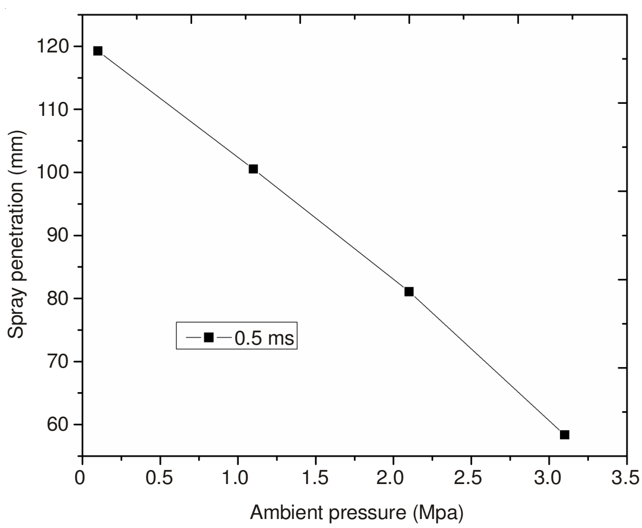


Fig. 2. Change of emulsion spray penetration with ambient pressure

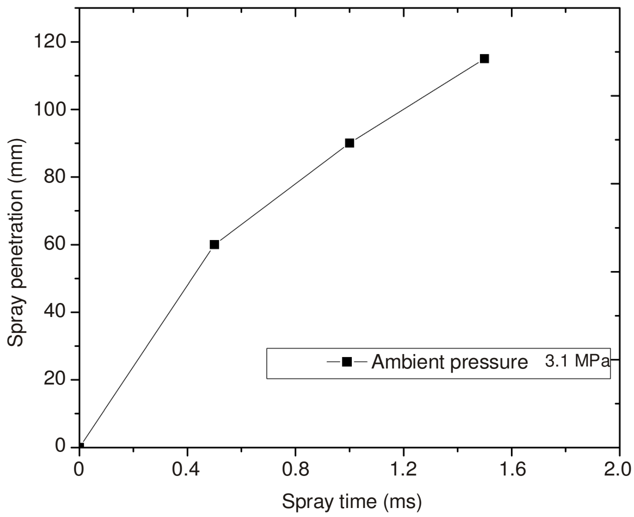


Fig. 3. Change of emulsion spray penetration with time

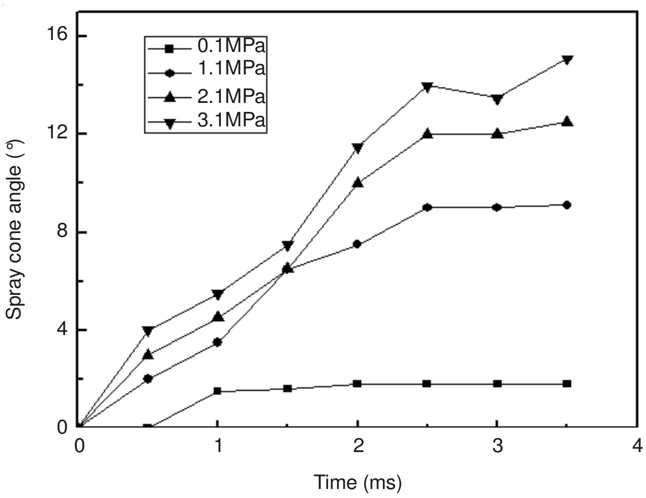
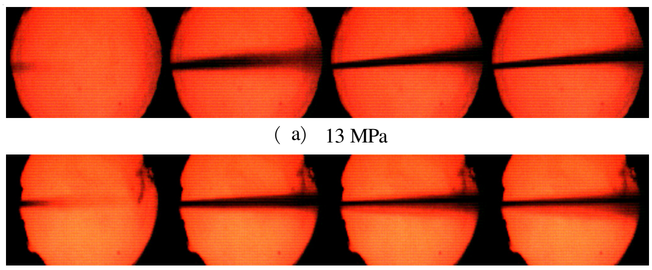


Fig. 4. Spray cone angle of emulsion under different ambient pressures

Influence of injection pressure: Fig. 5 shows the spray when the ambient pressure is 0.1 MPa and the injection pressure is set to 20 MPa and 13 MPa. These pictures illustrate that the spray penetration of D70M10W20 emulsion increases with the increase of injection pressure. The reason is that the initial momentum increases with the increase of injection pressure, thus the spray penetration increases.



(a) 13 MPa

(b) 20 MPa

Fig. 5. Spray of D70M10W20 emulsion under different injection pressures

The measured values of D70M10W20 emulsion spray cone angle under different injection pressures is shown in Fig. 6, it can be seen that the spray cone angle increases at first and then decreases. The main reason is that when emulsion enters into the gas environment, tiny gas pellets begin to move to the spray border. This makes gas entrainment enter into spray and widen the spray, so the spray cone angle increases. When the mix of spray and gas reach a steady period and the spray cone angle decreases a little. When the injection pressure is 13 MPa, the phenomenon is not obvious. The reason is that 13 MPa is lower than 20 MPa, so the entrainment is not so intensity under 20 MPa. Meanwhile, Fig. 6 also shows that the spray cone angle increases with the increase of both the ambient pressure and nozzle pressure. With the increase of injection pressure, the velocity of spray increases and this makes the spray disperse sharply.

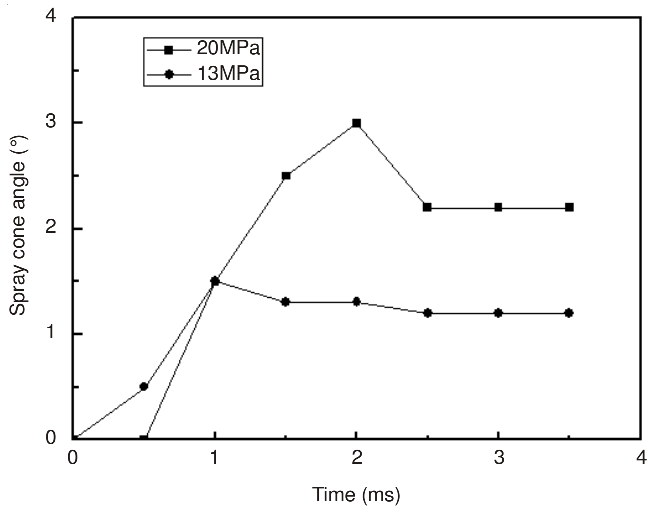


Fig. 6. Spray cone angle of emulsion under different ambient pressures

Comparison with emulsion and diesel: The diesel spray is shown in Fig. 7 under the same conditions of Fig. 5(b). These two groups of pictures are under the same condition except for spray fluid. Fig. 8 compares the spray cone angle between emulsion and diesel. Through the contrast of emulsion and 0# diesel, we can get the conclusion that the spray penetration of D70M10W20 emulsion is longer than that of diesel and the spray cone angle is less than diesel. This is because that the viscosity, density and surface tension of liquid would remarkably affect the spray process. Based on the property analysis[4], the density and surface tension of D70M10W20 emulsion is larger than that of diesel and the viscosity of D70M10W20 emulsion is also four times larger than that of diesel. The higher liquid density, the mass and kinetic energy is higher. This makes emulsion spray broken into droplets more difficultly and spray is not easy to spallation and gasification, thus spray penetration increases and spray cone angle decreases.

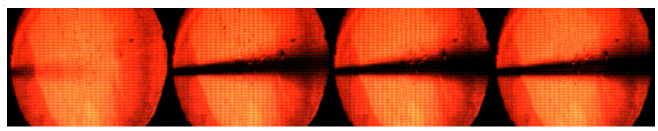


Fig. 7. Spray of 0# diesel

From Fig. 5(b) and Fig. 7, we also find that the concentration of emulsion spray center is higher, while some light spots are barely visible on the inside of diesel spray and maybe it is due to the lower concentration in the center. The cause of the phenomenon is that the viscosity of emulsion is greater than that of diesel, so atomizing effect of emulsion is better than diesel and the larger average diameter of particles make worse transparency. Therefore, for a better atomization, the feature that the atomization of emulsion is worse than that of diesel must be considered and higher injection pressure should be chosen. Due to the spray penetration of emulsion is greater, the emulsion spray wall impingement must be taken into account.

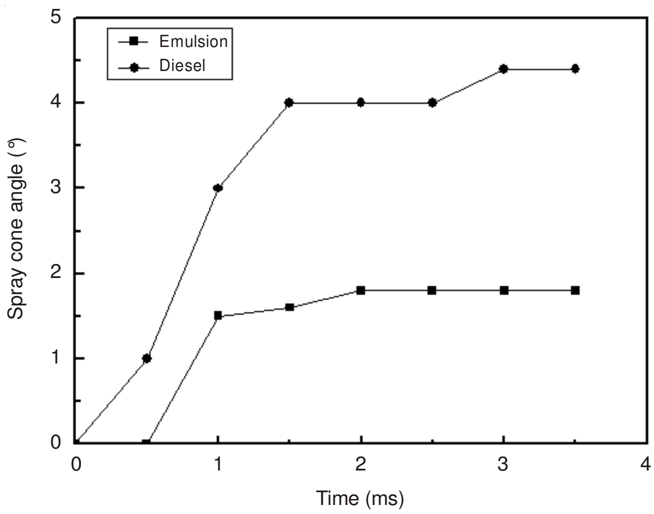


Fig. 8. Comparison with emulsion and diesel on the spray cone angle

Conclusions

Based on the studies of the diesel-methanol-water emulsion spray using high-speed photography experiment, we concluded that:

• In a constant bomb with the increase of ambient pressure, the spray penetration of diesel-methanol-water emulsion decreases, but the spray cone angle increases.

• Both of the spray penetration and spray cone angle of diesel-methanol-water emulsion increase when the nozzle pressure increases.

• Emulsion has worse atomization than that of the diesel because of the difference of the liquid physical properties. Under the same conditions, the spray penetration of diesel-methanol-water emulsion is longer than that of diesel, while the spray cone angle is less than that of diesel.

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