Expansion characteristics of butanol-diesel spray and droplet

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Abstract. Butanol is one of the most promising alternative fuels. This study is conducted focusing on the expansion characteristics of butanol-diesel spray. In this work, a high-speed common rail system is used for generating direct spray, and single droplet of tested fuel is heated, the radial diffusion of the whole spray and the expansion of butanol-diesel droplet are observed and analyzed. Results show that the addition of butanol enhances the radial development of butanol-diesel value, while the addition of butanol would bring a little negative effect on the speed of radial diffusion. Additionally, the addition of butanol makes the deformation of the mixed fuel droplets more intense.

1. Introduction

Nowadays, the most widely used fuel in the transport field is diesel. The used fuel is very closely related to the performance and behavior of working engine. Due to the increasing pressure in decreasing reserve of oil all over the world, as well as the increasing concern about pollution from the use of fossil fuel, finding a new kind of alternative fuel becomes more and more popular among researchers.

Based on the above background, long-chain alcohol, the alcohol with a carbon chain containing four carbon atoms, comes into researchers’ sight. Excellent miscibility with diesel [1] and blending stability [2] make them much more beneficial to be used in existing diesel engines than short-chain alcohols.

In a range of long-chain alcohols, butanol is the one with least carbon atoms on its carbon chain, and it is one of the cheapest kinds of long-chain alcohols. Compared with alcohols with lower carbon atom number (such as ethanol), butanol has higher calorific value, smaller latent heat of vaporization, shorter ignition delay, no need to add emulsifier when mixing with diesel oil, and the blended fuel has better stability. Due to these advantages, a lot of research has been done on the use of butanol in diesel engines [3-5].

Although several studies are conducted focusing on the spray characteristics of blended fuels with butanol as the alternative fuel, seldom study is conducted focusing on the expansion characteristics of butanol-diesel spray. So in this work, the radial diffusion of the whole spray and the expansion of butanol-diesel droplet are observed and analyzed.

2. Experimental setup

Figure 1 shows the experimental system for spray experiments. The experimental system is mainly composed of high pressure common rail injection system and visualized constant volume pressure vessel. The high pressure common rail injection system provides the injection pressure needed in the
experiment. Constant volume pressure vessel is used to simulate the real engine environment by controlling the ambient pressure. The container is made of stainless steel and designed to withstand a maximum back pressure of 16MPa. The environmental pressure in the container is adjusted by supplying nitrogen through a nitrogen cylinder. There are three observation windows with a diameter of 90mm on the wall of the container, and the spray process is captured through the observation window through the optical path system. The optical system is a high-speed photography system based on schlieren method. The light source is an LED lamp, and the light emitted is changed into parallel light through three convex lenses, then passes through the constant volume device and is received by the high-speed camera. Table 1 shows the physics properties of tested fuels.

Table 1. Physics properties of tested fuels.

| Properties                      | Diesel  | BD10   | BD20   | BD40   |
|---------------------------------|---------|--------|--------|--------|
| Density(@15℃, kg/m³)           | 822.043 | 805.753| 798.140| 786.233|
| Viscosity(@40℃, mm²/s)         | 1.365   | 1.243  | 1.173  | 1.110  |

3. Results and discussion

3.1 Maximum width of spray

In previous study, usually the factor used for indicating the radial development of spray is spray cone angle. However, the determination of spray cone angle tends to read the width in a fixed axial plate, e.g. half of spray tip penetration. In this study, the maximum width value of the spray is used for evaluating the radial development of the spray.

As can be seen in figure 2, at the earlier period of spray development, the four test fuels show similar maximum width values. With the further penetrate of the spray, there appears difference. In general, the spray fueled with diesel shows the smallest maximum width. With the addition of butanol, the maximum width value is enlarged. This phenomenon reveals that the addition of butanol enhances the radial development of butanol-diesel value.

The change of fuel properties caused by adding butanol can be used for analyzing this enhancement. As the butanol is added, the fuel density is reduced, as well as the fuel viscosity. Smaller density decreases the initial momentum for the fuel injection, and furtherly makes it harder for the spray to penetrate axially. Instead, the radial diffusion of injected spray is enhanced. At the same time, the fuel viscosity decreased, this change weakens the resistance for the spray radial diffusion given by the fuel itself. Under the effects of the above two changes, the radial development of spray is enhanced, and then the maximum width value is enlarged.
3.2 Axial location corresponding to the maximum width

Figure 3 shows the axial location corresponding to the appearance of the spray’s maximum width. It can be indicated from figure 3 that although the addition of butanol makes it easier for the fuel injection to expand radial during its spray process. However, the axial coordinate seems shows a little enlargement with the addition of butanol.

As we know, if the corresponded axial coordinate value is enlarged, it might be harder for the fuel to reach its maximum radial diffusion. Based on the above analysis, it can be found that the addition of butanol would bring a little negative effect on the speed of radial diffusion.

3.3 Expansion of heated droplet

The single droplets of tested fuels are also heated at 823K, to study the deformation of single droplet during the real spray process. Figure 4 shows the visualization of the process of pure diesel and diesel-butanol mixture, the number directly below each picture is the corresponding time. It can be deduced from this that for pure diesel, there are not many other phenomena in the process except evaporation and combustion. The addition of butanol makes the deformation of the mixed fuel droplets more intense, and expansion and internal liquid and gas injection begin to occur throughout the process.
It can also be seen in figure 4 that for blends with a higher proportion of long-chain alcohol, the injection holes tend to become larger. This is because the evaporation of the internal long-chain alcohol leads to an increase in the volume of gas in the fuel droplets.

4. Conclusions
In this study, butanol is used as alternative fuel of diesel and is mixed with diesel, the volume proportions of butanol in the blended fuels are set as 0%, 10%, 20% and 40%. The direct spray is analyzed, and the heat process of single droplet is observed.

1. With the addition of butanol, the fuel density and fuel viscosity both decreased. Under the effects of the above two changes, the radial development of spray is enhanced, and then the maximum width value is enlarged.

2. In terms of the difficulty of radial development, the addition of butanol would bring a little negative effect on the speed of radial diffusion.

3. The addition of butanol makes the appearance of deformation during the single droplet heat process. Besides, there also appears expansion and internal liquid and gas injection phenomena throughout the process fueled with blended fuels.

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