Experimental study on single droplet evaporation characteristics of Jatropha curcas oil (20%) mixed diesel

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Abstract

Biodiesel is mostly used in combination with diesel for in-cylinder combustion of diesel engines. On the one hand, it can reduce the consumption of diesel fuel, on the other hand, it can reduce the density and kinematic viscosity of biodiesel. In order to explore the evaporation process and mechanism of jatropha biodiesel blended fuel, biodiesel was prepared by alkaline fat exchange method, and the evaporation characteristics of 20% diesel blended with jatropha oil were studied by thermocouple hanging drop technique under different ambient temperatures. The results show that increasing the ambient temperature not only changes the evaporation rate of the droplets, but also increases the heat transfer rate of the environment and droplets. The nucleation and accumulation of bubbles inside the droplets increases the microburst strength and shortens the survival time of the droplets. However, the evaporation rate of the droplets is not inversely related to the lifetime.

Keywords

Jatropha biodiesel, droplet evaporation, puffing, microburst, evaporation rate.

1. Introduction

Energy is a basic requirement for the development of the world economy. However, in the context of increasing global oil resource consumption and global energy shortage, human beings are facing the dual crisis of fossil fuel reduction and environmental degradation. [1-3]。Biomass fuel as a renewable energy source has similar physicochemical properties to diesel, with less environmental benefits such as CO2 and pollutant emissions, and low-cost economic benefits. [4]。Jatropha curcas is a drought-resistant perennial plant [5-7], with strong environmental adaptability, short growth cycle, and seed oil content of 30% to 50%. Compared with diesel, Jatropha oil has higher hexadecane. The value [8] does not require changing engine operation, so it is an ideal alternative fuel. In order to understand the characteristics and mechanism of Jatropha biodiesel cylinders, domestic and foreign scholars have carried out extensive research on Jatropha curcas oil and its blended fuels, including engine performance, combustion emissions, spray atomization, noise vibration and proportion of mixed fuel. *Chetankumar Patel* [9] mixed diesel and Jatropha biodiesel in 5%, 10%, 20%, and 30%. Studies have shown that the use of Jatropha curcas and blended fuels can reduce BTE (brake thermal efficiency) and increase BSFC, but significantly reduce emissions of CO2, HC and soot. The evaporation process and evaporation quality of the fuel directly determine the effect of spray atomization, which in turn affects the ignition, combustion and emission performance of the diesel engine [10]. Therefore, studying fuel evaporation characteristics (including evaporation rate, droplet life) and micro-explosions that may occur during evaporation are critical to improving atomization quality, improving combustion efficiency, and improving engine performance.

In this paper, we will use the drop-drop technique to study the evaporation characteristics of Jatropha biodiesel/diesel blended fuel at ambient temperatures of 573K, 723K and 873K. Therefore, taking JME20 fuel as an example, the evaporation characteristics of droplets at different ambient temperatures, including swelling characteristics, droplet life, average evaporation rate, etc., will be studied to investigate the effect of ambient temperature on droplet evaporation.

2. Fuel preparation and experimental device

2.1 Fuel preparation

Jatropha biodiesel (JME) is prepared by alkaline lipid exchange reaction, which is not only simple and easy to operate, but also ideal for preparation.,Expressed by the general formula as：

$$RCOOR' + R''OH \leftrightarrow RCOOR'' + R'OH \quad (1)$$

The physical and chemical properties of pure diesel and jatropha biodiesel are shown in the table. JME20 refers to 20% of jatropha biodiesel mixed with diesel. The physical and chemical properties of diesel and jatropha oil are shown in Table 1.

Tab. 1. Physical and chemical properties of fuel

Properties	Diesel	JME	Biodiesel Standard ASTM 6751-12
Density (kg/m3)	840	880	860-900
Viscosity	4-5	5-6	1.9-6.0
Cetane number	45-55	50	47
Heating value	45.343	41.6	-
Boiling point (K)	453-603	593-713	-
Flash point (℃)	50	170	130

2.2 Experimental device

Figure 1 is a schematic diagram of the test device, mainly including high temperature heating furnace, hanging drop quartz wire, droplet pushing device, backlight and high speed camera. The droplets were hanged through the 2 μL microsyringe to the end of a 120 μm diameter quartz wire. After the droplet is hung, it is pushed into the focus position of the high-speed camera in the high-temperature heating furnace which has been preheated to the target temperature by the droplet pushing device controlled by the motion law. The droplet pushing device can ensure that the droplets reach the target position at the same time and speed in each set of experiments. In the test, the droplet evaporation process was recorded at 1024×1024 resolution and 500 frames/s shooting frequency using Photron's Fastcam SA4 high-speed camera and Nikon Micro-ED200mmf/4 micro-focus lens.

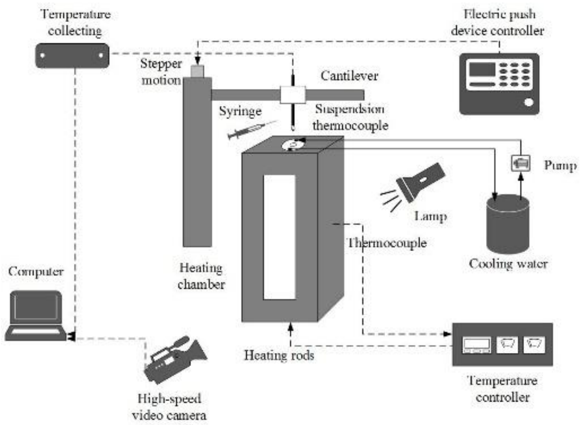

Fig. 1. Schematic diagram of the droplet evaporation experimental apparatus

3. Results and discussion

3.1 Experimental verification

In order to verify the consistency of the test, two repeated tests were performed using JME20 fuel at an ambient temperature of 573 K, and the test results were compared, as shown in FIG. It can be seen that the squared droplet diameters are consistent in the two experiments, the error is negligible, and the evaporation time is basically the same.

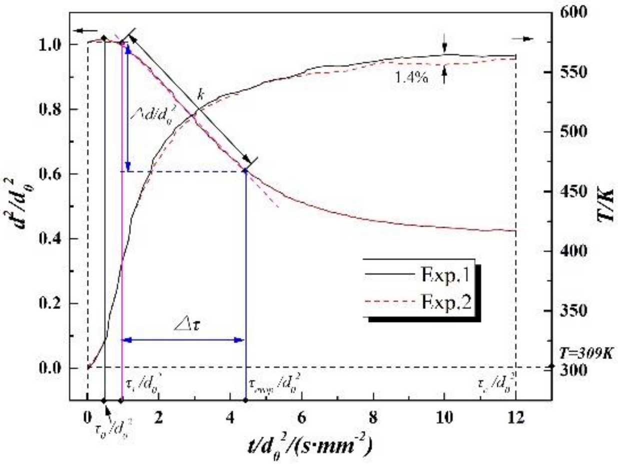

Figure 2. Test consistency verification and the definition of the evaporation phase

3.2 Analysis of results

Figure 3 shows the contrast curves of the normalized droplet diameter and the droplet temperature variation during the evaporation of JME20 droplets at different ambient temperatures. It can be seen that at low temperature 573K ambient temperature, the droplet evaporation process is very clear and can be divided into initial heating phase, equilibrium evaporation phase and slow evaporation phase. However, as the ambient temperature increases, the evaporation process of the droplets changes significantly.

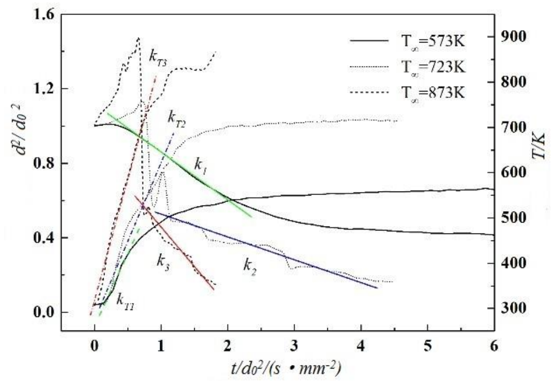

Fig.3 Comparison of the droplet normalized square diameter and droplet temperature at varying ambient temperatures

First, the droplet expands more and the expansion time is longer. This is due to the increased ambient temperature and increased heat transfer rate between the environment and the droplets. The heat absorbed by the droplets is not only used for the temperature rise and expansion of the droplets itself, but also causes the evaporation of light components inside the droplets to cause nucleation and agglomeration of the bubbles. The surface tension and viscous force of the droplets cannot be overcome in a short time, and the bubbles are trapped in the liquid. The inside of the drop causes the droplet expansion time to become longer. Second, the violent expansion of the droplets results in a strong microburst. Moreover, it can be seen that the droplets undergo a more intense micro-explosion at 873K. Finally, the evaporation process of the droplets does not follow the d 2 law, and the equilibrium evaporation process is replaced by fluctuating evaporation. At the end of evaporation, the diesel in the droplets evaporates and the difference in the components of the Jatropha oil results in a weaker microburst strength.

Linearly fitting the droplet normalized diameter square curve and the temperature rise curve in Fig. 3, and obtaining the average evaporation rate k of the droplet equilibrium evaporation phase or the wave evaporation phase, and the temperature rise rate kT, the result of which is shown in Fig. 4 and

5 is shown. In Fig. 5, at the ambient temperature of 723K, the evaporation rate of JME20 fuel droplets decreases, and the evaporation rate increases as the temperature rises continuously, and the life of the droplets continues to decrease.

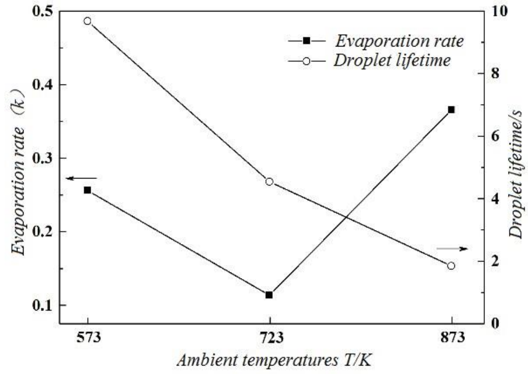

Fig.4 Comparison of fitting evaporation rate and droplet lifetime at varying ambient temperatures

During the two heating processes, the life of the droplets was reduced by 50.05% and 59.43%, respectively. Therefore, as the ambient temperature increases, the evaporation rate of the droplets does not necessarily increase, but the droplet life must decrease. The droplet evaporation rate affects the evaporation time, but does not determine the droplet life. The decrease in the evaporation rate of the droplets may be due to the micro-explosion resulting in a change in the composition of the droplets, as well as the energy dissipation of the droplets.

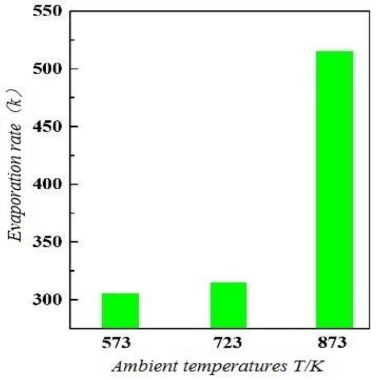

Fig.5 Droplet heating rate at varying ambient temperatures

As shown in Fig. 5, the ambient temperature increases the rate of temperature rise of the droplets, and the temperature rise rate of the droplets increases by 3.68% and 60.09%, respectively. In addition, there is a segment turning in the temperature rise curve of 873K, and the temperature rise first increases and increases. This is due to the expansion and micro-explosion of JME20 droplets during the evaporation process, the droplets are broken and carry a large amount of heat to eject, after which the droplets fluctuate slightly and the heating rate increases.

Figure 6 shows the high-speed image of the JME20 oil droplets evaporating at different times at an ambient temperature of 873K.As shown in the figure, the droplet volume expands continuously from 0 to 0.7019 $s\cdot mm^{-2}$, and from the time of 0.0789 $s\cdot mm^{-2}$, microbubbles are gradually generated inside the droplet. Subsequently, the bubbles continued to condense and swell, and significant bubbles appeared at 0.5459 $s\cdot mm^{-2}$.

In addition, the intense movement of the bubbles inside the droplet causes the droplet to deviate from the center position of the thermocouple, and the local heat is too high to cause the droplet to burst slightly, as shown by the time of 0.7019 $s\cdot mm^{-2}$. After that, the droplet volume is reduced, and the tiny bubbles inside the droplet and the distortion effect cause the droplet to fluctuate, but the fluctuation amplitude is small.

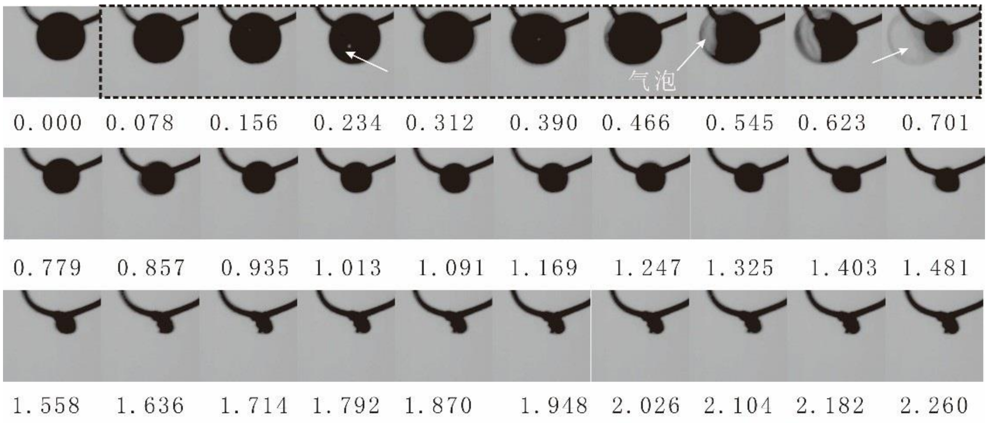

Fig.6 Morphologic change for JME20 droplet evaporation process (T∞=873K)

4. Conclusion

The evaporation characteristics of JME20 at different ambient temperatures were studied experimentally. Taking JME20 as an example, the effects of increasing ambient temperature on droplet evaporation, including droplet expansion, micro-explosion and mechanism, were analyzed in detail.

(1) When the ambient temperature is 573K, the droplet evaporation process conforms to the evaporation rule of single-component fuel droplets. The evaporation phase can be divided into initial heating, equilibrium evaporation and slow evaporation phase, in which the equilibrium evaporation phase satisfies the law.

(2) When the ambient temperature is 723K, the evaporation process of the droplets no longer conforms to the evaporation rule of the single-component fuel droplets, but differentiates into two distinct evaporation stages, and each stage includes droplet expansion and equilibrium evaporation. process. At the same time evaporation time is shortened.

(3) When the ambient temperature is 873K, the evaporation process of the droplets is similar to that at 723K, but the evaporation process fluctuates more frequently. Therefore, according to the variation rule of the droplet normalized diameter square curve, the evaporation process is divided into an expansion phase, a wave evaporation phase, and a slow evaporation phase.

(4)For JME20 fuel droplets, the results show that increasing the ambient temperature not only changes the evaporation rate of the droplets, but also increases the heat transfer rate of the environment and droplets. The nucleation and accumulation of bubbles inside the droplets increases the microburst strength and shortens the survival time of the droplets. However, the evaporation rate of the droplets is not inversely related to the lifetime.

(5) The influence of ambient temperature on the evaporation characteristics of mixed Jatropha oil droplets was obtained, which provided theoretical guidance for the application of Jatropha biofuel in internal combustion engines.

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