



Evaporation characteristics of a palm methyl ester droplet at high ambient temperatures



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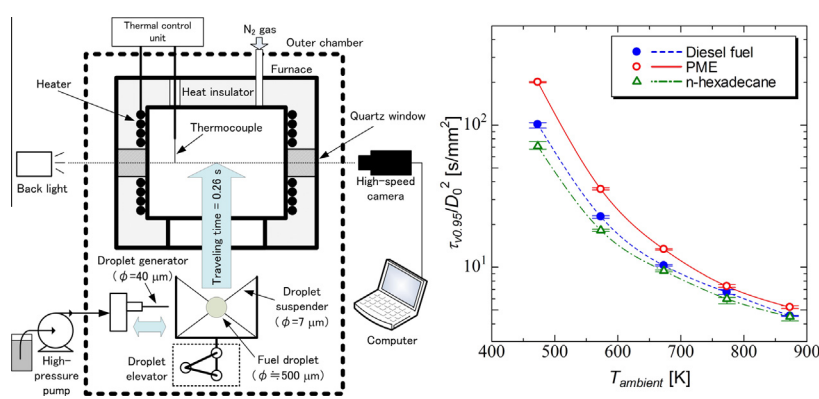
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HIGHLIGHTS

- We investigate evaporation characteristics of palm methyl ester (PME) droplet.
- Results for PME, diesel fuel and n-hexadecane droplets were compared.
- Thermogravimetric and differential thermal analyses were also conducted.
- Droplet lifetime of PME is longer than that of diesel fuel and n-hexadecane.
- Exothermic polymerization reactions occur during PME droplet evaporation.

GRAPHICAL ABSTRACT



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ABSTRACT

To investigate the evaporation characteristics of a palm methyl ester (PME) droplet at high ambient temperatures, droplet evaporation experiments were conducted. Thermogravimetric and differential thermal analyses (TG–DTA) were also conducted to investigate the presence of exothermic reactions during fuel evaporation. The results for PME were compared with those for diesel fuel and n-hexadecane. The results show that the initial heating period decreases and the average evaporation coefficient increases with increasing ambient temperature for all fuels. As a result, the droplet lifetime decreases with increasing ambient temperature for all fuels. It was found that the droplet lifetime of PME is longer than that of diesel fuel and n-hexadecane. The average evaporation coefficients of PME and diesel fuel are almost equal. The longer initial heating period of PME due to the higher boiling points of the components leads to the longer droplet lifetime. It was also found that exothermic reactions occur during PME droplet evaporation. The exothermic reactions are considered to be polymerization reactions of the unsaturated fatty acid methyl esters. The volume of the residue formed by the polymerization reactions decreases with increasing ambient temperature due to the shorter reaction time before complete evaporation.

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1. Introduction

Biodiesel fuel has attracted a great deal of attention as a renewable energy resource from the viewpoint of environmental impact and the rising price of fossil fuels. Palm oil is one of the

Nomenclature

D	droplet diameter [mm]
D_0	initial droplet diameter [mm]
k_{inst}	instantaneous evaporation coefficient [mm^2/s]
k_{ave}	average evaporation coefficient [mm^2/s]
t	time [s]
$T_{ambient}$	ambient temperature [K]

Greek Symbols

τ_{evap}	main evaporation period [s]
τ_i	initial heating period [s]
$\tau_{v0.95}$	95% volume lifetime [s]

most promising liquid biomass fuels because palm trees have a very high oil yield compared to other crops [1], and its oxidation stability is greater than that of other liquid biomass fuels [2]. Because of these advantages, the production of palm oil for use as a biofuel has been continuously increasing [3]. The use of straight palm oil for engines or gas turbines, however, sometimes causes problems due to the high viscosity of straight vegetable oil. Therefore, esterification is generally employed to convert straight vegetable oil to biodiesel fuel, which has lower viscosity. Palm methyl ester (PME) is produced by the esterification of palm oil and is used as an alternative fuel for diesel engines. Some researchers have conducted combustion experiments on the use of PME for diesel engines and have found good combustion performance [4–8]. However, the main weak point of PME as a fuel for automobiles is its high pour point. On the other hand, PME may be used as an alternative fuel for thermal power plants with a gas turbine [9] or a boiler [10]. Fuel temperature control for power plants is easy, in contrast to that for automobiles. Another drawback of the PME is its low lower heating value (LHV).

To reduce emissions such as NOx and soot in the exhaust gas from a combustor, various designs of combustors can be considered [11]. For instance, NOx emission from the combustion of PME can be reduced by employing a burner configuration that promotes the prevaporization of fuel [12]. To efficiently optimize the combustor design for a specific fuel, the main characteristics of the fuel, which are its atomization, evaporation, and combustion reaction characteristics, should be known. In particular, the evaporation characteristics are very important because they affect flame stabilization, NOx emission and soot production in a flame. Although some researchers have experimentally investigated the evaporation characteristics of biodiesel fuel droplets [13,14], no experimental data for PME droplet evaporation has been reported as far as the authors know.

In this study, the evaporation characteristics of a PME droplet in a high-temperature environment were investigated in detail. Droplet evaporation tests using a high-temperature chamber [15] were conducted. Thermogravimetric and differential thermal analyses (TG–DTA) were also conducted to investigate the presence of exothermic reactions.

2. Fuel properties

Table 1 shows the properties of the fuels used in this study. As well as PME, diesel fuel and n-hexadecane were also used as the reference fuels. PME is produced by the esterification of palm oil, and its chemical formula is expressed as follows:



where R represents a chain hydrocarbon group.

The LHV of PME is about 10% lower than that of diesel fuel. The flash point, ignition point and pour point of PME are higher than those of diesel fuel.

Table 2 shows the chemical formula, molecular weight and normal boiling point for main components of PME. Distillation curves for PME and diesel fuel are shown in Fig. 1. The dashed line in the figure indicates the boiling point of n-hexadecane. From the figure, it is expected that the vaporization rate for PME droplets will be lower than that for diesel fuel. It should be noted that the temperature range of the boiling points for the components constituting PME is narrower than that for the components constituting diesel fuel. It should also be noticed that the boiling point of n-hexadecane is higher than the initial boiling point of diesel fuel and lower than the final boiling point of diesel fuel, i.e., diesel fuel consists of components whose boiling points are both lower and higher than that of n-hexadecane.

3. Experimental apparatus

Fig. 2 shows a schematic of the experimental apparatus used for the droplet evaporation test. The inside of the outer chamber was filled with N₂ gas before the experiment to observe a pure evaporation phenomenon without a combustion reaction. The temperature inside the furnace was arbitrarily controlled in the range of 400–900 K by a thermal control unit. A fuel droplet with a diameter in the range of 500–550 μm was generated and suspended at the intersection point of two thin fibers, which were set outside the furnace. The fibers were made of alumina/silica and had a diameter of 7 μm . The fuel was pumped by a micro flow pump to the tip of the glass needle (outer diameter: 40 μm) of the droplet generator. After the fuel droplet was suspended at the intersection point of the droplet suspender, the glass needle of the generator was evacuated in preparation for the insertion of the droplet into the furnace. The traveling time of the droplet during the insertion into the furnace was 0.26 s. Images of an evaporating droplet were taken by backlit photography. A high-speed camera (Vision Research Inc., Phantom Miro 3) was used to record changes in the droplet diameter. The recording rate was changed from 10 to 250 images/s so that the total number of images in each test was above 130, which was sufficient to measure the droplet lifetime and the instantaneous droplet evaporation rate. The droplet diameter, D , was measured by a computer-aided image analyzer. Each digital image of a droplet was divided into horizontal line sections with a vertical thickness of 5 pixels as shown in Fig. 3. Average horizontal intensity profiles were calculated for each section. The edge of a droplet was determined as the farthest position from the suspender at which the intensity was less than $(I_A + 2I_B)/3$, where I_A and I_B are the average intensities of the background and droplet, respectively. Then the volume of the droplet was calculated by an ellipsoidal approximation using the determined edge. Finally, the droplet diameter was defined as the diameter of a sphere having the same volume. The measurement limit of the droplet diameter using the image analyzer was under 0.078 mm, which corresponds to D^2/D_0^2 of 0.025.

The uncertainty of the measurement of the droplet diameter was estimated. Using a solid sphere with a known diameter, the

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