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初期液滴直径が正デカン燃料液滴列の火炎燃え広がり速度に及ぼす影響

Effects of Initial Droplet Diameter on Flame Spread Speed along a n-Decane Droplet Array

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1. Introduction

In recent years, sustainable energy has emerged as an alternative to fossil fuel energy, and research on biomass fuels and e-fuel is progressing in the field of internal combustion engines. It is essential to elucidate the combustion mechanism of liquid fuels and to adapt various types of energy to existing internal combustion engines for efficient combustion. Therefore, we focused our attention on spray combustion. The mechanism of spray combustion has not yet been fully elucidated because it is difficult to observe. In addition, the size and direction of movement of each droplet in spray combustion are different and the complex phenomenon proceeds simultaneously. As an approach to elucidate the mechanism of spray combustion, research has been conducted on a simple one-dimensional droplet array, a portion of which has been cut off from a three-dimensional model of a sprayed fuel droplet. An important parameter governing spray combustion is the droplet diameter. The droplet diameter of the actual spray is on the order of micrometers. However, to ensure experimental accuracy and from an observational point of view, droplet diameters of about 1 mm have been used in many previous experiments. In this study, a fuel droplet array is used to perform experiments with the smallest possible initial droplet diameter with high accuracy to clarify and discuss the effects on flame spread speed.

2. Experimental apparatus and conditions

2.1. Experimental apparatus

Figure 1 shows a schematic diagram of the experimental apparatus. The experimental setup mainly consists of internal modules (droplet array holder, droplet array slider, droplet array generator, igniter, etc.), pressure vessel, optical devices such as camera, control unit, wireless LAN interface, and power supply. Figure 2 shows the droplet array holder. It consists of a frame made of bent stainless-steel tube of 0.6 mm in outer diameter and 0.4 mm in inner diameter, and an H-shaped base that supports the frame. SiC fibers with diameters of 14 μm are suspended from the frame at equal intervals, and glass beads are attached at the midpoint of the suspension lines to support a droplet array. The suspension lines are stretched by hand using a dedicated tool and fixed with heat resistant inorganic adhesive. The ignition system uses a hot wire ignition method in which the first droplet is ignited by heating a 0.29 mm-diameter iron-chromium wire by energizing it. The droplet diameter is measured by a CCD camera using a backlight method with LED illumination. The emission of the SiC fibers holding the droplet is measured by a high-speed camera. Figure 3 shows the image of droplet array. The droplet diameters were measured by using self-made analysis software. In each experiment, all 10 droplets in the droplet array were measured. The initial droplet diameter d_0 is the average of the diameters of the third through the ninth droplets. A high-speed camera was used to capture the spreading phenomenon of the droplet arrays and to obtain data on flame spread. The experiments were conducted in a microgravity environment created by a small drop tower installed in NihonUniversity. The microgravity facility (drop tower) has a total height of 8.6 m, a free-fall distance of 5.4 m, and a deceleration range of 0.9 m. The microgravity time was about 1.1 seconds.

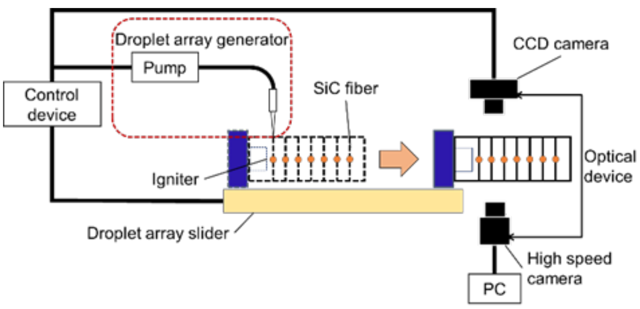

Figure 1. Schematic diagram of the experimental device.

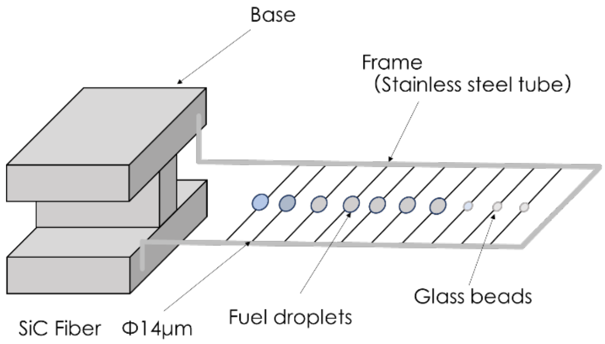

Figure 2. The droplet array holder.

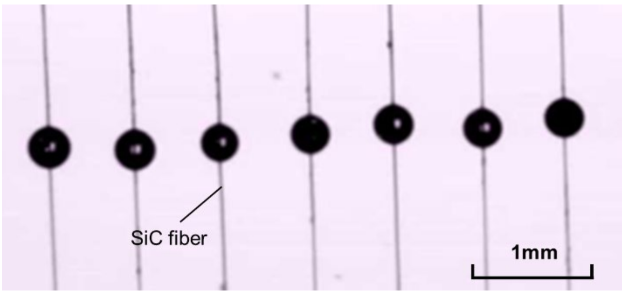

Figure 3. The image of droplet array.

2.2. Experimental conditions

The test fuel is n-decane ($C_{10}H_{22}$), which is used as aviation fuel. The pressure and temperature were set to atmospheric pressure and room temperature, respectively, and the gravity environment was microgravity. The nondimensional droplet spacing was fixed at 2. The initial droplet diameters were set to 0.35 and 0.48 mm and adjusted to within ±5%. The flame spread speed was measured as the average spread speed from the third to the ninth droplet, taking the ignition into account.

3. Results and Discussion

Figure 4 shows image of flame spread behavior taken by a high-speed camera. The fibers are emitting light due to the spreading flame. The analysis program was used to detect the emission of the suspension line, and the time one frame before the first time when the threshold value was exceeded was set as the time of ignition of the droplet.

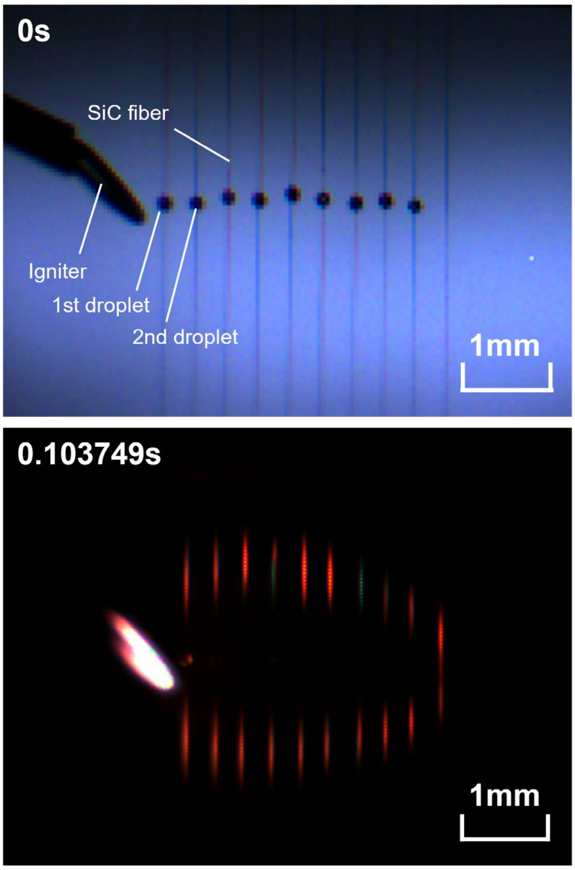

Figure 4. Flame spread behavior.

Figures 5 and 6 show the relationship between droplet ignition time and droplet position for initial droplet diameters of 0.48 mm and 0.35 mm. After confirming the steady-state flame propagation, the flame spread speed was calculated. The relationship between droplet position and droplet ignition time was plotted for each experiment to confirm whether a linear approximation was possible.

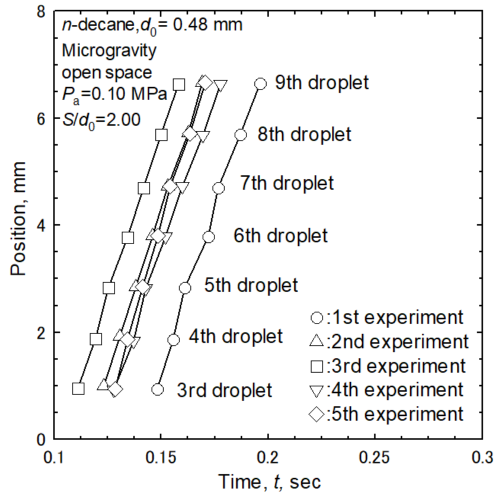

Figure 5. Relationship between droplet ignition time and droplet position (d_0 = 0.48 mm).

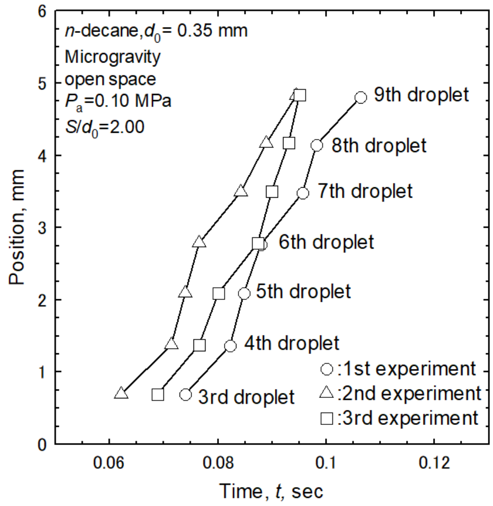

Figure 6. Relationship between droplet ignition time and droplet position (d_0 = 0.35 mm).

Figures 7 and 8 show the relationship between the initial droplet diameter of 0.48 mm and 0.35 mm and the normalized flame spread speed. The slope of the plot of ignition time versus initial droplet position was linearly approximated by the least-squares method, and the flame spread speed was normalized by the initial droplet diameter to obtain the normalized flame spread speed. In this experiment, the normalized flame spread speed did not vary significantly, and stable data were obtained. The ignition time history indicates that the flame propagates at a constant speed.

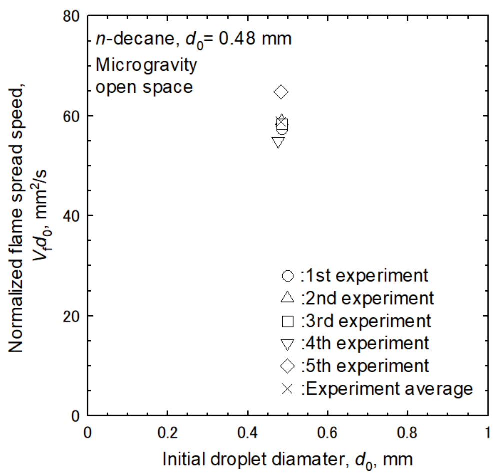

Figure 7. Relationship between initial droplets diameter and normalized flame spread speed (d_0 = 0.48 mm).

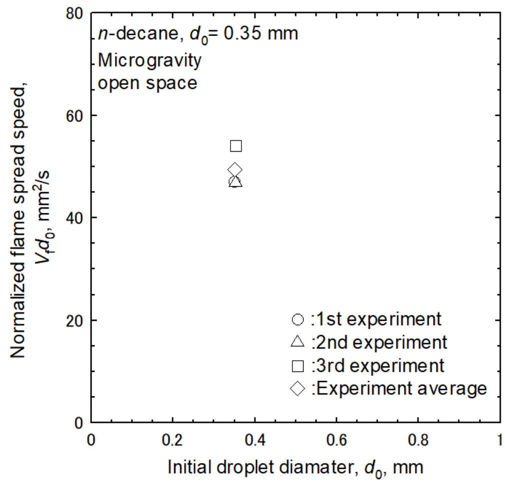

Figure 8. Relationship between initial droplets diameter and normalized flame spread speed (d_0 = 0.35 mm).

Figure 9 shows the relationship between initial droplet diameter and normalized flame spread speed obtained in the present experiment. The normalized flame spread speed increased with increasing initial droplet diameter. In this condition, the similarity rule did not hold. It is thought that the characteristic time of the chemical reaction independent of the initial droplet diameter, rather than the characteristic time of the initial droplet heating or heat conduction, which is proportional to the square of the initial diameter, governs the flame spread speed. It is necessary to clarify the relationship between the flame spread speed and the characteristic time by conducting experiments by changing the initial droplet diameter and nondimensional droplet spacings.

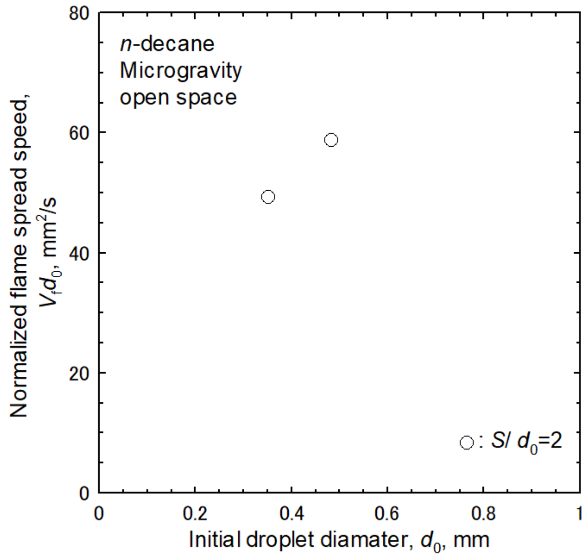

Figure 9. Relationship between the initial droplet diameter and normalized flame spread speed obtained in the present experiment.

4. Conclusions

1. In the case of the initial droplet diameter of 0.35 and 0.48 mm, and the nondimensional droplet spacing of 2, data on the flame spread speed with little variation were obtained.

2. The similarity law is not valid between initial droplet diameters of 0.48 and 0.35 mm. Suggesting that the chemical reaction time cannot be neglected when the phenomenon becomes faster.