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P30

強制点火装置を用いた冷炎燃え広がり現象の観察

Observation of Cool Flame Spreading Phenomenon by Forced Ignition Device

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1. Introduction

Hydrocarbon fuels are widely used in internal combustion engines. In high-temperature, high-pressure environments, the fuel may undergo a two-stage combustion process in which a cool flame, a low-temperature oxidation reaction, is followed by a hot flame, a high-temperature oxidation reaction. The cool flame reaction is known to affect the subsequent hot flame. Therefore, it is important to clarify the combustion characteristics of the cool flame to understand the details of combustion phenomena.

The objective of this study is to clarify the combustion characteristics of cool flame by focusing on the spreading phenomenon of the cool flame. Experiments were conducted using a device in which a fuel droplet was inserted under an arbitrary ambient temperature and the droplet was forced to ignite to generate the spread of the cool flame.

2. Experimental Apparatus and Procedure

Figure 1 shows the outline of the experimental apparatus. The experimental apparatus consists of igniter, combustion chamber, droplet array support system, droplet generator, droplet array elevator, temperature controller, optical system, wireless LAN interface, and power supply system. The ignition system consists of an ignition wire with a nickel wire of 0.10 mm diameter and an ignition circuit with automatic power adjustment. The ignition circuit based on principle of hot-wire velocimetry was used to forced ignition of a droplet array. The ignition circuit consists of a Wheatstone bridge, differential amplifier, transistor, and other components. This circuit has a temperature control function that enables forced ignition of a cool flame and maintenance of the generated cool flame.

The droplet array support system consists of SUS tubes with diameters of 1.0 and 1.6 mm, with silver brazing at the intersection points. The support frame is fixed to a plate made of ceramics, which has low thermal conductivity.

Cool flame spread experiments were conducted under three ambient temperatures of 473, 498, and 523 K in the combustion chamber. Five droplets were suspended on the droplet array support system so that the ignition wire surrounded the first droplet. The igniter was activated 1.2 or 2.7 seconds after the droplet array support system had fully risen to the measurement position in the combustion chamber. The ignition wire temperature was set to approximately 1015 K. n- decane was used as the fuel to allow comparison with the experimental results of other researchers. The initial droplet diameter d_0 of the first droplet as the ignition source was 1.0 mm, and the initial droplet diameter d_0 of the second to fifth droplets was 0.75 mm. The droplet spacing was 2 mm. The current waveforms of the ignition system were recorded by an oscilloscope. The temperature of the droplet generate position was kept between 20 and 25 °C to avoid differences in the conditions for droplet evaporation. The droplet diameter was measured using the backlit method, in which the droplet is backlit from behind, and the outline of the droplet is captured by a CMOS camera. The droplet diameter was analyzed from the captured droplet images using a self-made program. The effect of ambient temperature on the cool flame spread of a fuel droplet train was then investigated.

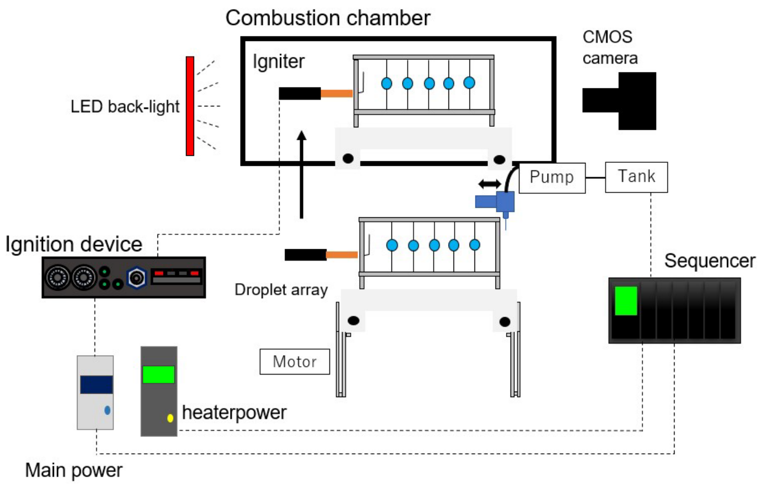

Figure 1. Experimental apparatus.

3. Results and Discussion

The experiments were conducted at ambient temperatures of 473, 498, and 523 K in the combustion vessel with ignition waiting time (I_{gw}) of 1.2 and 2.7 seconds. Figure 2 shows the droplet diameter histories at each ambient temperature with an ignition waiting time of 1.2 seconds. The droplet diameter histories at both 1.2 and 2.7 seconds of ignition waiting time did not show any change in the slope of the fifth droplet. Therefore, the fifth droplet was excluded and the results from the first to the fourth droplet were used. The droplet diameter histories of the second droplet at an ignition waiting time of 1.2 seconds and an ambient temperature of 473 K showed that the slope of the second droplet changed significantly at 2.2 seconds. This indicates that the second droplet was ignited by a cool flame. No clear change in diameter history was observed after the third droplet at an ambient temperature of 473 K and ignition waiting time of 1.2 and 2.7 seconds. This indicates that the second droplet was cool flame ignited. This suggests that cold flame spread occurred up to the second droplet. Similarly, at an ambient temperature of 498 K, cool flame spreading was observed up to the third droplet for all the operation waiting times. At 523 K, cool flame spread was observed up to the fourth droplet at all waiting times.

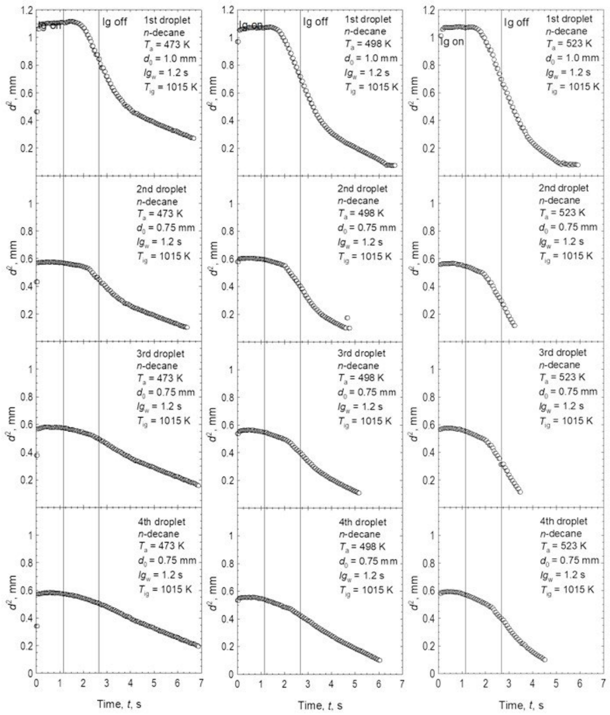

Figure 2. Droplet diameter by ambient temperature (I_{gw}=1.2 s.).

Figure 3 shows the relationship between cool flame ignition time and droplet position obtained from the droplet diameter history. Figure 4 shows the effect of the ignition waiting time on the cool flame spread rate. The slope of the cool flame spread speed was calculated by the least-squares method for the ignition times from the second to the fourth droplet and from the second to the third droplet, because there existed a condition in which the flame did not spread to the fourth droplet. Next, the cool flame spread speed was averaged over three of the five experiments conducted at each ambient temperature. The average cool flame spread speed increased with the increase in the ignition activation waiting time. This indicates that the decrease in the time required for fuel vapor formation affects the spread speed.

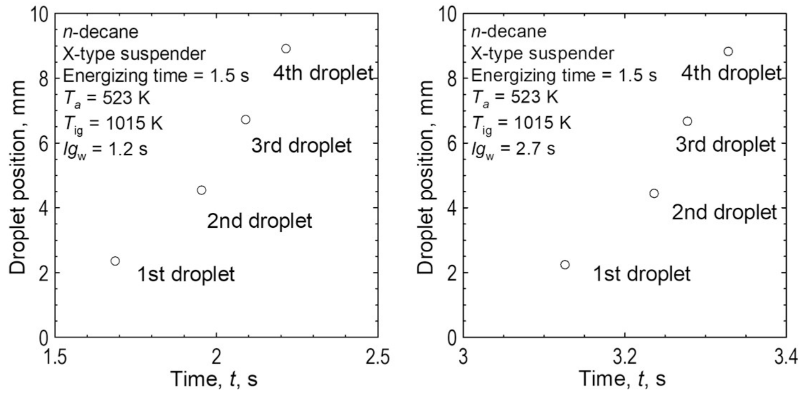

Figure 3. Relationship between ignition time and droplet position (I_{gw}=1.2 and 2.7 s).

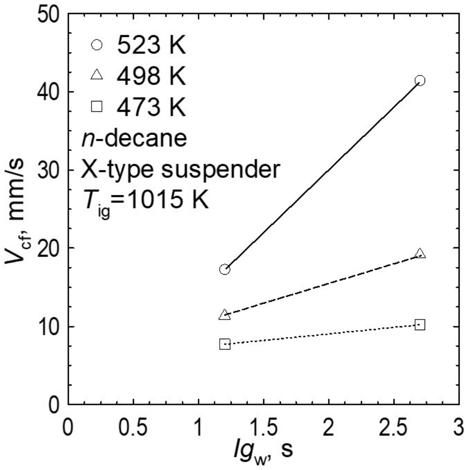

Figure 4. Effect of ignition waiting time on the cool flame spread speed.

Figure 5 shows the dependence of the cool flame spread speed on ambient temperature. In the case of ignition waiting time is 1.2 seconds, the cool flame spread speed increased linearly with increasing ambient temperature. On the other hand, in the case of ignition waiting time is 2.7 seconds, the cool flame spread rate increased exponentially with increasing ambient temperature. This is due to the exponential increase in laminar combustion velocity with increasing fuel vapor temperature, which has the same temperature dependence as the laminar combustion velocity of the flame.

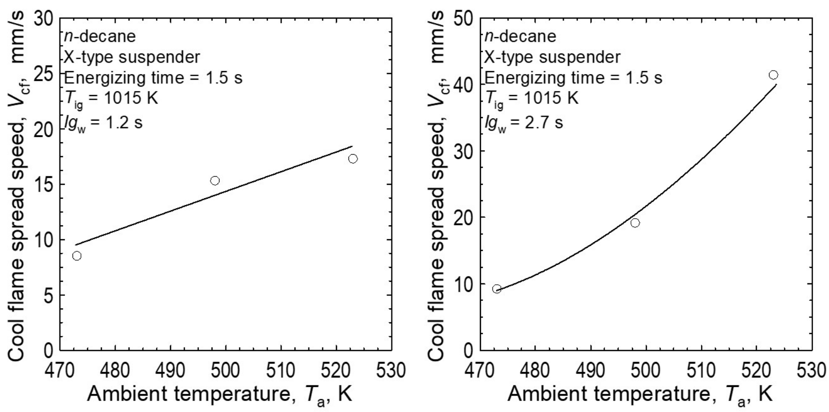

Figure 5. Dependence of the cool flame spread speed on ambient temperature (I_{gw}=1.2 and 2.7 s).

4. Conclusion

- The cool flame spreading phenomenon of the fuel droplet array was observed using forced ignition device.
- The cool flame spread speed increased with increasing ambient temperature.
- The trend of the temperature dependence of the cool flame spread speed depended on the ambient temperature.