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Microgravity experiments on flame spread along fuel-droplet arrays at high temperatures

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Abstract

Microgravity experiments on droplet-array combustion were conducted under high-ambient-temperature conditions. n-Decane droplet arrays suspended on SiC fibers were inserted into a high-temperature combustion chamber and were ignited at one end to initiate the flame spread in high-temperature air. Flame-spread modes, burning behavior after the flame spread, and flame-spread rate were examined at different ambient temperatures. Experimental results showed that the appearance of flame-spread modes and the flame-spread rate were affected by the ambient temperature. The flame-spread rate increased with the ambient temperature. These facts are discussed based on the temperature effects on the droplet heating and the development of a flammable-mixture layer around the next droplet. A simple model was introduced to analyze these effects. The effects of the ambient temperature on the appearance of group combustion of the array after the flame spread and the scale effect in the flame spread are also discussed.

Keywords: Spray; Droplet array; Flame spread; High temperature; Microgravity

1. Introduction

Flame spread over fuel droplets occurs after ignition in diesel engines and near the flame base in gas turbines. Since it largely affects the appearance of the group combustion of the whole spray, it is important to elucidate the flame-spread mechanism. Flame spread between droplets is of scientific interest because the phenomenon consists of not only the diffusion combustion seen in the single-droplet combustion but also the ignition of an unburned droplet and the premixed combustion. The linear droplet array is one of the basic droplet-system configurations used in analyzing the mechanism of the flame spread between the droplets. Many studies on this topic have been conducted [1–10]. Reichenbach et al. [1] performed flame-spread experiments of n-octane droplet arrays in normal gravity. They report that the immersion of the high-temperature region by the flame was

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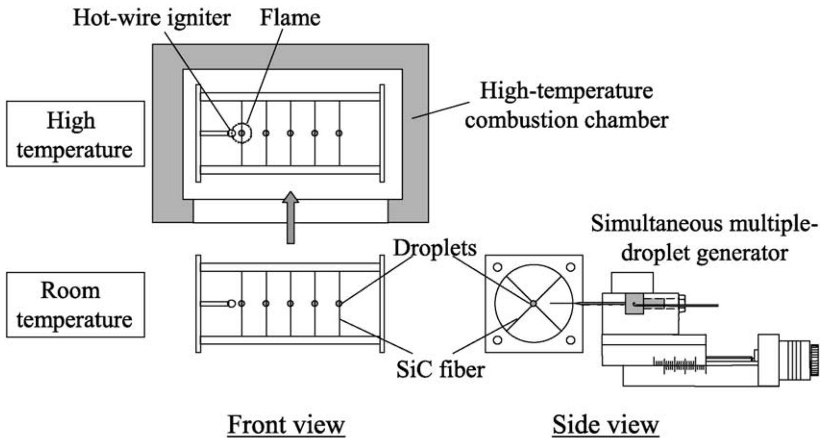

Fig. 1. Schematic diagram of flame-spread experiment of a droplet array at high temperature.

important in the autoignition of unburned droplets and the following flame spread. Brzustowski et al. [2] and Okajima and co-workers [3,4] conducted the same type of experiments in microgravity to investigate the effect of the immersion depth on the flame spread in detail. While they used relatively high-volatility fuels whose prevaporization is substantial, they gave no information on the amount of prevaporized fuel at the start of the flame spread. Kato et al. [5] conducted flame-spread experiments using relatively low-volatility fuels whose prevaporization is negligible. They show that the flame-spread rate attains maximum at a certain droplet spacing in normal gravity experiments using n-decane and n-hexadecane as fuels and clarify the dependency in a microgravity experiment using n-decane. Mikami et al. [6] recently developed a simultaneous multiple-droplet generation technique for microgravity experiments. They demonstrated flame-spread experiments in microgravity using SiC-fiber-supported droplet arrays and reexamine the dependence of the flame-spread rate on the droplet spacing. All these experiments, however, were performed at room temperature. Although most practical sprays burn at high temperatures, no experiments have been conducted on the flame spread of fuel-droplet array at high temperature. Umemura [7,8] theoretically predicts the dependence of the flame-spread mode on the ambient temperature and the droplet spacing. Kikuchi et al. [9,10] validate it through numerical simulation.

We performed flame-spread experiments at high temperatures in microgravity. First, we generated the droplet array on fine SiC fibers by using the simultaneous multiple-droplet generation technique [6] at room temperature and inserted the array into the high-temperature combustion chamber. Then, the forced ignition of an end droplet initiated the flame spread. We discuss the temperature effects on the flame-spread mode and the flame-spread rate.

2. Experimental apparatus and procedures

A schematic of the experimental apparatus is shown in Fig. 1. The fuel-droplet array is generated in atmospheric room-temperature air, and then is transported into the high-temperature combustion chamber. An end droplet of the array is ignited by a hot wire igniter to initiate the flame spread in high-temperature air. The combustion chamber is covered by heat-insulation materials and its inside temperature is precisely controlled. The experimental technique by which droplet experiments are conducted under high-temperature ambient conditions by transporting the droplet into a high-temperature combustion chamber has been used in droplet vaporization experiments at high temperature [11] and in droplet ignition experiments [12,13]. The present experiment employed a multiple-droplet generation technique by which the liquid fuel is supplied to the intersections of X-shape 14-μm SiC fibers through fine glass tubes, which is explained in detail in Ref. [6].

The sequence of the present microgravity experiment is described below: First, the tips of the fine glass tubes were moved to their corresponding intersections of X-shape SiC fibers at room temperature in normal gravity. The liquid fuel, n-decane, was supplied through these fine glass tubes. Second, a SiC-fiber-supported droplet array was formed by simultaneously retracting the glass tubes in microgravity. The shutter of the preheated combustion chamber was then opened and the droplet array was inserted into the combustion chamber (W 50 mm × H 60 mm × L 120 mm). Finally, a wire loop heated electrically ignited an end droplet (the first droplet) to initiate