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微小重力実験に向けた大気圧・低温環境での低沸点燃料の液滴生成および高温環境での燃焼の試み

Attempts at generation of single droplet of low-boiling-point fuel at atmospheric pressure and low temperature and combustion at high temperature for microgravity experiments

森隼人 [1*]，坂野文菜 [1]，三上真人 [1]，

Hayato Mori[1], Ayana Banno [1], Masato Mikami [1]

[1] 山口大学大学院，**Yamaguchi University#1,**

* Correspondence: e027vdv@yamaguchi-u.ac.jp

Abstract: Spray combustion is widely used in diesel engines, oil-fired furnaces, and gas turbines, but the detailed mechanism remains unclear. To improve understanding, many studies have examined droplet combustion in microgravity as a fundamental study. Most have used hydrocarbon fuels that are liquid at room temperature and atmospheric pressure. This study focused on *n*-butane, which exists as a gas under room temperature and atmospheric pressure. We attempted to generate a single *n*-butane droplet in a droplet-generation area cooled to 268 K. Futheremore, we attempted to insert the droplet into an electric furnace over 700 K to observe its vaporization and combustion behavior in normal gravity. As a result, liquid *n*-butane was supplied to the tip of the fuel-supply glass needle. However, it was not possible to suspend the droplet at the intersection of the SiC fibers within a limited number of trials. In the future, we aim to suspend the droplet at the fiber intersection and observe its vaporization and combustion behavior, as preparation for microgravity experiments.

Keywords: *n*-Butane, Droplet generation, Droplet vaporization, Droplet combustion, High temperature

1. Introduction

Spray combustion is widely used for practical combustors such as diesel engines, oi-fired furnaces, and gas turbines. However, the detailed mechanism remains unclear because various phenomena proceed simultaneously. In order to improve understanding of its mechanism, it is essential to investigate the fundamental perspective through elemental research focusing on fuel droplets. Since Kumagai and Isoda[1)] first performed single-droplet combustion experiments in microgravity, a number of other droplet-combustion experiments have been performed. However, most previous researches have focused on hydrocarbon fuels which exist as liquids at room temperature and atmospheric pressure. In contrast, fuels that are gaseous under such conditions are difficult to handle as a liquid, and as a result, experimental studies on their droplet combustion are limited. Ammonia is a representative example of such fuels. In recent years, however, droplet vaporization and droplet combustion experiments have enabled by utilizing high-pressure environments. For instance, Matsuura et al. [2)] succeeded in forced-ignition experiments of a single ammonia droplet under room temperature, high-pressure and microgravity conditions. Furthermore, Khuong et al. [3)] observed the vaporization behavior of a single ammonia droplet under high-pressure, high temperature and normal gravity conditions. **Figure 1** shows the vapor-pressure curve of ammonia. The red circle indicates the condition that the vapor pressure is same as the atmospheric pressure, visually shows the boiling temperature at which ammonia liquefies. Liquefaction requires cooling the system below this point, indicating a relatively high energy demand. In contrast, *n*-butane, which also exists as a gas under room temperature and atmospheric pressure, but its vapor pressure characteristics are different. **Figure 2** shows the vapor-pressure curve of *n*-butane, where the red circle similarly marks the vapor pressure same as atmospheric pressure. This indicates that *n*-butane can be liquefied at a higher temperature than ammonia, implying a lower energy requirement for liquefaction. In light of this, we focused on *n*-butane and attempted to generate a single *n*-butane droplet using a cooled droplet-generation system with a cooling circulator and to observe its vaporization and combustion behavior under atmospheric pressure and high-temperature conditions. This is a preliminary study conducted in normal gravity for future microgravity experiments.

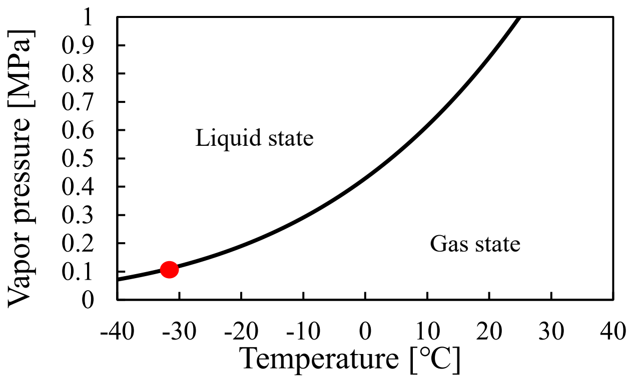

Figure 1 Ammonia vapor-pressure curve based on NIST thermodynamic data[4]

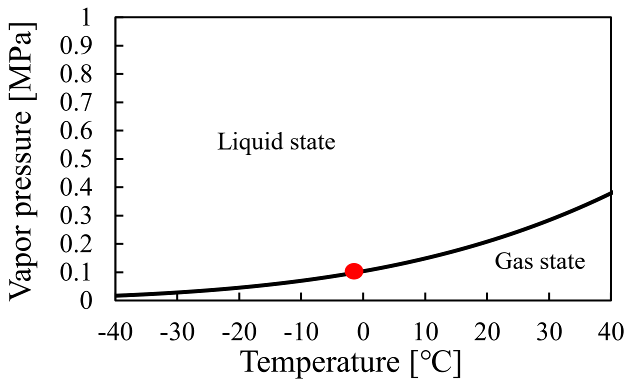

Figure 2 *n*-Butane vapor-pressure curve based on NIST thermodynamic data[4]

2. Experimental apparatus and procedure

Figure 3 shows the schematic of the experimental apparatus, which consists of two main parts: the droplet-combustion area and the droplet-generation area. The droplet-combustion area, located in the upper section, consists of an electric furnace, heat insulator, observation windows, K-type thermocouples. The lower section is the droplet-generation area, which consists of a droplet elevator, a fiber base with crossed SiC fibers as a droplet suspender, a syringe, a fuel-supply system including glass needle, a traverse stage for the glass-needle positioning, K-type thermocouple. As *n*-butane exists as a gas under room temperature and atmospheric conditions, this area is cooled to generate an *n*-butane droplet. For this purpose, the droplet-generation area is enclosed in a cylindrical shell wrapped with copper tubing filled with coolant at 263 K supplied by a cooling circulator, and dry ice is additionally placed outside the shell to enhance cooling, enabling the space to be maintained at approximately 268 K. A droplet is suspended onto the intersection of two crossed SiC fibers with a diameter of 14 μm (Hi-Nicalon, Nippon Carbon), as shown in **Fig. 4**. After suspension, the glass needle is retracted, and then the droplet is inserted into the electric furnace by the droplet elevator. The distance from the droplet-generation position to the test position in the electric furnace is 140 mm, over which it takes 0.85 seconds for the droplet to be transported. Droplet images are recorded at 2000 fps using a high-speed camera (IDT, CCM3530) in a back-illumination system. We conducted the experiment in normal gravity at atmospheric pressure while the furnace temperature was maintained at 723 K.

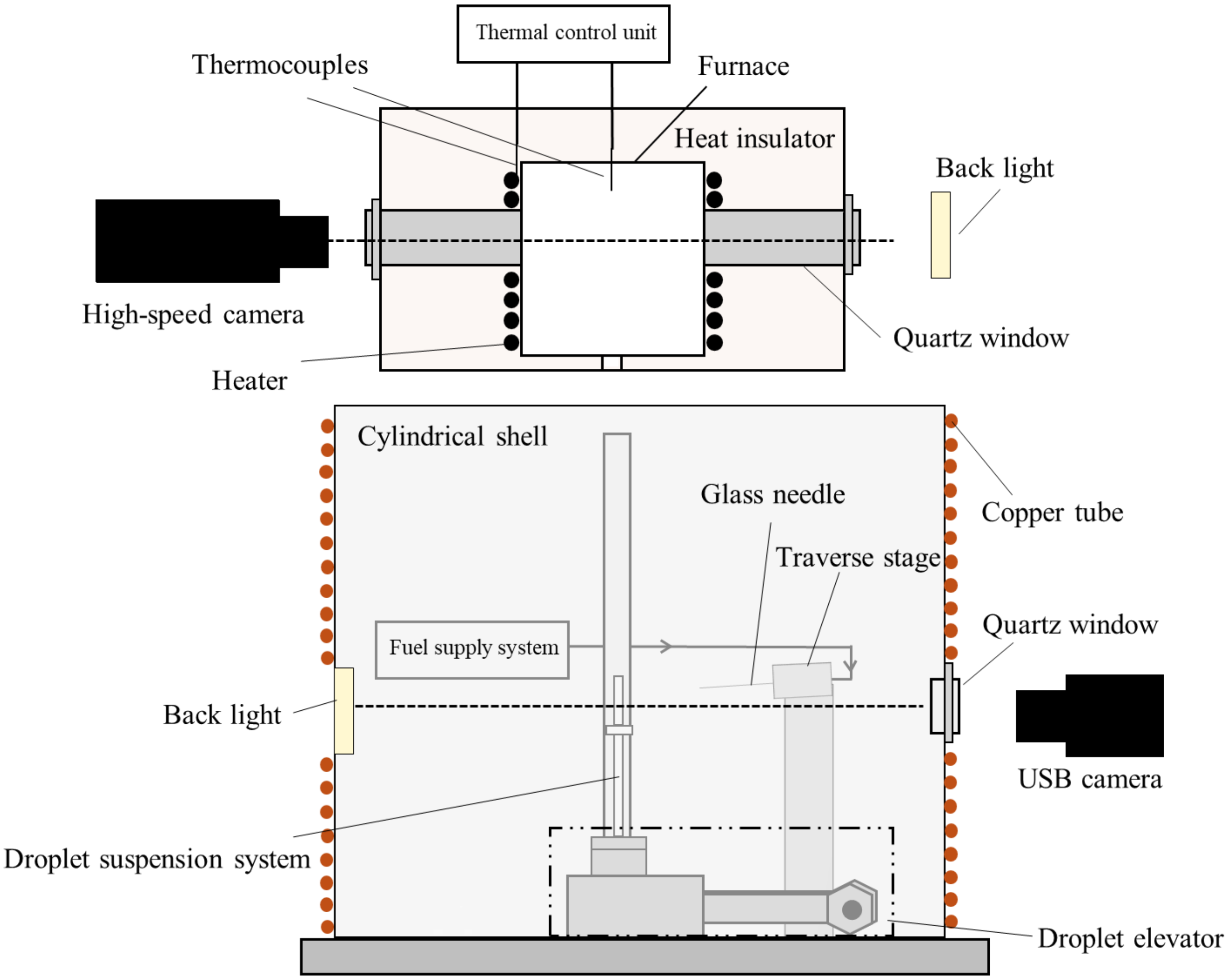

Figure 3 Schematic of the experimental apparatus

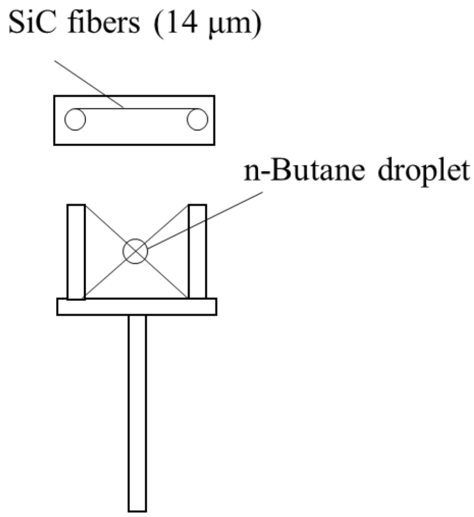

Figure 4 Schematic of droplet suspension system

3. Results

Droplet generation was attempted while maintaining the droplet-generation area at 268 K under atmospheric pressure. As shown in **Fig. 5**, *n*-butane was supplied to the tip of the fuel-supply glass needle by pushing the plunger of the syringe storing liquid *n*-butane with a stepping motor. However, we failed to suspend the droplet at the intersection of the SiC fibers within a limited number of trials at the present stage.

Figure 5 Supply of liquid *n*-butane at the tip of the fuel-supply glass needle and droplet formation

4. Summary

Liquid *n*-butane was supplied to the tip of the fuel-supply glass needle while maintaining the droplet-generation area at 268 K under atmospheric pressure. However, it was not possible to suspend a droplet at the intersection of the SiC fibers within a limited number of trials.

5. Acknowledgement

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6. References

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