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TEXUS ロケットを用いた微小重力下での複数液滴冷炎点火実験　―液滴の蒸発および点火―

Multiple Droplet Cool Flame Ignition Experiment under Microgravity using TEXUS Rocket -Droplet evaporation and ignition-

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1. Introduction

Atomization of fuel droplets, evaporation, and flame spreading along the droplets have been studied as basic research for elucidating the group combustion mechanism of spray combustion. The cool flame is a low-temperature oxidization that precedes the high-temperature flame and plays an important role in the ignition process. This project aims to elucidate the dynamics of cool flames in multiple droplets[1)]. The cool flame ignition phenomena near the ignition limit temperature were observed and the ignition delay, ignition position, etc. were investigated in detail. Experiments were also conducted by varying the droplet spacing to investigate droplet spacing and cool flame ignition. Since the experimental conditions required a microgravity environment for a long duration, the experiment was conducted using a TEXUS rocket under an international collaboration between Japan and Germany. This paper reports on the evaporation and ignition of the droplets.

2. Experimental Apparatus and Conditions

The experimental apparatus consists of a combustion chamber with a shutter, a droplet array suspension system, a droplet array generator, a fuel feed pump, a droplet array elevator, CMOS video cameras, a high-speed video camera, and LED backlights. A droplet array is generated outside the combustion chamber and inserted into the combustion chamber through the slit at the bottom of the combustion chamber by the droplet array elevator just before observation. Liquid fuel is supplied from a Micro syringe to the droplet array generator by a stepper motor. For details on the experimental equipment, please refer to the previous report[2)]. The backlit images required for droplet diameter analysis were acquired using a high-resolution CMOS video camera (Imaging Source, DMK33UJ003). The resolution was 14.9 pix/mm, and the frame rate was 14 fps. To obtain sufficient resolution for droplet diameter analysis, two cameras were arranged side-by-side to capture the entire droplet array.

The experimental apparatus was equipped with two combustion chambers, with the internal temperatures of Unit 1 set to 570 K and Unit 2 set to 590 K. However, since Unit 2 did not work, the data presented in this report are only for Unit 1 (570 K).

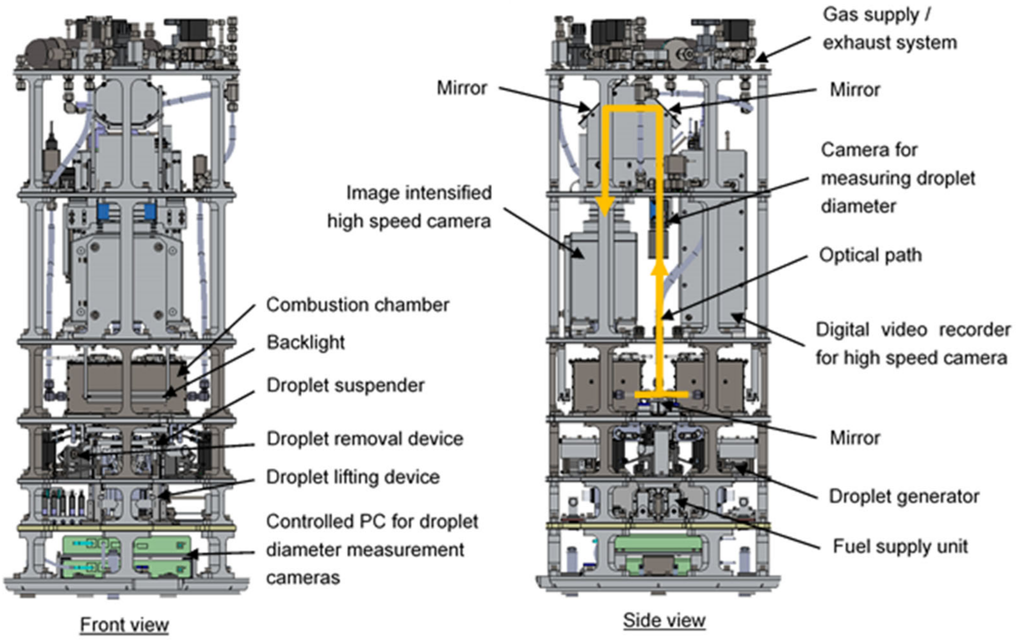

Figure 1. 3D model of experimental apparatus[2).

3. Results and Discussion

Figure 2 shows a backlit image of the droplet array. Droplet spacing was 8 mm, and the array was an arrangement of two droplet pairs. The droplet diameter was measured from this image. Figure 3 shows the droplet diameter history. The origin of the horizontal axis is the time when the droplet array came to stopped at the experimental position in the combustion chamber. Normalized times from 0 to 2 s/mm^2 represent the initial heating period. Normalized times from 2 to 5 s/mm^2 represent the evaporation period, and the slope of the plot for this period indicates that the evaporation rate constant is K= 0.15 mm^2/s. In the graph on the right side of Figure 3, the droplet diameter decrease rate increases after normalized time 5.5 s/mm^2, suggesting that the droplet ignited with a cool flame. The slope of the normalized time from 5.5 to 6.5 s/mm^2 indicates that the burning- rate constant with cool flame is K= 0.35 mm^2/s. Nayagam et al. conducted combustion experiments with single 4 mm n-decane droplets and reported that the evaporation rate constant with cool flame after the radiative extinction of hot flame was K= 0.39–0.40 mm^2/s[3). Since the intersection of the evaporation period and the combustion period is the time of cool flame ignition, under these conditions, 5.5 s/mm^2 was cool flame ignition. The ignition time of the cool flame could be confirmed from the droplet diameter history.

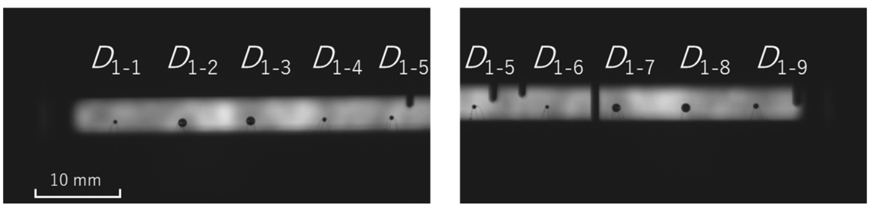

Figure 2. Backlit image of droplet array. (S= 8 mm)

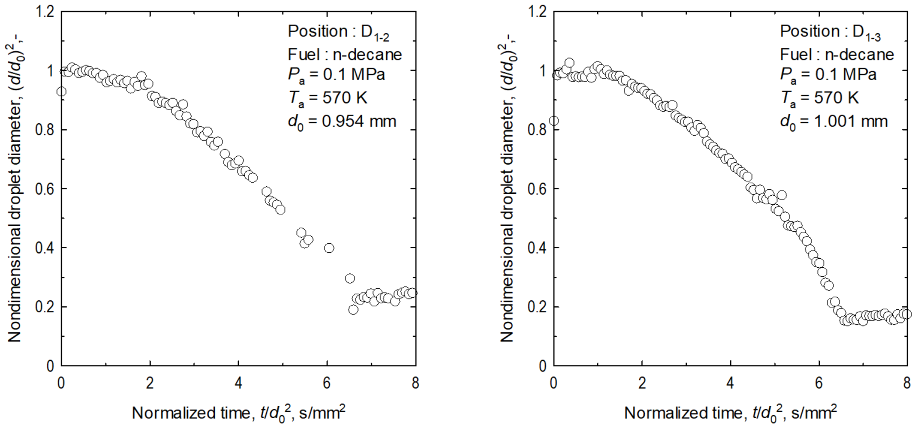

Figure 3. Histories of squared nondimensional droplet diameter.

4. Conclusion

Microgravity experiments were conducted using the TEXUS rocket to obtain data for clarifying cool flame dynamics. The droplet diameter history analysis confirmed that a cool flame was generated, and the time of the cool flame ignition was estimated.

References

1) M. Tanabe, M. Saito, Y. Suganuma, M. Mikami, M. Kikuchi, Y. Inatomi, O. Moriue and H. Nomura: Scope of PHOENIX-2 Sounding Rocket Experiment, "Cool Flame Dynamics in Multi-droplet Ignition", Int. J. Sci. Appl. **37** (4) (2020) 370401-1, DOI: 10.15011/jasma.37.4.370401.
2) Y. Suganuma, M. Saito, Y. Goto, S. Yamamoto, M. Nokura, M. Mikami, M. Kikuchi, Y. Inatomi, O. Moriue, H. Nomura and M. Tanabe: Hardware Development for Cool Flame Combustion Experiment of Fuel Droplets using Sounding Rocket, Int. J. Sci. Appl. **37** (4) (2020) 370403-1, DOI: 10.15011/jasma.37.4.370403.
3) V. Nayagam, D.L. Dietrich, M.C. Hicks, F.A. Williams, Cool-flame extinction during n-alkane droplet combustion in microgravity, Combust. Flame 162 (2015) 2140–2147, DOI: 10.1016/j.combustflame.2015.01.012

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