JASMAC Conference of the Japan Society of Microgravity Application

OS4-9

Group Combustion-2 におけるモデリングと数値解析

Modeling and simulation in Group Combustion-2

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1. Introduction

"Group Combustion-2, Elucidation of Flame Spread and Group Combustion Excitation Mechanism of Randomly Distributed Droplet Clouds-2" has been selected as a "KIBO" utilization feasibility study theme in 2019 with following the successful completion of "Group Combustion"[1]. In Group Combustion, the unique behavior such as the large-scale ignition of the droplet cluster and the low-speed flame propagation in the burned region has been observed around the limit condition of the appearance of the group combustion. It is suggested that the cool flame formed by the hot flame's radiation extinction plays an important role in these phenomena. Based on the consideration, the purpose of Group Combustion-2 is to clarify the contributions of the cool flame and the radiation extinction in the flame spread in the micro-gravity condition. The deeply understanding of the phenomena can help developing the percolation model, combustion sub-models, and the high-fidelity numerical simulation technology.

For the development of the high-fidelity numerical simulation technology, it is essential to understand the chemistry and the flame behavior during the ignition process. In this study, a numerical simulation in which the detailed chemical mechanism is treated is employed to clarify the behavior. The final target is to propose a numerical simulation technology to predict the practical scale flame spread with the combustion model developed in this study.

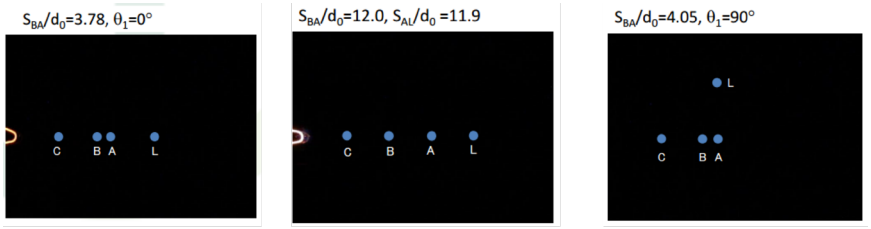
2. Numerical simulation

The variable density, low-Mach number, reacting flow equations with two-way coupling between the continuous phase and dispersed phase are solved by using the unstructured, finite volume method based parallel computing code, FFR-Comb[2,3], that was partially developed in the Academia-Industry Cooperative Project of the Combustion Society of Japan in this study. The Eulerian-Lagrangian method is used to treat the gas-droplet two-phase reacting flow. The droplet is individually treated as a point source with the PSI-CELL method[4], while it would be important to consider the occupation volume by the existence of the droplets in terms of the length scale ratio between the particle size and the distances of the droplets. This is because the capability of the point source treatment should be discussed to apply this numerical procedure to the practical scale applications.

The mass, momentum, enthalpy, and chemical species conservation equations for the gas phase discretized in space using a second-order finite volume formation are solved without any averaging and filtering treatments. The droplets evaporate in high temperature region, and the evaporated fuel gas reacts with oxygen. As described earlier, the droplets are tracked individually in a Lagrangian manner, and a first-order implicit Euler method is used for the time advancement. For the evaporation, a hybrid model of a non-equilibrium Langmuir-Knudsen evaporation model[5,6] and a boiling evaporation model[7] is used. The radiative heat transfer is computed by the DO method[8]. The radiation property for the gas phase is evaluated by the non-gray narrow band model[9].

It is important to capture the low temperature oxidation behavior in addition to the high temperature oxidation by the employed chemical mechanism. As found in Williams and Nayagam[10], the six elementary reaction steps are used to describe the low-temperature alkane chemistry. Qiu et al.[11] proposed the reduced mechanism with 77 species and 287 reactions for n-decane oxidation including this procedure is employed in this study.

As a first step of the examination by the numerical simulation, the condition examined in "Group Combustion". Fig. 1 shows the three cases examined that vary the locations of the four droplets. The fuel is neat n-decane. S_{BA} is the distance between Droplet A and B, and d_0 is the droplet diameter. Droplet C is heated up and ignited first by the ignitor shown on the left side and the flame will propagate from Droplet C to in the order of B, A, and L. Droplet L is the target and the ignition time from Droplet A to L is evaluated in the experiment.

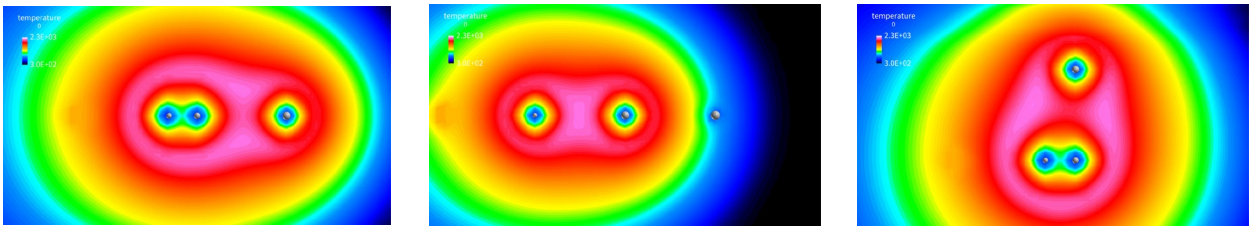


(a) Case 1 (b) Case 2 (c) Case 3

Fig. 1 Cases performed.

3. Results and discussion

Fig. 2 shows the instantaneous distribution of gas temperature for the three cases at 3.0 sec. from the beginning of the computation. It is found that Droplet L has already ignited at 3.0 s for Cases 1 and 3, while it is still in the middle of heating-up. The difference in the ignition timing is attributed to the difference in the heat flux from the flame of the group combustion by Droplet A and B. Fig. 3 shows the comparison of the variation of the square of the droplet L diameter. It is obviously understood that the decrease in diameter of Droplet L for Case 3 is faster than that for Case 2. This means that Droplet L for Case 3 locating at the position where the angle between B-A and A-L is 90 deg. receives the largest heat flux. Table 1 shows the comparison of the ignition time from Droplet A to L with the experiment. It is confirmed that the trend obtained in the experiment has been captured by the numerical simulation.



(a) Case 1 (b) Case 2 (c) Case 3

Fig. 2 Instantaneous distribution of gas temperature at 3.0 s.

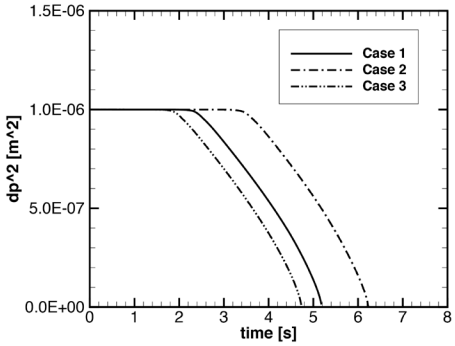


Fig. 3 Comparison of variation of dp^2 of Droplet L.

Table 1. Comparison of ignition time from Droplet A to L.

Cases	Simulation [s]	Experiment [s]
Case1	0.92	0.73
Case2	1.21	1.23
Case3	0.46	n/a

4. Summary and ongoing works

In this paper, the numerical simulation was validated by the comparison of the ignition time with the experiment, and the ignition timing was discussed with the temperature distribution and the variation of the droplet diameter. As a next step, the underlying physics in the ignition process will be discussed in terms of the low temperature oxidation by the presented numerical procedure in the conditions of "Group Combustion" in which the cool flame is supposed to play the important role.

Acknowledgements

This work was supported by the feasibility study program of "Group Combustion-2, Elucidation of Flame Spread and Group Combustion Excitation Mechanism of Randomly Distributed Droplet Clouds-2". The part of this work was supported by the Academia-Industry Cooperation Program: Development and Validation of Combustion Simulation Platform for Advanced Industrial Design Process in Combustion Society of Japan.

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