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Phoenix2 微重力実験における燃料液滴初期温度の推定

Estimation of initial temperature of fuel droplet in Phoenix 2 microgravity experiments

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1. Introduction

Global warming is urgent issue to be solved.　Therefore, it is important to select alternative fuels which are carbon neutral.　In the Phoenix 2 project, Sustainable Aviation Fuel (SAF) was focused.　Ignition characteristics of fuel affect performance of internal combustion engines.　Cool flame droplet-ignition of normal decane fuel, which is one of main components of SAF, was examined at microgravity produced by the TEXUS sounding rocket.　Effect of initial droplet temperature on the burning rate constant of a droplet is small, but that on the ignition delay time is large.　In this report, the droplet temperature just when a droplet was positioned at the test position in the combustion chamber was estimated for the single droplet experiment.

2. Experiments and numerical simulation

Cool flame ignition experiments for five different droplet arrangements were performed with Phoenix 2 Droplet Combustion Unit (DCU2) installed in the TEXUS #60 sounding rocket.　The droplet arrangement of two single droplets (droplet spacing was 32 mm) was the target of this report.　Detailed information of the experimental apparatus and procedures is described in Ref. 1.　The droplets were generated under the heated combustion chamber and inserted into the chamber just when the experiment was started.　During the travel from the slit of the combustion chamber to the test position, the droplets were heated by the hot air in the

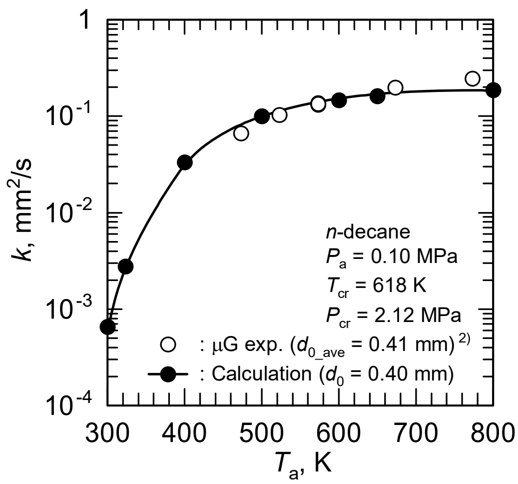


Figure 1. Comparison between the evaporation rate constants of n-decane obtained from the numerical one-dimension simulation and the microgravity experiments.

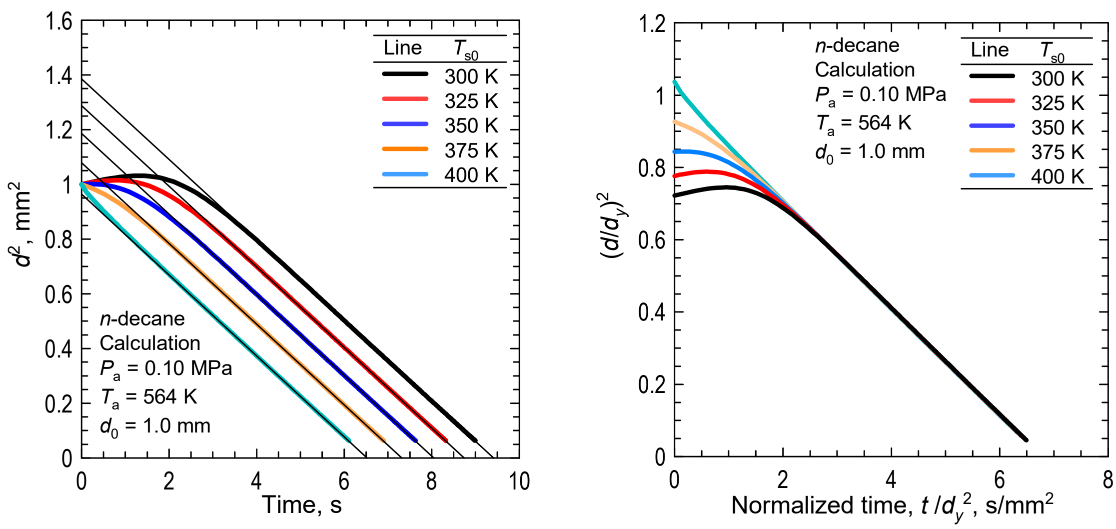
combustion chamber. Therefore, the droplet temperature when the droplet was positioned at the test position in the combustion chamber, which will be called as initial droplet temperature, was unknown. We tried to estimate the initial droplet temperature by using a numerical simulation of unsteady droplet evaporation in nitrogen atmosphere.

The employed numerical simulation of droplet evaporation in nitrogen environment is 1D of spherical-symmetry and consists of the Fick's law equation, the Fourie's law equation, and the Wagner equation of vapor pressure[3]. The van der Waals equation of state was adopted for the gas phase. The temperature in a droplet is uniform. The calculation area is 50 times as large as the droplet. The outer boundary was set as a free boundary. Properties of n-decane and nitrogen depend on temperature. Calculations of droplet diameter and temperature as a function of time were performed with MATLAB. Comparison between the numerical simulation and microgravity experiment[2] results of the evaporation rate constant were shown in Figure 1. The same definition[4] of the evaporation rate constant was employed for both numerical and experimental results. Except for the high temperature conditions, both results agree well.

3. Estimation procedure of the initial droplet temperature

Numerical simulations were performed at the same ambient temperature of 564 K as the experiment, with the initial droplet temperature varied from 300 to 400 K. Figure 2 shows the results of squared droplet diameter history with the straight line from which the evaporation rate constant was obtained. One can understand that the initial droplet temperature does not affect the evaporation rate constant. The y-intercept of the straight line was expressed as d_y^2. Figure 2(b) shows the results of normalization of Figure 2(a). Both the squared droplet diameter and time were normalized by d_y^2. The effect of the initial droplet temperature on the droplet history is remarkable in the initial droplet heat-up period. The square of normalized droplet diameter at a normalized time of 0.5 s/mm² when the droplet vibration due to its insertion into the combustion chamber was sufficiently damped was obtained from Figure 2(b) and plotted in Figure 3 as a function of the initial droplet temperature. It is found that the square of normalized droplet diameter at a normalized time of 0.5 s/mm² increased linearly with the increase of the initial droplet temperature.

In the Phoenix 2 experiments, sequential backlit images of an evaporating droplet (frame speed: 14 fps, resolution: 45 pix/mm) were recorded. After the recovery of TEXUS rocket, the sequential images were analyzed to measure droplet diameter with the self-made image analyzer[4]. From the squared droplet diameter history before ignition, the d_y^2 of the experimental data was obtained and used for the normalization of the entire squared droplet diameter history. If no quasi-steady evaporation period appears before ignition, this estimation method of the initial droplet temperature cannot be applied. From the squared droplet



(a) (b)

Figure 2. Effect of initial droplet temperature on droplet diameter history. (a) Calculated results, (b) normalized results by d_y^2.

diameter histories normalized, the square of normalized droplet diameter at a normalized time of 0.5 s/mm^2 were obtained and shown as dashed lines in Figure 3. Value between two discrete data were calculated by linear approximation of the two data. The initial droplet temperature of the experimental result can be estimated as the initial droplet temperature of the intersection of the solid line of calculation results and the dashed line of experimental results in Figure 3.

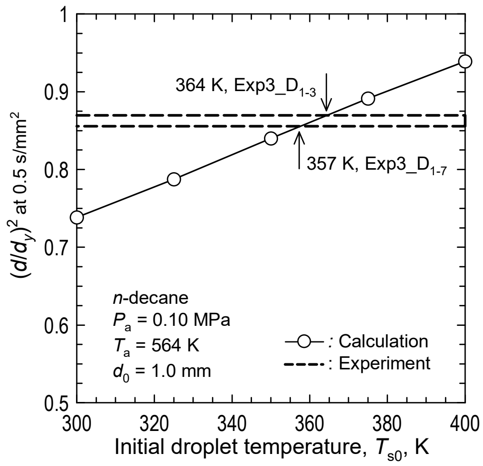
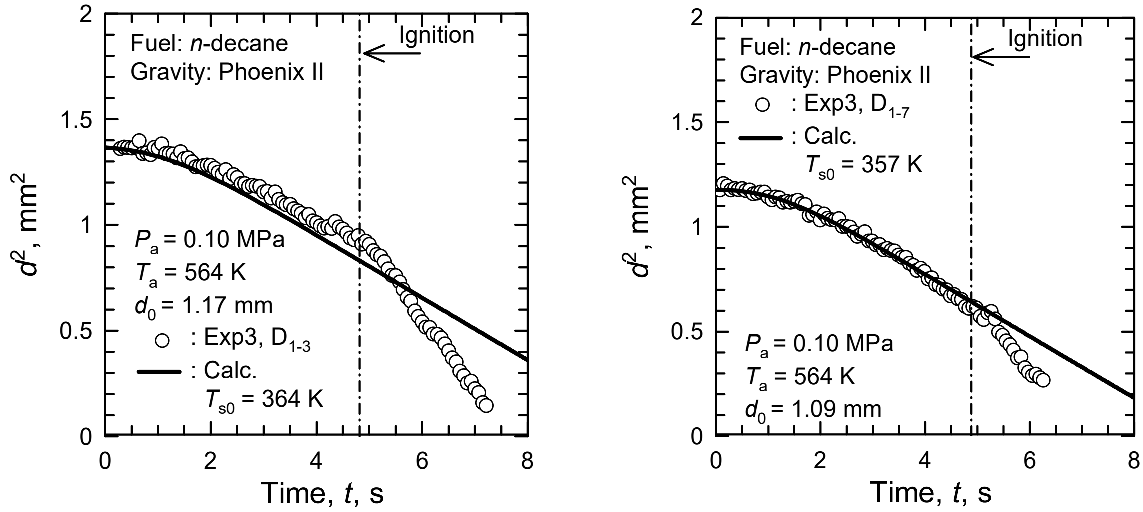


Figure 3. Relationship between the square of normalized droplet diameter at 0.5 s/mm^2 and the initial droplet temperature.

4. Results and discussion

From Figure 3, the initial droplet temperatures of the droplets placed at the droplet positions $D_{1\text{-}3}$ and $D_{1\text{-}7}$ in the third experimental sequence were estimated as 364 and 357 K, respectively. With use of these initial droplet temperatures the droplet evaporation simulations were done. The calculation results were normalized by the d_y^2 obtained from the calculation results and then made dimensional by the d_y^2 obtained from the experimental results as shown in Figure 4. Even if the droplet diameter at the time of 0 s was unknown due to the vibration of the droplet, one can estimate the initial droplet diameter by this procedure. Since the simulation results agree well with the experimental results in the case of Figure 4(b), it is understood that the estimations of the initial droplet temperature and the initial droplet diameter were successful. On



(a) (b)

Figure 4. Comparisons of the squared droplet diameter histories obtained by experiments and simulation.

the other hand, in the case of Figure 4(a), underestimation of the droplet diameter was observed. Estimated initial droplet temperature is affected strongly by the square of normalized droplet diameter at a normalized time of 0.5 s/mm^2. The experimental squared droplet diameters around the normalized time of 0.5 s/mm^2 are scattered in Figure 4(a). It was found that this scatter of the squared droplet diameter data caused the differences between the experimental result and simulation result. It is necessary to find a suitable smoothing method to eliminate the influence of scattered data.

5. Conclusion

Estimation of the initial droplet temperature from the squared droplet diameter history during the quasi-steady evaporation period was succeeded. However, this estimation is influenced strongly by noise of droplet diameter data.

Acknowledgments

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