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雰囲気の組成と温度が正デカン単一液滴の冷炎振動に与える影響

Influence of Composition and Temperature of Atmosphere on Cool Flame Oscillation of Single Droplet of *n*-decane

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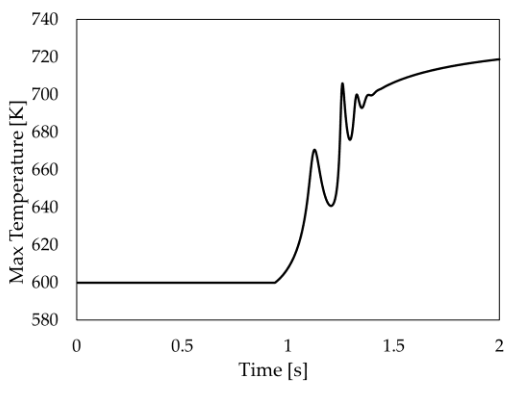
Abstract: Numerical simulations of cool flame oscillations were performed for a single fuel droplet under three different ambient gas conditions: N2/O2, He/O2, and Xe/O2. The ambient temperature was set to 580 K, 600 K and 650 K. And the ambient pressure was maintained at 1 atm. The fuel used was *n*-decane (*n*-$C_{10}H_{22}$). Quantitative evaluations of cool flame oscillations at different Lewis numbers revealed that the oscillation dumping rate was lower at high Lewis numbers, higher at higher ambient temperatures. Furthermore, experimental investigations were conducted to complement the numerical simulations.



Keywords: Combustion , Cool flame , Droplet

1. Introduction

In recent years, to improve engine performance there is a demand for reducing environmental impact, suppressing abnormal combustion and improving thermal efficiency. Many internal combustion engines, such as jet engines, liquid rocket engines, and diesel engines have adopted a combustion method called spray combustion. In addition, with the recent progress toward carbon neutrality, sustainable aviation fuel (SAF) has been attracting attention. SAF contains a high proportion of straight-chain higher hydrocarbons. It is known that higher hydrocarbon-based fuels produce a low-temperature flame called a cool flame during the spontaneous ignition process. Tanabe et al. demonstrated that the cool flame dominates the spontaneous ignition delay time of the hot flame.[1)] The PHOENIX-2 project was conducted to clarify the droplet interactions in cool flame dynamics near the autoignition limit. [2] Mikami et al. experimentally studied the phenomenon that occurs around droplets existing outside the flame propagation limit under microgravity conditions.[3] Cool flame dynamics include a phenomenon called cool flame oscillation, in which the concentration and temperature of active chemical species fluctuate. Tanabe et al. constructed a mathematical model of cool flame oscillation.[4] And Iemura et al. constructed a mathematical model that takes dimensionless factors into consideration.[5] The mathematical model that takes dimensionless numbers into account is shown in equations (1) and (2).

$$\frac{dC}{dt} = k_1 C - k_2 C - \frac{1}{Le}\frac{k^*}{Da}(C - C_a) \tag{1}$$

$$\frac{dC}{dt} = k_2 C q - \frac{k^*}{Da}(T - T_a) \tag{2}$$

Where k_i is reaction rate constant , T_a is ambient temperature , C_a is ambient concentration , q is incidence rate , Le is Lewis number and Da is Damkohler number.

In this study, we quantitatively evaluated the influence of the Lewis number on cool flame oscillations using numerical simulations.

2. Numerical simulation conditions and experimental conditions

The geometry and conditions used in the numerical simulation are shown **Fig.1** and **Table 1**.

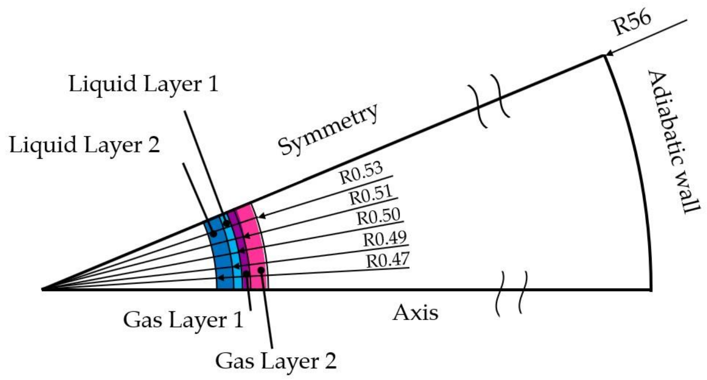


Figure 1. Numerical simulation domain for an isolated droplet.

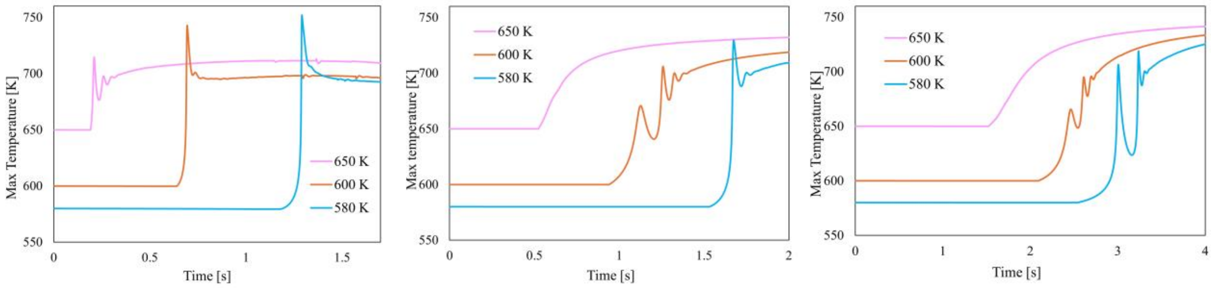
Table 1. Numerical simulation conditions

Fuel	n-decane
Initial Droplet Diameter [mm]	1
Initial Ambient Pressure [MPa]	0.1
Initial Ambient Temperature [K]	580,600,650
Ambient Gas	He/O2, N2/O2, Xe/O2
Lewis Number	High: He/O2 Base:N2/O2 Low: Xe/O2
Chemical reaction	77 species,287 reactions[6]
Simulation	2D axisymmetric

3 Results and Discussion

3.1 Numerical simulation results

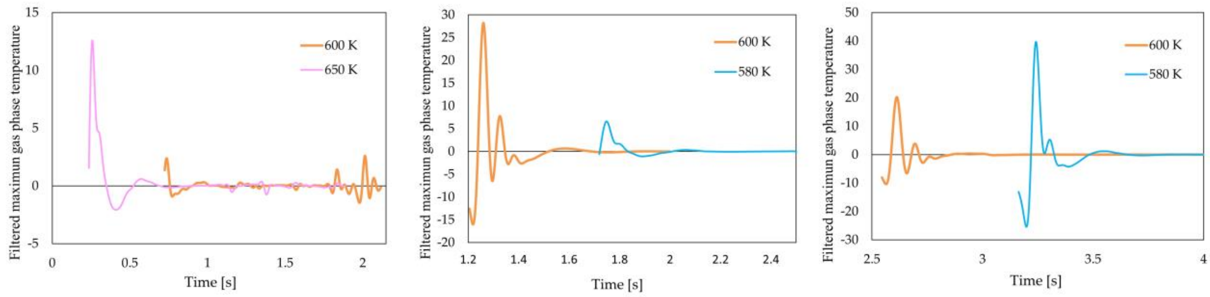
The numerical simulation results are shown **Fig.3**. Lewis number is lowest for Xe/O2 mixed gas, followed by N2/O2 mixed gas, and highest for He/O2 mixed gas.



(a)He/O2 (b)N2/O2 (c)Xe/O2

Figure 3. Graph showing cool flame oscillations by atmosphere gas and ambient temperature

We focused on oscillation amplitude and dumping rate in order to quantitatively evaluate oscillation. To extract only the oscillation component after removing the overall temperature rise trend, we applied a bandpass filter to remove low-frequency and high-frequency components. The main frequencies were determined by FFT, and the cutoff frequency was set based on the results. In this study, a band-pass filter with cut-off frequencies of 3 Hz (high-pass) and 20 Hz (low-pass) was applied. **Table 3** and **Table 4** summarizes the amplitude and dumping rate. The amplitude was calculated as the difference between the maximum and minimum values, and dumping rate was derived using the logarithmic attenuation method. The conditions marked with lines are those for which no oscillation occurred.



(a)He/O2 (b)N2/O2 (c)Xe/O2

Figure 4. Graph of cool flame oscillation with bandpass filter applied

Table 3. Amplitude(Numerical simulation)

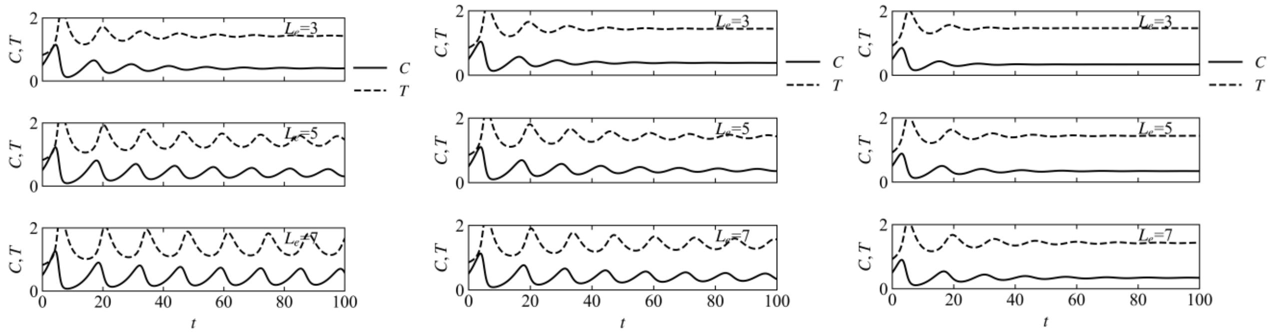
	He/O2 (High *Le*)	N2/O2	Xe/O2 (Low *Le*)
580 K	-	6.60	39.7
600 K	2.59	28.2	20.3
650 K	12.6	-	-

Table 4. Dumping Rate(Numerical simulation)

	He/O2 (High *Le*)	N2/O2	Xe/O2 (Low *Le*)
580 K	-	0.56	2.11
600 K	1.20	1.46	2.31
650 K	2.99	-	-

As can be seen in **Table 4**, the higher the Lewis number is the lower dumping rate is vice versa. In addition, no effect of the Lewis number or ambient temperature on the amplitude was observed in the simulation. As the Lewis number increases, the effect of heat diffusion becomes stronger. As a result, it is thought that heat dissipation makes it easier to reactivate and sustain oscillation. Additionally, the reason why the dumping rate increases as the ambient temperature rises is thought to be because as the temperature increases, dumping rate also increases, and oscillation in temperature and concentration stabilize, leading to the dumping of oscillations.

3.2 Mathematical model results



(a)580 K (b)600 K (c)650 K

Figure 5. Graph of cool flame oscillation

Fig.5 shows a graph of cool flame oscillation derived from a mathematical model. The maximum amplitude and dumping rate of the derived oscillation are shown in **Table 5** and **Table 6**.

Table 5. Amplitude(Mathematical model)

	Le = 3	*Le* = 5	*Le* = 7
580 K	1.15	1.38	1.49
600 K	0.99	1.20	1.30
650 K	0.72	0.88	0.96

Table 6. Dumping Rate(Mathematical model)

	Le = 3	*Le* = 5	*Le* = 7
580 K	0.62	0.24	0.13
600 K	1.13	0.39	0.24
650 K	1.37	0.86	0.65

In cool flame oscillation derived from the mathematical model, the amplitude increased as the Lewis number increased and decreased as the ambient temperature rose. In addition, the dumping rate decreased as the Lewis number increased and increased as the ambient temperature rose. This was consistent with the trends observed in the numerical simulation results.

3. Conclusions

A quantitative evaluation of the effects of Lewis number and ambient temperature on cool flame oscillation yielded the following findings.

・The higher the Lewis number, the lower the oscillation dumping rate, and the higher the ambient temperature, the higher the dumping rate. This is due to the influence of heat diffusion.

・Dumping rate showed a similar trend in both the mathematical model and numerical simulation results.

Acknowledgments

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