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# Direct Numerical Simulation of Premixed Flame in a Circular Micro Channel with Detailed Kinetic Mechanism

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There have been many efforts to develop micro combustors. Miniaturization of combustor increases the surface area to volume ratio, which causes difficulties in stable flame holding. Maruta et al. [1] have investigated the behavior of flame in a micro channel such as the steady flame, the oscillating flame and the flame repetitive extinction and ignition (FREI). However, the detailed mechanism of FREI has not been fully clarified yet. In this study, DNS of micro combustion of methane-air mixture in a narrow circular channel with axial wall temperature gradient is conducted. Micro combustion characteristics are investigated, and the distinct definition of FREI is given.

The steady/unsteady phenomena in a circular micro channel are studied by DNS in an axi-symmetric cylindrical coordinate system with various axial wall temperature conditions. The radius of channel is fixed to $R$ = 0.5 mm. A detailed kinetic mechanism (GRI-Mech 3.0) including 53 species and 325 elementary reactions is employed to represent methane-air reaction. Temperature dependences of the transport coefficients and physical properties are considered by linking CHEMKIN packages. The pressure of premixed methane/air mixture is set to 1 atm. The equivalence ratio is 1.0. The inlet velocity distribution is given by the Poiseuille flow. The axial wall temperature distribution has a hyperbolic tangent profile with lower temperature at inlet $T_{\mathrm{w}}^{in}$ and higher at outlet $T_{\mathrm{w}}^{out}$. Average inlet velocity is 0.3 times as the burning velocity of the corresponding mixture temperature. The wall temperature gradient is expressed by the thermal thickness, $\delta_T = (T_{\mathrm{w}}^{out} - T_{\mathrm{w}}^{in}) \,/\, (\mathrm{d}T/\mathrm{d}z\,|_{\max})$. $T_{\mathrm{w}}^{out}$ is 1600 K and $T_{\mathrm{w}}^{in}$ is 700 K. Here the effect of $\delta_T$ is investigated within 2 mm $\leq \delta_T \leq$ 9.6 mm. Different types of flames are observed with increasing $\delta_T$: the steady flame, the oscillating flame and the FREI. A DNS with the same condition to previous experiment by Maruta et al. [1] is performed. The wall temperatures at the inlet and outlet are $T_{\mathrm{w}}^{in} = 300$K and $T_{\mathrm{w}}^{out} = 1350$K, respectively. The flame behavior exhibits FREI with this condition, which is consistent with experimental results [1].

In Fig. 1, total heat transfer through the wall, $Q$, is plotted for three representative cases with respect to the wall temperature corresponding to the maximum heat release rate position. The negative $Q$ means that the mixture gains the thermal energy through the wall. For FREI, variation in $Q$ becomes significant, and the negative $Q$ is observed in the trajectory from extinction to ignition. Therefore, appearance of the negative $Q$ represents the origin of FREI.

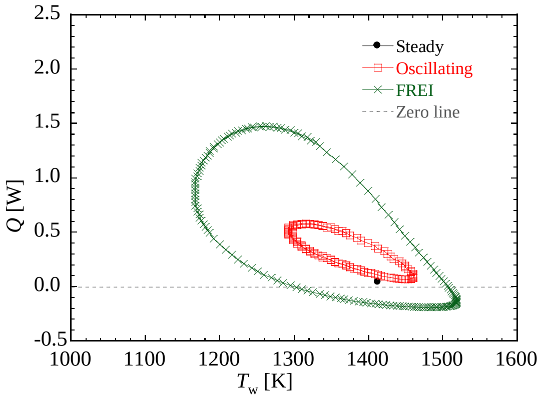


Figure 1. Total heat transfer, $Q$, through wall and temperature at the streamwise position where heat release rate show its maximum on the center axis.

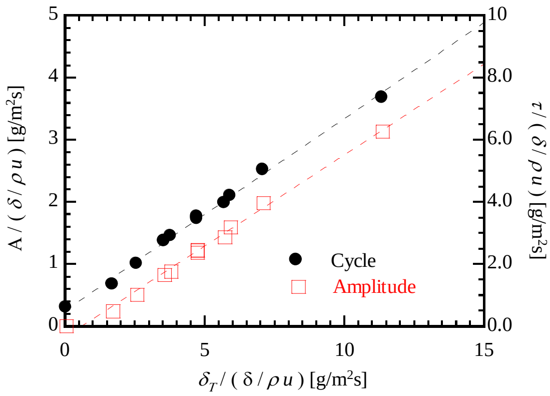


Figure 2. Normalized period (right axis) and amplitude (left axis) of flame motion for FREI cases.

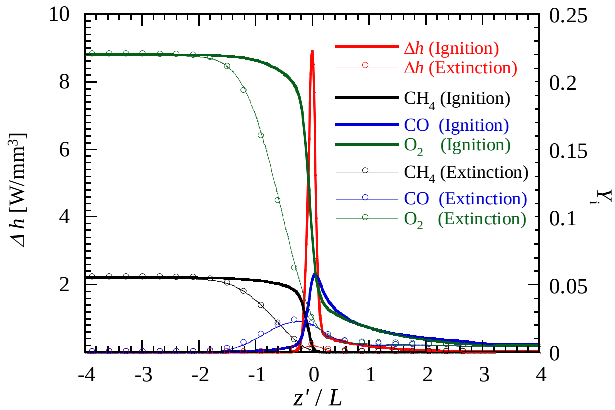


Figure3. Distribution of heat release rate and chemical species at the center axis for FREI.

Figure 2 shows the amplitude and period of FREI against the thermal thickness, $\delta_T$ base on the temperature at the wall. Data under different the wall temperature gradient,γ, are indicated in a single plot normalized by $\delta/(\rho u)$, where $\rho u$ is the mass flux and $\delta$ is the thickness of steady flame in the corresponding condition. Both the normalized period and amplitude of FREI in different conditions can be scaled by the thermal thickness, $\delta_T/(\delta/(\rho u))$.

Figure 3 shows distribution of the total heat transfer, $Q$, the heat release rate, $\Delta h$, and mass fraction of $CH_4$, CO and $O_2$ at the center axis in flow direction for FREI state with $T_w^{out}$ = 1350K. The flame position, $z'$ = 0, is defined where the heat release rate takes its maximum. The maximum heat release rate of flame propagating toward upstream has a much larger peak value and thinner profile compared to that of the steady flame.

In this study, FREI is defined by the possession of negative total heat transfer through the wall. The amplitude and frequency of the heat release rate variation can be scaled by thermal thickness.

## REFERENCES

[1] K. Maruta, T. Kataoka, N.I. Kim, S. Minaev and R. Fursenko, Characteristics of combustion in a narrow channel with a temperature gradient. *Proc. Combust.* Inst., Vol.**30**, pp. 2429-2436, 2005.