가열된 동축류내 정상-헵탄 층류 부상화염의 특성에 관한 수치해석적 연구

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A numerical study of the characteristics of laminar lifted *n*-heptane jet flames in heated coflow air

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Autoignited non-premixed jet flames have drawn great attentions because they are observed in various combustion applications such as gas turbine combustors and diesel engines. Studies of laminar lifted flames under autoignitive condition are also actively carried out due to the importance of understanding the fundamental flame characteristics of autoignited lifted flames [1,2].

Recently, Noman et al. [3] performed an experimental study of the autoignition characteristics of laminar lifted iso-octane and n-heptane jet flames in heated coflow air, and they found the unusual liftoff height, H_L, variations with the change of fuel jet velocity, U_0. To be specific, there exists the regime where the liftoff height shows the appreciable increase with the increase of U_0 when the flame mode of the autoignited lifted flames is changed from the conventional tribrachial edge flame to the Moderate or Intense Low-oxygen Dilution (MILD) combustion. Therefore, the main purpose of the present study is to numerically elucidate the unusual liftoff characteristics of laminar lifted *n*-heptane jet flames in heated coflow air.

The detailed numerical simulations are carried out in a two-dimensional axisymmetric coordinate in the radial, *r*-, and the axial, *z*-, directions with adopting laminarSMOKE code [4,5], which is an OpenFOAM based laminar reacting flow solver.

Figure 1 shows the schematic of the present computational domain. The configuration of the computational domain is identical to that of previous experimental study [3], and the main domain size is 4.25 cm × 50 cm in the *r*- and *z*-directions, respectively. The inner and outer radius of the fuel tube is 0.188 cm and 0.238 cm, respectively. An 8 cm fuel tube is attached to the main domain, which protrudes 1 cm above the coflow air inlet. In the *r*- direction, a uniform grid space of 50 μm is distributed for $0 \le r \le 1.5$ cm, and a stretched grid is applied to the remaining domain. In the *z*- direction, a uniform grid of 50 μm is applied.

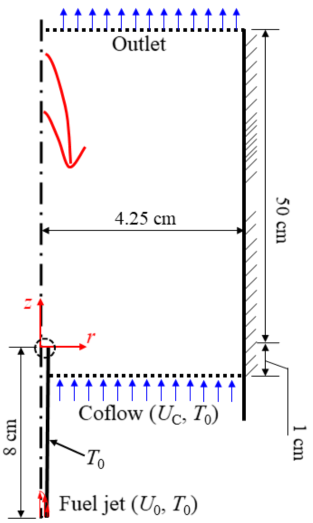

Figure 1. Schematic of the present computation domain.

For boundary conditions, fully developed pipe flow velocity profile, for which mean velocity is U_0, is applied at the fuel inlet, and the coflow inlet velocity is 1.0 m/s. Zero-gradient outflow boundary condition is applied at the outlet. Adiabatic wall boundary conditions are applied for all the wall, except for the fuel tube where fixed value of 1025 K is applied. The details of the inlet boundary conditions are summarized in Table 1.

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Table1. Inlet boundary conditions

Fuel jet velocity, U_0 [m/s]	3.5 ~ 10
Coflow velocity, U_C [m/s]	1.0
Temperature, T_0 [K]	1025
Fuel mole fraction (X_F)	0.02

Figure 2 shows the H_L variation of the autoignited laminar n-heptane jet flame as a function of U_0, together with previous experimental results. It is readily observed from the figure that our simulation results qualitatively well capture the unusual H_L variations observed in previous experiment. Although not shown here, the lifted flames with relatively low U_0 cases (i.e., $U_0 \leq 6.5$ m/s) exhibit the tribrachial edge flame structure, while the combustion mode of the lifted flames changes to MILD combustion as U_0 increases equal to or higher than 6.7 m/s.

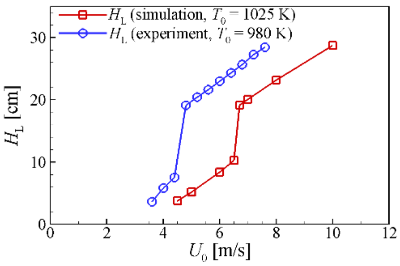

Figure 2. The variations of H_L as a function of U_0 for the autoignited laminar lifted n-heptane jet flames.

To better understand this appreciable liftoff height change, the temperature and mass fraction of OH isocontours of the lifted flames for U_0 = 6.5 and 6.7 m/s cases are shown Fig. 3, for which the significant liftoff height change occurs between two cases. For U_0 = 6.5 m/s, the temperature profile at the upstream of the flamebase is invariable to T_0, indicating that the autoignition has nothing to do with the flame stabilization. On the other hand, for U_0 = 6.7 m/s, the temperature profile at the upstream of the flamebase is notably higher than T_0, and hence, it implies that the autoignition process contributes to the flame stabilization at the relatively high U_0 cases. Therefore, the unusual liftoff variations in the laminar n-heptane jet flame would be closely related to the contribution of autoignition on the flame stabilization.

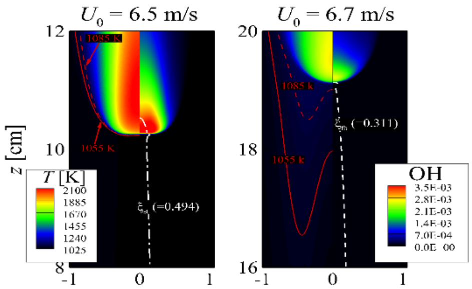

Figure 3. The temperature and mass fraction of OH isocontours for laminar autoignited n-heptane jet flames

Conclusions

In this study, the liftoff characteristics of a laminar n-heptane jet flame are investigated by using 2-D numerical simulations by varying the fuel jet velocity. The present simulation results successfully capture the regime where liftoff height appreciably changes with the change of fuel jet velocity, which is observed in previous experiment, Based on the temperature and mass fraction of OH isocontours, the contribution of autoignition on the flame stabilization would mainly lead to the unusual liftoff height variations of the jet flame. The additional numerical simulations will be carried out as a future work.

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