가열된 동축류의 희석 효과가 메탄/수소 자발화 층류 부상화염에 미치는 영향에 대한 수치해석적 연구

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A numerical study of the coflow dilution effect on the flame characteristics of autoignited laminar lifted methane/hydrogen jet flames

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The emissions of air pollutants generated in the processes of combustion have caused many environmental problems. Therefore, Moderate or Intense Low-oxygen Dilution (MILD) combustion is recently highlighted as a novel combustion technology because of its advantages in reducing pollutant emission [1]. MILD combustion is generally achieved by flue gas recirculation, which leads to the increase of inlet temperature and decrease the concentration of oxygen. It allows the reactant to autoignite itself because temperature is above the autoignitive temperature, while the excessive amount of flue gas leads to retard the autoignition delay time. This induces distributed reaction zones in the combustion chamber, and consequently, the maximum flame temperature can be decreased under the MILD combustion condition.

However, due to the low concentration of oxygen, the flame stabilization of the MILD combustion is one of the most challenging issues. Therefore, the purpose of the present study is to gain a fundamental understanding of the relation between the dilution level on the coflow and the liftoff height for the laminar methane/hydrogen jet flames.

The numerical simulations are performed in an axisymmetric coflow burner configuration using laminarSMOKE code [4,5], which is an openFOAM based laminar reacting flow solver.

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Figure 1 shows the schematic of the computational domain for the simulations. The domain size is 6.65 cm × 50 cm in the radial r- and the axial z- directions. The inner and outer diameter of the fuel nozzle are 3.76 mm and 4.76 mm, respectively, and this configuration is identical to that of the previous experiment and numerical simulation [2,3]. The inlet boundary conditions for the simulations are summarized in Table 1. For comparison purposes, we also perform additional numerical simulations of methane jet flames in heated coflow. The boundary conditions for the additional simulations are summarized in Table 2.

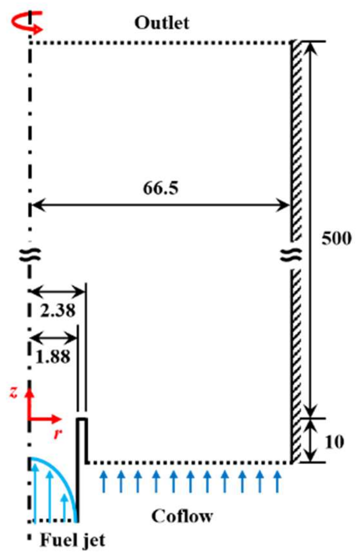

Fig. 1. Schematic of the computational domain for simulations

Table. 1. Boundary conditions for methane /hydrogen jet flames

Fuel velocity, U_0 [m/s]	4~30
Coflow velocity, U_{CO} [m/s]	1.1
Temperature, T_0 [K]	940
Fuel mole fraction, X_F	0.2
Hydrogen ratio in fuel, R_H	0.35
Oxidizer mole fraction in coflow, X_{O2}	0.10~0.21

Table. 2. Boundary conditions for methane jet flames

Fuel velocity, U_0 [m/s]	10~30
Coflow velocity, U_{CO} [m/s]	1.1
Temperature, T_0 [K]	1160
Fuel mole fraction, X_F	0.2
Oxidizer mole fraction in coflow, X_{O2}	0.10~0.21

Figure 2 shows the variation of liftoff height, H_L, for methane/hydrogen and methane jet flames as a function of U_0. For methane jet flame (see Fig. 2b), the H_L increases with the increase of U_0, and the overall H_L further increases as X_{O2} decreases. This is because the increase of N_2 in the mixture increases/ decreases the ignition delay time/laminar flame speed.

For methane/hydrogen jet flames (see Fig. 2a), H_L generally decreases with the increase of U_0, which is mainly attributed to the differential diffusion effect between CH_4 and H_2 molecule [3]. An interesting point in the present study is that the H_L variation is almost invariable, or even slightly decreases with the decrease of X_{O2} when U_0 is higher than 20 m/s. Since the flame temperature continuously decreases with the decrease of X_{O2}, it indicates that the methane/hydrogen jet flame is more favorable to exhibit the stationary lifted flames with MILD combustion mode.

We conjecture that the unusual H_L behavior of the methane/hydrogen flames at relatively-high U_0 regime is caused by the high diffusive nature of hydrogen molecule, as in the previous study [3]. The detailed simulations to identify the effect of diffusivity of hydrogen on the flame stabilization will be carried out in a future work.

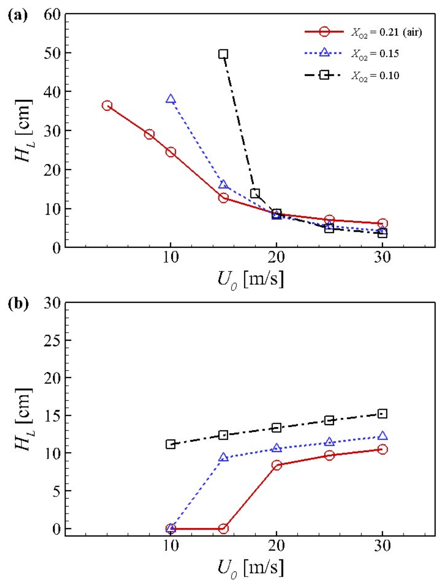

Fig. 2. Variations of liftoff height for auto-ignited laminar lifted (a) methane/hydrogen and (b) methane jet flames

Conclusions

In this study, we investigate the liftoff characteristics of laminar methane/hydrogen jet flames by varying the mole fraction of oxygen in the oxidizer coflow. Unlike typical autoignited laminar lifted jet flames such as methane jet flame, the liftoff height of the methane/hydrogen jet flame remains nearly the same with the decrease of the oxygen levels. It suggests that the hydrogen addition in the fuel jet can play a critical role in stabilizing lifted flames in the MILD combustion. Additional numerical/experimental studies will be carried out to elucidate the effect of hydrogen addition on the flame stabilization.

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