

자발화 한계 근처에서의 난류 동축류 수소 제트 화염의 특성에 대한 직접수치모사 연구

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Direct numerical simulations of the turbulent lifted hydrogen jet flames near the autoignition limit

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Turbulent lifted jet flames are observed in many of combustion appliances such as diesel engine, gas turbine, and commercial boiler. A number of research have been carried out to understand the fundamental characteristics of the turbulent lifted jet flames. Among them, flame stabilization is one of the key issues for the integrity of the combustion systems. As coflow temperature exceeds the autoignition temperature, the autoignition is known to play an important role in flame stabilization [1,2].

In this study, we carry out three-dimensional direct numerical simulations of spatially-evolving turbulent lifted hydrogen slot-jet flames in heated coflow air. We focus on the coflow temperature which is marginally greater than the autoignition limit and investigate the effect of autoignition on the flame stabilization.

Figure 1 shows the schematic of the present simulations. Diluted hydrogen fuel (mole fraction of hydrogen, X_{H_2} , is 0.65, and X_{N_2} is 0.35) is issued from the central slot jet with an inlet temperature, T_j , of 400 K. The slot jet width, H , is 2 mm, and the overall computational domain size is $15H \times 20H \times 3H$ in the streamwise, x , transverse, y , and spanwise, z , directions. The mean inlet axial velocity, U_{in} , is specified as

$$U_{in} = U_c + 0.5(U_j - U_c) \left(\tanh\left(\frac{y+H/2}{2\delta}\right) - \tanh\left(\frac{y-H/2}{2\delta}\right) \right)$$

where U_j and U_c are the mean inlet jet (240 m/s) and coflow velocities (2 m/s), respectively,

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and $\delta = 0.05H$. The compressible Navier-Stokes, species conservation equation, and total energy equations are computed by using the Sandia DNS code, S3D [3], with detailed hydrogen oxidation chemical kinetic mechanism [4]. The jet Reynolds number, Re_j , is approximately 8,000.

Coflow air temperature, T_c , is set to 850 K (case 1) or 950 K (case 2). Figure 2 shows the 0-D homogeneous ignition of H_2 /air mixture at various temperature. As shown in Fig. 2, ignition delay time of the mixture significantly varies between 850 ~ 950 K. Therefore, an autoignition limit of hydrogen would be in between these two temperature conditions.

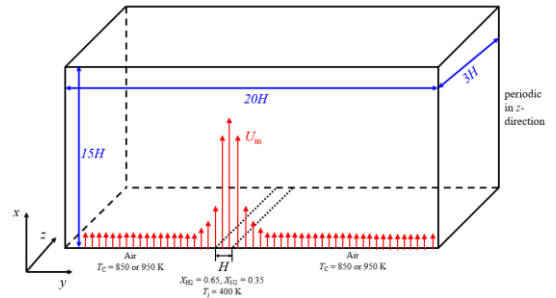


Figure 1. Schematic domain of the present simulations.

Figure 3 shows the instantaneous snapshots of mass fraction of HO_2 and heat release rate [J/mm^3s] for both cases in a two-dimensional x - y plane ($z = 0$). Here, solid and dashed line denote the flame zone (i.e., $Y_{OH} = 0.001$) and stoichiometric mixture fraction isoline, ξ_{st} ($=0.199$), respectively. As shown in Fig. 3, the formation of HO_2 at the upstream of flamebase is not clearly shown in both cases. Since the

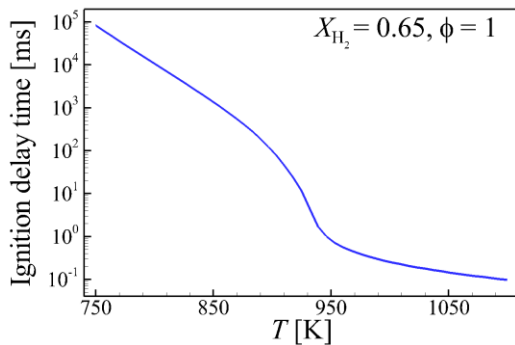


Figure 2. 0-D ignition delay time of stoichiometric H_2 /air mixture with various temperatures.

HO_2 is an ignition marker for the H_2 /air jet flames [1], it indicates that the contribution of autoignition to the flame stabilization is marginal for both cases. Heat release at the upstream of the flamebase is also not distinct for both cases as compared to that of T_c of 1100 K case [1] (not shown here).

Note that the 0-D ignition delay time of the most reactive mixture at $T_c = 950$ K is approximately 1.5 ms, which is highly explosive condition. In this regard, the marginal effect of autoignition on the flame stabilization of turbulent jet flames would be related to the turbulent structure developing at the upstream of the flamebase. This will be investigated further as a future work.

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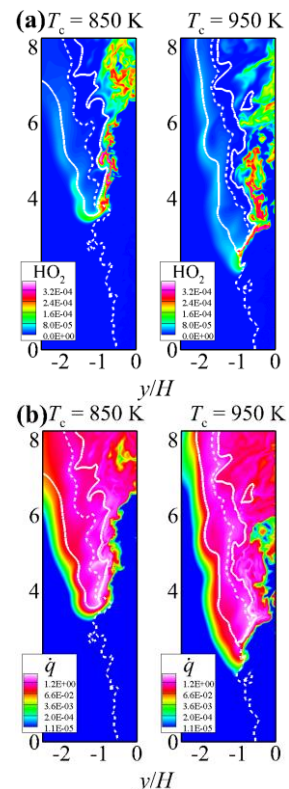


Figure 3. Instantaneous snapshots of (a) mass fraction of HO_2 and (b) heat release rate for turbulent jet flames at (left) $T_c = 850$ K and (right) $T_c = 950$ K.