Structures and Extinctions in Hydrogen Non-Premixed Lifted Turbulent Jet Flame

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Abstract

Two dimensional direct numerical simulation of H_2-air lift-off flame with height jet velocity is performed with full chemical kinetics. Hydrogen non-premixed turbulent jet flame structure is obtained and its quenching process at the lifted position is examined.

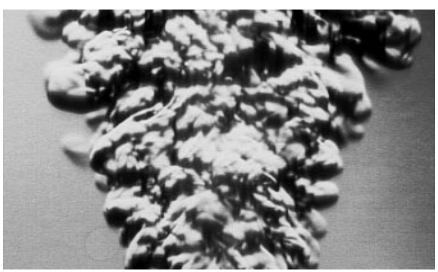
Introduction

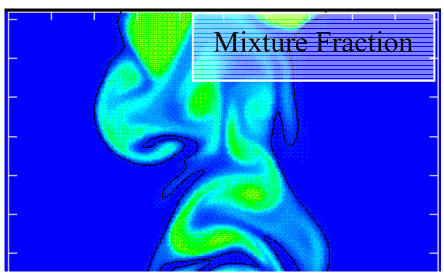
Non-premixed as well as premixed jet flame is widely used in industrial combustion systems. Flows in these combustion devices are turbulence and the study of their detailed mechanisms is required for efficiency and safety. Fundamental research of flame structure, lift-off, blow off, and quenching, is indispensable for practical combustors as well as applied research. Many works have been done on those fundamental subjects [1-5]. However, as far as the issue of turbulence is concerned, there are always difficulties for theoretical and numerical studies. Recently, with the increase of computational power, the direct numerical simulation (DNS) has become easier to handle than the time when Kim calculate channel flow and become an essential tool to understand combustion problems [6].

The aim of this study is an investigation of the unsteady behavior of lift-off jet flame in two dimensions using DNS. Chemical reactions are considered H_2-air system with full kinetics. Particular interest is dedicated to quenching process of the flame.

Numerical Formulations

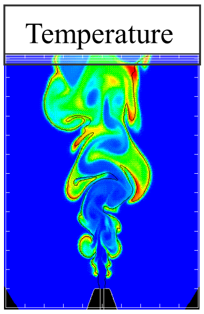
A lifted H_2 jet flame under consideration was shown in Fig.1. The flame obeys the conservation of the mass, momentum, energy, and species mass for reacting flow [7]. The mixture is regarded as ideal gas and the state relation holds. Thermodynamic and transport properties are based on CHEMKIN package [8]. As for the chemical reaction, 19 elementary reactions with 9 species of H_2, O_2, O, H, HO_2, H_2O_2, H_2O , and N_2 are considered [9].





V_{H2JET}=670m/s

(a)



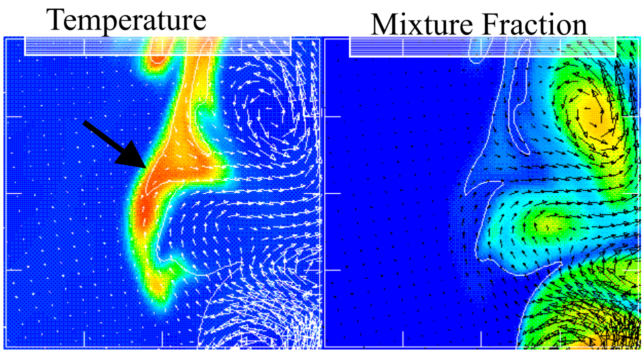
(b)

Fig. 1 H_2-Air Flame jet; (a) Shilieren picture (b) Numerically visualized picture

Simulations are performed for the turbulent jet flame in two-dimensions based on the standard finite difference method. Reaction stiffness difficulties are avoided by using the point implicit method to integrate chemical productions and the explicit method for others. The Harten-Yee's non-MUSCL modified-flux type TVD scheme [10-11] is applied to discrete convective terms while the second order central difference scheme is applied to discrete dissipative terms.

In this calculation, the computational domain size is selected to be 4cm x 6cm and the grid size is 300x350 in stream wise and cross-stream wise respectively. Initial conditions are given as H_2 jet with 670m/s injects into the still air at 1atm and 300K. On boundaries, (a) Isothermal, slip, and non-catalytic for burner wall, (b) Thompson non-reflection conditions [12] for outer side of stream-wise, and fixed pressure with zero normal gradient values for others, are given. Ignition heat are added at the moment the fuel and the air mixed up. Calculations are performed on the FUJITSU VPP700 supercomputer at RIKEN and partly on the NWT at National Aerospace Laboratory.

RESULTS



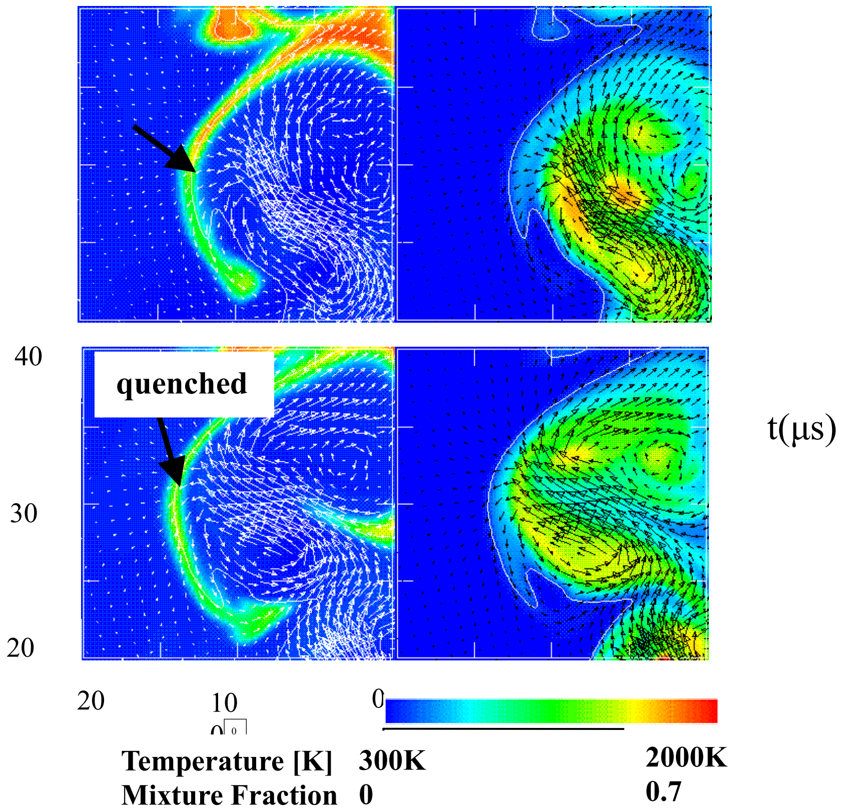


Fig. 2. Flame structures and extinctions

We obtained fully developed turbulent field in the region by calculating about 1ms. The jet is built up by Kelvin-Helmholtz instabilities and the lift off height agrees with experimental value [13]. Shown in Fig. 1(b) are distributions of temperature and mixture fraction. The state is unsteady and changed every instant. Their time dependency for the jet flame shows in Fig. 2. The figure shows clearly that the extinction occurs when the large structure of cold fuel flows into and strains the reaction zone.

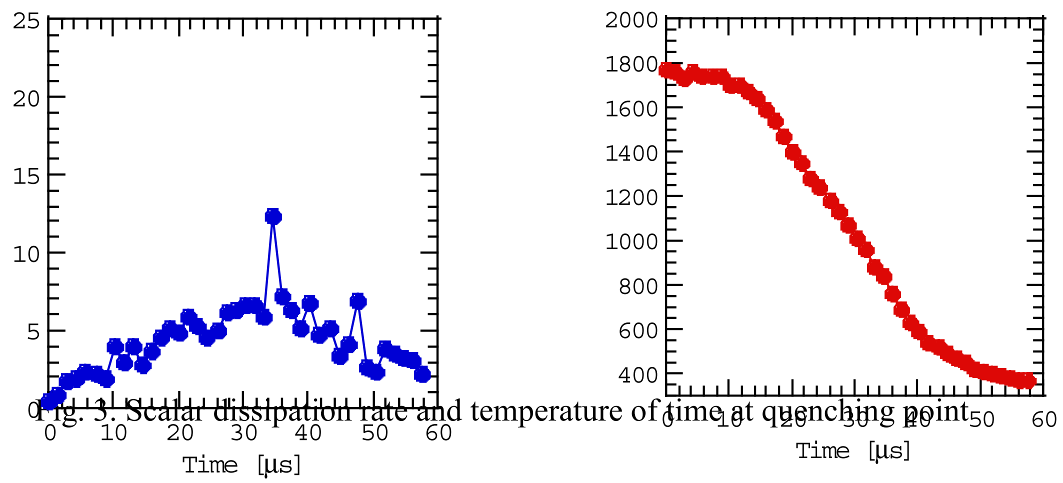


Fig. 3. Scalar dissipation rate and temperature of time at quenching point

Fig. 3 shows temporal evolutions of scalar dissipation rate and temperature at the quenching point. Quenching is happened when the scalar dissipation rate exceeds a critical value, as Peters and Williams have mentioned in their earlier work (14).

In our two dimensional simulations, the process of quenching was shown, but further work will be done on the control of fuel-oxidant mixing to improve combustion efficiency.

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