A Study of Mutual Interaction of a Jet Flame and the Horizontal Wall

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Introduction

Using flame as the heating source is the most primitive and prevailing way to obtain thermal energy. The interactions between the wall and the flame play an important role in the process of extracting thermal energy from the flame. However, the mutual interactions between the flame and the heated surface are far too complicated to explore in details. They include complex physical and chemical processing of aerodynamics as well as thermodynamics and chemical kinetics. The researches in the literature about the relationship between the flame and wall could be classified by the basic orientation of the flame relative to the wall as: a jet flame impinging on the wall [1-2], a flame and the lateral wall [3-4], and flame propagation in the cavity of quiescent fuel-air mixture, etc. Aerodynamic strain [5], boundary condition [6], buoyancy, heat transfer and thermal quench [7-9], flame extinction and flame stretch [10-12] are the major issues of the interaction process, which have been intensively studied. The interaction between the flame and the wall is mutual and vitally dependent on each other. However, seldom has been addressed in this aspect. The existing of the wall in the flowfield of the flame affects the flame structure, temperature distribution and the velocity distribution of streamline in itself. On the contrary, the approaching flame affects the temperature gradient of the near-wall zone as well as heat transfer to wall. Therefore, the objective of this study is to analyze the variation of flame property by approaching horizontal wall.

Experimental setup

As show schematically in Fig. 1, compressed air from the tank and propane from the bottle are filtered, metered and premixed in the pipeline. The premixed fuel and air then passes through a settling chamber to rectify the flow quality. The size of exit port is 6×40mm and an adiabatic wall made of ceramic fibers is placed perpendicular to the jet stream with various characteristic distances. Flow visualization is a simple way to observe and categorize the evolution of flame structure with variable wall distances. The visualization system consists of a 3 W Ar ion laser as the light source, a cylindrical lens to spread the laser beam into a sheet, a triggerable CCD camera to capture the phase-locked images and a professional video recorder to record the images for analysis. In addition, the laser induced OH fluorescence imaging technique is also employed to map the reaction zone structure at various wall distances. A narrowband tunable KrF excimer laser is used to excite the $P_2(8)$ rotational line of the A-X(3,0) transition at λ=248.46 nm. The laser beam is expanded into a thin sheet of 25 mm height and 0.2mm thick passing through the flame axis. The OH fluorescence signal is imaged onto an intensified CCD camera and then the images are processed in the computer. Other instruments used for measurements are: the shadowgraph visualization to observe the evolution of outer buoyancy vertices, R-type thermocouples for temperature, and the gas analyzer system for post-flame pollution concentrations.

Results and Discussion

First of all, plain flame images could effectively show the variation of the flame shape when the horizontal wall moves toward the flame. It is due to the outer buoyancy vortices of the flame that are affected by the approaching of the horizontal wall and that in turn vary the flame shape. In short, the effects of horizontal wall approaching vary the flame shape, structure and even the dynamic behavior, including variation of the flame bulge and flame winding as wall as flame fluttering. Qualitatively, the evolution of the flame structure can be categorized into 7 zones: the jet flame zone, ordinary zone, elongation zone, strengthening zone, fluttering zone, attachment zone, and stagnation flame zone (see Fig 2). When the wall is moving closer to the flame, the flame bulge near the tip changes from triangle- to tetragon-shape and becomes larger in area (see Fig. 2 phenomenon 1-2). When the distance between the wall and flame is reduced close to the flame length (see Fig. 2 phenomenon 3), winding and fluttering phenomena occur at the flame tip. Even then, as the distance approached 19.5 cm (flutter zone), two types of flame structures appear alternatively: attached and detached flames. Depending on the wall distance, there are two interacting mechanisms influencing each other: the buoyancy and the momentum mechanisms. For the most part, the buoyancy mechanism is due to outer buoyancy vortices induced by the temperature gradient between the flame and outer quiescent cold air and the momentum mechanism is due to velocity gradient of the jet flow and the flame. As to the temperature distribution (see Fig. 3), when the distance between the wall and flame is reduced, the distribution area of high-temperature flame zones is increased and the maximum temperature zone is found near the top wall. For OH radical distribution (see Fig. 4), it is found to depend on the distance between the wall and flame. To shorten the distance is to increase the concentration of the OH radical. It is similar to the temperature distribution. For pollution emissions, no obvious change on NO_x emission can be found, and CO emission is increased as the horizontal wall moves toward the flame (see Fig 5). In summary, the existence and approaching of the wall have an apparent and profound influence on the fundamental physical phenomenon and dynamic response of the flame. It is an essential course of the basic combustion research.

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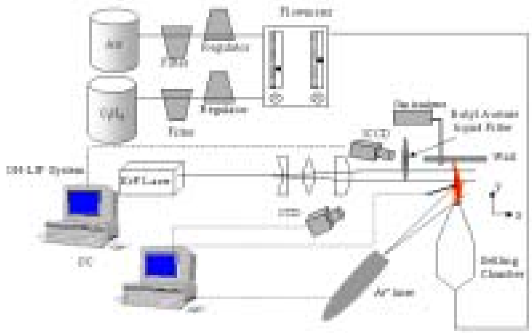

Fig. 1. Experimental apparatus

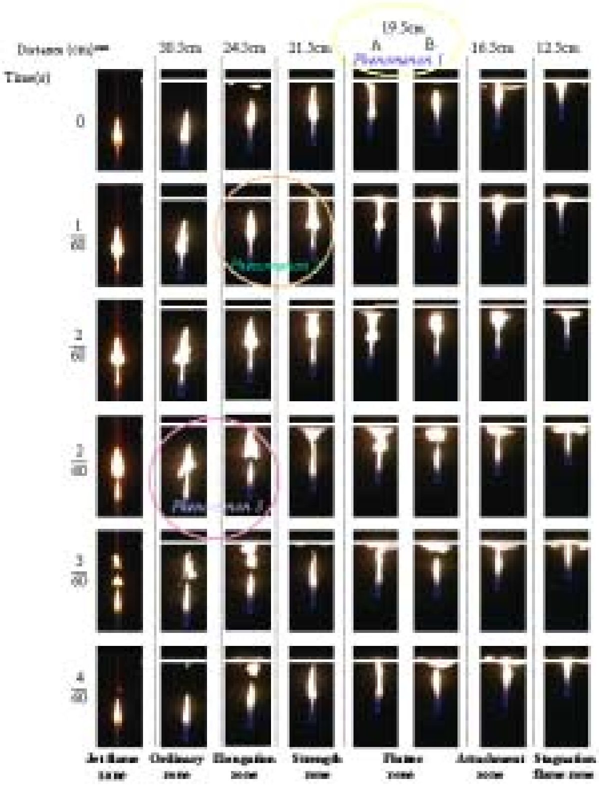

Fig. 2. The evolution of flame structure

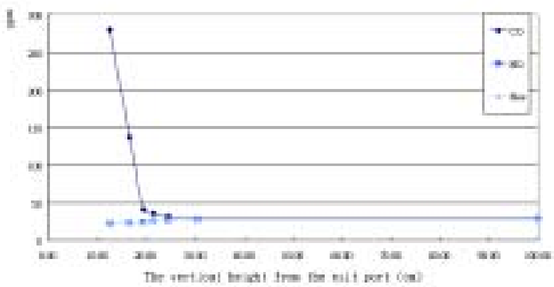

Fig. 5. The pollutant emission in different boundary conditions

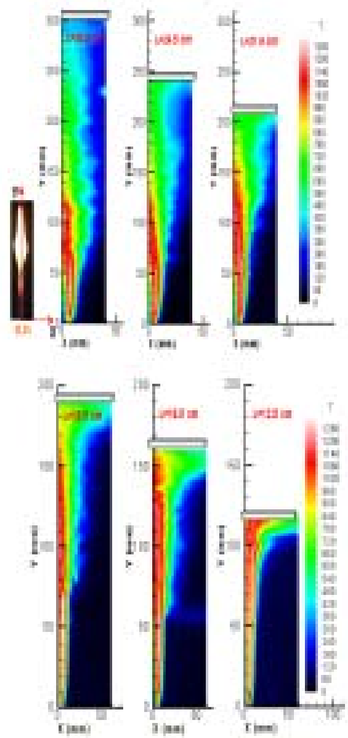

Fig. 3. The distribution of temperature in different boundary conditions

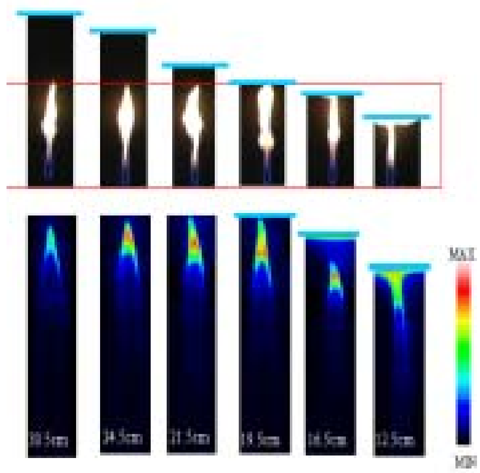

Fig. 4. OH radical distributions in different boundary conditions