A STUDY OF THE INTERACTION BETWEEN A JET FLAME AND A LATERAL WALL

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Introduction

Flame-wall interaction has long been an important basic subject of combustion research. This sort of interaction constitutes the fundamental configuration of extracting energy from the flame and of fire hazard. The stagnation flame sustained by a fuel jet impinging on the wall provides a useful flame structure for basic flame studies. Most flame-wall interaction researches in the past few decades were focused on this feature, e.g., ref. [1-3]. On the other hand, the interaction of a flame and a lateral wall can be found in furnaces and hazardous fire propagation along the wall. The lateral wall may provide fuel vapor to sustain the propagation of the flame, a configuration most the boundary-layer flame studies employed, or the wall may be used for transferring heat with adiabatic or constant temperature wall boundary conditions, a configuration which has less been studied form the combustion point of view. Escudié et al. [4] studied the interaction of the lateral wall and a "V"-shaped flame stabilized by a thin wire. However, the flame configuration is less practical and the mutual interaction between the flame and the lateral wall was not explored in details. Therefore, the main objective of the present research is to study dynamic process of the flame-wall interaction and the effects of the mutual interaction on flame structure and heat transfer to the wall.

Experimental Setup

The experiments are carried out on a coaxial burner consisted of a 10 mm-diameter central nozzle from which the fuel (propane) emerges and a very low speed 100 mm-diameter annular coflowing air jet which serves to seed the flow for LDV measurements. An adiabatic wall made of ceramic fibers is placed parallel to the jet axis with various separation distances. The air is supplied from the tank and propane from the bottle. The fuel is partially premixed with air to an equivalence ratio of 4, however, variation of the equivalence ratio is also made for comparison. The exit Reynolds number based on the diameter of the central nozzle is maintained at 2000 and a higher speed case at Re=14000 is used for comparison. The flame/flow visualization technique with aluminum oxide seeding through the coflow is employed to observe the flame and the outer buoyant vortical structures. Instruments used for measurement are: the laser Doppler velocimetry (LDV) system for velocity and turbulence, an R-type thermocouple for temperature, and the gas analyzer system for pollution concentrations. Essentials of the experimental arrangement are shown schematically in Fig. 1. To improve the resolution the flow-field measurements are phase-locked to the naturally periodic oscillation of the flame flickering. The diameter of the R-type thermocouple is 25μm, which is fine enough to resolve the major periodic characteristics of the flame flickering. Thermocouple output is also used as the reference signal for phase-locked flow and flame measurements. Flame flickering frequency can be identified through fast-Fourier-transform power spectrum of the fine thermocouple placed near the edge of the flickering flame.

Result and Conclusion

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The images of flame/flow visualization in Fig. 2 clearly show the importance of the outer buoyant vortical structure in the complicated flame-wall interaction process. It has been observed and theoretically studied [5-11] that the observed flame flickering is mainly due to the evolution of the large-scale buoyant vortices in the immediately vicinity of the flame. The buoyant flow due to the combustion hot products induces the Kelvin-Helmholtz vortex. As indicated, the outer buoyant vortex induced by the hot combustion products is usually periodic in a low frequency around 10-20 Hertz with a convective velocity of approximately 0.8m/s. The evolution of the vortex ring may significantly distort the flame surface into a flame bulge between two consecutive buoyant vortices. The periodic passing of the flame bulges produces a stable flickering frequency. For the unexcited case the buoyant vortex is usually axisymmetric. As the lateral wall approaches to certain distance, the buoyant vortex and the flame structure on the wall side are distorted while on the free side those stay almost undisturbed. The flame tip is seen to bend toward the wall and finally the flame may attach to the wall. When attached to the wall if the distance is further reduced the flame length is significantly elongated. The presence of the lateral wall will also sustain an attached high speed jet flame on the wall, even it is blown out originally. The distortion and dissipation of the buoyant vortices on the wall side plays the key role on the bending and attachment of the flame as the lateral wall approaches. The variation of the flame structure and the outer buoyant vortices as the lateral wall approaches can be categorized into four stages based on the ratio of the size of flame bulge on the right (disturbed by the wall) and the left (undisturbed) sides, as shown in Fig2. (1) When the distance between the wall and the jet axis $L/d > 4$, there is no obvious variation of the flame structure. (2) When $2.5 < L/d < 4$, the outer vortices on the wall side become smaller due to shear dissipation of the wall and the flame bulge between the two adjacent vortices becomes lager. (3) When $1.5 < L/d < 2.5$, the outer buoyant vortices near the wall disappear, the flame bulge become smaller and then disappear, and the flame is seen to incline toward the wall automatically. (4) When $0.5 < L/d < 1.5$, incomplete combustion due to flame quench on the wall can be observed. The average convective velocity on both sides of the flame at two typical axial locations is compared in Fig. 3. The convective velocity can be related to buoyancy force of the combustion hot gas and the entrainment of the buoyant vortices. The convective velocity is accelerated along the downstream location. As the wall approaches, the convective velocity on the free side remains unchanged and that on the wall side increases significantly when the distance is roughly smaller than 3. This implies that as the wall approaches the vortex on the wall side becomes slender and the rotation of buoyant vortex on the wall side is accelerated. The entrainment velocity is therefore increased. A pair of low-speed counter-rotating streamwise vortices can be observed on the wall side in the cross-sectional images of the flame/flow visualization (not shown). The temperature measurement results in Fig. 4 clearly reveal the bending and attaching process of the flame-wall interaction. The results also show that the flame temperature on the wall side is increased to a maximum at $L/d = 1.5$, as shown in Fig.4, and the wall temperature also reaches a maximum as the buoyant vortices disappear and the flame starts to incline toward the wall. The NO_X emission index (EINOx) has no obvious change, and CO emission (EICO) increases as the lateral wall moves toward the flame. In summary, the size and the wall dissipation of the buoyancy induced large-scale outer vortices play the central role on the dynamic response of flame bulge, bending and attachment in the mutual interaction process of a jet flame and the lateral wall.

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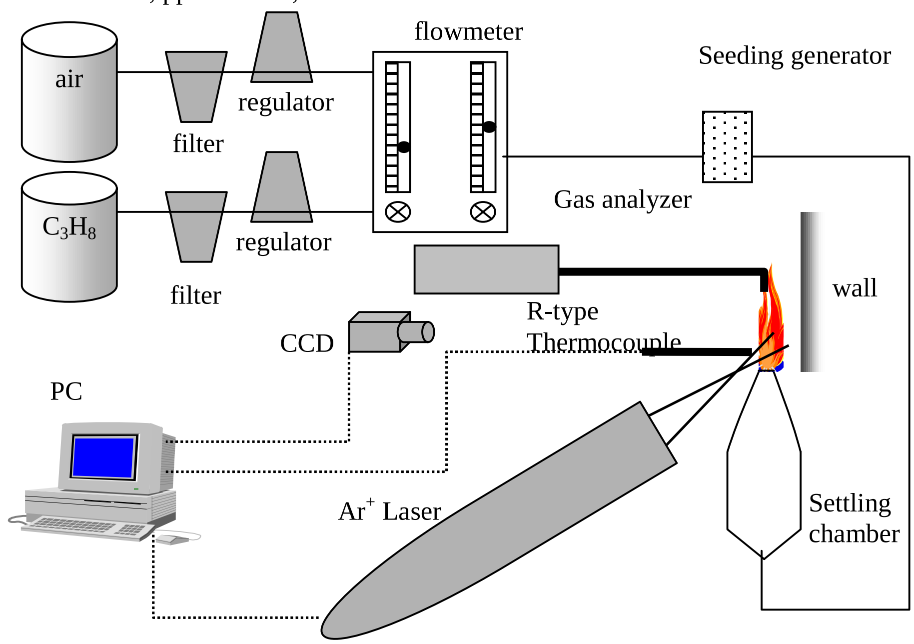

Fig. 1 Experimental setup and apparatus

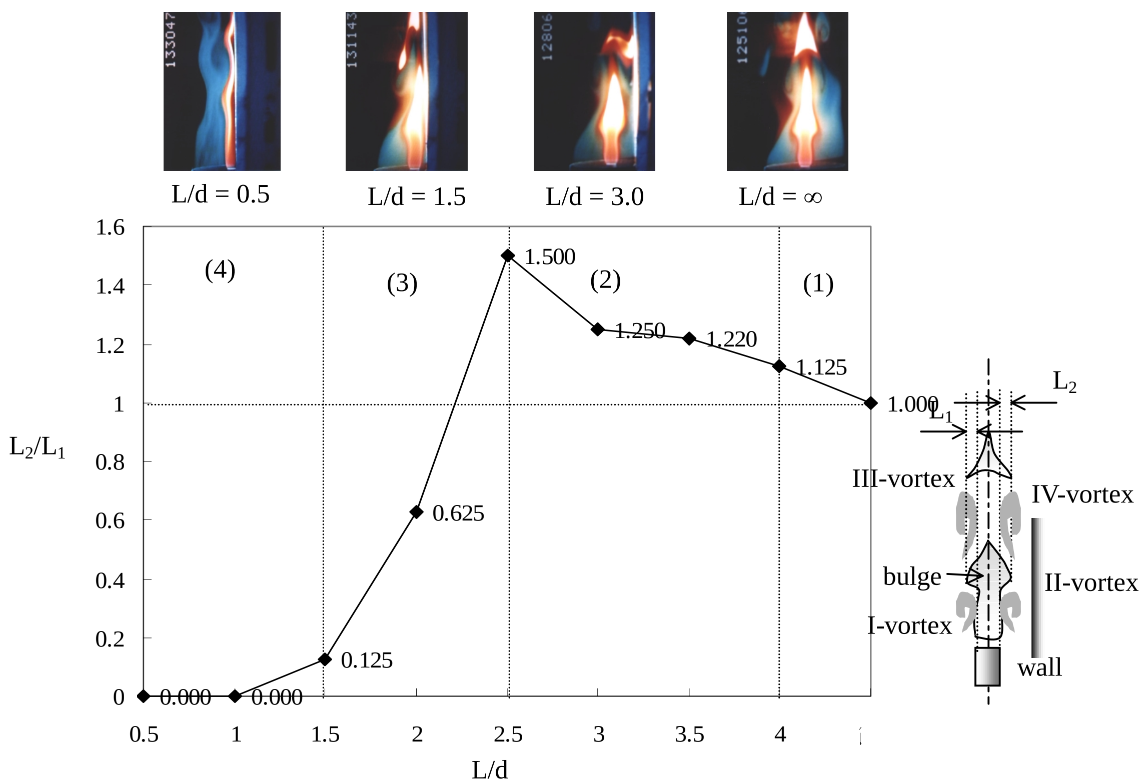

Fig.2 The images of flame/flow visualization and variation of the ratio of the size of flame bulge on the right (disturbed by the wall) and the left (undisturbed) sides as the wall moves toward the flame

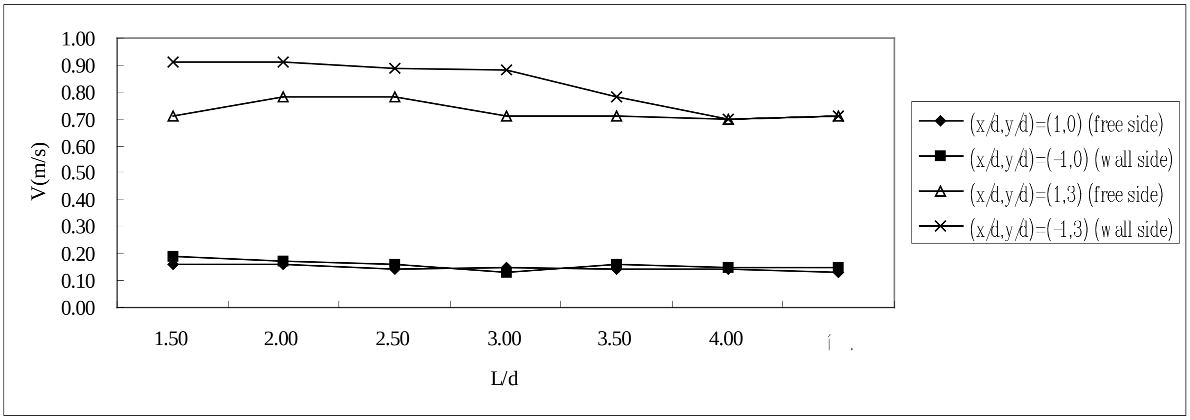

Fig. 3 Variation of the average convective velocity with the separation distance (L/d) on both sides of the flame at two typical axial locations

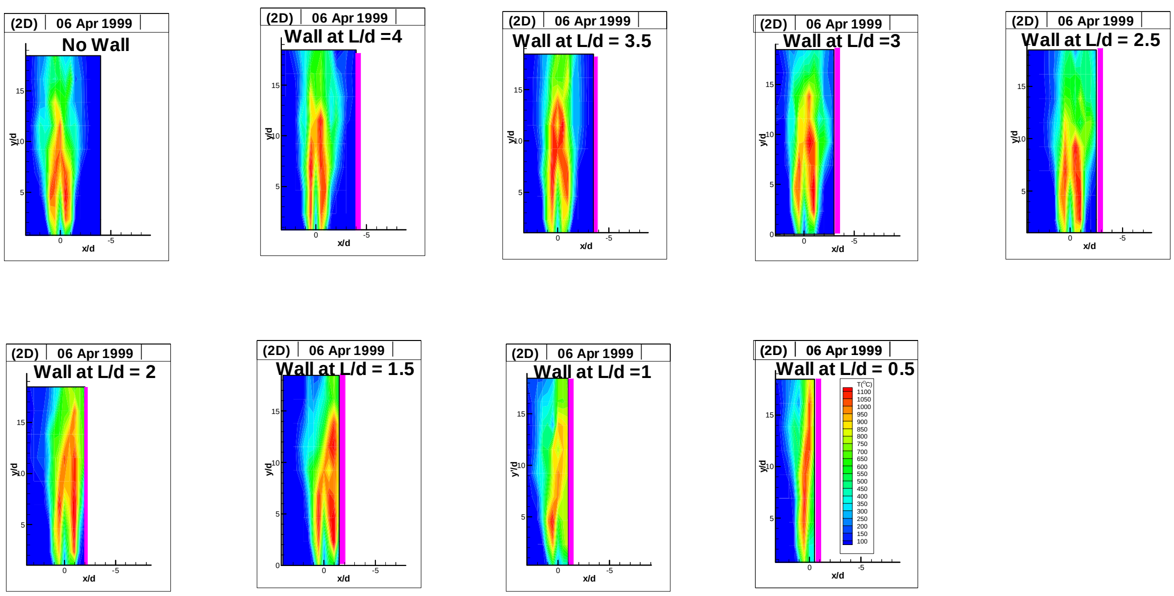

Fig. 4 The flame temperature contours for cases of different distances between the wall and the jet axis (L/d).