FIRE-INDUCED FLOW ALONG THE VERTICAL CORNER WALL

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ABSTRACT

Upward flame spread along the vertical corner wall is a severe phenomenon due to its rapid spread rate in building fires. We conducted this study to investigate what kind of flow will be developed along the vertical corner wall by fires using a room corner model and placing a square gas burner on the floor. The parameter changed is the location of the burner respect to the walls. After a steady state condition was achieved, stream lines were visualized by particles illuminated by a laser sheet, and recorded by a 35mm camera. Results revealed that the oscilation of the flame, the long-range action of the turbulent plume and the swirl produced under some condertions are critical elements for understanding of turbulent entraiment and flame spread processes of the room corner fire.

KEYWARDS: Compartment Fire; Fire Spread; Fire Plume.

INTRODUCTION

Turbulent upward flame spread along a vertical wall has been studied intensively in our previous work [1]. The upward flame spread along the vertical corner wall, however, is not well understood, in spite of the fact that the phenomenon is an important subject in fire safety due to rapid spread rate and high intensity radiant emmission from flame and burning walls. This is because of the lack of understanding of turbulent entrainment and turbulent mixing processes in corner fires. Experimental data and prediction model are largely limited to axisymmetric flames and plumes in an open environment. Limited information is available for flames against a wall or in a corner of two walls. The techniques of flow visualization have been used with some notable success in studing the coherent structures of turbulent flows in recent years. In the previous study, smoke streak lines were used to visualize flow patterns; some vortex characteristics of the fire-induced flow were revealed [2]. In the present experiment, instantaneous stream lines were visualized by particle track method that can lead to a quantitative visualization by PIV(Particle Image Velocimetry) technique in the next step. To understand the transient nature of fire spread, it may be useful and necessary to understand the simpler steady state scenario. Thus, in this study, visualization of steady fire-induced flow along the corner wall is conducted and characteristics of the flow are discussed.

EXPERIMENTAL METHOD

A schematic of the experimental apparatus is shown in Fig.1. The walls are made of Marinite boards(noncombustible/heat insulating material) with 2cm thickness which are backed up by 1.5cm thickness particle board for heat insulation and are fixed on a steel frame. Each of the two walls is 1.6m in height and 1.0m in width. A square gas burner whose exit dimension is 0.15x0.15m was placed on a corner of floor. The level of floor was the same as the burner exit to eliminate flow disturbances by the burner. Blue propane-air premixed flames were

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used for flow visualization to suppress the emission from soot and to obtain clear visualization results. The heat release rate of the burner was changed up to 22.5kW. It was found that the heat release rate is a weak parameter to influence fire-induced flow. Hence experiments were performed by changing the burner stand-off distances(x,y) as shown in Fig.1, and the heat release rate was fixed at 6.0kW. The 50% intermittent flame height that is defined as the average of flame tip and continuous flame height is about 0.25m [3]. Ambient air was seeded with a few micron magnesium oxide particles. These particles can float in the air approximately 5 minutes following the flow faithfully. A 5 watt argon-ion laser was used to produce a sheet of laser light that slices through the plume region of the fire vertically and horizontally. Tracing particles are illuminatted by the laser sheet and the instantaneous flow stream lines were visualized and recorded by a still camera with a shutter speed 1/8 s. The location of the laser sheet is determined from the equation of the plane in which the laser sheet lies.

RESULTS AND DISCUSSION

1.Turbulent Characteristics

The flow visualization photographs presented in Fig.2 clearly show the complex turbulent flow field. As is well known, the transition of laminar flame to turbulent occurs with increasing velocity and scale. At the same time, the luminous height of the buoyancy-contralled flame begins to oscillate. This oscillation is due to the aerodynamic instability caused by the interference between the flame and the surrounding air [3]. These fluctuation dominated turbulent entrainment; turbulent mixing processes are shown in side view photoghaphs in Fig.2(a), (b), (c) and (f). We found that the air flow already becomes non-uniform with the fluctuation in velocity before it enters into the plume, even it is far away from the plume. The velocity fluctuation as a function of time is shown in Fig.2(a), (b) and (c), and distorted stream lines are shown in Fig.2(c) and (d). Hence the turbulent fluctuations generated in the plume area are not only carried away in down stream(by convection) but also transferred normal to the stream lines, and not only directly in adjacent layers of fluid(by diffusion) but also over a great distance. This phenomenon is so called "long-range action" of the turbulence [5]. Note that the turbulence long-range action is not only in the transverse direction, but also becomes important in reverse direction in a low speed flow field, like the natural convection induced by fires. The long-range action may be attributed to the transmission of pressure fluctuation over a distance.

2.Vortex Characteristics

Swirl formation is another important feature in the fire-induced flow along vertical corner walls. A non-symmetric location of the burner respect to the walls would produce a large swirl around the flame which could change the entrainment rate significantly [2,6]. Photographs in Fig.2(d), (e) and (g) show the instantaneous stream lines in a horizontal section for three different locations of the burner. Some representative flow patterns of the induced convection current around the plume are shown in Fig.3. In vertical section the flow pattern(Fig.3(a)) is similar to that of the flow field induced by a turbulent jet from a floor [7]. When the two edges of the burner are flush with the corner walls, the plume will attach itself to the walls. The plume in the corner can be thought of as one quarter of a free plume, four times as strong, shown in Fig.3(b). In an idealized situation the entrainment rate of a fire plume placed in a corner will only be a quarter of that of the four times stronger plume placed far from a wall. When the burner is moved away from the walls, a couple of vortices are found at two edge of the burner, see Fig.2(g) and Fig.3(c). When the burner is closer to or flush with one wall, one of the vortices bocomes stronger and dominates the induced current in the corner(see Fig.3(d)). A side part of the flame is detached from the main body by the axial flow of the vortex as shown in Fig.2(e)-(f). But the breakdown of the vortex occurs quickly after it was produced.

SUMMARY

The flow visualization experiments resulted in the following conclusions: (1)The oscillation of the flame and the long-range action of the turbulent plume phenomena are important in air entrainment of corner fires because the constrains of the air entrainment by the presence of the walls. (2)A non-symmetry location of the burner respect to the walls likely produces a vortex at one edge of the burner. The vortex with a strong axial flow that detach the flame may enhance the flame spread rate largely. Hence the oscillation of the flame, the long-range action of the turbulent plume and the swirl in the flame are critical elements for understanding of turbulent entrainment and turbulent mixing processes in a room corner fire. (3)The flow process is novel and warrants further investigation. This work was supported by NIST grant #60NANB1D1142.

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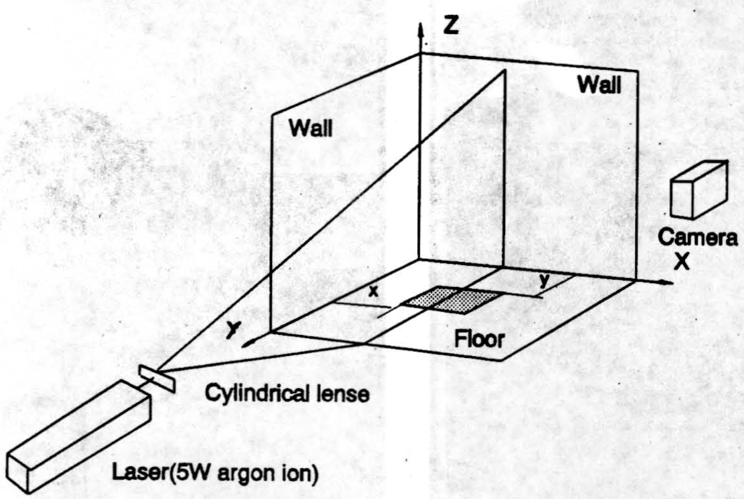
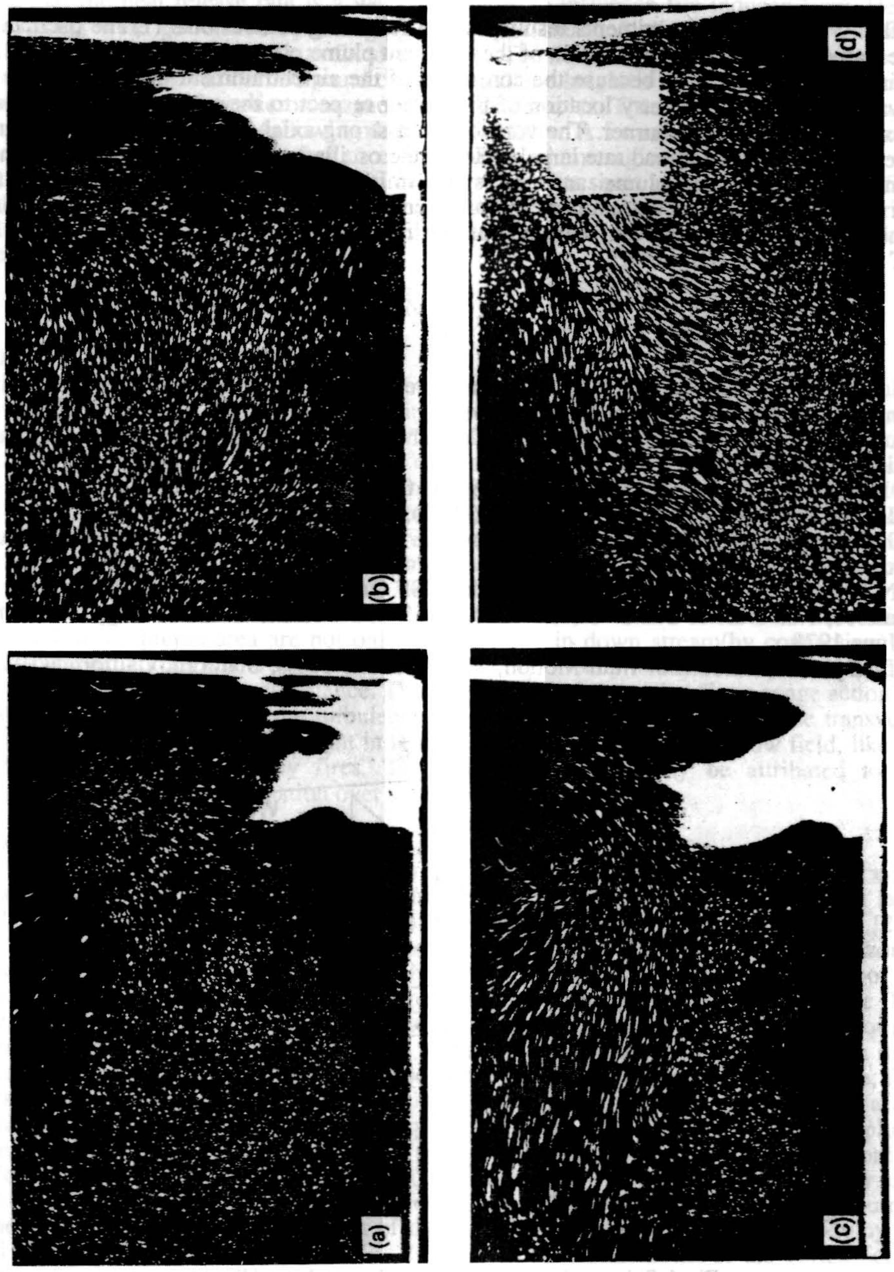
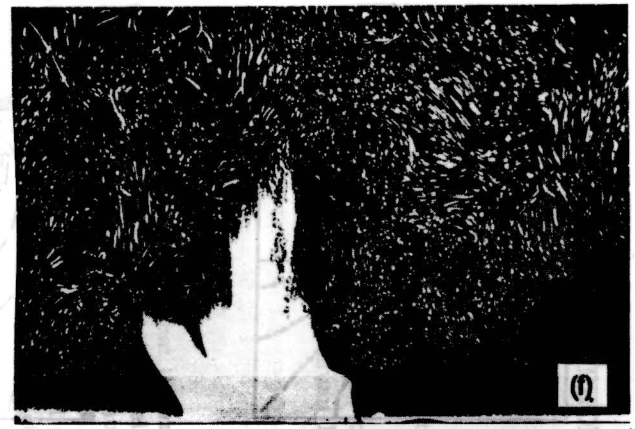


Fig.1 Schematic of the illumination and coordinate system for the model of room corner fire


(a)
(b)
(c)
(d)



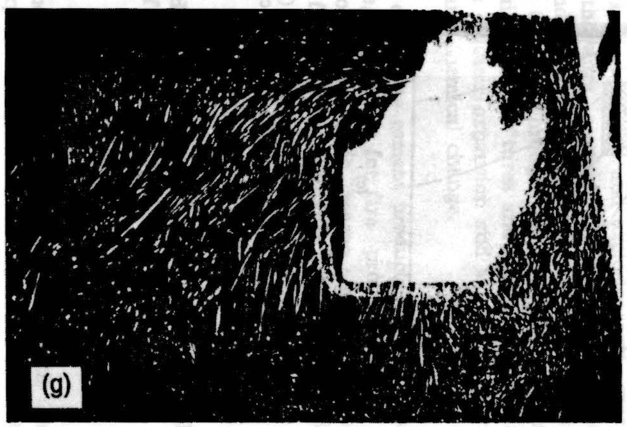


Fig.2 Instantaneous stream lines of the fire induced flow in some typical sections for three different burner stand-off distances, as follow:

Fig.(2)	Stand-off(M)		Section illuminated by laser sheet (M)
	x	y	
(a),(b),(c)	0.0	0.0	x=0.075
(d)	0.0	0.0	z=0.150
(e)	0.2	0.0	z=0.150
(f)	0.2	0.0	y=0.075
(g)	0.1	0.1	z=0.150

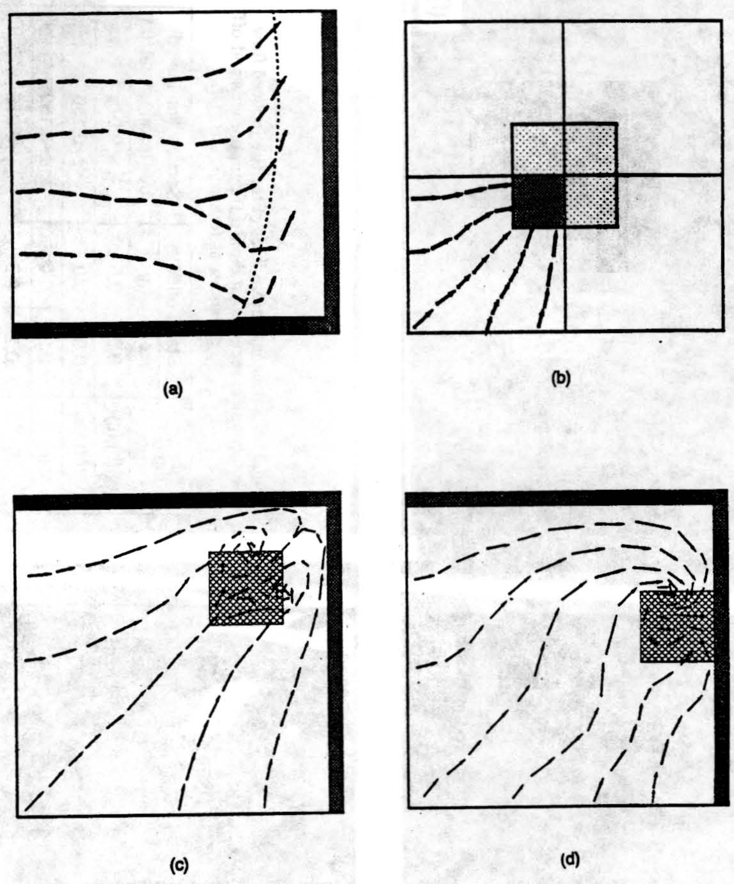


Fig.3 Typical flow patterns: (a) vertical section, (b) quarter model for a corner plume, (c) and (d) horizontal sections.