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Full-scale burning tests on studying smoke temperature and velocity along a corridor

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Abstract

Full-scale burning tests were conducted in a long corridor to study the variations in smoke temperature and velocity. The results were compared with the expressions proposed in the literature. It appeared that the reduction in temperature down the corridor can be fitted by an exponential function on the distance. The power law equation by Bailey et al. [Bailey, J.L., Forney, G.P., Tatem, P.A., Jones, W.W., 2002. Development and validation of corridor flow submodel for CFAST. J. Fire Prot. Engg. 22, 139–161] also agreed fairly well with the measured data for dimensionless distance away from the fire source less than 0.4 or when the distance from the fire source is less than 35 m. The distribution of velocity along the corridor can also be fairly well fitted by exponential equations.

Keywords: Smoke temperature; Velocity; Decay; Corridor; Tunnel; Fire

1. Introduction

Consequent to the arson fire in a long tunnel in Daegu Korea on February 18, 2003, killing 198 people, and two more arson fires in Hong Kong and Russia, there are concerns on tunnel or long corridor fires. Statistics have shown that smoke was the most fatal factor in fires (Babrauskas et al., 1998; Besserre and Delort, 1997), especially in tunnel fires where large amount of toxic gases were released due to incomplete combustion. In order to provide appropriate fire safety, the physics of smoke spreading should be well understood first (Buchanan, 1994, 1999). Zone models have been developed to predict the smoke layer. The results are useful in assessing the critical time of smoke descending to the dangerous height. The basic assumption of these zone models is that the temperature of the upper smoke layer is the same everywhere, and the time taken to form the ceiling jet is potentially ignored (Fu and Hadjisophocleous, 2000; Jones et al., 2000; Jones, 2001). In tunnels or long corridors, there are at least two steps in smoke spreading:

- the ceiling jet forming phase;
- the smoke layer descending phase.

The smoke temperature and velocity will be reduced significantly at positions away from the fire source. It might take a long time to form a smoke layer. In other words, zone models might not be applicable for studying smoke spreading in tunnels or long corridors (Bailey et al., 2002; Chow, 1996; Forney, 1997; He, 1999; Jones and Quintiere, 1984). There were proposals on dividing the tunnel into smaller zones. However, entrainment in the ceiling jet might be different in a tunnel.

There are some studies on reduction in smoke temperature and velocity along the tunnel as reported in

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the literature. The spread of smoke under a beamed ceiling had been studied by Delichatsios (1981). An expression for the average distribution on ΔT average temperature rise at distance x along the beamed channel was derived as follows:

$$\frac{\Delta T}{\Delta T_0}\left(\frac{l}{H}\right)^{1/3} = 0.49\exp\left\{-6.67\,St\frac{x}{H}\left(\frac{l}{H}\right)^{1/3}\right\}, \quad (1)$$

where ΔT_0 is the temperature rise near the ceiling over the fire source, l is one half of the corridor width, H is the ceiling height and St is the Stanton number.

The temperature decay along the corridor appears to follow an exponential function. Some exponential expressions were established by Evers and Waterhouse (1978) empirically and verified by Kim et al. (1998) in a corridor of length 11.83 m (He, 1999; Evers and Waterhouse, 1978; Kim et al., 1998).

However, a power law distribution was also proposed by Bailey et al. (2002) from their three-dimensional computational fluid dynamics model with large eddy simulation LES3D and tests in an 8.51 m long corridor as follows:

$$\Delta T = \Delta T_0\left(\frac{1}{2}\right)^{x/16.7}. \quad (2)$$

Whether changes in smoke temperature distribution will follow an exponential or power law decay along a long corridor with length larger than 50 m is still unknown. This should be studied carefully before using the results for designing smoke control systems in real tunnels.

Information on smoke velocity should be well understood. An empirical exponential expression on the smoke layer advance velocity u at position x was also established by Hinkley (1970) for distribution of buoyancy-driven corridor flow

$$\frac{u}{u_0} = \exp\left\{-(x-x_0)\frac{2kl}{3mc_p}\right\}, \quad (3)$$

where u_0 is the smoke velocity at a reference distance x_0 and k is the heat transfer coefficient.

In this study, full-scale burning tests were conducted in an 88 m long corridor. Smoke temperature under the ceiling was measured and the corridor flow velocity was calculated. Whether the decay of smoke temperature and velocity can still be described by exponential distribution in such a long corridor will be discussed. The results are also compared with Bailey's expression to see whether it can be used in such long corridors.

2. Simplified theoretical analysis

The spread of the smoke front along the ceiling can be seen as one-dimensional as shown in Fig. 1. Taking into account the air entrainment, friction with the ceiling (shear stress τ) and heat loss to the ceiling (heat flux $\dot{q}$), the steady-state equations for the ceiling jet front were obtained as follows (Kunsch, 1999):

$$\text{Continuity}: \quad \frac{d}{dx}(\rho h u) = \rho_a w_e, \quad (4)$$

$$\text{Momentum}: \quad \frac{d}{dx}(\rho h u^2) - \frac{d}{dx}\left[\frac{1}{2}g_e(\rho_a-\rho)h^2\right] = -\rho_a w_e u_a - \tau, \quad (5)$$

$$\tau = \frac{1}{2}c_f\rho u^2, \quad (6)$$

$$\text{Energy}: \quad \frac{d}{dx}(\rho h u T) = \rho_a w_e T_a + \dot{q}. \quad (7)$$

The entrainment velocity w_e can simply be taken as proportional to the velocity of the ceiling jet

$$w_e = \beta u. \quad (8)$$

The heat loss to the ceiling mainly depends on the heat transfer to the ceiling. The temperature of the contact surface far away from the fire is assumed to be equal to the temperature of the air flow. With these assumptions, the heat loss of the ceiling jet front to the ceiling material can be expressed as follows (Kunsch, 1999):

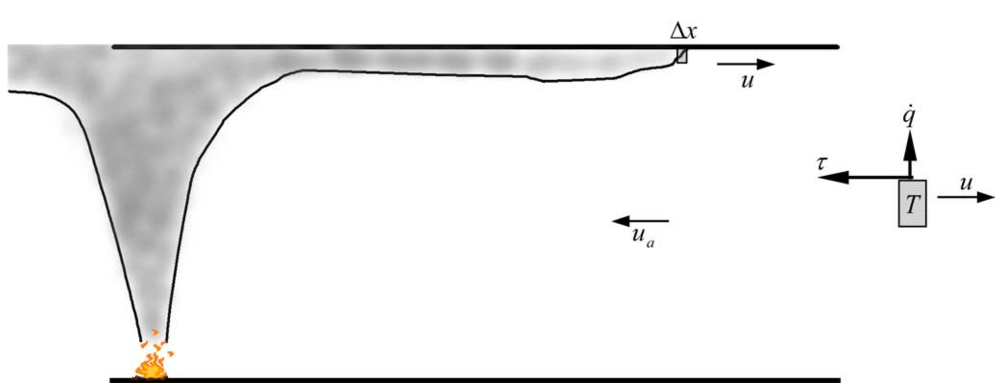

Fig. 1. Simplified model for infinitesimal analysis.