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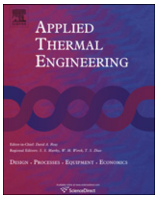

An experimental investigation and correlation on buoyant gas temperature below ceiling in a slopping tunnel fire

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HIGHLIGHTS

- ► Experiments are carried out in a reduced scale model tunnel.
- ► Gas temperature data beneath the ceiling in a slopping tunnel fire is obtained.
- ► Tunnel slope factor is included into the current equations.
- ► Modified equations agree well with the measured data.

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ABSTRACT

The effect of tunnel slope on the fire induced hot gas temperature profile beneath the ceiling has not been clarified nor included in existing models. Thus, in this paper experiments are carried out in a reduced scale model tunnel with dimensions of 6 m (length) × 1.3 m (width) × 0.8 m (height), which is positioned within a 72 m long wind tunnel. The slopes of the model tunnel are varied at three typical different degrees, 0%, 3% and 5%. A LPG porous gas burner is used as fire source. Both the maximum gas temperature and the temperature distribution along the tunnel ceiling are measured and compared with previous models. Results show that those models overestimates the maximum temperature beneath the ceiling of a slopping tunnel fire. The gas temperature decays faster along the ceiling for tunnels with higher slope. Empirical correlations are then proposed to modify the current models to include the tunnel slope factor. The predictions by the modified equations of this work agree well with the measured data in both the maximum temperature and temperature decay beneath the ceiling of the tunnel with different slopes.

1. Introduction

Fires in tunnels have attracted increasing attention in recent years due to its catastrophic consequence, such as the fire of Hokuriku railway tunnel in Japan with 30 people killed and 715 hurt, that in Mont-Blanc tunnel Austria in 1999 and Dague Korea in 2003 killed 41 and 198 people respectively. The hot gas flow spreads along the tunnel ceiling driven by buoyancy induced by the fire and at the same time transports poisonous combustion products to long distance away. Study on buoyant gas flow temperature distribution along the ceiling in a tunnel is fundamental in fire science, and also critical in fire safety engineering due to the following facts [1–17]:

1. The tunnel has much larger length-to-height aspect ratio than the ordinary compartment. This makes common zone type models, which assumes the gas temperature spatially uniform beneath the ceiling, is not applicable in such a structure [1–12]. The accuracy of the CFD simulation depends on the accuracy of the physical models employed in the CFD codes. CFD simulation of tunnel fires, where complex interaction between longitudinal ventilation air flow and combustion occurs, is still at the development stage and physics inside is not yet good enough solved. We need equation models to predict the gas temperature at any distance away from the fire in engineering applications.
2. The maximum gas temperature beneath the ceiling above the fire is a critical parameter in designing and evaluation of the fire-proof material performance of the tunnel ceiling [13–15]. It also differs from that of the compartment fire, as the longitudinal ventilation air flow in a tunnel deflects the flame and

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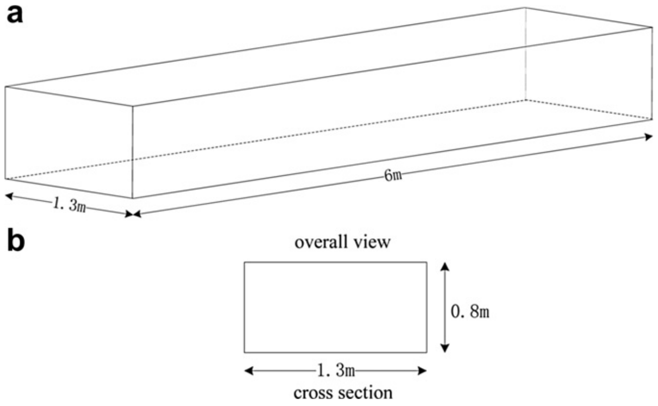


Fig. 1. Dimensions of the model tunnel.

plume. Such interaction between the inertial force of the longitudinal ventilation air flow and the buoyancy strength of the fire source needs to be quantified to predict the maximum gas temperature beneath the ceiling in a tunnel.

3. The buoyancy strength of the gas flow decays due to its temperature decrease along the tunnel. This will result in a critical situation that at a distance away from the fire source, the buoyancy force is weaker than the inertial force of the longitudinal ventilation air flow leading to the loss of the hot-gas-cool-air stratification structure [16,17]. This is a very dangerous situation for the people in evacuation below the gas flow. So, knowing the gas temperature at any distance away from the fire is very important for this evaluation of the stability of the stratification.

The gas temperature at any distance away from the fire source can be predicted if we know: a) the maximum temperature beneath the ceiling right above the fire source; and b) how the gas temperature decays with distance along the tunnel.

Oka [18,19] conducted experiments to characterize the effects of longitudinal ventilation on flame properties in case of tunnel fire and developed empirical correlation models for flame tilt-angle, maximum temperature of smoke layer under the ceiling and its position. For the maximum gas temperature beneath the ceiling above the fire, Kurioka [13] proposed following empirical equation based on the correlation of scale model experimental results:

$$\frac{\Delta T_{\max}}{T_a} = \gamma\left(\frac{\dot{Q}^{*2/3}}{Fr^{1/3}}\right)^{\varepsilon} \qquad (1)$$

$$\dot{Q}^{*2/3}/Fr^{1/3} < 1.35,\ \ \gamma = 1.77,\ \ \varepsilon = 6/5$$

$$\dot{Q}^{*2/3}/Fr^{1/3} \geq 1.35,\ \ \gamma = 2.54,\ \ \varepsilon = 0$$

where $\dot{Q}^{*}$ is the dimensionless heat release rate of the fire defined as:

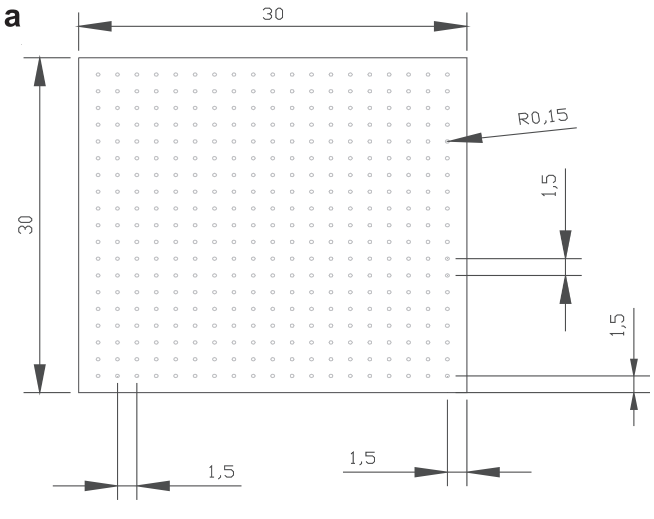
$$\dot{Q}^{*} = \frac{\dot{Q}}{\left(\rho_a C_p T_a g^{1/2} H_d^{5/2}\right)} \qquad (2)$$

Fr is the Froude number given by:

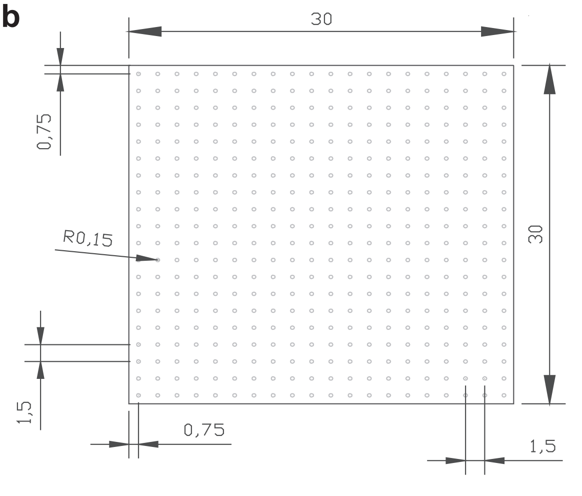
$$Fr = \frac{u^2}{gH_d} \qquad (3)$$

Table 1
Experimental conditions.

Test no.	Tunnel slope (%)	Ventilation velocity (m/s)	Heat release rate (kW)				
1–5	0	0	20	40	60	90	120
6–10		0.3	20	40	60	90	120
11–15		0.6	20	40	60	90	120
16–20		0.9	20	40	60	90	120
21–25		1.2	20	40	60	90	120
26–30	3	0	20	40	60	90	120
31–35		0.3	20	40	60	90	120
36–40		0.6	20	40	60	90	120
41–45		0.9	20	40	60	90	120
46–50		1.2	20	40	60	90	120
51–55	5	0	20	40	60	90	120
56–60		0.3	20	40	60	90	120
61–65		0.6	20	40	60	90	120
65–70		0.9	20	40	60	90	120
71–75		1.2	20	40	60	90	120



top surface



middle layer

Fig. 2. Porous gas burner fire source.