Journal of Wind Engineering & Industrial Aerodynamics 170 (2017) 141–148

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia

Experimental study on thermal smoke layer thickness with various upstream blockage–fire distances in a longitudinal ventilated tunnel

Fei Tang *, Qing He, Qin Shi **

School of Automotive and Transportation Engineering, Hefei University of Technology, Hefei, Anhui, 230009, China

ARTICLE INFO

Keywords:
Tunnel fires
Longitudinal ventilation
Blockage
Smoke layer thickness
Vertical temperature

ABSTRACT

In order to study the effect of varied blockage-fire source distances (rectangular cylinder shape) on the smoke layer thickness in a longitudinal ventilated tunnel, a series of experiments were conducted in a 1/6 model tunnel platform. Varied longitudinal ventilation velocities, fire heat release rates, and blockage-fire distances D were considered. The vertical region temperature was measured by using a thermocouple tree, and the integral ratio method was used to calculate the smoke layer thickness. It was determined that the smoke temperature at any specified height decreased with increasing longitudinal ventilation velocity. The smoke layer thickness increased with increasing longitudinal ventilation velocity irrespective of the presence or absence of vehicular blockage, and the smoke layer thickness in the presence of vehicular blockages was smaller than that in the absence of blockages.

1. Introduction

In the last few decades, the increase in the incidence of fire accidents in tunnels has manifested worldwide as a growing operational management and construction problem (Harish and Venkatasubbaiah, 2014). Higher smoke temperature and pollutant concentration exert a significant impact on personnel escape evacuation and is likely to result in increased mortality in the case of fire accident (Nævestad and Meyer, 2014; Zhao et al., 2015); particularly, under the condition of vehicle jam, the longitudinal ventilation velocity plays a critical role in accelerating fire accident (Chen et al., 2011). Therefore, understanding smoke spread and transport phenomena mechanisms is highly critical in terms of tunnel fire safety.

Previous studies have mainly focused on the four classic characteristic parameters of smoke flow in ventilated tunnel, including (a) maximum temperature profile (Kurioka et al., 2003; Li et al., 2011; Liu et al., 2016; Tang et al., 2017c)—Kurioka et al. (2003) proposed a model to predict the maximum smoke temperature under the tunnel ceiling based on scale model experiments. Li et al. (2011) proposed a maximum smoke temperature model based on the theory of plume entrainment; (b) longitudinal temperature decay (Kashef et al., 2013; Gong et al., 2016; Ji et al., 2016; Liu et al., 2017; Meng et al., 2017)—Kashef et al. (2013) studied the effects of tunnel geometry and fire location on ceiling temperature decay and smoke movement in natural ventilation tunnel; (c) smoke back-layering length (Hu et al., 2008; Li et al., 2010; Gannouni and Maad, 2016; Fan and Yang, 2017)—Li et al. (2010) proposed the following non-dimensional model to predict the back-layering flow length based on theoretical analysis and validated it by using experimental data, and (d) critical ventilation velocity (Tsai et al., 2010; Li et al., 2010; Tang et al., 2013; Yi et al., 2014; Chow et al., 2015)—Tsai et al. (2010) conducted small-scale experiments and numerical simulations to investigate critical ventilation velocity for cases in which two tunnel fires occur simultaneously; moreover, Chow, et al. (2015) studied critical ventilation velocity in tilted tunnel model with angles of 0°, 3°, 6°, and 9°, and proposed a corrected empirical formula for critical velocity in a tilted tunnel based on the experimental and numerical results.

Owing to large tunnel traffic flow, vehicles straightforwardly form blockage in case of tunnel fires; the blockage is like a rectangular cylinder. In recent years, extensive works have been reported that reveal in detail the characteristics of near-wake flow structure and dispersion past a square cylinder, building, and street canyon. For example, Yen and Yang (2011) studied the flow patterns and vortex shedding behavior behind a square cylinder. Hu et al. (2012) revealed the fire behavior in the near wake behind a square cylinder under a horizontal wind flow and quantified the leaning behavior of the flame. It is reported (Durao et al., 1988; Li and Stathopoulos, 1997; Olvera et al., 2008; Yen and Yang,

* Corresponding author.
** Corresponding author.
E-mail addresses: ftang@hfut.edu.cn (F. Tang), shiqin@hfut.edu.cn (Q. Shi).

http://dx.doi.org/10.1016/j.jweia.2017.08.003
Received 2 January 2017; Received in revised form 11 July 2017; Accepted 5 August 2017

Nomenclature

A	cross-sectional area (m^2)
D	blockage–fire distance (m)
h	smoke layer thickness (m)
H	tunnel height (m)
H_D	hydraulic tunnel diameter height (m)
H_{int}	The layer interface height (m)
ℓ_F	full size (m)
ℓ_M	model size (m)
$\dot{Q}_F$	full-size heat release rate (kW)
$\dot{Q}_M$	model heat release rate (kW)
R	The size of the "recirculation zone"
r	integral ratio
to	total
v	longitudinal wind speed (m/s)
v_F	full-size longitudinal ventilation velocities (m/s)
v_M	model longitudinal ventilation velocities (m/s)
W	tunnel width (m)
X	cross-sectional perimeter (m)
Z	vertical coordinate of tunnel height (m)

2011; Moonen et al., 2011; Hu et al., 2012; Pesic et al., 2016) that when the wind flow passes around a cylinder (or building or street canyon), a near wake recirculation flow region will be formed behind the blockage cylinder.

In a ventilated tunnel fire, vehicle blockage complicates the longitudinal ventilation velocity flow. The pressure variation between the windward and leeward sides of the rectangular cylinder is altered (Hu et al., 2012; Hu et al., 2013), and thus, the characteristics of the smoke flow in the vicinity of the vehicle blockage is affected. Recently, Lee (Lee and Tsai, 2012) determined that critical ventilation velocity decreased when ventilation flow reached the fires and discussed the mechanism of vehicle blockage in tunnel fire. Tang et al. (2013) proposed a non-dimensional model to describe back-layering length and critical velocity to account for the blockage effect. Zhang et al. (2016) conducted experiment to study the effect of blockage on the smoke back-layering in subway tunnel fires. Tang et al. (2017a) experimentally study on the effect of blockage-heat source distance on maximum temperature of buoyancy-induced smoke flow beneath ceiling in a ventilated tunnel.

Table 1
Summary of test scenarios.

Test no.	Longitudinal ventilation velocities (m/s)	Blockage-fire distance D (m)	HRR (kW)
1–24	0	None, 0, 0.25, 0.5, 1.0, 1.5, 2.0, 3.0	25, 40, 55
25–48	0.3	None, 0, 0.25, 0.5, 1.0, 1.5, 2.0, 3.0	25, 40, 55
49–72	0.5	None, 0, 0.25, 0.5, 1.0, 1.5, 2.0, 3.0	25, 40, 55
73–96	0.8	None, 0, 0.25, 0.5, 1.0, 1.5, 2.0, 3.0	25, 40, 55

However, the knowledge on the thermal smoke layer under blockage is inadequate, particularly for the detailed effect of various blockage–fire distances (the distance between blockage and fire source) on the thermal smoke layer evolution characteristics in tunnel fires. As is known, thermal smoke layer characteristics is a critical parameter for personnel evacuation in tunnel fires. Previous studies mainly focus on the vertical thermal smoke layer (Bofah et al., 1991; Nyman and Ingason, 2012; Lai et al., 2013; Oka et al., 2016; Li et al., 2016; Mei et al., 2017) without considering blockage effect. Therefore, the aim of this study was to

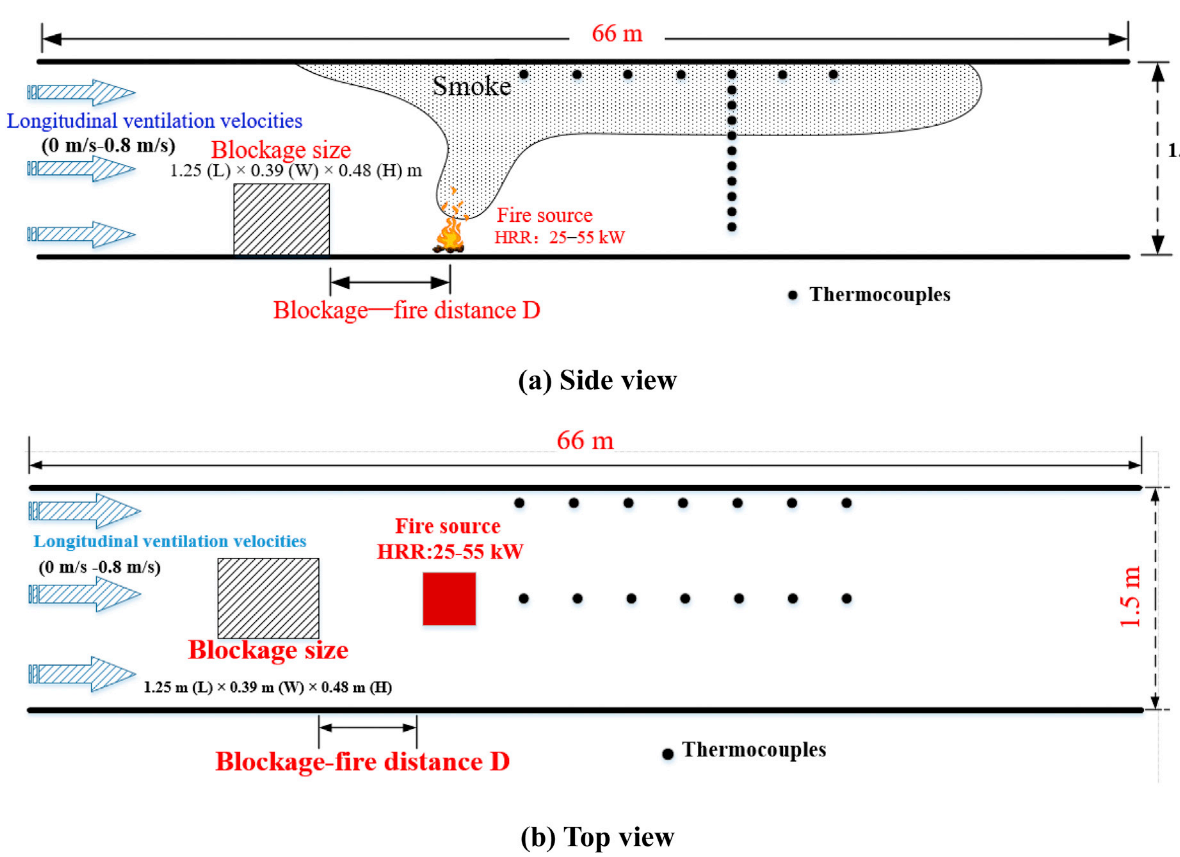

Fig. 1. Sketch of the experimental tunnel.