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Experimental study on flame radiation fraction of facade fire ejected from opening of a compartment

Fei Ren, Longhua Hu *, Xiepeng Sun, Kaizhi Hu

State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei, Anhui 230026, China

HIGHLIGHTS

- Flame radiation fraction of facade fire ejected from opening quantified.
- A calculation methodology on flame radiation fraction of facade fire.
- Flame radiation fraction decreasing with increasing excess HRR.
- A new model for flame radiation fraction of facade fire brought forward.

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ABSTRACT

This paper quantifies experimentally the flame radiation fraction of facade fire ejected from opening of a compartment, which has not been quantified in the past. However, its value is essential for estimating the radiation impact to surroundings. A series of experiments were conducted by employing a cubic compartment with an opening attached by a vertical facade wall. The radiation heat flux under different compartment ventilation conditions (opening sizes) was measured by a radiometer placed at side direction (parallel to the facade wall). A new calculation method on flame radiation fraction of facade fire was proposed and it was found that the flame radiation fraction decreases with increasing excess heat release rate outside the opening. A non-dimensional correlation was proposed to describe its evolution for openings of various dimensions. The new findings and the proposed non-dimensional correlation provide a fundamental base for understanding essentially the flame radiation fraction of facade fire ejected from the opening of a fire compartment.

1. Introduction

A facade fire ejected from the window of a fire compartment can lead to catastrophic loss of life and property. It will pose serious adverse impact to adjacent buildings through intense radiation [1–5], which is affected by the combustion condition inside the compartment as well as the characteristics of the ejected flame over the facade. There are considerable experimental works reported in the literature [e.g., 1, 3, 6] on the total radiation flux emission in the direction normal to the facade, which should include those from the opening, the ejected flame as well as the heated facade. In those works, the radiometer was placed facing the facade that the total radiation from all above emission sources were captured, and cannot be separated. For example, the radiation fraction of the flame, which is essentially an important parameter to estimate the radiation impact of fire [7–10], cannot be quantified for this facade fire scenario. There is still no experimental data or quantification reported about the evolution of flame radiation fraction of such facade fire.

So, in this work, a series of experiments were carried out to measure the flame radiation fraction of a facade fire ejected from the opening of a fire compartment with a facade wall, for various heat release rates and opening dimensions (ventilation conditions). A non-dimensional correlation was proposed to describe the evolution of flame radiation fraction of facade fire with increasing heat release rate for various opening ventilation conditions.

2. Experiments

Fig. 1 shows the experimental setup, which consists of a vertical facade wall (1.2 m wide and 1.6 m high) and a reduced-scale cubic fire compartment having dimension of 0.4 m. The vertical facade wall and the side surface (opening located) of the compartment

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* Corresponding author.
E-mail address: hlh@ustc.edu.cn (L. Hu).

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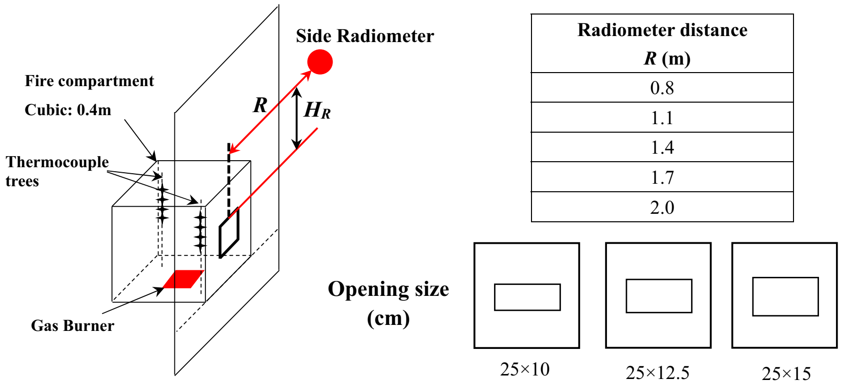

Fig. 1. Experimental setup.

are in the same plane. The fire compartment is inner-lined with 0.03 m thick ceramic fiber boards for thermal insulation. Thermal properties of ceramic fiber boards is density –285 kg/m^3, thermal conductivity –0.18 W/(m·K) and specific heat –1390 J/(kg·K), with thermal inertia can be calculated to be about 267 J/(m^2·K·S$^{0.5}$).

A square porous gas burner (dimension: 0.2 m) placed at the center and flushed with the compartment floor was employed as fire source. Propane was used as fuel with a supply rate monitored and controlled by a mass flowmeter with accuracy of 1 dm^3/min. Three openings were considered, representing different ventilation factors ($A\sqrt{H}$: A is the opening area with unit of m^2; H is the opening height with unit of m). The experimental conditions are summarized in Table 1, each experimental condition was repeated 3 times.

A radiometer (sensitivity: 2 μV/(W/m^2)) was mounted at side direction (parallel to the facade wall) to measure the ejected flame radiation heat flux, meanwhile those from the opening and the heated facade wall can then be excluded. The distance of the radiometer from the opening was defined in Fig. 1 and the height was 0.3 m above the upper edge of the opening.

3. Results and discussion

Fig. 2 plots the measured radiation flux with total heat release rate (HRR) for different openings. It can be observed that: 1) in the first internal combustion regime (well-ventilated condition), the radiation heat flux measured is nearly zero; 2) the radiation heat flux increase with increasing the heat release rate (HRR) in the second regime when the flame is observed to be ejected outside the opening (under-ventilated condition).

The flame radiation fraction (χ_R) was derived from the measured radiation flux (I_R, unit: kW/m^2), based on the single-point assumption method, as widely applied in the previous works [11–13]:

$$\chi_R = \frac{4\pi R^2 I_R}{\dot{Q}} \tag{1}$$

where R is the distance of radiometer to flame center (unit: m), $\dot{Q}$ is the heat release rate of the flame due to combustion of fuel with air (unit: kW). For the condition of a facade flame considered here, the above formula should be modified as follows as a hemisphere model (as shown in Fig. 3(a)), and the heat release rate of the flame should be the excess heat release rate due to further combustion of un-burnt fuel outside the opening ($\dot{Q}_{ex} = \dot{Q}_{total} - \dot{Q}_c$) [14–17]:

$$\chi_R = \frac{2\pi R^2 I_R}{\dot{Q}_{ex}} \tag{2}$$

where $\dot{Q}_{total}$ is the total heat release rate of the supplied fuel from the fire source (unit: kW) and $\dot{Q}_c$ is the fuel supply critical heat release rate (unit: kW), beyond which the flame is observed to eject outside the opening (under-ventilated condition reached).

For the single-point assumption model, the distance between the radiometer and the flame is a crucial parameter, which should be enough to satisfy the assumption that the flame can be deemed as a point source. Fig. 3(b) presents the variation of flame radiation fraction calculated by Eq. (2) against the excess heat release rate for different radiometer distances. It can be observed that the calculated flame radiation fraction first increases and then keeps unchanged with increasing radiometer distance for same heat release rate, which indicates that a distance of 1.4 m is at least required to satisfy the single-point model. Then, the average value of the flame radiation fractions calculated with the distances of 1.4 m, 1.7 m and 2.0 m is used for further analysis (the relative error of radiation heat flux measured with the distance of 1.4 m, 1.7 m and 2.0 m was found to be 4.4%, 3.6% and 5.2%, respectively), which is shown to decrease with increasing excess heat release rate. Fig. 4 plots the evolution of flame radiation fraction obtained against the non-dimensional excess release rate $\left(\dot{Q}^*_{ex} = \frac{\dot{Q}_{total}-\dot{Q}_c}{T_\infty \rho_\infty c_p A\sqrt{gH}}\right)$, which means the heat released outside the opening through the burning of ejected unburnt hot gas with under-ventilated fire condition reached [14–17], where T_∞ is the environment temperature

Table 1
Summary of experimental conditions.

Test series	Opening dimensions (m)		Ventilation factor	Radiometer distance (m)					Total heat release rate (kW)
	Width (*W*)	Height (*H*)	($A\sqrt{H}$, m$^{2.5}$)						
1	0.250	0.100	0.008	0.8	1.1	1.4	1.7	2.0	3.07–46.12
2	0.250	0.125	0.011	0.8	1.1	1.4	1.7	2.0	3.07–53.81
3	0.250	0.150	0.015	0.8	1.1	1.4	1.7	2.0	3.07–92.24