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Experimental study of non-monotonous sidewall effect on flame characteristics and burning rate of n-heptane pool fires

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HIGHLIGHTS

- The non-monotonous sidewall effect on flame characteristics and burning rate was found.
- A series of experiments with heptane pools of four fuel shapes was conducted.
- The burning rate obtained the peak value near the sidewall, rather than attached to the sidewall.
- A higher burning rate did not necessarily lead to a larger ceiling flame length.

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ABSTRACT

To study the influence of sidewall effect on flame characteristics and burning rate, a series of experiments with heptane pools was conducted. The results showed that as the fires were placed close to the sidewall, the flames inclined to the sidewall due to the restriction on air entrainment, and the burning rate increased on the whole, which could be mainly due to the enhanced radiation from the heated sidewall and ceiling flame. However, regardless of fuel pool shape, the burning rate obtained the peak value when the fire was near the sidewall, rather than attached to the sidewall, resulting from less flame radiation from the vertical flame part to the fuel in the latter case. The ratio of longitudinal ceiling flame length to transverse length tended to decrease with the fire moving close to the sidewall. For cases with the largest length and wall fires, the ratio was nearly 0.5, which could be explained according to the theory of mirror effect. Also, due to the non-monotonous sidewall effect, a higher burning rate did not necessarily lead to a larger ceiling flame length.

1. Introduction

Because of narrow structure of channels, such as tunnels and corridors, a flame could easily touch the ceiling and then extend along it in a large fire. It is very worthwhile to make a study of burning rate and flame characteristics for structure protection, fire detection and hazard assessment. In reality, a fire could occur at any location in a channel, and sometimes could be very close to the sidewall [1], which could influence air entrainment of fire plume and other characteristic parameters, such as burning rate and ceiling flame length. Unfortunately, this influence has not been paid much attention to.

There have been many studies on flame characteristics under unconfined ceilings [2–6], and on wall fires without flame touching ceiling [7–13], while limited researches have focused on fire characteristics influenced by both ceiling and walls [14,15]. In previous studies on flame characteristics [16,17], porous gas burner was commonly used as fire source, to generate a stable heat release rate. However, in real fires, the radiation from ceiling and sidewall to unburned fuel could influence the heat release rate significantly. Hinkley et al. [14] performed experiments in a model representing the corridor with a fire at one end. Most of the experiments employed a gas burner to represent the fire, which cannot reflect the effect of radiation from ceiling and sidewall to unburned fuel, namely the effect on heat release rate. Moreover, the influence of distance between fire source and sidewall was not changed, thus the sidewall effect was neglected. In the work of Lattimer et al. [15], a series of tests was conducted in a corridor apparatus similar to that used by Hinkley et al. The sidewall effect was also neglected and propane gas was used as the fuel. Gao et al. [17] investigated

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Nomenclature

d	distance between fire source center and sidewall (m)
L	ceiling flame length (m)
L_l	longitudinal flame length under ceiling (m)
L_t	transverse flame length under ceiling (m)
L_v	latent heat of evaporation (kJ/g)
$\dot{m}$	burning rate (g/s)
n	pool aspect ratio
$\dot{Q}_{rad}$	radiation feedback from flame and environment to fuel (kW)
$\dot{Q}_{f,rad}$	radiation feedback from flame to fuel (kW)
$\dot{Q}_{s,rad}$	radiation feedback from smoke to fuel (kW)
$\dot{Q}_{w,rad}$	radiation feedback from external wall surface to fuel (kW)
z	distance from channel bottom (m)

the sidewall fire case and the experiments setups included fires in the open space, flush with a wall without ceiling, at the longitudinal centerline of a channel and flush with the channel sidewall with gas burner. Although the results of tests with fire at the longitudinal centerline of the channel and flush with the channel sidewall were compared, the distance between fire source and sidewall was not changed detailedly in the tests.

This study aimed to investigate flame characteristics and burning rate of pool fires (the more practical and popular fire simulated style [18–22]) under channel ceiling with variant distances between fire and sidewall. As channel ceiling and sidewalls are generally constructed with concrete, combustible wall fires were not considered in this study. Rectangular heptane pools were used as fire source, and the aspect ratio of the pools was also taken into account.

2. Experiments

The experiments were conducted in a small scale channel with scale ratio of 1:6, as shown in Fig. 1. The channel was 6 m long, 2 m wide and 0.86 m high. The ceiling, floor and one sidewall (actually the left sidewall with test instruments installed) were made of 20 mm thick fireproof board. The other sidewall was comprised of windows of 10 mm thick fireproof glass set in steel frames for observation.

Four pools of heptane with the same area of 225 cm^2 but different aspect ratios (ratio of long rim to short rim) were used: $n = 1$ (15 cm/15 cm), $n = 2$ (21.2 cm/10.6 cm), $n = 4$ (30 cm/7.5 cm) and $n = 8$ (42.4 cm/5.3 cm). Pools were made of 2 mm thick steel plate with inner depth of 4 cm. In each test, the initial fuel mass was 300 g and the fuel thickness was about 2 cm.

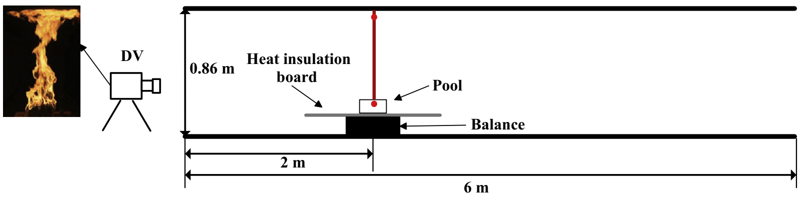
The pool was located 2 m away from the left end of the channel. A digital balance was used to record the fuel burning rate ($\dot{m}$) with precision of 0.1 g. The distances between pool center and sidewall (d) were 1, 0.4, 0.3, 0.2 and 0.1 m, respectively. Besides, there were wall fire tests, with one long rim against the sidewall. Due to similarity in geometry, the test with the square pool ($d = 0.1$ m) can be regarded as the wall fire case. Tests with d between 0.4 and 1 m were not conducted due to that no evident difference of the important parameters between cases with $d = 0.9$ m (or 0.8 and 0.7 m) and 1 m was expected. After conducting tests with $d = 0.4$ and 1 m, it was found both burning rate and ceiling flame length had only a quite small increase from $d = 1$ to 0.4 m.

A vertical thermocouple tree with seven K-type thermocouples (to measure the temperature of smoke or flame) and seven wall-mounted thermocouples (to measure the temperature of sidewall) at 0.1 m interval was positioned along the sidewall (from $z = 0.2$ to 0.8 m), as shown in Fig. 1b. A water cooled heat flux sensor (Schmidt–Boelter) was arranged near the fuel pool (towards the ceiling) to measure the radiation to fuel approximately. Another heat flux sensor was installed at $z = 0.8$ m (towards the fuel pool) along the sidewall, which could be used to reflect indirectly the magnitude of the radiation feedback from sidewall to fuel for different tests as it cannot be distinguished from flame radiation to fuel. One digital video was located at the left end of the channel to record the transverse flame development and the other near the fireproof glass to record the longitudinal flame development.

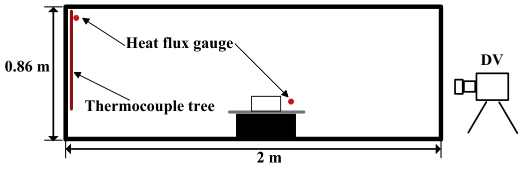
3. Results and discussion

3.1. Flame shape

Flame images at steady burning stage are shown in Fig. 2. For $d = 1$ and 0.4 m, the flame shape is approximately symmetrical, proving an insignificant influence of the sidewall. Afterwards, with decreasing d, the flame inclines to the sidewall and forms a com-



(a) Side view



(b) Front view

Fig. 1. Experiment rig of the scale model.