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Burning rate of merged pool fire on the hollow square tray

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HIGHLIGHTS

- Burning rates are significantly different for identical pool surface of hollow trays.
- Fire merging results in 50–100% increases of burning rates and fire heights.
- The presence of longitudinal wind significantly decrease the burning rate.
- Burning rate evolves differently with increasing wind speed for different hollow trays.
- An empirical correlation was presented to predict critical burning rate of fire merging.

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ABSTRACT

In order to characterize fire merging, pool fires on hollow trays with varying side lengths were burned under quasi-quiescent condition and in a wind tunnel with the wind speed ranging from 0 m/s to 7.5 m/s. Burning rate and flame images were recorded in the whole combustion process. The results show that even though the pool surface area was kept identical for hollow trays of different sizes, the measured burning rates and fire evolutions were found to be significantly different. Besides the five stages identified by previous studies, an extra stage, fire merging, was observed. Fire merging appeared possibly at any of the first four stages and moreover resulted in 50–100% increases of the fire burning rates and heights in the present tests. The tests in wind tunnel suggested that, as the wind speed ranges from 0 m/s to 2 m/s, the burning rates decrease. However with further increase of the wind speed from 2 m/s to 7.5 m/s, the burning rate was found to increase for smaller hollow trays while it remains almost constant for larger hollow trays. Two empirical correlations are presented to predict critical burning rate of fire merging on the hollow tray. The predictions were found to be in reasonably good agreement with the measurements.

1. Introduction

In relation to fire safety of liquid fuels in industrial process or practical energy generation systems, considerable efforts have been devoted to the study of pool fires on rectangular, square, and round trays to investigate the burning rate, flame height and its pulsation, thermal radiation, soot formation, energy transfer and air entrainment mechanisms, etc. Wherein, the burning rate [1–4] is one of the most fundamental parameters in pool fire studies, by which the heat release rate, fire height, thermal radiation etc. can be determined directly or indirectly. For liquid fuels, the burning rate is generally taken as the mass loss rate of the liquid fuel or the evaporation rate of liquid fuel.

In accidental spills which can result from an oil tank leakage on the land or a ship deck oil leakage on the sea, besides the above mentioned pool shapes, another representative fuel surface shape is a hollow pool with no fuel in the core region. Above a hollow pool, the annulus band fire could be observed at the initial stage and then either remain the same shape or transmit to a merged fire. Such merged fire generally involves intense burning and exhibits remarkably more dynamic fire behavior than the ordinary pool fire with the same area due to strong thermal radiation and convection. It is hence of importance to gain insight of such fire behavior involving merging.

Previous research on fire merging has largely been devoted to multiple fires [5–10], associated with city fires. It was found that fire merging exhibits much larger burning rate, which leads to larger flame height and surface. Resultantly, more radiative heat

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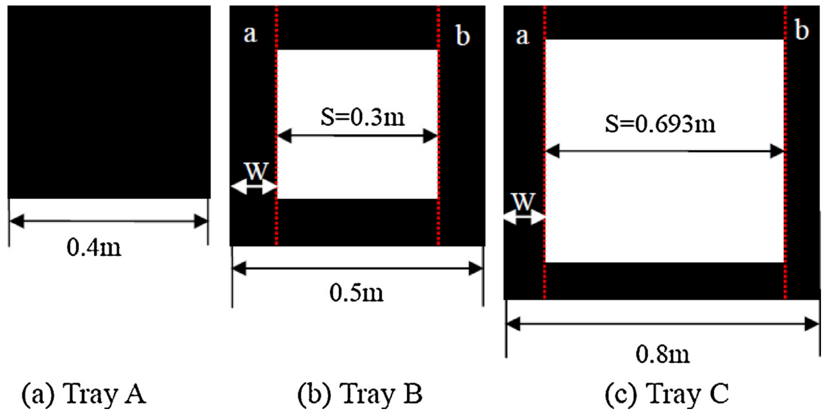

Fig. 1. Schematic of the three trays for the pool fire tests.

is brought to the surroundings. Fire merging is believed to make the fire destructive and bring difficulty in fire fighting. Some physical modeling [5,6] and empirical analyses [7] have been conducted. Critical conditions for fire merging [8] and semi-empirical correlations [9,10] have also been developed. However, little has been carried out to understand and characterize fire merging behavior on hollow trays. What will happen when fire merging occurs on the hollow tray? How do the burning rate and fire height etc evolve, as compared to those on the ordinary trays? How to determine the critical condition of fire merging? Especially under the longitudinal wind, how to figure out these?

In present study we mainly addressed above questions and focused on the burning rate of merged fire on the hollow pool and physically interpreted it by the variations of fire interactions under different conditions. To approach this, the square and hollow square pools were burned first under quasi-quiescent condition and then under the longitudinal wind with varying speed. The tested liquid fuel is jet fuel (JP5).

2. Experimental setup

Free burning pool fire tests were performed in a large test hall (22.4 m × 11.9 m × 27.0 m) with ceiling exhaust vents at the State Key Laboratory of Fire Science in the University of Science and Technology of China. The doors and windows were closed so that the wind effect was negligible during the tests. Since fire area and height are much smaller than those of this test hall, enough fresh air can be entrained to support the combustion, and therefore the influence of walls and airflow restrictions were also considered to be negligible.

As shown in Fig. 1, two hollow square trays with the same pool area of 0.16 m^2 along with an ordinary square tray (Tray A) of 0.4m × 0.4 m were used. The outer edges of the two hollow square trays were 0.5 m (Tray B) and 0.8 m (Tray C), respectively. To keep same the distance between the fuel surface and the top edge of the tray at the initial stage, three trays have the same depth of 50 mm. Moreover, two liters of jet fuel (JP 5) were used for each test with the initial thickness of the fuel layer around 12.5 mm.

In wind-aided fire experiments, the longitudinal wind was produced by a 20.2 m wind tunnel as shown schematically in Fig. 2. Its cross section at the exit was square shaped with the side length of 1.8 m. The fuel trays were placed in the region with uniform wind speed and close to the exit of wind tunnel. The exact location was determined by the upstream trees of anemometer probes close to the exit. The wind speed ranged from 0 to 8 m/s with fluctuations of less than 4%.

Table 1 lists all the tests conducted. Three identical tests were repeated for each case to ensure test data reliability. A top-loading

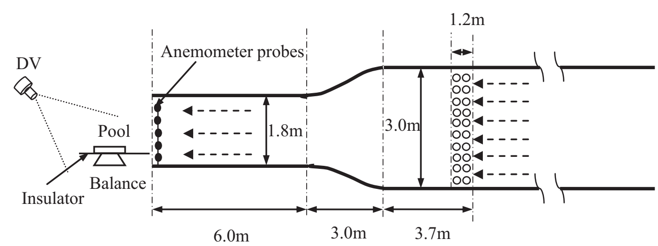

Fig. 2. Schematic of the wind tunnel and the test setup.

Table 1
Summary of the cases tested.

Case	Tested Tray	Pool area/m^2	Wind speed/(m/s)
1	A	0.16	0
2	B	0.16	0
3	C	0.16	0
4	A	0.16	2
5	A	0.16	4
6	A	0.16	6
7	A	0.16	7.5
8	B	0.16	2
9	B	0.16	4
10	B	0.16	6
11	B	0.16	7.5
12	C	0.16	2
13	C	0.16	4
14	C	0.16	6
15	C	0.16	7.5

balance with an accuracy of 0.1 g was positioned below the tray to measure the fuel mass loss. To reduce heat transfer from the tray to the balance as much as possible and let the balance fall in its work temperature range, a 50 mm thick insulator was placed between them as shown in Fig. 2. It should be noted that, in experiment, the thermocouple was also used to measure the balance temperature and it was found that the latter were less than 10 K above the ambient temperature. A digital video with 25 fps was used to record the flame image.

3. Fire merging under quasi-quiescent condition

3.1. Burning behavior

For an ordinary pool fire, if the fuel thickness is large or can be regarded as infinite, generally three stages of fire development can be observed, i.e., initial growth, steady burning, and decay as reported by Chatris et al. [2] and Quintiere [11]. But for a limited thick or relatively thin pool fire with the initial fuel temperature less