Experimental investigation on the flame characterization and temperature profile of single/multiple pool fire in cross wind

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1 Abstracts

An experimental study is carried out for investigate the flame characterization and temperature profile for single and multiple pool fire with the influence of cross wind. There are 13 test cases in total, categorized circle and rectangle fuel pans, with diameter (or equivalent diameter) ranged for 50 mm to 300 mm. Kerosene is used for the fuel of pool fire. Some K-type thermocouples are arranged around the flame to monitor the flame temperature, while the flame tilt angle is measured base on the photograph of flame for different case. Firstly, it can be found that there are three phases, including preheating, steady burning and extinguishing phase, during the flame evolution. The temperature near by the fuel surface is higher than flame plume, with maximum temperature approximately 1040 K and 600 K, respectively, in the steady burning phase of circle single pool fire (D=300 mm), while the average burning rate is ~1.525 g/s. In addition, the burning rates of all cases are measured and compared with the current predicted method. Typically, the flame morphology of single/multiple pool fire at different cross wind speed (ranging from 0 to 3.5 m/s) is analyzed, and it is found that the results for single pool fire is according to Thomas model and AGA model well, but not suitable for multiple pool fire.

2 Introduction

The storage and transportation of hydrocarbon fuels, e.g. crude oil, LNG, kerosene, is very important for the processing and production in energy and chemical industries [1, 2]. Pool fire is one of the most common accident forms in the storage and transportation of hydrocarbon fuels [3, 4]. The development process of pool fire accidents has a crucial influence on fire rescue, including fire prevention and extinguishing, safety evacuation [3, 5, 6]. Meanwhile, it is an important fundamental topic in combustion and flame field [7-9], which has been studied for decades. In general, there are many research achievements on pool fires, focusing on burning rate [7-10], flame geometry [9-12], temperature profile [9, 13, 14], and soot and radiation [13, 15, 16], etc.

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Most of the researches about the pool fire driven by buoyancy and in cross wind were carried out in recent years. Based on previous results, many improvement work has been carried out by taking different factors into account to develop more precise predicted model. Hu [17] quantified experimentally the pool fire flame tilt angle in a wind and measured the mass burning rate simultaneously for the pool dimension ranging from 10 to 25 cm in diameter. Lam et. al. [18] measured the flame drag, flame tilt and length, based on a 2 m diameter pool fire with Jet A fuel. They proposed the semi-empirical correlations in wind. Muñoz et. al. [16] measured the radiation intensity with different pool sizes and flame positions by infrared camera. Hu [12] investigated the radiation feedback of flame on square pool with dimensions of 10-25 cm in cross wind. Planas-Cuchi [19] measured the temperature distribution around the flame with hexane (4 m^2) and kerosene (12 m^2) multiple pool fire, without taking wind speed into consideration. Fukuda [20] and Delichatsios [21] has carried out the research on multiple pool fire, but focusing on burning rate, flame length, and air entrainment, without taking temperature profiles into consideration. Generally, the majority of current work was focusing on single pool fire, the research on the multiple pool fire in wind is relatively limited. Especially, the temperature profile of multiple pool fire in cross wind is rarely reported. As a result, this work focuses on combustion process and flame characteristic of multiple pool fire in cross wind, including burning rate, flame tilt angle, temperature profile, with different pool dimensions.

3 Experimental setup

This work is conducted in a wind tunnel as shown in Figure 1. The total length of the wind tunnel is 4500 mm, with the sectional dimension of 1200 mm×1200 mm. The air flow is driven by a fan (230W, Wahson, China), which controlled by a frequency changer. In order to make the air flow uniform in the wind tunnel, three pieces of wire mesh was set as wind distributor. At the upstream of the tunnel, the cross wind speed is monitored by hot-wire anemometers (Testo 425, with accuracy 0.01 m/s, Germany). Two fuel pans, which are made of stainless steel with 2 mm thickness, are placed on electronic balances (Yingheng, with accuracy 0.1 g, China). The combustion process of pool fire is recorded by a digital camera. The fuel used in the experiment is kerosene, with approximately 2 cm thickness in the fuel pan. The poo fire is ignited with an electronic igniter. Each experimental cases will be repeated more than one time to reduce random error.

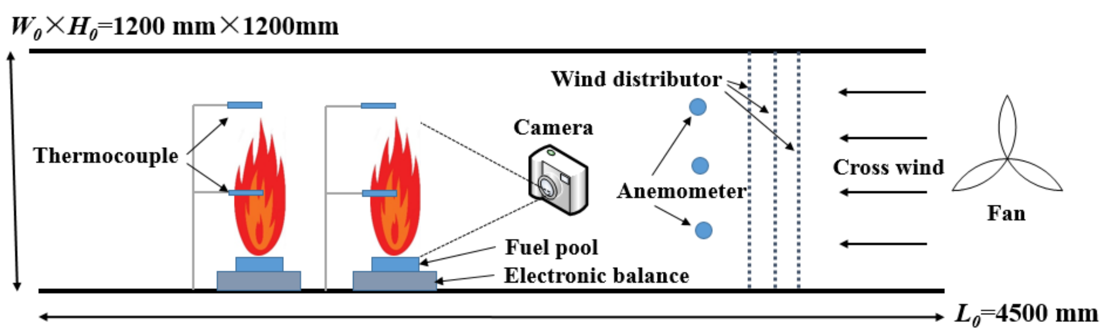

Figure 1. Experimental setup of single/multiple pool fire

In order to investigate the effect of pool shape and size, various fuel pans are designed, as shown in Table 1. Thirteen cases are studied in this work, including single pool fire and multiple pool fire on both circle fuel pan and rectangle fuel pan. For circle fuel pan, the diameter (D) ranges from 5 cm to 30 cm, while for rectangle pan the size ranges from 100 mm×100 mm to 300 mm×300 mm. The distance (d) between two fuel pans in the multiple pool fire cases is related to the pool size, as listed in Table 1.

Table 1 Geometrical parameter of various cases

NO.	Pool scale/mm	Pool type	*l*/mm	*d*/mm
Case-1	D=200	Circle, Single	150	-
Case-2	D=250	Circle, Single	200	-
Case-3	D=300	Circle, Single	250	-
Case-4	D=50	Circle, Multiple	50	25
Case-5	D=100	Circle, Multiple	100	50
Case-6	D=200	Circle, Multiple	150	100
Case-7	150*300	Rectangle, Single	150	-
Case-8	200*300	Rectangle, Single	150	-
Case-9	300*300	Rectangle, Single	150	-
Case-10	100*100	Rectangle, Multiple	150	50
Case-11	100*200	Rectangle, Multiple	150	80
Case-12	100*300	Rectangle, Multiple	150	100
Case-13	200*200	Rectangle, Multiple	150	100

4 Results and discussion

Taking the combustion process of Case-3 (D=300 mm, single pool fire, in still air) for example, the evolution of flame shape and the temperature profiles in the center of fuel pan at different elevation are shown in Figure 3 (a) and (b), respectively. After the fuel was ignited for $t \approx 40$ s, the flame start to grow and the temperature increases gradually. According to the flame temperature variation, the combustion process could be divided into three phases: preheating phase, steady burning phase, and extinguishing phase. In preheating phase, the flame height keeps growing and the flame temperature increases gradually to approximately 1040 K. The evaporation rate increases with the heat release rate of combustion increases. The heat flux feedback from flame to fuel surface is determined by conduction, convection and radiation [17, 36]. Starting from $t \approx 137$ s, the flame turns into a fully turbulent regime from the initial laminar regime, and the combustion goes into steady burning phase. It can be found there is a strong fluctuation for the fire even in still air, which may be caused by air entrainment during the combustion process. In addition, it can be observed that the flame height is about 400 mm. As the fuel exhausts, the flame temperature decreases quickly until the extinguishing, which lasts about 50 s. The average burning rate is estimated to be 1.525 g/s, from ignition to extinguishing.

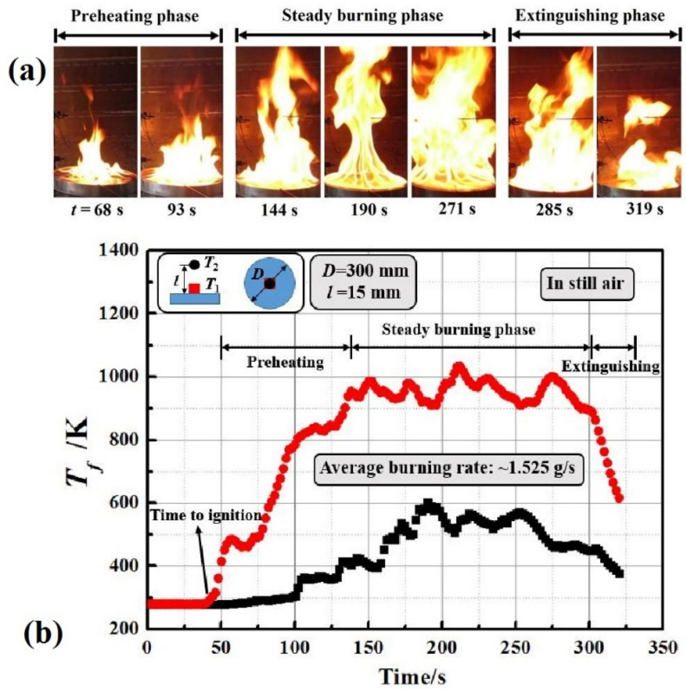

Figure 3. Flame shape (a) and temperature profile (b) of single pool fire (D=300 mm)

According to a previous study, the pool diameter (D) is one of the most important factors for burning rate in still air [25]. For circle pool fire, the pool diameter is equal to the fuel pan scale, while the equivalent diameter of rectangle pool could be calculated by Eq. (1):

$$D = 2\bullet\sqrt{\frac{S_{pool}}{\pi}} = 2\bullet\sqrt{\frac{L \times W}{\pi}} \tag{1}$$

where, S_{pool} is the area of rectangle pool, L and W is the length and width, respectively.

For the pool fire in still air, an empirical expression proposed by Babrauskas [37] is widely used for predicting the burning rate, which is controlled by convection or radiation feedback:

$$\dot{m}'' = \dot{m}''_{\infty}(1 - e^{-k\beta D}) \tag{2}$$

where, $\dot{m}''$ is the mass burning rate per unit area, g/(s·m^2); $\dot{m}''$ is the infinite-diameter pool mass burning rate, g/(s·m^2); D is the diameter of fuel pool, m; k and β is extinction coefficient (m^{-1}) and mean beam length corrector, respectively. The parameter, , k and β are obtained from Babrauskas's work [37].

The experimental and calculation results of the burning rate for all pool fire cases in still air are shown in Figure 3. The experimental results of single pool fire agrees well with the prediction (Case-1, Case-2, Case-3, Case-7, Case-8 and Case-9). However, for multiple pool fire cases, significant differences exist between the experimental and calculation results (Case-4, Case-5, Case-6, Case-10, Case-11, Case-12 and Case-13). In multiple pool fire cases, the fuel in one pool could be heated by the flame of neighboring pool fire. Thus the average burning rate is most likely to be promoted comparing with the single pool fire. In addition, as the pool size decreases in multiple pool fire case, the deviation of the calculated results increase. For instance, the measured and predicted burning rate for left pool in Case-4 is ~0.191 g/(s⋆m2) and ~0.006 g/(s⋆m2), respectively.

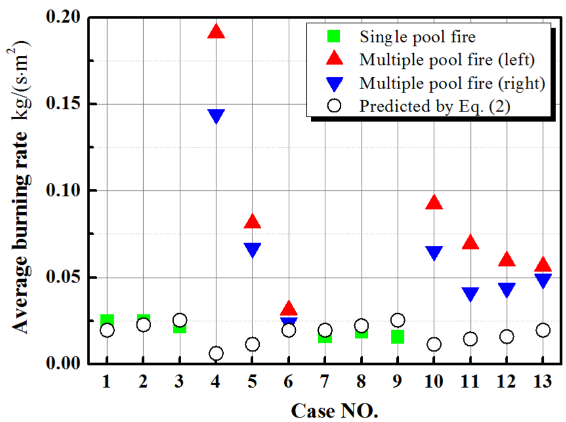

Figure 3. The average burning rate of different pool fire

The tilt of flame is one of the most remarkable morphological characterizations of pool fire in wind. Usually, pool fire takes place in open environment, which is easy to be affected by wind. As aforementioned, the heat feedback to fuel surface will change and the burning rate will increase in wind. In addition, the temperature profile around the pool fire, the effect area of the pool fire on surroundings such as neighboring fuel tank and firefighters will also change. As a result, it is very important to investigate the flame tilt angle and temperature profile (in Section 3.3) of pool fire in wind. The flame morphology of single/multiple pool fire at different cross wind speed (ranging from 0 to 3.5 m/s) is shown in Figure 4. Case-3 and Case-12 are selected as the representative for single and multiple pool fire, respectively.

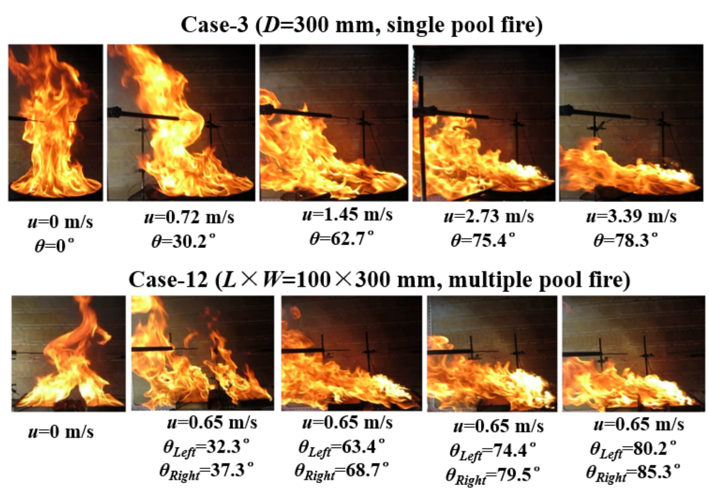

Figure 4. Flame shape of single/multiple pool fire in wind (Case-3 and Case-9)

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