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Short communication

An experimental investigation of the flame height and air entrainment of ring pool fire

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ABSTRACT

A serial of experiments have been conducted to investigate the flame height and air entrainment rate of the ring pool fire. The outside diameters of ring pool fires are 15 cm, 20 cm, 25 cm, 35 cm, 45 cm and 55 cm, respectively. The difference between the inner diameter and the outer diameter is 10 cm for each pool. It was found that the flame height of ethanol changes slightly with the increasing equivalent pool diameter, while the ones of *n*-heptane increases obviously. A unified correlation considering the air entrainment has been developed for both two fuels, and the measurement collapsed well with the physical model.

1. Introduction

The combustion characteristic of pool fire, including the burning rate, flame height, air entrainment rate, and flame tilt angle, has been investigated for decades [1–6]. A classical correlation of flame height for the rectangular pool fire has been found [1]. The flame height is 2/(2n + 3) power function of dimensionless heat release rate, which has been found that the evolution of flame height is relative to the air entrainment rate seriously [1]. Tang et al. [2] found that the flame height of the rectangular pool fire under different aspect ratios is relatively higher in reduced pressure. A revised entrainment coefficient factor was proved and used to describe relative change of flame height in reduced pressure [7]. Tao et al. [4] proposed a global model to clarify the relationship between flame height and entrainment rate for the buoyancy-controlled jet flames. An implicit expression of flame height based on the heat release rate and air entrainment rate has been given for the rectangular pool fire by Quintiere [5].

However, the combustion characteristic of the ring pool fire (a hollow in the central of the pool), including the flame height and air entrainment rate, is very different from solid pool. In this paper, Experiments have been conducted to study the evolution of flame height and air entrainment rate of the ring pool fire.

2. Experimental setup

The facility consisted of t thermocouples, ring pools, electronic balance, data acquisition system, CCD cameras and PC. The ethanol and *n*-heptane are used as the fuel. As shown in Fig. 1, the flame temperature are measured by thermocouples [8], which are set in the central line of the pools. The mass loss is measured by the electronic balance, whose resolution is 0.01 g. The visible flame are recorded by the CCD cameras with 25 fps.

As shown in Fig. 1b, D_1 is the inside diameter, D_2 is the outside diameter. The size of inside diameter (D_1) are 5, 15, 20, 25, 35, 45 cm respectively, while the difference between the outside diameter and inside diameter is 10 cm (namely, $D_2-D_1 = 10$ cm).

3. Results and discussion

3.1. Flame height

Fig. 2 shows that the evolution of flame shape of the ring pool fires, including the initial stage, the flame merging stage, and the decay stage. The flame height has been obtained during the steady stage based on the Otsu method [9]. Image processing steps can be found in previous literature [10]. An equivalent ring pool diameter (D) can be expressed as:

$$D = 2\sqrt{\frac{S_p}{\pi}} \quad (1)$$

As shown in Fig. 3, the flame height of *n*-heptane increases with increasing D, while the ones of ethanol changes slightly. The experimental data based on D is close to the value obtained by the solid pool [11,12].

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Nomenclature

C_p	specific heat of air at constant pressure
D	the equivalent pool diameter
D_1	the size of inside diameter
D_2	the size of outside diameter
g	gravitational acceleration
L_f	flame height
$\dot{m}$	mass loss
$\dot{m}''$	mass loss rate
$\dot{m}_e$	the entrainment mass flow rate
M	the molecular weight
n	aspect ratio ($=A/B$)
$\dot{Q}$	heat release rate
$\dot{Q}_s^*$	dimensionless heat release rate based on nozzle diameter
s	the molar stoichiometric oxygen to fuel ratio
S_p	the pool area
T	temperature
u	the vertical flame velocity
$Y_{O_2,\infty}$	the oxygen mass percentage concentration in ambient air
z	vertical height

Greek symbols

α	air entrainment coefficient
ρ	density

Subscript

fuel	for the fuel
O_2	for the oxygen
r	for the ring pool fire
s	for the solid pool fire
∞	air ambient

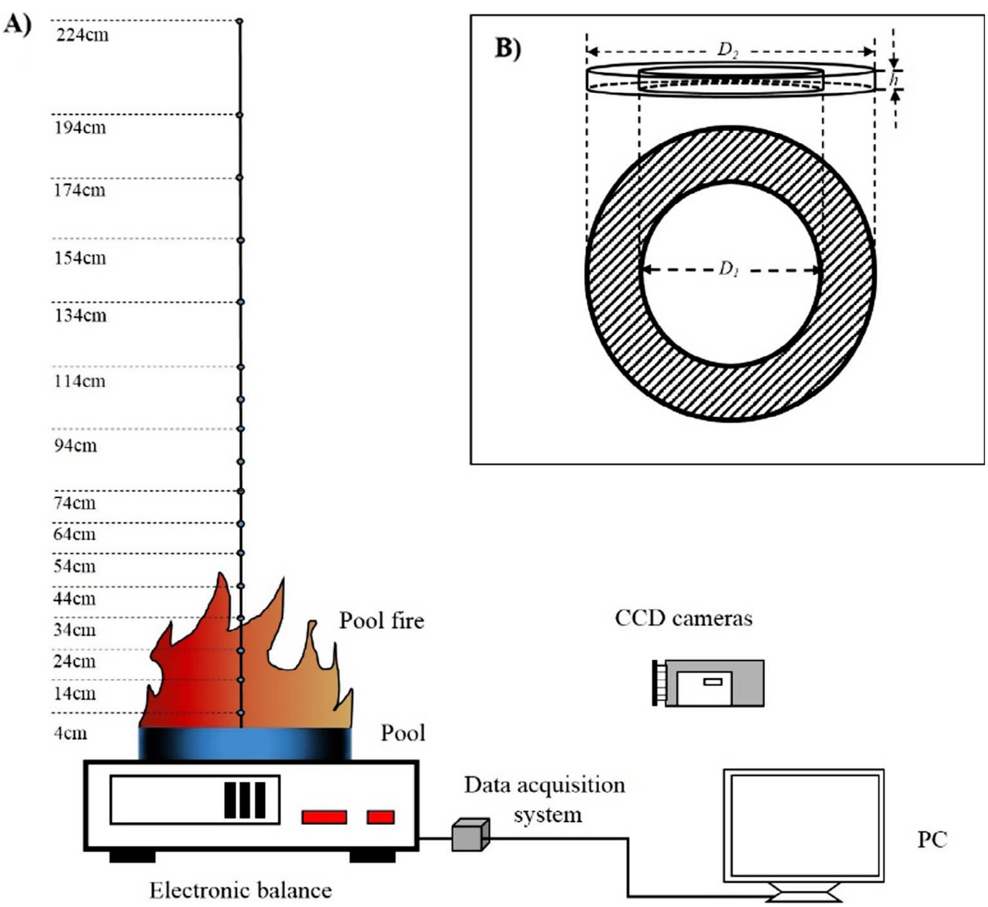

Fig. 1. Schematic of the experimental apparatus. A) Measurement setup; B) Ring pool.

3.2. Air entrainment rate

The geometrical shape of pool will influence the air entrainment rate [2,4]. The air entrainment rate can be described as [4,11]

$$\alpha^{\frac{4}{5}} = 0.232\dot{Q}_s^{*2/5} D\left(\frac{T_\infty}{T_f - T_\infty}\right)^{3/5} z^{-1} \tag{2}$$

where $\dot{Q}_s^* = \frac{\dot{Q}}{\rho_\infty T_\infty c_p \sqrt{g D^5}}$. Based on Eq. (2), the air entrainment rate α can be estimated for the solid pool fire and also the ring pool fire.

The mass loss ($\dot{m}$) is a function of the entrainment mass flow rate [13]

$$\frac{\dot{m}}{M_{fuel}} \sim \frac{\dot{m}'' D^2}{M_{fuel}} \sim \frac{\dot{m}_e Y_{O_2,\infty}}{M_{O_2} s} \tag{3}$$

where $Y_{O_2,\infty}$ is 23.2%, s is 11 for heptane and 3 for ethanol in the chemical reaction equation [11,13], the detailed fuel physical properties can be found in [14]. Since $\dot{m}_e \sim \rho_\infty u S$, $u \sim \sqrt{gD}$, and $S \sim L_f D$, then it gives that:

$$\dot{m}_e \sim \rho_\infty (gD^3)^{1/2} L_f \tag{4a}$$

For the ring pool fire, the air can be entrained from the hole, then