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Published in:
Energy Procedia

Published: 01/01/2015

Document Version:
Final Published version, also known as Publisher's PDF, Publisher's Final version or Version of Record

Published version (DOI):
10.1016/j.egypro.2015.02.012

Publication details:
Chen, X., Lu, S., & Liew, K. M. (2015). Preliminary Experimental Study of Horizontal Opening Effect on Pool Fire Behavior. *Energy Procedia*, *66*, 181-184. https://doi.org/10.1016/j.egypro.2015.02.012

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 66 (2015) 181 – 184

Energy Procedia

The 12th International Conference on Combustion & Energy Utilisation – 12ICCEU

Preliminary experimental study of horizontal opening effect on pool fire behavior

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Abstract

A series of experiments were conducted in a ceiling vented compartment to obtain the horizontal opening effect on pool fire behavior. Three pan diameters and six horizontal opening sizes were adopted and measurements included the mass loss, oxygen concentration and temperature in the horizontal opening. A dimensionless horizontal ventilation parameter coupling horizontal opening and pool fire areas was proposed to deal with these measuring parameters obtained. Results show that the burning rate varies with the horizontal opening parameter, as well as the oxygen concentration at extinction. Moreover, the maximum and average temperature difference in the horizontal opening present similar poisson distribution with an increase in horizontal ventilation parameter.

Peer-review under responsibility of the Engineering Department, Lancaster University

Keywords: Horizontal ventilation parameter, Ceiling vented compartment, Fire behavior, Temperature difference

1. Introduction

Many studies have been devoted towards vertical opening effect on compartment fire behavior[1][4], and the term $A\sqrt{H}$ is commonly known as the ventilation factor to evaluate flashover fire[5]. Whereas for the horizontal opening effect, brine/water analog was considered as a clear and simple way to study opening effect with a ratio of vent thickness and equivalent vent diameter (L/D)[6][8].

There are some differences between brine/water analog and real fire experiments due to the unsteady heat source, and much work has been carried out real fire experiments into the horizontal opening effect on burning rate[9], temperature in the cabin[10] and some special fire behavior[11]. Previous studies only focused on the size[12], the form[13] and the location of the openings[14]. However, the effects coupling horizontal opening and fire on these fire parameters have not been studied.

This paper reports preliminary results of the horizontal opening effect on pool fire behavior in a ceiling vented compartment. Firstly, the experimental facilities and sets of small-scale tests are described in detail, and several parameters are obtained, such as mass loss, oxygen concentration, temperature in the horizontal opening. Then, a horizontal ventilation parameter coupling horizontal opening and fuel areas was proposed to deal with horizontal opening effect on the fire behavior. Moreover, the effects of

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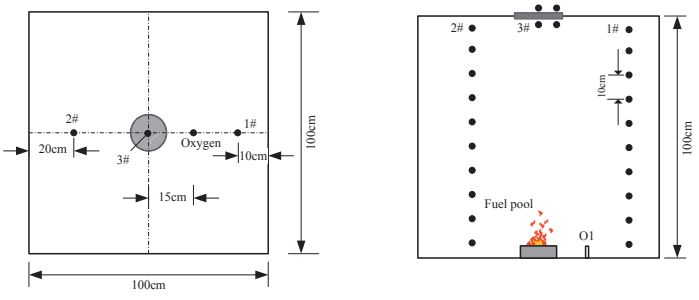
Peer-review under responsibility of the Engineering Department, Lancaster University
doi:10.1016/j.egypro.2015.02.012

horizontal ventilation parameter on burning rate, temperature in the vent, oxygen concentration were also studied.

2. Experimental

The experiments were conducted in a confined compartment with a horizontal opening, and the inner dimensions were 1.0m (L) × 1.0m (W) × 1.0m (H) (as shown in Figure 1). Every side of the compartment was built with toughened glass and the rest part was built with stainless steel. Three circle pans of various sizes (D=7cm,10cm and 14cm) with height of 4cm were used. The depth of fuel was kept 1.3cm before ignition and n-heptane was selected as fuel in each experiment. In order to investigate the horizontal opening effect on pool fire behavior, the opening size will be changed from 5cm to 50cm. A Shimadzu load cell with a maximum capacity of 6.2kg and a resolution of 0.1g was used to obtain the mass loss at a intervals of 1s. Three thermocouple trees were positioned in the compartment, each thermocouple was K-type with diameter of 1mm. Two of these trees were measured the gas temperature in the compartment and the rest one tree was measured the gas temperature variation in the horizontal opening. Gas analyzer was used to measure oxygen concentration at the base of fire and calibrated before every experiment.



(a) (b)

Figure 1. Experimental arrangement: (a) top view, (b) lateral view.

3. Results analysis

Utiskul proposed a simplified method to obtain the ventilation parameter $A_0\sqrt{H}\rho_\infty\sqrt{g}/A_f$ for the two vertical openings, which was in accordance with Bullen[1]. On the basis of the Epstein's empirical equation[6] and Utiskul's method[4], the dimensionless horizontal ventilation parameter $A_0^{5/4}\rho_\infty\sqrt{g}/A_f\dot{m}''_{f,\infty}$ is deduced to use in this paper to deal with the pool fire parameters (The detailed derivation will not be presented in this paper). Refer to the reference[15], the free burning rate per area will not change much with the pan size, and we take the free burning rate $\dot{m}''_{f,\infty}$ just for heptane of 0.015kg/m^{2}s in this study. Thus, the dimensionless horizontal ventilation parameter $\beta A_0^{5/4}/A_f$ will be used to deal with fire parameters, and β is a constant of 250 (m$^{1/2}$) just for heptanes in this study.

3.1. Burning rate

Previous studies of pool fire burning rate in the confined compartment were focused on the opening sizes effect. Figure 2(a) presents the diameters of 7, 10 and 14cm pool fire burning rate under different vent sizes. The burning rate values rises with the opening size increasing, and the burning rate values are linear correlation with the vent size.

The opening size cannot comprehensively present the coupling effect between the opening and fire sizes on the burning rate, thus, the horizontal ventilation parameter will be more suitable to discuss this parameter. The variation in average burning rate values with the dimensional horizontal ventilation parameter $\beta A_0^{5/4}/A_f$ is illustrated in Figure 2(b). The average burning rate values were calculated over the stable burning period or the whole burning period. It is evident from Figure 3 that a similar exponential

distribution is found for average burning rate with an increase in $\beta A_0^{5/4}/A_f$, and the slope of the distribution curve becomes steep with increasing the pool fire sizes.

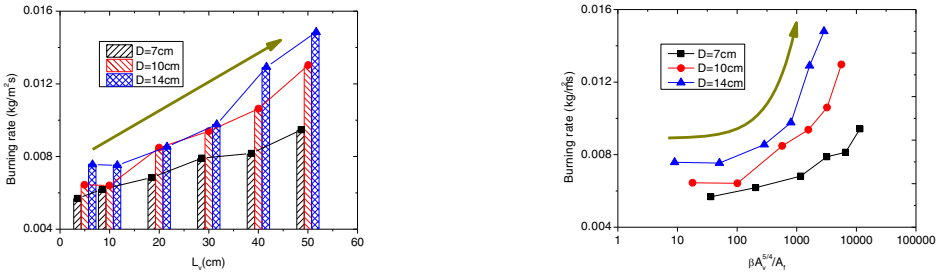


Figure 2(a) Variation in burning rate values with vent sizes, and(b) dimensional horizontal ventilation parameter.

3.2. Oxygen concentration

The oxygen concentrations (volume concentration) at extinction time are plotted against the horizontal ventilation parameter (Figure 3). An increase was found in the oxygen concentration with rising the horizontal ventilation parameter $\beta A_0^{5/4}/A_f$, and a similar power distribution was discovered in these data. When the horizontal ventilation parameter $\beta A_0^{5/4}/A_f$ was smaller than 300, the oxygen concentration increased steeply, and in this region, oxygen concentration value changed from 13.9% to 16.3% due to lack of fresh air. While the parameter $\beta A_0^{5/4}/A_f$ was larger than 300, the oxygen concentration varied from 17.5% to 20.6%, and changed not much with the horizontal ventilation parameter increasing.

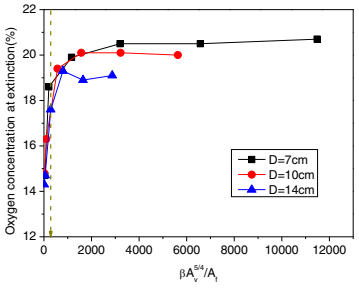
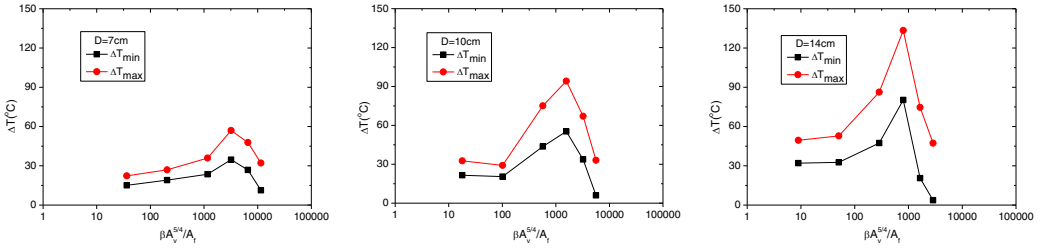


Figure 3 The oxygen concentration at extinction of three different pool fires

3.3. Temperature in the opening

Temperature profiles of smoke vent flow were measured by thermocouples in the horizontal opening (as shown in Figure 1). Temperature profiles were thought as the easy way to express the horizontal flow characteristics.



(a) (b) (c)

Figure 4 The effect of dimensional horizontal ventilation parameter on temperature difference in the horizontal opening for 7cm (a),10cm (b) and 14cm (c) pool fires.

Figure 4 illustrates that the maximum and average values of hot smoke temperature rise in the horizontal opening($T_v - T_{amb}$) vary with horizontal ventilation parameter $\beta A_0^{5/4}/A_f$ for the 7cm (a),10cm (b) and 14cm (c) pool fires. The maximum values of temperature rise were the peak values during the smoke

flow period, and the average values of temperature rise were calculated over the whole flow period. An apparent trend from Figure 4 is that the maximum and average temperature rise values increase with an increase in horizontal ventilation parameter for a fixed opening size. Compared to the figures (a), (b) and (c), it can be seen that the pool fire size will affect the variation trend and temperature peaks, i.e. for a larger pool fire (D=14cm), the maximum and average temperature peaks were equal to 133^{o}C and 80^{o}C, which were observed larger than that under other pool fire.

4. Conclusions

An experimental study of pool fire behavior in a confined compartment was conducted considering horizontal opening effect. Many parameters were obtained, including burning rate, oxygen concentration and gas temperature in the opening. Some conclusions are presented in this paper as follows: (1)A dimensionless horizontal ventilation parameter coupling horizontal opening and fuel areas was proposed to deal with the fire behavior. (2)Burning rate presents the exponential distribution and oxygen concentration shows the power distribution varying with the horizontal ventilation parameter. (3)The maximum and average temperature rise in the vent present similar poisson distribution with an increase in horizontal ventilation parameter.

Acknowledgement

This work was supported by the Research Fund for the Doctoral Program of Higher Education of China under Grant No.20123402110048.

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