International Journal on Engineering Performance-Based Fire Codes, Volume 10, Number 3, p.63-74, 2011

EXPERIMENTAL DATA ON SCALE MODELING STUDIES ON INTERNAL FIRE WHIRLS

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(Received 3 August 2011; Accepted 6 December 2011)

ABSTRACT

An internal fire whirl induced by a pool fire in a vertical shaft was studied experimentally with scale models. Different fuels including methanol, ethanol, propanol and gasoline were burnt in pools of different sizes. Wood chips and cribs were also tested as burning materials. Experiments on electrical heaters at a constant thermal power output were carried out to compare with burning liquid fuels involving combustion. Experimental data will be reported in this paper. Further analysis will be reported later, particularly on studying the aerodynamics for tests with and without combustion.

1. INTRODUCTION

Experiments have been carried out before on induction of internal fire whirls by scale models on a vertical shaft with a propanol pool fire with results reported earlier [1,2]. An internal fire whirl would be induced under appropriate ventilation provision as discussed, after which the burning rate of pool fire would increase with the flame height extended.

Experiments in the same scale model were carried out with different fuels including methanol, ethanol, propanol and gasoline of different pool sizes. Wood and electric heater were also used respectively in the tests for comparison of the effects. All the observations and raw data compiled will be reported in this paper.

Note that results reported in this paper are only experimental observations. Further analysis on aerodynamics in the vertical shaft will be reported later. Scaling laws used for studying smoke movement [3-5] will be reviewed later for its suitability in application to fire whirl studies.

2. SCALE MODELING STUDIES

Experiments were carried out in a vertical shaft model of size 35 cm by 34 cm and height 145 cm as shown in Fig. 1. The model was made of wood, equipped with a transparent plastic sheet for observation of the flame shape and recording by photography. A pool fire was set up and placed on the ground of the shaft model center as shown in the figure. Earlier scale model experiments with propanol of 7 cm diameter indicated that an internal fire whirl would be induced with a vertical gap of width 3.6 cm.

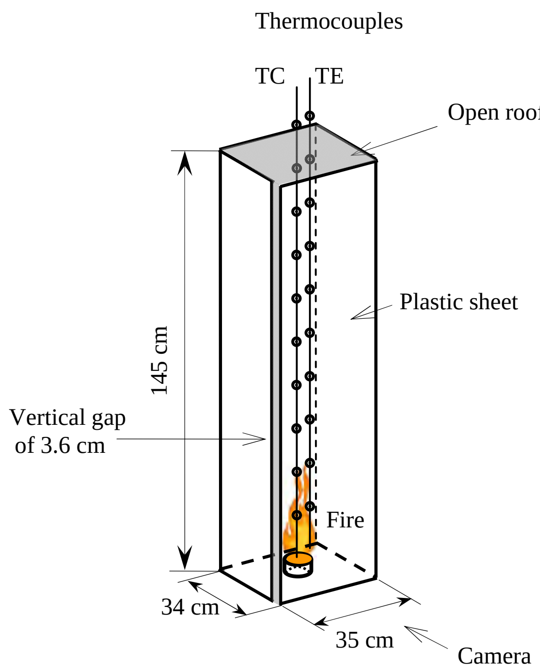
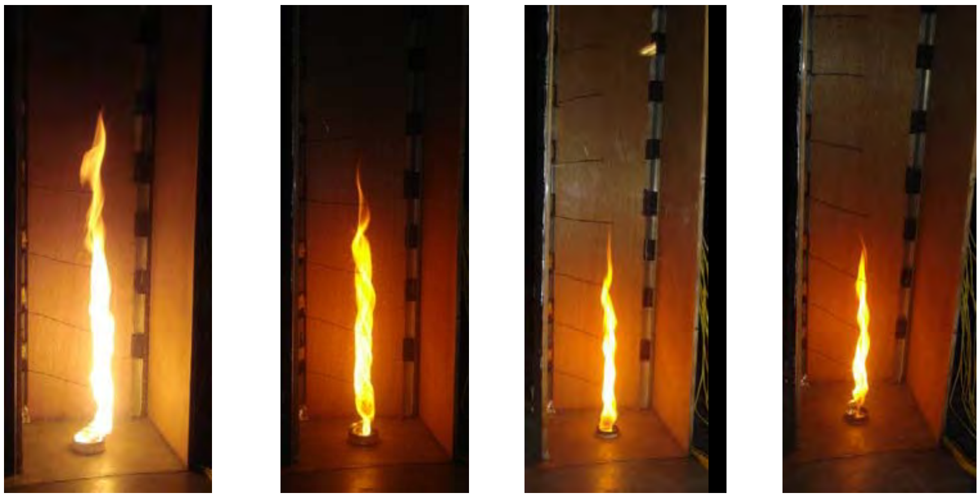


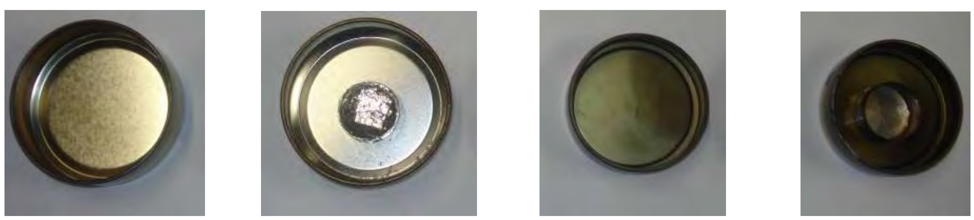
Fig. 1: The vertical shaft model

Scale model tests of burning pool fires in the shaft model with a gap width at 3.6 cm were then carried out and their results are reported in this paper. Four propanol fires of different sizes were considered; they were labeled P1 to P4 of area 39 cm^2, 33 cm^2, 26 cm^2 and 21 cm^2 respectively as in Fig. 2. P1 and P2 were of the same pool diameter of 7 cm, whereas P3 and P4 were of 5.8 cm. However, the setups further differ in that part of the surface areas for P2 and P4 were blocked, whereupon the surface areas for P1 and P3 remain unobstructed.

Burning those pool fires in free space would give heat releases of 1.5 kW, 1.2 kW, 1 kW and 0.8 kW respectively, in separate estimation, using the mass lost rate deducted from results for propanol shown in Fig. 3c. The volume of fuel used was 20 ml, the relevant thermochemical data [6] for which is shown in Table 1.



Diameter: 7 cm, Pool area: 39 cm^2 | Diameter: 7 cm, Pool area: 33 cm^2 | Diameter: 5.8 m, Pool area: 26 cm^2 | Diameter: 5.8 m, Pool area: 21 cm^2

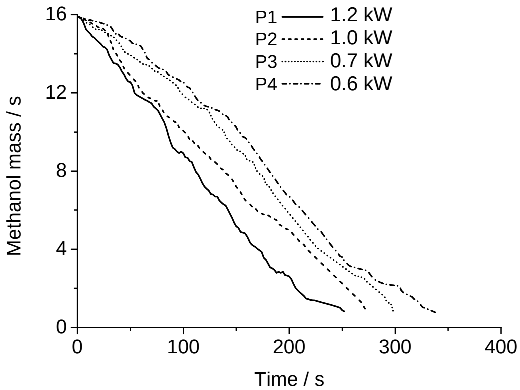


(a) P1: 1.5 kW (b) P2: 1.2 kW (c) P3: 1 kW (d) P4: 0.8 kW

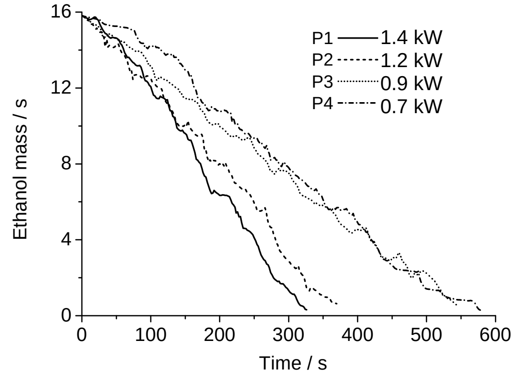
Fig. 2: Fire whirl with propanol pool fires of different pool sizes

Table 1: Chemical data of fuel

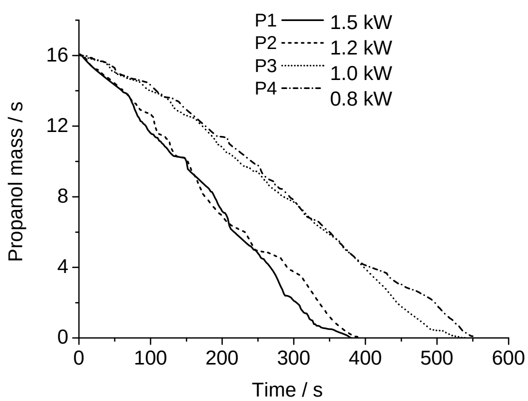
Material		Gross calorific value	Net calorific value
Gasoline		46.8	43.7
Methanol		22.68	19.94
Ethanol		29.67	26.81
Propanol	n-propanol	33.61	30.68
	iso-propanol	33.38	30.45
Wood	beech	20.0	18.7
	birch	20.0	18.7
	douglas fir	21.0	19.6
	maple	19.1	17.8
	red oak	20.2	18.7
	spruce	21.8	20.4
	white pine	19.2	17.8



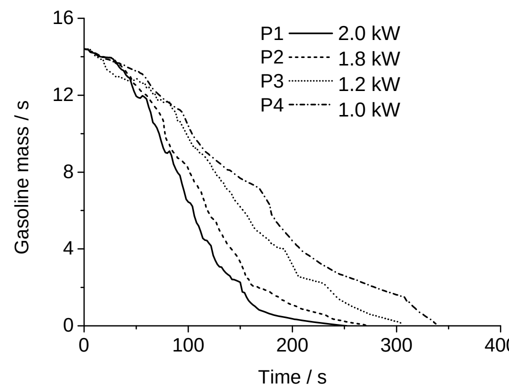
(a) Methanol



(b) Ethanol



(c) Propanol



(d) Gasoline

Fig. 3: Burning in the open space

The internal fire whirls induced are shown in Fig. 2. The vertical temperature profiles for P1 to P4 are shown in Fig. 4.

3. DIFFERENT LIQUID FUELS

Different fuels of methanol, ethanol and gasoline were tested in pools P1 to P4. A constant fuel volume of 20 ml was used for each setup.

The flame shapes of each pool fire while burning these fuels in free space are shown in Fig. 5. The mass lost rate curves on the pool fires burning outside are shown in Fig. 3.

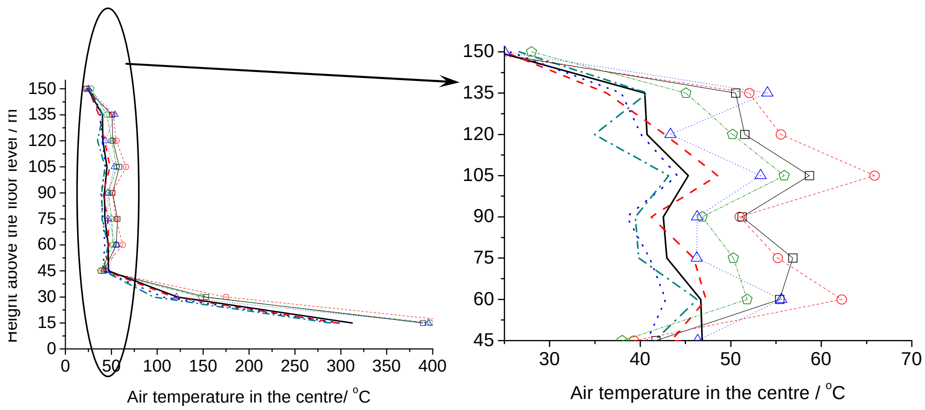
On the tests burning the pool fire inside the model, vertical temperature profiles are shown from Figs. 6 to 8. Internal fire whirls in the scale model were set up as in Figs. 9 to 12. Mass lost rate of fuel measured in the model with fire whirl induced are shown from Figs. 13a to d.

4. BURNING WOOD

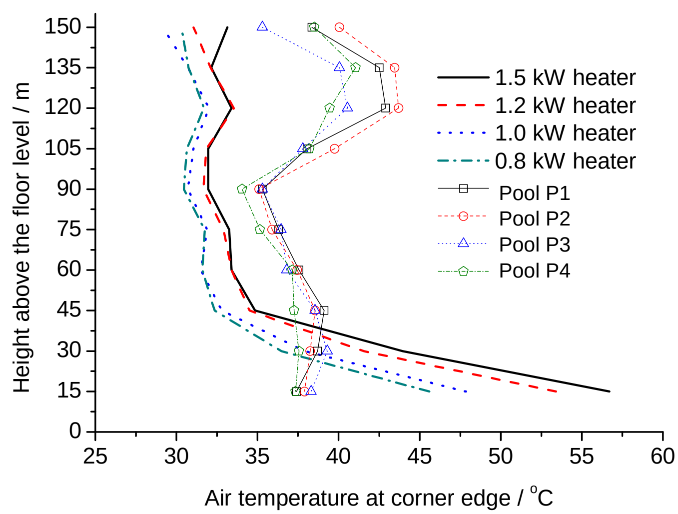
Two arrangements of wood were also burnt for further comparison and reference:

- Arrangement of a wood crib of size 6.5 cm by 6.5 cm by 5.0 cm (height) and mass 80 g as in Fig. 14a.
- Arrangement of wood chips of similar mass of 80 g as in Fig. 15a.

The net heat of combustion of wood is given as 15 kJg^{-1}. The mass of burnt wood was approximately 80 g with a burning time of 2300 s in free space. The average heat release rate was estimated by division of the mass lost by burning time, i.e. 15*80/2300 kW or 0.5 kW. Hence, the combustion of wood chips would reach a higher average heat release rate of 2 kW due to shorter burning time in free space.



(a) At centre



(b) At corner edge

Fig. 4: Vertical air temperature profiles for heaters and propanol fires

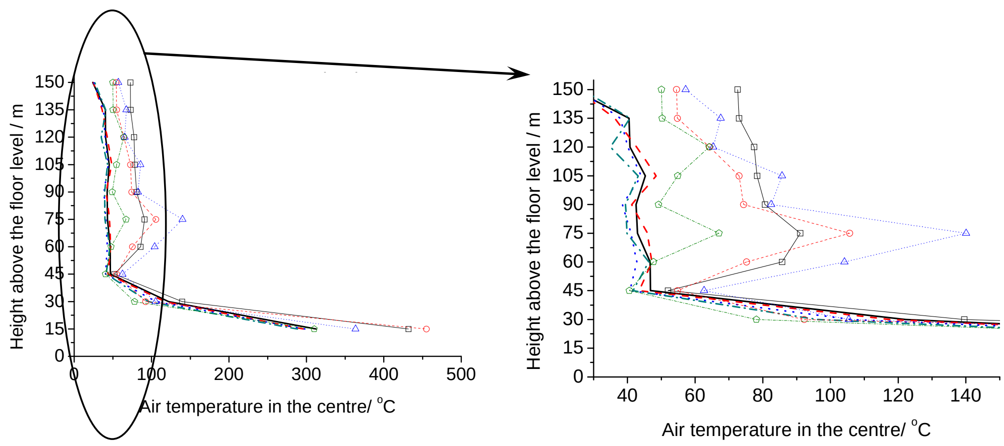
(a) 1.2 kW methanol fire

(b) 1.4 kW ethanol fire

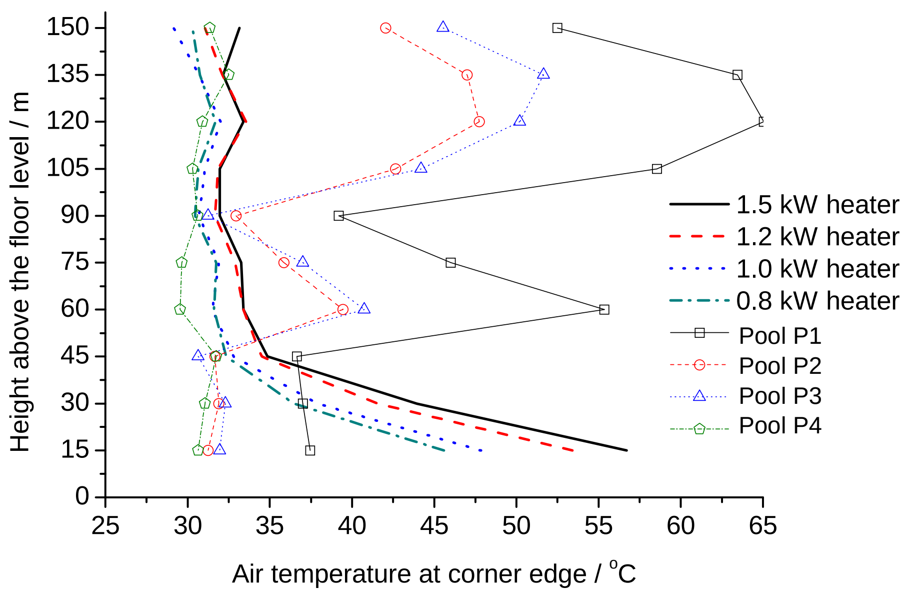
(c)1.5 kW propanol fire

(d) 2.0 kW gasoline fire

Fig. 5: Free burning fires for different fuels with pool P1

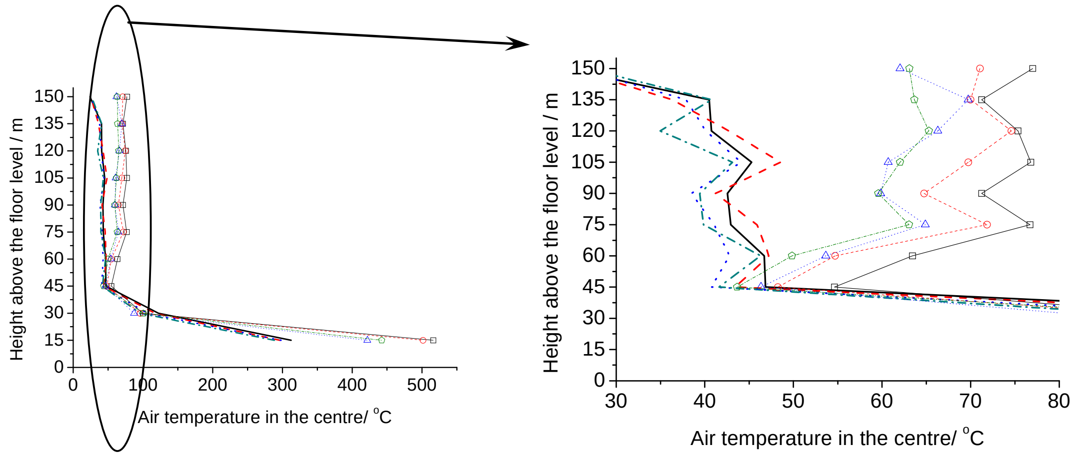


(a) At centre

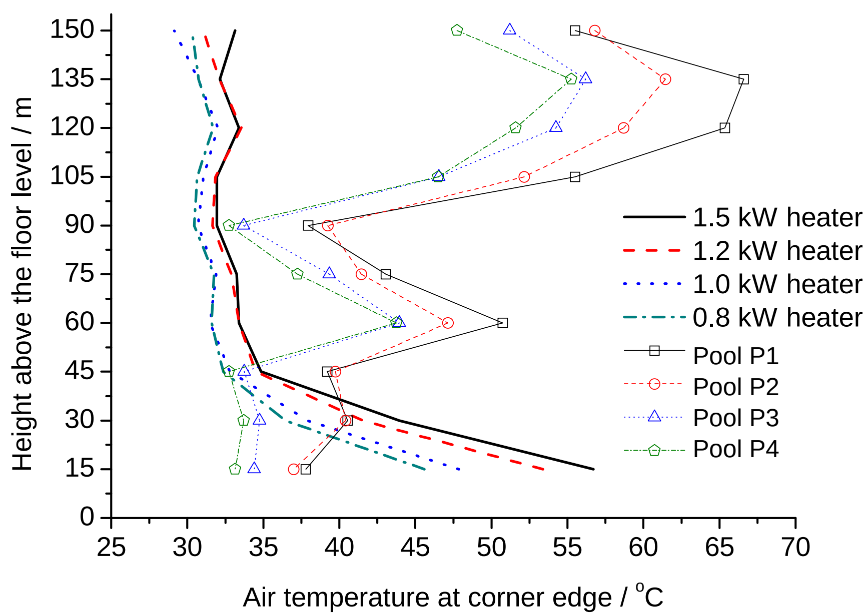


(b) At corner edge

Fig. 6: Vertical air temperature profiles for heaters and methanol fires

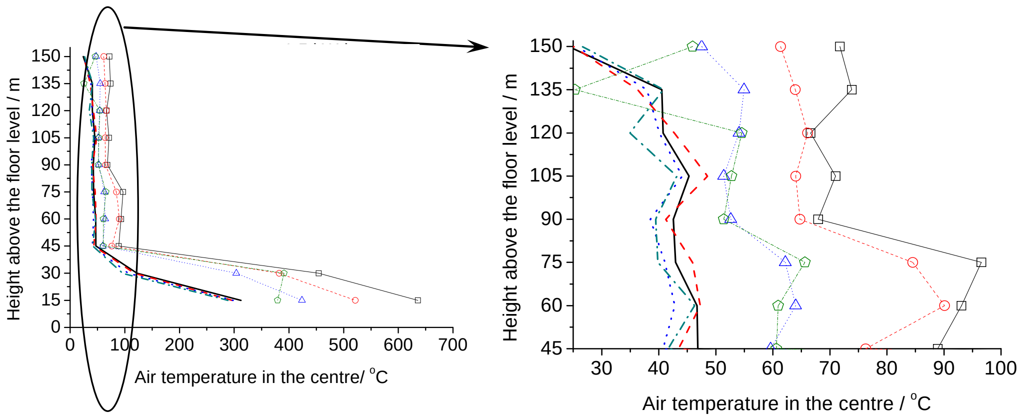


(a) At centre

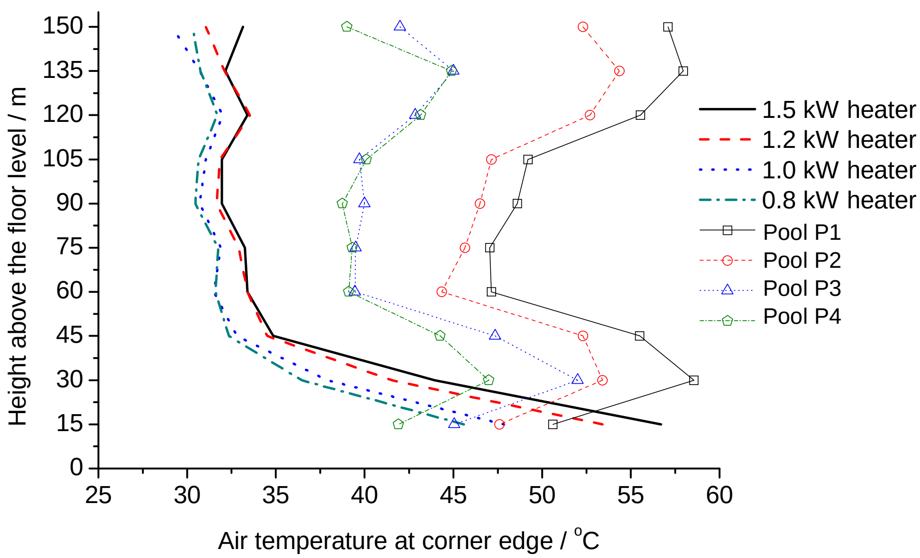


(b) At corner edge

Fig. 7: Vertical air temperature profiles for heaters and ethanol fires

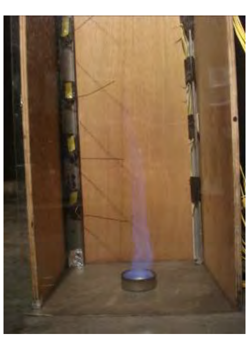


(a) At centre

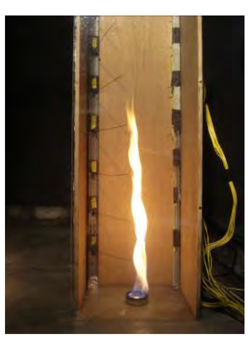


(b) At corner edge

Fig. 8: Vertical air temperature profiles for heaters and gasoline fires

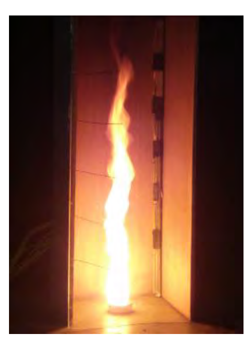


(a) Methanol fire



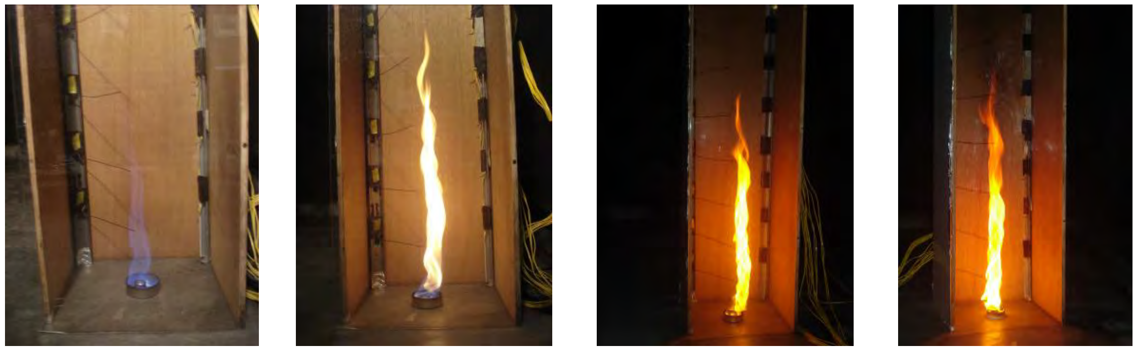
(b) Ethanol fire

(c) Propanol fire



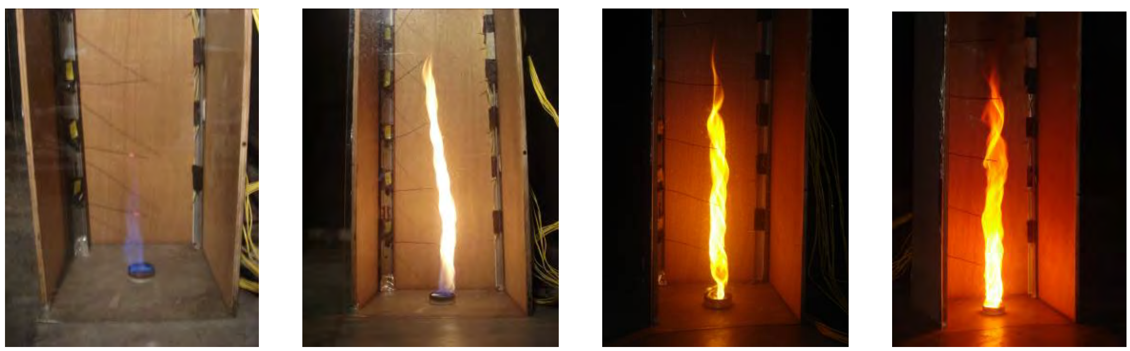
(d) Gasoline fire

Fig. 9: Fire whirl tests in the model for different fuels in tests with pool P1



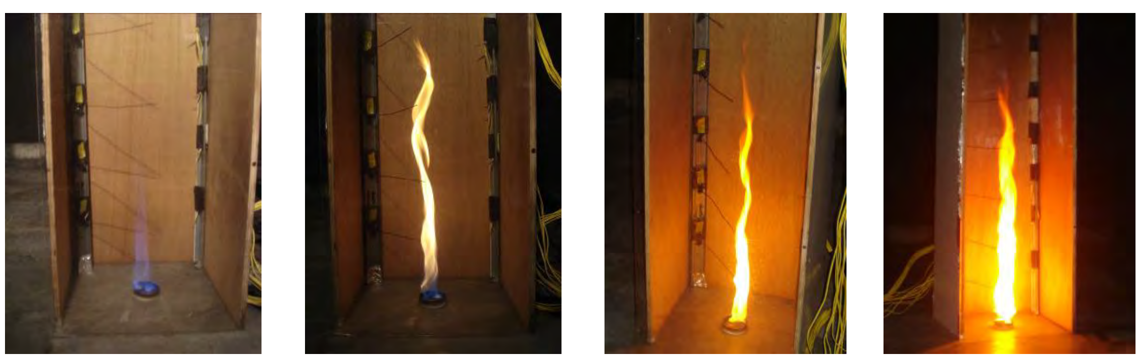
(a) Methanol (b) Ethanol (c) Propanol (d) Gasoline

Fig. 10: Fire whirl tests in the model for different fuels in tests with pool P2



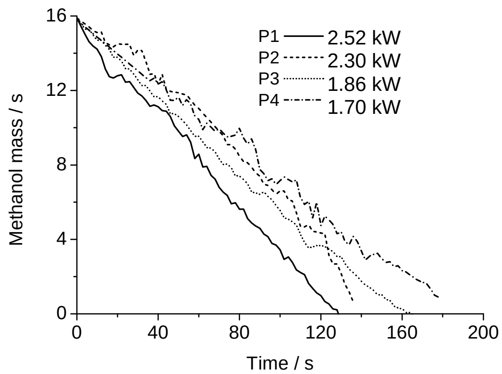
(a) Methanol (b) Ethanol (c) Propanol (d) Gasoline

Fig. 11: Fire whirl tests in the model for different fuels in tests with pool P3

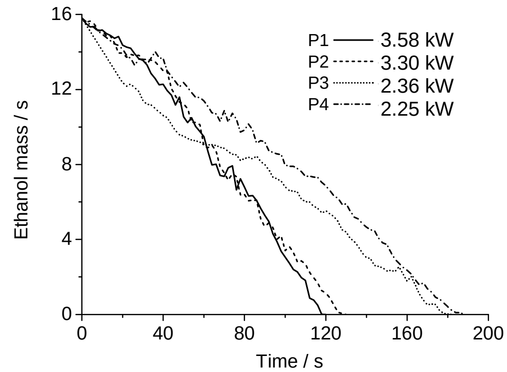


(a) Methanol (b) Ethanol (c) Propanol (d) Gasoline

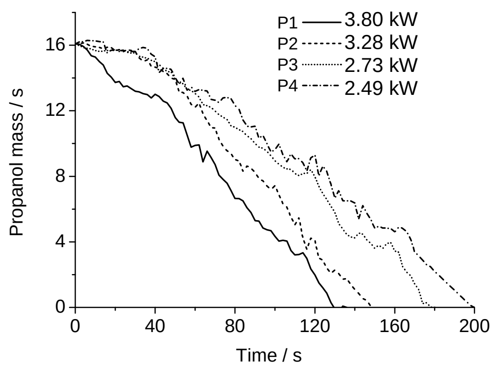
Fig. 12: Fire whirl tests in the model for different fuels in tests with pool P4



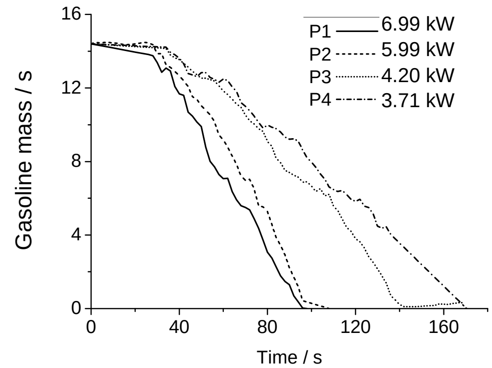
(a) Methanol



(b) Ethanol



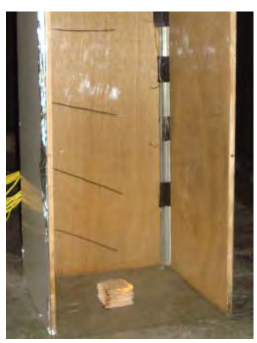
(c) Propanol



(d) Gasoline

Fig. 13: Mass loss rate of fuel in the shaft model

(a) Wood crib



(b) Start burning

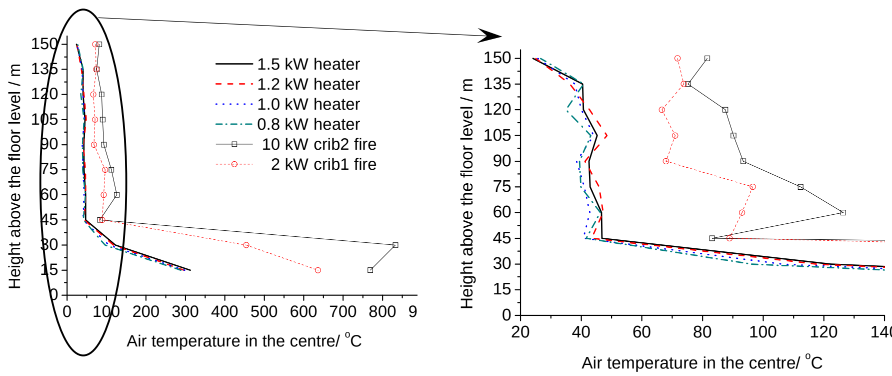
(c) Normal flame height of 25 cm

(d) Maximum flame height of 55 cm

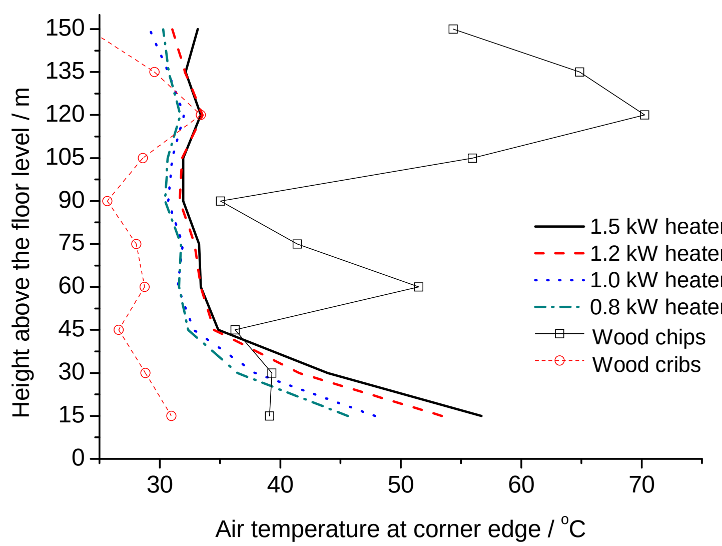
Fig. 14: Fire whirl tests in the shaft model with small wood crib

(a) Wood chips (b) Start burning (c) Normal flame height of 70 cm (d) Maximum flame height of 95 cm

Fig. 15: Fire whirl tests in the shaft model with small wood chips



(a) At centre



(b) At corner edge

Fig. 16: Vertical air temperature profiles for heaters and wood crib fires

Fire whirls induced are shown in Fig. 14b to d and Fig. 15b to d respectively. Vertical temperature profiles are shown in Fig. 16. The mass lost rates are shown in Fig. 17. Burning durations for wood chips and cribs in the model were 900 s and 1200 s, much shorter than those for liquid fuels.

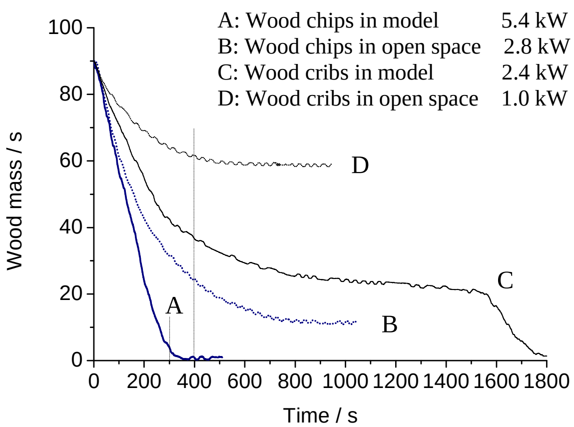
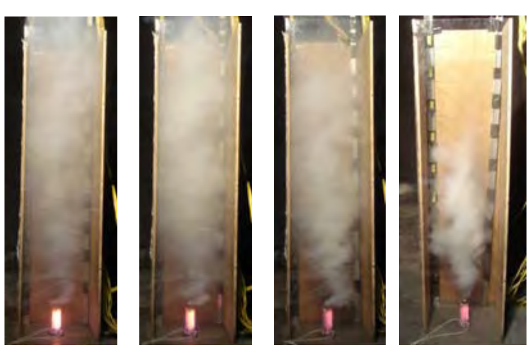


Fig. 17: Mass loss rates of wood chip and wood crib

5. ELECTRIC HEATER

Tests were repeated with electric heaters of thermal power 0.8 kW, 1 kW and 1.2 kW. No opening was made at the bottom of the model. Swirling motion inside the model was not so clearly observed. Tracer gas from smoke pellets was emitted, the results of which are shown in Fig. 18.

Air temperatures were measured by two thermocouple trees TC and TE as shown in Fig. 1. Results are plotted in Fig. 4 for burning propanol pool fires. Vertical average temperatures for tests with electric heaters are also plotted against the height in Fig. 4.



1.5 kW	**1.2 kW**	**1 kW**	**0.8 kW**
Maximum height:			
0.9 m	0.8 m	0.7 m	0.6 m

Fig. 18: Comparison of smoke swirling heights

6. CONCLUSION

The following observations have been concluded [1,2,7] from the above scale modeling experiments:

- Internal fire whirl will be induced in a vertical shaft of appropriate width, say 3.6 cm, even with a pool fire of small size.
- Burning different fuels in the pool would not affect the onset of a fire whirl; however flame length will be different.
- Electrical heater as a heat source might not be able to induce a fire whirl as shown in the temperature profile.

This paper is on reporting the relevant experimental data for different applications. Further theoretical analysis [8] and numerical experiments with Computational Fluid Dynamics [9] will be reported in later publications.

ACKNOWLEDGEMENT

The work described in this paper was supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China for the project "Appropriate safety for lift shafts and adjacent lobbies of evacuation elevator systems for supertall buildings under big fires" (PolyU 5148/08E).

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