IOP Conf. Series: Materials Science and Engineering **201** (2017) 012027 doi:10.1088/1757-899X/201/1/012027

Influence of stack effect on the heat feedback to the n-heptane pool fires

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Abstract: A set of experiments was conducted in a 1/3 scale building model to study the influence of stack effect on the heat feedback to the n-heptane pool fires. The height of opened window and pool size were varied. Results show that the conduction heat feedback fraction slightly decreases and the radiation heat feedback fraction increases with the increase of the strength of stack effect, while the convection heat feedback fraction remains almost invariant.

1. Introduction

In recent years, a lot of high-rise building fires caused great casualties and property loss and attracted more and more attentions. Once a fire occurs, it is easy to form stack effect in high-rise building. Stack effect is the mechanism of air movement caused by the pressure difference generated from the density difference of hot and cold airs inside and outside of the building, respectively [1]. The stack effect can suck more fresh air into the fire room, and may make small fire become larger quickly [2]. The characteristics of smoke movement, the influence of stack effect on fire behaviors in high-rise buildings and the effect of wind on building fire behaviors and heat feedback to pool fires have been studied previously [1-7]. The characteristics of smoke flow and flame behaviors are related to the combustion condition. The heat feedback is a very important parameter reflecting the combustion conditions. But the evolution of heat feedback under the effect of stack effect has not been studied before. To study the heat feedback to n-heptane pool fires in a compartment of high-rise building, a set of experiments was conducted in a 1/3 scale building model.

2. Experimental

Experiments based on Froude modeling were conducted in a facility consisting of a room, an atria and a vertical stairwell, where more details have been described in [2,4], as shown in Figure 1. The 1/3 scale building model with 12 floors is 12.2 m high. The ground floor is 1.2 m high and the other floors are 1.0 m. Each floor has a single window with a size of 0.7 m (width) × 0.9 m (height) in the stairwell. The horizontal cross-sections of stairwell, atria and room are 1.5 m × 1.0 m, 0.8 m × 0.8 m, 0.8 m × 0.8 m, respectively. Each floor has three doors connecting with the stairwell, atria, room and the outdoor, with the size of 0.4 m (width) × 0.6 m (height).

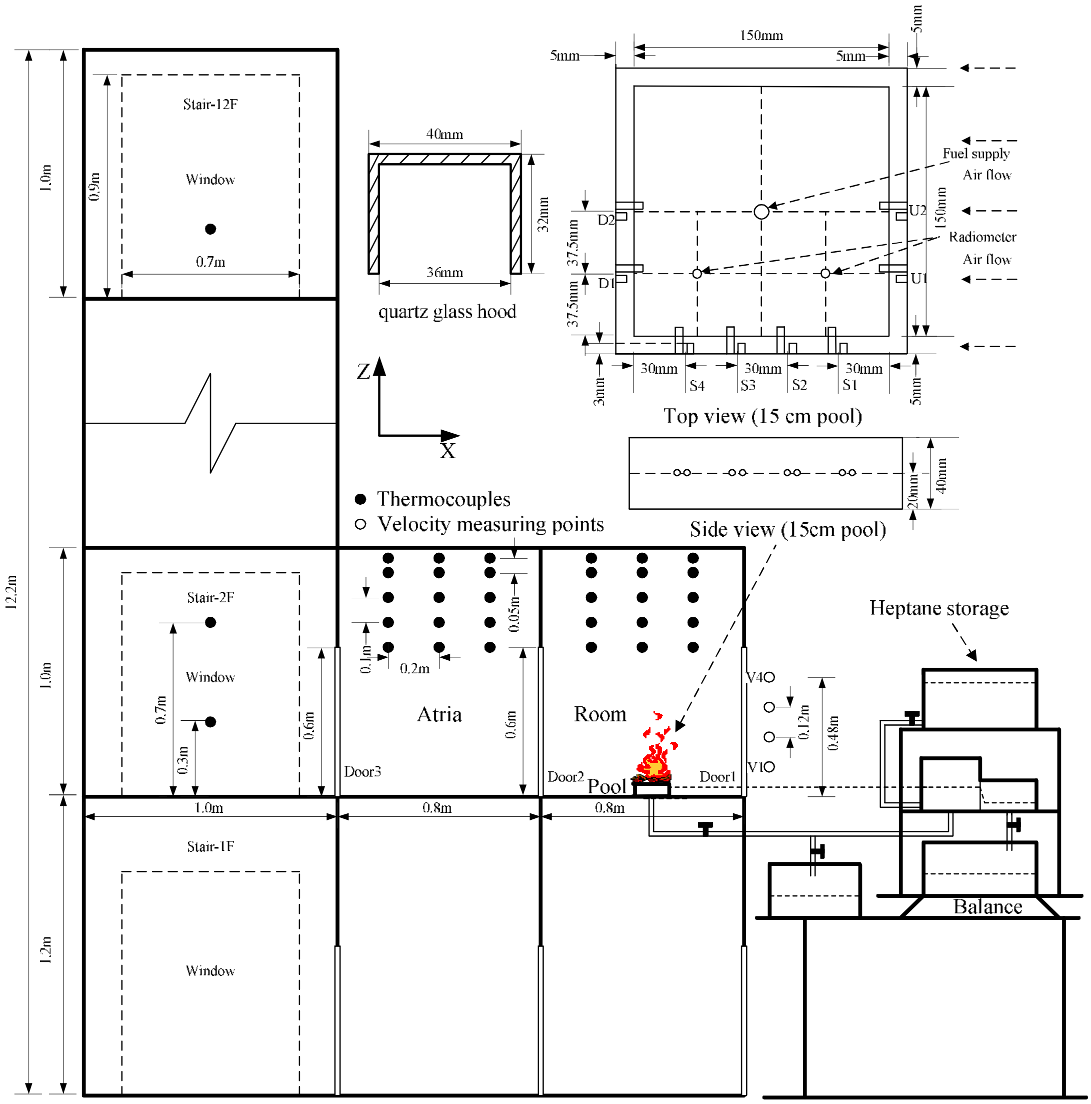

Figure 1. The experimental facility and locations of thermocouples and velocity measuring points

The K-type thermocouples with 1.0 mm in diameter were used in the experiment. Four hot-wire anemometers with a resolution of 0.01 m/s were installed 5 cm away from door 1, as shown in Figure 1. The 10 cm and 15 cm square pools were used with heptane as fuel. The pools are made by 5 mm thick steel plate with inner depth of 4 cm. The fuel surface level is maintained at 3 cm. The fuel was supplied from the bottom of the pool to maintain the height of the fuel surface level. A radiometer was positioned at the bottom of the pool to measure the radiation received by the fuel surface. The radiometer was covered by a quartz glass hood to protect it. The thermocouple with 1 mm diameter for measuring the wall temperature was embedded into a hole and the depth was 3 mm. That for adjacent fuel was 1 cm away from inner wall surface. The positions of the hole supplying fuel, the radiometer and the thermocouples are shown in Figure 1. The experimental facility which maintains the height of the fuel surface level is placed on the first floor, so the fire is placed in the center of the room on the 2nd floor, and the plane connecting the first floor and 2nd floor in the stairwell is blocked by the 8 mm thick fireboard. The fire floor is used as the benchmark and the ground of the fire floor is marked as 0 m in the experiment. The fuel mass was measured using an electronic balance with a resolution of 0.1 g.

During the experiments, door1, door2, door3 were all opened. The ambient temperature was about 293 K. The windows of 4th floor, 6th floor, 8th floor, 10th floor and 12th floor are opened respectively. A digital camera with a frequency of 50 frames per second was used to record the transient flame shapes. Each case was repeated two times to assure its reliability and repeatability.

3. Results and discussion

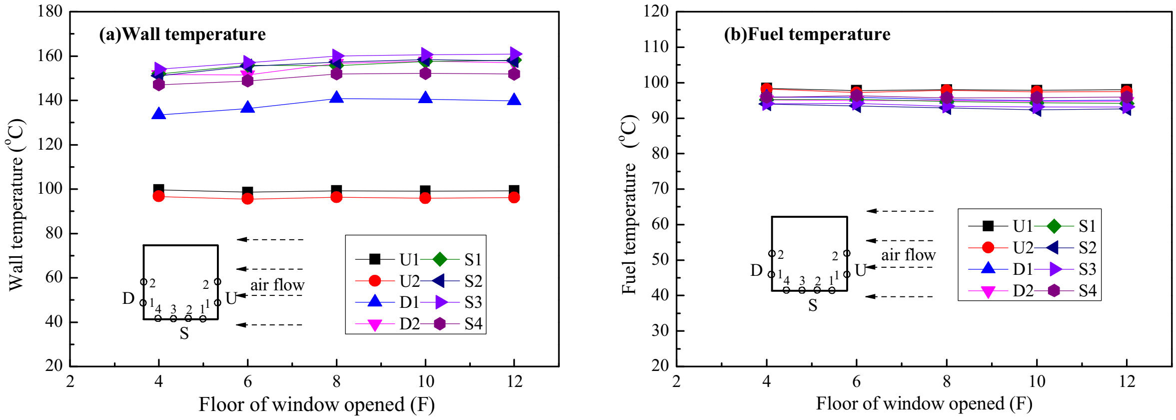

Figure 2. Temperatures of pool wall and adjacent fuel of 15 cm pool

The temperatures of pool wall and fuel of 15 cm pool are shown in Figure 2. It can be found that the upstream side temperature of pool wall remains invariable at about the boiling point of heptane (98.4 °C). The pool wall temperatures of the downstream side and the stream-wise side increase due to its direct heating by the deflected flame [7]. But it does not increase significantly with the increase of the height of opened window. The fuel temperature remains invariable at about the boiling point of heptane (98.4 °C).

The heat flux from the pool side wall to the fuel is calculated by [8]

$$\dot{q}'' = h(T_w - T_l) = \begin{cases} 0.59\dfrac{k_l}{L^{1/4}}\left[\dfrac{g\beta}{\nu\alpha}\right]^{1/4}(T_w - T_l)^{5/4} & 10^4 \le Ra_L \le 10^9 \\ 0.10k_l\left[\dfrac{g\beta}{\nu\alpha}\right]^{1/3}(T_w - T_l)^{4/3} & 10^9 \le Ra_L \le 10^{13} \end{cases} \tag{1}$$

where L is taken here as the constant fuel thickness, 0.03 m. The pool wall conduction heat feedback received by the fuel is calculated by

$$\dot{q}_{cond} = 2\times\dot{q}''_{U_1}Ld/3 + \dot{q}''_{U_2}Ld/3 + 2\times\dot{q}''_{D_1}Ld/3 + \dot{q}''_{D_2}Ld/3 + 2\sum_{i=S_1}^{S_4}\dot{q}''_iLd/4 \tag{2}$$

where d is the pool length, m.

The radiation heat feedback received by the fuel surface is calculated by

$$\dot{q}_{rad} = \sum_{i=1}^{n}\dot{q}''_{rad,i}\cdot s_i \tag{3}$$

The variations of the conduction and radiation heat feedback with the height of opened window are shown in Figure 3. It can be found that both the conduction and radiation heat feedback increase with the height of opened window, but the conduction heat feedback remains almost invariant when the height of opened window is relatively higher.

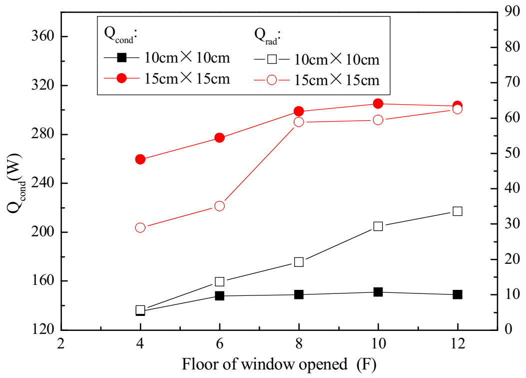

Figure 3. The conduction and radiation heat feedback

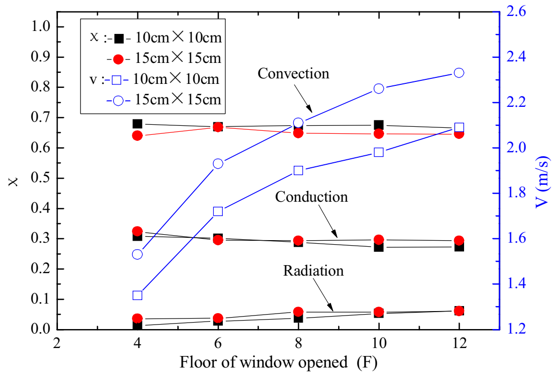

Figure 4. Evolution of heat feedback fractions and corresponding air flow velocity

The heat for the evaporation of liquid heptane can be given by [8]

$$\dot{Q}_{fuel} = \dot{m} \cdot \left[c_p (T_{boil} - T_0) + h_{fg} \right] \quad (4)$$

The wall conduction heat feedback fraction is calculated by $\chi_{cond} = \dot{q}_{cond} / \dot{Q}_{fuel}$. The radiation heat feedback fraction is calculated by $\chi_{rad} = \dot{q}_{rad} / \dot{Q}_{fuel}$. Then we can calculate the convection heat feedback fraction $\chi_{conv} = 1 - (\chi_{cond} + \chi_{rad})$.

The evolution of heat feedback fractions and corresponding air flow velocity with the height of opened window are shown in Figure 4. It can be found that the air flow velocity increases with the height of opened window. The air flow velocity varies from 1.35 m/s to 2.35 m/s. With the height of opened window increasing, the conduction heat feedback fraction decreases from 31.8% to 27.3%, the radiation heat feedback fraction increases from 1.3% to 6.2% and the convection heat feedback fraction remains almost invariant about 67.3% for 10 cm pool size. The conduction heat feedback fraction decreases from 32.4% to 29.4%, the radiation heat feedback fraction increases from 3.6% to 6.1% and the convection heat feedback fraction remains almost invariant about 65.0% for 15 cm pool size. The results of two pool sizes indicate that the convection heat feedback fraction remains almost invariant and it is the dominating one that influences the combustion process most, the conduction heat feedback fraction decreases and the radiation heat feedback fraction increases with the increase of the air flow velocity.

The variation of convection heat feedback fraction with air flow velocity is consisted with the results of Ref. [8] that the convection heat feedback fraction changes little with wind velocity when the Froude number is larger than 1.0. But the variations of conduction heat feedback fraction and the radiation heat feedback fraction with air flow velocity are different from the results of Ref. [8].

The mean flame length and average flame tilt angle are shown in Figure 5. It is found that the mean flame length remains almost invariant for a certain pool size under different opened window heights. That is to say, the projection of the tilting flame shows basically unchanged. But the mass loss rate increases with the height of opened window, as shown in Figure 6. Thus, it can be expected that the width of the flame should increase with the height of opened window and the air flow velocity. And the increase of the flame volume results in the increase of radiation from the flame to the fuel surface and the radiation heat feedback fraction increases. The temperature difference between the pool wall and the fuel has no remarkable increase with different air flow velocities, so the conduction heat feedback fraction decreases.

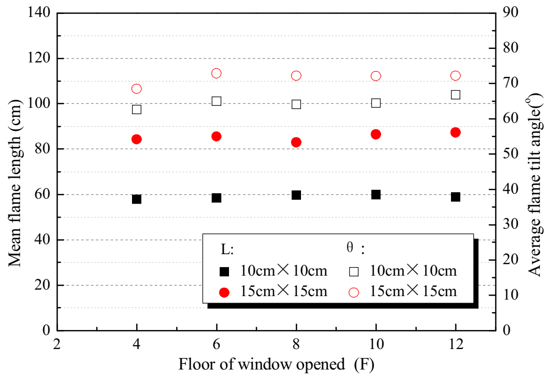

Figure 5. The flame length and flame tilt angle

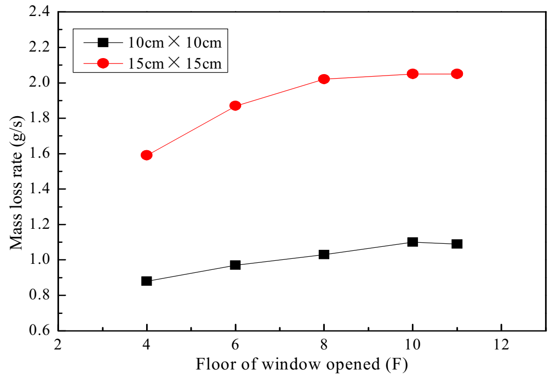

Figure 6. The mass loss rate

4. Conclusions

A set of experiments was conducted in a 1/3 scale building model to study the influence of stack effect on the heat feedback to the n-heptane pool fires. Results show that the convection heat feedback fraction remains almost invariant, the conduction heat feedback fraction slightly decreases and the radiation heat feedback fraction increases with the enhancing of stack effect.

Acknowledgements

This work was supported by the National Key Research and Development Plan under Grant No. 2016YFC0800106 and the Fundamental Research Funds for the Central Universities under Grant No. WK2320000033. Jie Ji was supported by the National Top-Notch Young Talents Program.

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