Influence of Wind Direction on Fire Spread on the Exposed XPS insulation Wall

Lanfang Zheng¹, Liang Zhou²*, and Xiangtao Jia³, Xiaokang Li¹

¹Fire Protection Engineering Department, China People’s Police University, 065000 Langfang, China
²Department of Safety Science and Engineering, University of Science and Technology Beijing, 100083 Beijing, China
³Gannan Detachment of Qiqihar Fire and Rescue Detachment, 161000, Heilongjiang province, China
*Corresponding author’s e-mail: zhouliang959@hotmail.com

Abstract: Medium-sized wall fire experiments were carried out using extruded polystyrene (XPS) panels to build an insulation layer to simulate the flame spread over the exterior thermal insulation system during the exposed stage. During the experiments, the influences of the wind direction on the lateral and vertical flame spread speed without fire barrier designs under the wind speed of 2.5m/s were studied quantitatively and qualitatively. According to the experimental results, it is found out the averaged peak lateral flame spread rate increases and the averaged peak vertical flame spread rate decreases when the angle between the wind direction and the wall increases from 0° to 60°. It can be seen from the analysis that the largest average lateral flame spread rate and the largest average vertical flame spread rate also show regular changes at same wind direction. This study results can provide valuable references for optimizing the fire safety design of exterior insulation system.

1. Introduction
According to the statistical data in the China Building Energy Consumption Research Report (2017), it is found that China’s construction energy consumption in 2015 is 857 million tons of coal, accounting for 20% of the total national energy consumption. Exterior wall is the largest component of building enclosure structure, accounting for 23%~34% of the heat transfer energy consumption of the whole building. The use of exterior wall insulation system can largely reduce building energy consumption. Organic insulation materials, especially polystyrene foam, are widely used because of their light weight, excellent insulation effect, low cost, low production energy consumption and convenience during construction. But this kind of materials has high fire hazard.

Extruded polystyrene (XPS) adopted in this paper is one of the most widely used insulation materials in Chinese construction industry. The exterior insulation wall fire will not only be driven by thermal buoyancy, but also affected by outdoor wind. Under the influence of wind, the angle of inclination of flame and fire plume will change, and then both the lateral and vertical flame spread rate will change too.
2. Experiments

2.1. Experimental platform
The main experimental platform is a frame made of steel. A piece of fire proof gypsum board with thickness of 1 cm, height of 2.6 m, and width of 1.2 m was fixed on the steel frame and acted as a layer of fire barrier. Since the length and width of the insulation panel used in this experiment is 1.2 m*0.6m, in order to better explore the flame spread characteristics, the overall height of the insulation wall is set to be 2.4 m by applying 4 panels. The width and the thickness of the insulation layer are 1.2 m and 5 cm respectively.

2.2. Wind-generating device
The wind generating device is composed of three parts: a blower, a variable frequency controller and wind outlets. Two wind speeds adopted in this study was designed as 1.5m/s and 2.5m/s. In addition, the influence of wind direction were explored by varying the angle between the wind and the platform to be 0°, 30°, 60° and 90°.

2.3. Measurement setup
One columns of type K thermocouples (Omega, model # TJ280CAXL-18U-6-CC-XCIB, 15 cm (6”) long TJ probe, OMEGACLAD® XL sheath and 3.2 mm (1/8”) OD), referred as line M, were used to record the temperature changes close to the wall surface during the burning process. Line M was located at the central line of the wall. There were 6 thermocouples evenly distributed along the line M where the lowest thermocouple was located 115 cm above the bottom of the insulation panel and numbered as 1, while the highest thermocouple located at the upper edge of the wall was numbered as 6.

A 150°wide-view-angle water cooled Schmidt-Boelter radiometer with a sapphire window to cut off convective heat flux (Shanghai TecFront Electronics Corp., model # STT-25-20-RWF, testing range 0– 20 kW/m², expanded uncertainty of ±3% and repeatability of ±0.5%) located 30 cm apart from the insulation wall was used to measure the radiation heat flux received from the whole flame. The radiometer was aligned right to the center of the wall with its surface parallel to the wall too. And the data was collected by an OMEGA OM-DAQ-USB-2401 Data Acquisition Module.

3. Experimental results of flame spread rate
The flame spread behavior of wall fire are not only affected by the properties of the insulation material, but also influenced by the exterior temperature, humidity, tilt angle and other factors. Among all the factors, the outdoor wind may have the largest impact on the shape and tilt of flame, heat transfer processes as well as the growth and the spread of fire.

Because the direction of the vertical fire spread is the same with the preheating direction of the plume, the vertical spread of the flame is far more dangerous than the lateral fire spread, the vertical spread of the flame becomes the focus of the wall fire research. In general, the largest average flame spread rate of the wall fire is calculated by dividing the largest travel distance of the pyrolysis front by the time. For non-carbonized thermoplastic materials, the position of the pyrolysis front can be identified from infrared images taken at different moments as shown in Fig 1.
During the processing of the recorded infrared images, the moment when the XPS material was just ignited was set as the starting point, and a flame image was extracted every 15s after ignition until the flame front reached the upper boundary of the insulation wall. A vertical coordinate axis was set at the center of the panel as the reference point. Then the position of the largest vertical flame front was marked by drawing a line perpendicular to the coordinate axis through the highest point of the flame front. And the position of the largest lateral flame front was marked by drawing a line parallel to the coordinate axis through the farthest point of the flame front. In that way, both the largest average vertical and lateral spread distances during a certain period can be identified. When the angle between the wind direction and the wall is set 90°, the wind generator will be put right in front of the frame, so the infrared image cannot be taken. That’s why only the flame propagation rates under the angle of 0°, 30°, 60° were calculated and discussed here. The calculation formula is as follows:

\[
V_t = \frac{S_f^{(t+\Delta t)} - S_f^t}{\Delta t}
\]

(1)

Since the changing trend of the flame spread rate is basically the same with different wind speeds, the experimental results using the wind speed of 2.5m/s under three different wind directions were presented here. At the early stage of fire growth, the flame front was not obvious as shown in the first picture in Fig 5. Therefore, the largest average flame spread rates after 15s were calculated and presented. For example, the largest average flame spread rates of vertical and lateral propagation between 15s and 30s can be calculated as follows:

\[
\nu_1 = \frac{S_1^{15} - S_1^{0.6}}{15} = 0.6 \, \text{cm/s}
\]

\[
\nu_2 = \frac{S_2^{15} - S_2^{3.6}}{15} = 2.73 \, \text{cm/s}
\]

In this way, both the largest average flame spread rates of vertical and lateral propagation during every 15s under three wind directions were obtained, as shown in table 1 and table 2 and plotted in Fig. 2. All the tests were terminated once the flame reaches the edge of the insulation wall.
Table 2 The largest average vertical flame spread rate using the wind speed of 2.5m/s under three different wind directions

| Time (s) | 0-2.5  | 30-2.5 | 60-2.5 |
|----------|--------|--------|--------|
| 15-30    | 2.73   | 2.27   | 1.2    |
| 30-45    | 2.13   | 2.5    | 1.73   |
| 45-60    | 2.73   | 2.47   | 2.4    |
| 60-75    | 5.13   | 4.06   | -      |

Fig. 2 The largest average flame spread rate using the wind speed of 2.5m/s under three different wind directions

(a) Lateral flame spread

(b) Vertical flame spread
From Fig. 2, it can be shown that the largest average lateral flame spread rates increase with the increase of the angle between the wind direction and the wall at the beginning and then decrease with further increase of the angle when the angle is smaller than 60°. While the largest average vertical flame spread rates decrease with the increase of the angle between the wind direction and the wall at the beginning and then increase with further increase of the angle when the angle is smaller than 60°. It should be pointed out that the test under the wind angle of 60°, the flame spread beyond the border of the panel and the test was terminated before it reached 75s, so there is no relevant data on the Fig. 2. And it can be noted that both the lateral and vertical flame spread rates increase with time for both wind speed conditions when the wind angle is set at 60°.

4. Summarization
According to the above experimental results, when the angle between wind direction and the wall increases from 0° to 60°, the largest average lateral spread rate of the flame increases, while the largest average vertical flame spread rate decreases. When the wind direction is fixed, the largest average lateral spread rate of the flame increases at the beginning and then remains almost constant or even drops during the later part of the test. When the angle between wind direction and the wall is fixed at 0° or 30°, the largest average vertical flame spread rate decreases at the beginning and then increases during the later part of the test. When the angle between wind direction and the wall is fixed at 60°, both the largest average lateral and vertical spread rates increase during the whole test and are comparatively higher than the data measured at the same time under other wind direction conditions.

Acknowledgement
The authors gratefully acknowledge the support of Natural Science Foundation of Hebei Province under the General Program Grant Number: E2018507025.

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