Simulation study on the influence of ventilation conditions on temperature distribution in a narrow space

Yupeng Yang*, Keye Chen and Xiangkai Guo
School of Shanghai Maritime University, Shanghai, China
*Corresponding author e-mail: 786200459@qq.com

Abstract: Taking a college building corridor as an example, the fire simulation software FDS is used to study the fire characteristics of narrow space. By creating a numerical model, the temperature field in the space is monitored, moreover the effect of ventilation conditions on the distribution of temperature in the channel is researched to provide a reference for the setting of the temperature detector in the channel.

1. Introduction

The longitudinal length of the narrow space is much larger than the space width and height, such as tunnels, highway passages, and the like. In recent years, domestic and foreign scholars have carried out a large number of simulation and experimental research on narrow space fires, and accumulated a lot of results.

In 1965, Switzerland conducted an early experimental study on the characteristics of tunnel fires, and studied the distribution and smoke flow of temperature in the channel [1]. O. Vauquelin et al. [2] achieved the best smoke extraction effect by establishing a small-size narrow channel model by changing the position of the vent and the power of the fire source. In 1985, British fire researchers conducted numerical simulations of narrow-space fires, and studied the distribution of temperature fields and the thickness of the smoke layer under longitudinal ventilation conditions [3].

In China, Tsinghua University and Southwest Jiaotong University have done a lot of research work on narrow space fires. Liu Nailing et al. [4] studied the temperature field distribution in a narrow space by numerical simulation and compared it with the experiment to verify the feasibility of the numerical simulation results. In this paper, the fire dynamics simulation software FDS is used to simulate the narrow space fire, and the effect of different ventilation conditions on the distribution of temperature in the narrow and long channels is analyzed.

FDS is a computational fluid dynamics fire developed by the National Institute of Standards and Technology (NIST) and the Building and Fire Research Lab (BFRL) based on the Large Eddy Model (LES). Simulation software [5]. Based on the thermal properties of the material, FDS solves the low-speed flow Navier-Stokes equations on the rectangular element grid based on the finite element method to calculate the smoke propagation and heat transfer in the fire. One of the fire simulation...
software.

The basic equations for FDS solving are as follows:

Continuous Equation: \[ \frac{\partial \rho}{\partial t} + \nabla \cdot \rho \vec{u} = 0 \]  
(1)

Momentum Conservation Equation:
\[ \rho \left( \frac{\partial \vec{u}}{\partial t} + \frac{1}{2} \nabla |\vec{u}|^2 - \vec{u} \times \omega \right) + \nabla p - \rho g = \vec{f} + \nabla \cdot \sigma \]  
(2)

Energy Conservation Equation:
\[ \frac{\partial}{\partial t} \left( \rho h \right) + \nabla \cdot \left( \rho h \vec{u} \right) = \frac{\partial p}{\partial t} + \vec{u} \cdot \nabla p - \nabla \cdot \vec{q} + \nabla \cdot \left( k \nabla T \right) + \sum_i \nabla \cdot \left( h_i \rho D_i \nabla Y_i \right) \]  
(3)

Component Conservation Equation:
\[ \frac{\partial}{\partial t} \left( \rho Y_i \right) + \nabla \cdot \left( \rho Y_i \vec{u} \right) = \nabla \left( \rho D_i \nabla Y_i \right) + m_i'' \]  
(4)

State Equation:
\[ p_0 = \rho TR \sum_i \left( \frac{Y_i}{M_i} \right) \]  
(5)

2. fire numerical model

Taking a college building corridor as an example, an FDS is used to simulate a narrow channel with a size of 8m×1.5m×2.5m, and a constant wind speed vent is set on one side of the channel. The fire source is located at a center area 1m away from the vent, and the fire source size is 0.4m×0.4m, the heat release power of the fire source is 2000KW/m², the burning time is 300s, the channel is made of non-combustible concrete material, the wall is inert and the grid size is 0.1m×0.1m×0.1m. The wind speeds are set to 0.2m/s, 0.3m/s and 0.5m/s respectively, which are stable during the combustion process and there are no other obstacles in the channel.

A longitudinal temperature monitoring point is set in the roof of the channel, starting from the top of the fire source center, and 10 temperature monitoring points with an interval of 0.4 m are arranged along the air outlet. A temperature monitoring plane of Y=1.5m was created to study the variation of fire plume under different longitudinal wind speeds. Figure 1 to Figure 5 show the numerical model of the narrow and long channel, the vertical plane temperature distribution and the horizontal temperature of the roof at different wind speeds at 300s.

---

Fig.1 FDS numerical model

Fig. 2 When the wind speed is 0.2m/s, the temperature distribution of Y=0.75m plane
Fig. 3 When the wind speed is 0.3 m/s, the temperature distribution of Y=0.75 m plane

Fig. 4 When the wind speed is 0.5 m/s, the temperature distribution of Y=0.75 m plane

Fig. 5 Horizontal temperature distribution of the roof at 300s

It can be seen from Fig. 2 to Fig. 4 that as the wind speed increases in a narrow space, the lateral offset angle of the flame increases, and the force of the fire plume weakens against the roof under the action of the wind, and the plume hits the roof position. Change, the lower part of the channel is relatively high under the action of large longitudinal wind. It is known from Fig. 5 that the highest temperature of the roof of the narrow channel moves with the increase of the wind speed, and the wind speed is larger, and the position of the highest temperature point is farther away from the fire source. When the wind speed changes from 0.2 m/s to 0.5 m/s, the maximum temperature of the roof of the channel increases first and then decreases, indicating that the longitudinal wind speed exceeds a certain range, which will cause greater interference to the fire plume and lower the temperature inside the channel.

3. Conclusion
In the narrow space under the action of different longitudinal winds, the fire plume generated by the fire source in the channel is disturbed by the longitudinal wind and moves in the horizontal direction. The higher the wind speed, the farther the roof temperature is from the fire source. The wind speed increases from small to large, and the maximum temperature in the channel increases first and then decreases, indicating that ventilation can effectively reduce the temperature inside the channel.
References

[1] Tu Wenxuan. Experimental Study on Railway Tunnel Fire [J]. Fire Protection Technology and Product Information, 1997, 10: 32-36.

[2] O. Vauquelin, O. Megret. Smoke extraction experiments in case of fire in a tunnel Fire Safety Journal [J]. 2002, 37: 525-533.

[3] Kumar S, Cox G. Mathematical modeling of fires in road tunnels [A]. France, 1985: 61-76.

[4] Liu Nailing, Chen Zhaotao et al. Numerical Simulation and Experimental Study on the Influence of Ventilation on Temperature Distribution in Narrow Space [J]. Heating, Ventilating and Air Conditioning, 2008, 38(8): 22-25.

[5] Kevin, Bryan MK, Simo H, et al. Fire dynamics simulator (Version 5) user's guide [M]. New York; NIST, 2007, 2-89.