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Influence of draft curtain height on smoke exhaust effect in a large area metro depot

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Abstract. The metro depot area has the characteristics of large area and high storey and the smoke diffusion under fire conditions in these areas are more complicated. It is important to investigated smoke exhaust effect which is closely related to the safety of firefighters. FDS (Fire Dynamics Simulator) numerical simulation method was adopted to investigate the influence of draft curtain height on the performance of smoke exhaust fan which were installed on the inside wall of the metro depot area. The curtain heigh was set as 0.5m,1.0m,1.5m,2.0m,2.5m,3.0m respectively. The propagation of fire smoke, the concentration of CO_2 at the exhaust outlet and the exhaust efficiency was analyzed. For the smoke vents set on the side wall, the height of the draft curtain would have greatly influence on the smoke exhaust efficiency. As the height of the draft curtain increases, the spread distance of smoke in the horizontal direction becomes short.it is beneficial to improve the exhaust efficiency of the fan on side wall. The research results could provide references for the fire protection design of the subway depot area.

1 Introduction

Nowadays, with the development of urban modernization, more and more buildings are constructed on the top of the subway depot area. It is generally to set the smoke exhaust vents indirectly on the subway cover. The dimensions of the depot internal space are wide and tall. However, there is a great risk of fire. Once the fire cannot be extinguished in time and the smoke cannot be controlled, it will pose a threat to the internal personnel and other vehicles. It is difficult for mainly areas to meet the natural smoke exhaust conditions. Therefore, mechanical ventilation is a good way to solve the smoke exhaust problem in subway depot areas.

Zhang et al. [1] conducted a study on the combined smoke exhaust mode in the throat area of the subway depot. The specific form is to use mechanical smoke exhaust in the internal area surrounded by the draft curtain. The place outside the draft curtain adopts natural smoke exhaust. Feng and Zhang et al. [2] used numerical simulation method to study the influence of smoke exhaust openings at different positions in the depot on the buildings of subway cover, and analyzed the influencing factors and diffusion laws of smoke spread. Zhu et al. [3] used the research methods of downsizing test and numerical simulation to study the smoke movement characteristics of the depot, and believed that the mixed ventilation system can control the smoke better than the natural ventilation system. Wang et al. [4] studied the fire performance of the buildings on subway cover and the fire characteristics of the subway.

At present, there are few researches on fire protection in subway depots. Although some scholars have studied the smoke exhaust methods including the use of draft curtain for the depot area and throat area of subway depots.

However, in the subway depot storage area, the influence of the smoke outlets which are set on the side wall on the smoke exhausting efficiency has not been considered.

This paper used the FDS simulation method to consider the train fire condition in the subway depot storage area. A practical engineering case was selected to study the influence of different draft curtain heights on smoke exhausting efficiency.

2 Numerical model

2.1 Physical model

This study is based on an actual engineering of a subway depot. The sizes of the computational model are 200 m (L) × 120 m (W) × 10 m (H). With a large building area and high height, it is impossible to divide the

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conventional smoke control zones according to the fire prevention technical specifications. The smoke prevention zones shown in Fig.1 was divided according to the performance-based design requirements.

There are 6 carriages in the train. The dimensions of train are 120 m (L)× 4 m (W)× 3 m (H). The train is parked near the side wall and the fire source is set at the end of the train.

The entire subway depot area is divided into 4 smoke-proof zones by draft curtain, as shown in Fig.1. Area No.1 in the figure is one of the smoke-proof zones. The enlarged view of smoke prevention zone No.1 is shown in Fig.2. There are 5 smoke exhaust ports in area 1, and the sizes of each exhaust port are 2.0 m (L)× 1.0 m (W). The lower edge of the smoke outlet is 1.5 m away from the ceiling, and the upper edge is 0.5 m away from the ceiling. According to previous studies, the simulated fire source power is selected as 7.5 MW [8-9].

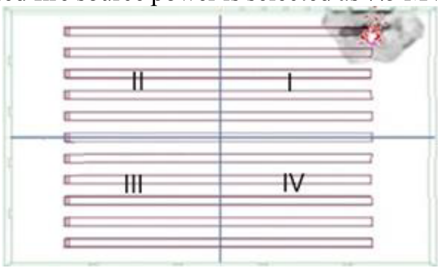


Fig. 1. Numerical model and schematic diagram of smoke-proof zones.

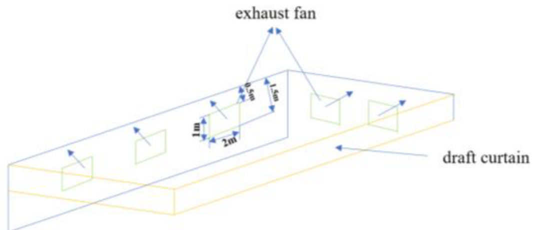


Fig.2. Schematic diagram of smoke-proof zone No.1

2.2 Meshing

The most critical quantity affecting the grid is the characteristic diameter of the fire source $D*$. The most important factor affecting the characteristic diameter of the fire source is the heat release rate of the fire source. The conversion calculation between the two is shown in the following formula.

$$D^* = \left(\frac{\dot{Q}}{\rho_\infty C_P T_\infty \sqrt{g}} \right)^{\frac{2}{5}} \quad (1)$$

$$\overset{*}{D} / \delta x = 4 \sim 16 \quad (2)$$

In the formula, Q represents the heat release rate of the fire source, the unit is Kw; g represents the acceleration of gravity, the unit is m/s^2; ρ_∞ represents the ambient air density, the unit is kg/m^3; C_p represents the constant pressure specific heat, the unit is $J/(kg{\cdot}K)$; T_∞ represents the ambient air temperature, the unit is K; δx represents the grid size.

In this paper, six grid size conditions are simulated, which are：0.25 m × 0.25 m × 0.25 m，0.5 m × 0.5 m × 0.25 m，0.5 m × 0.5 m × 0.5 m，0.5 m × 0.25 m × 0.25 m，0.25 m × 0.5 m × 0.25 m. Fig.3 shows the distribution law of the temperature in the vertical direction at a distance of 30 m from the fire source at 500 s. When the grid size is 0.5 m × 0.5 m × 0.5 m, the temperature distribution curve is relatively rough. The temperature distribution curve is relatively smooth under the condition of the grid size is 0.25 m × 0.25 m × 0.25 m. Compared with the simulation results under other grid system, it was found that the temperature distribution under this condition is closer to the actual working condition. Therefore, the grid size used in this paper is 0.5 m × 0.5 m × 0.25 m. When the size of grid is 0.25m, $D^*/\delta x$ =8.592, and when the size of grid is 0.4m, $D^*/\delta x$ =4.296, both are within the ratio range of 4 to 16 recommended by the FDS user guide. Therefore, the grid size of 0.5 × 0.5 × 0.25 satisfies the requirement.

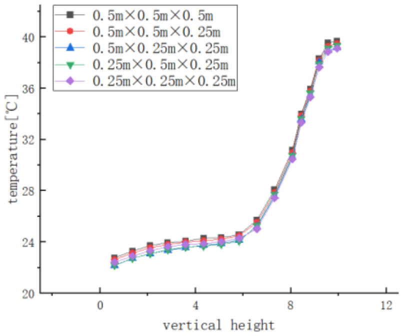


Fig.3. Vertical temperature distribution at the 30m on the longitudinal section of the centre of the fire source under the conditions of different centre grid sizes

2.3 Measuring point layout

In order to analyze the smoke exhaust situation of the exhaust port, it is necessary to measure the amount of smoke exhausted from the exhaust port. CO_2 concentration of the exhaust port reflects the exhaust volume of the exhaust port. Therefore, 9 CO_2 concentration measuring points are set at each exhaust port, the specific layouts are shown in Fig.4. When calculating the exhaust volume of a certain exhaust port, it is essential to calculate the average value of 9 measuring points. So the CO_2 concentration and smoke volume of the smoke outlet at a certain time could be obtained.

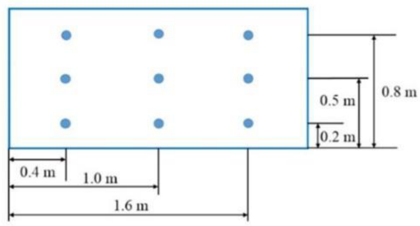


Fig.4. Schematic diagram of measuring point layout of side wall smoke outlet

2.4 Calculation of smoke exhaust

In some current engineering cases, the area method is often used to decide the smoke exhaust volume, and the specific area smoke emission index of 30 m³/(h.m²) is used based on the performance design.

The construction area of the subway depot storage area, A, is 24000 m²(200m ×120m). The total smoke exhaust volume rate, Q, is 720000m³/h (24000×30m).

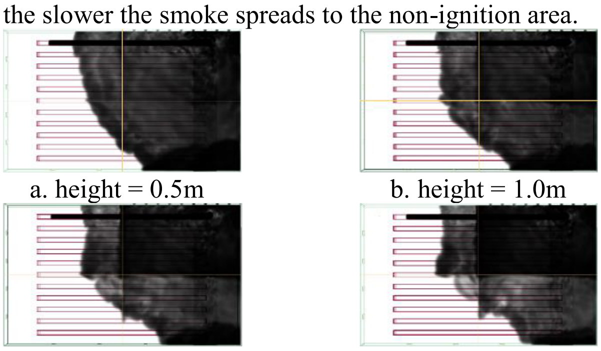
Dividing the storage area of the subway depot into four smoke-proof zones, and the smoke emission Q_1 of each smoke-proof zone is one quarter of Q, the value is 180000 m³/h. Five smoke exhaust fans are set up in smoke prevention zone No.1, The exhaust volume of a single smoke exhaust fan is one-fifth of Q_1, the value is 3600m³/h. According to the specification, about 20% air volume margin shall be guaranteed for each fan. The selected axial fan has an air volume of 40000 m³/h, a full pressure of 690Pa and a rotational speed of 1450rpm.

3 Result and discussion

3.1 Analysis of smoke diffusion state

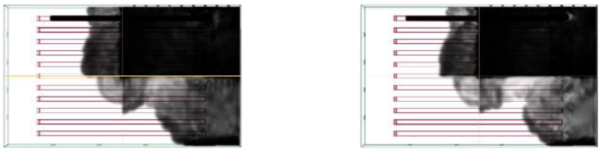
Fig.5 shows the smoke diffusion state at 300 s under different draft curtain heights. It can be clearly observed that under the same conditions, the higher the draft curtain, the less smoke to spread from the ignition area to the non-ignition area. The draft curtain is beneficial to prevent the smoke diffusion.

According to Fig.5 (a) and Fig.5 (b), when the height of the draft curtain is 0.5 m and 1.0 m, the smoke had filled the ceiling space of area 1 at 300s. In addition, the some had spread to other three areas at the same time. Among them, the amount of smoke diffused to area 4 is the largest. Observing Fig.5 (c) and Fig.5 (d), when the height of draft curtain is 1.5 m and 2.0 m, the smoke had filled the ceiling space in area 1 and had also spread to the other three areas at 300s. However，the amount of smoke from fire area spread to the non-ignition area are gradually decreased. It indicats that the increase of the draft curtain height plays a blocking role in suppression of smoke diffusion. According to Fig.5 (e) and Fig. (f), when the height of the draft curtain is 2.5 m and 3.0 m, the smoke had filled the ceiling space of area 1 and had also spread to the other 3 areas at 300s. Nevertheless, the amount of smoke spread to the non-fire area is more obviously reduced. It shows that the draft curtain at heights of 2.5 m and 3.0 m have obvious effects on blocking the diffusion of smoke. The above results show that the higher the height of the draft curtain, the greater the obstacle to the diffusion of smoke along the ceiling, the slower the smoke spreads to the non-ignition area.



a. height = 0.5m b. height = 1.0m

c. height = 1.5m d. height = 2.0m



e. height = 2.5m f. height = 3.0m

Fig.5. The smoke diffusion state at 300 s after the fire occurs under the condition of different draft curtain heights

3.2 CO_2 concentration

In order to analyze the exhaust efficiency of area 1, the CO_2 concentration of each exhaust port was firstly analyzed. Fig.6 shows the distribution of the CO_2 concentration at the smoke outlet in area 1 over time under fire conditions. As can be seen from Fig.6, with the development of the fire, the CO_2 concentration of the smoke outlet gradually increased. When the height of the draft curtain is 0.5 m and 1.0 m, the CO_2 concentration of the smoke outlet is relatively low with the change of time. When the height of the draft curtain is 1.5 m, the overall CO_2 concentration of the smoke outlet is slightly higher than that of 0.5 m and 1.0 m, but it is not obvious. Until the height of the draft curtain reaches 2.0 m at 600s, the CO_2 concentration of the smoke outlet is greatly improved compared with that at 1.5 m. It shows that compared with 1.5m, when the height of draft curtain reaches 2.0m that is more capable to promote the increase of CO_2 concentration of the exhaust port. When the height of the draft curtain reaches 2.5 m at 600 s, the CO_2 concentration of the smoke outlet has a greater increase than that of 2.0 m. When the height of the draft curtain reached 3.0 m at 600 s, the CO_2 concentration of the smoke outlet was further increased, but the increase rate had decreased.

As Fig.5 shows, under the condition of diffrent draft curtain heights the trend of CO_2 concentration of the exhaust port is very close within 250s of the fire occurrence. Meanwhile, the growth rate is relatively low.

After the fire occurred 250 s, when the height of the draft curtain was 2.5 m and 3.0 m, the growth rate of CO_2 concentration at the smoke outlet was significantly higher than that of 0.5 m and 1.0 m. These are because the heat release rate of the fire reaches the maximum value at 200s, and the amount of smoke generated will further increase. At this time, the draft curtain can play a significant role in blocking smoke.

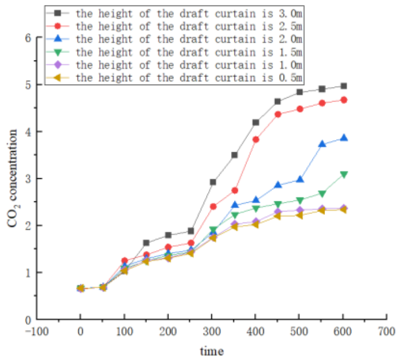


Fig.6. The distribution of CO_2 concentration at the exhaust port in area 1 with time

3.3 Smoke extraction efficiency

Fig.7 presents the variation of the smoke exhaust efficiency of the exhaust vents in area 1 with the fire time.

Within 250s after ignition, the overall smoke extraction efficiency presents the trend of gradually decrease. Under the condition of the draft curtain remains 2.5m and 3.0m, at aobout 450s after ignition, the somke extraction efficiency reached the maximum value. Then, the curve reached a relatively steady state.

When the height of the draft curtain is 1.5 m and 2.0 m, the smoke extraction efficiency of the smoke outlet generally decreases first, and then fluctuates and increases, but the increase is small. After 300s, the smoke extraction efficiency under which the draft curtain heights are 0.5m and 1.0m fluctuates and decraeses, the decrease is small.

These are mainly because in the early stage of the fire, the smoke exhaust volume and the overall smoke production are relatively small**.** Before the fire occurred 250 s, the rate of increase in smoke exhaust volume was less than that of the overall smoke production, so the smoke extraction efficiency shows a downward trend. In addition, before the fire broke out 250 s, the smoke in the first smoke-proof partition did not fill the entire area, and the draft curtain had little effect. When the fire occurs 250 s and before 450 s, the draft curtain plays a role. The higher the draft curtain is, the more smoke accumulates in area 1, and the smoke exhaust volume of the smoke outlet increases rapidly. At this time, the heat release rate of the fire source has reached the maximum value, and the overall smoke production increases steadily. Meanwhile the growth rate of the smoke output from the smoke outlet is greater than the overall smoke production. Therefore, the smoke extraction efficiency shows an increasing phenomenon during this period of time. After the fire occurred 450 s, the increase of the smoke exhaust volume of the smoke outlet decreased. However, the overall smoke production continued to increase with the development of the fire, so the smoke exhaust efficiency showed a downward trend.

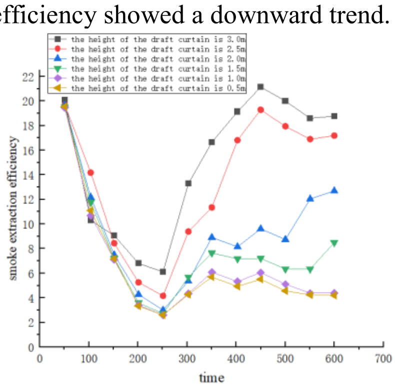


Fig.7. The smoke exhaust efficiency of the exhaust vents in area 1 varies with the fire time

4 Conclusion

This paper adopted numerical simulation method by FDS to analyse the influence of draft curtain height on smoke exhaust effect. The specific conclusions can be described as follows:

(1). When the height of draft curtain increases, the range of the smoke diffusion obviously narrowed. The amount of smoke near the ceiling in fire area is easier to accumulate and the smoke is more difficult to spread from the fire area to the non-fire area with the increase of the height of the draft curtain.

(2). For the smoke exhaust port set on the side wall, the higher the height of the draft curtain, the more difficult for the smoke in the fire area to diffuse to the non-fire area. Therefore, the amount of smoke in the upper space of the fire area would accumulate, and the thickness of the smoke layer will increase. It is beneficial to improve the smoke exhaust efficiency of the side wall fan.

(3). In order to reduce the spread of smoke from the fire area to the non-fire area and improve the smoke exhaust efficiency of the side wall exhaust fan, the height of the side wall smoke outlet should be considered when setting the height of the draft curtain. The height of the draft curtain should be greater than the distance from the lower edge of the side wall smoke outlet to the ceiling. For the smoke outlet with a distance of 1.5m from the lower edge to the ceiling, it is recommended that the height of the draft curtain should not be less than 2.5m.

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