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Influence of Setting Position of Tunnel Air Curtain on Smoke Prevention Effect

Influence of Setting Position of Tunnel Air Curtain on Smoke Prevention Effect

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Abstract. In this paper, the fire model of the tunnel is set up, the geometric model of the tunnel is established, a reasonable grid is divided, and the appropriate fire source power is selected firstly. Secondly, the method of air supply and air intake, the form of installation and arrangement, jet angle and jet speed of air curtain are selected reasonably. Finally, through the establishment of a corresponding physical model, CFD simulation software was used to simulate the movement of the smoke and the concentration of CO, visibility, and temperature of the tunnel under the influence of the piston wind over time by changing the installation position of the air curtain in the same fire environment. The result of the simulation shows that when the air curtain is set in the tunnel about 10-20m away from the fire source center, the smoke prevention effect is the best.

1. Introduction

With the increase of traffic volume and the development of engineering technology, more and more roads and railway tunnels have been built at home and abroad, and they have become longer and longer, bringing great convenience to the traffic[1]. However, the tunnel has brought us a series of security issues while facilitating our transportation. Due to the particularity of the tunnel structure, in the event of a fire, the toxic and harmful fumes generated by combustion and the heat released are not as easily emitted as in the open space, but rather with the tunnel's internal structure spread longitudinally, the visibility in the tunnel is reduced and the temperature rises sharply, which is not conducive to the evacuation and rescue of personnel, resulting in huge economic losses[2-4].The lack of air in the tunnel leads to insufficient combustion, resulting in a large amount of toxic and harmful gases (mainly CO), and these toxic and harmful gases are the main cause of casualties[5]. Due to the tunnel's sealing effect, the temperature in the tunnel rises rapidly in the event of a fire, and the temperature can even reach more than 1000°C when fully combusted, which seriously threatens the safety of the personnel. Due to the high temperature near the fire point, the tunnel load-bearing structure is vulnerable to damage, resulting in collapse, obstruction of traffic and rescue.

The curtain of air is sprayed by the air curtain to produce curtain air flow with a certain jet angle and velocity to block the spread of high-temperature smoke to prevent the smoke from entering the evacuation channel and to extend the time for evacuation without affecting the free movement of personnel[6]. Compared with other fire-fighting equipment, the air curtain has the advantages of simple and convenient installation, clean and environmental protection[7]. When scholars study the control of smoke in tunnel fires, they often ignore the influence of piston winds generated during the movement of the train on the smoke diffusion in the tunnel. Therefore, this paper considers the position of the air curtain under the influence of piston wind, so as to better block the spread of fire smoke and heat transfer in the tunnel.

2. Setting the model of fire in tunnel

2.1The establishment of a geometric model
In order to make the model simplified, this article has the following assumptions:

(1) The length of the tunnel selected in this paper is 4366m. According to the simulation results, the internal temperature, the concentration of CO and visibility of the tunnel 450m behind the fire source are far below the indexes under dangerous conditions[8], there is no need for research. In order to reduce unnecessary calculation, the geometric model of 450m long tunnel behind the fire source is simulated in this paper to study the effect of setting position of air curtain on fire smoke under the influence of piston wind.

(2) This article studies the installation of an anti-smoke air curtain near a fire source in a tunnel to prevent the high-temperature toxic and harmful smoke from spreading to the entire tunnel under the influence of piston wind, thereby threatening the personnel in the tunnel. Although, when a fire occurs somewhere in the tunnel, the toxic and harmful fumes generated by the fire will spread to both ends of the tunnel. However, when the train starts to enter the tunnel and gradually approach and even passes through the fire source, the transverse piston wind generated by the running train will cause the smoke to spread in the direction of the train, that is, to the other side of the tunnel. Therefore, in this paper, when simulating the law of movement of smoke in a tunnel, using the source of the fire as a reference point, assuming that there is almost no flue gas spreading on the left side of the fire source in the tunnel, the paper only simulate the spread of smoke on the right side of the fire source.

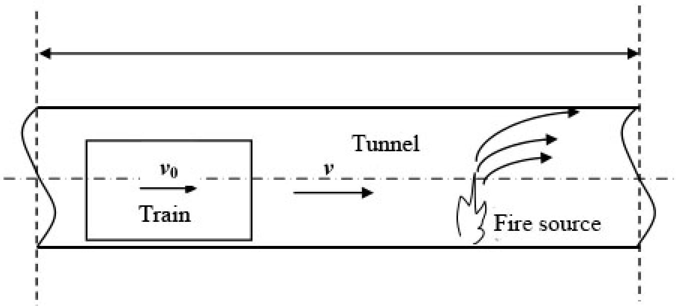


Figure 1. The spread of the flue gas under the effect of piston wind.

2.2Setting the grid
When a fire occurs inside a tunnel, the flue gas and heat are diffused to the surroundings (mainly to both ends). It is most dangerous near the center of the fire source, however, the changes in temperature, the concentration of smoke, and visibility are not obvious in places far away from the fire source. Therefore, when the model is edited, the mesh near the center of the fire source is small and dense, while the mesh farther away from the fire source is larger and sparse, so as to reduce time of the simulation and improve work efficiency. The layout of grids in this paper is as follows: The grid selected within a range of 50m near the fire source is denser, the single grid is 0.25×0.25×0.25, the single grid of another 400m is 0.5×0.5×0.5.

2.3Selection of fire source power of tunnel
The heat release rate (HRR) is a parameter that characterizes the size of a fire, the selection of the HRR is based on extensive research by domestic and foreign experts in tunnel fires[9]. Many scholars use computer software to simulate tunnel fires, and the fire source power is usually below 50MW. The setting of the fire source is mainly related to the contents of the numerical simulation of tunnel fires. For example, when studying the counter-current of smoke, the critical wind speeds and the design of

smoke control systems, a stable fire source release rate is often used. That is, the fire source power is not change with time. In summary, in the numerical simulation of tunnel fires in this paper, the HRR per square metre is set at $10MW/m^2$, the fire source area is 1.6m×1.6m, and the center of the fire source is as the origin.

3. The setting of the air curtain

The way of air supply of air curtain: From the view point of practicality, easy installation, easy maintenance and aesthetics, this paper takes the upwind air curtain as the research object.

The way the air curtain to get the wind: According to different installation locations, smoke-preventing air curtain can be divided into circulating and non-cyclical. The circulation one is installed in the same tunnel without a branching mouth, and the air flow at the outlet and the inlet is a self-contained circulation system, and the air intake mode is the downstream. The non-cyclic one refers to the air flow at the outlet no longer flows back to the suction outlet. It can be installed in the same tunnel and the wind is taken from the upstream. Generally, it can be installed at the junction of two tunnels. Since the tunnel model in this paper has no branching, we choose downstream wind as the circular air curtain.

The arrangement of air curtain: In terms of work efficiency, this article selects the series air curtain. Therefore, the air curtain used in this article is installed and arranged in the form of an upward-feeding circulation type (downstream air intake) series air curtain in single side, and the distance between the nozzles of the series air curtain jet is $2.5b_0$ (b_0 is the width for the outlet of a single air curtain).

The selection of the jet angle of air curtain: The previous study shows that, whether it is the cold side or warm side in outside, as long as the air curtain is installed in the room, it is recommended to make the spray direction toward to the outside and have a single of 15-20º with vertical direction[10]. Therefore, the jet angle of air curtain selected in this paper is 15º and toward the warm side.

The velocity of air curtain: According to reference[11], the minimum velocity of the air curtain under the influence of piston wind should be 14m/s. Therefore, from the view of economical, the jet velocity of the air curtain is chosen to be 14m/s.

4. Analysis of smoke prevention effect of installation position of air curtain

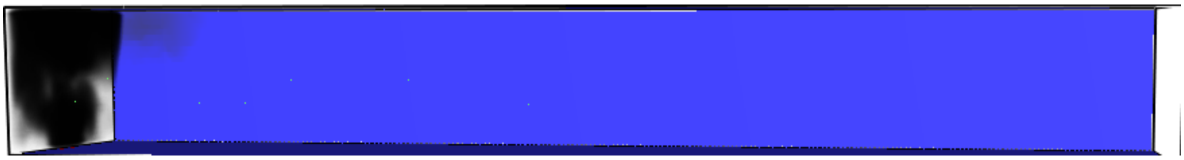
In order to verify the effect of the position of the air curtain on the effect of the smoke prevention, a model was set up for the series air curtain in different position, the jet velocity of the air curtain was 14m/s and other conditions were unchanged. The specific working conditions are shown in Table 1.

Table 1. Simulation condition of air curtain in different position.

The position of air curtain in the tunnel	The arrangement of air curtain	Spray angle of air curtain	Width of air curtain
5m	Series	15°	20mm
8m	Series	15°	20mm
10m	Series	15°	20mm
20m	Series	15°	20mm
40m	Series	15°	20mm
80m	Series	15°	20mm

4.1The movement of the smoke after the end of the simulation when the air curtain at different positions in the tunnel

(a)The movement of smoke at the end of the simulation when the air curtain in the position of 5m in tunnel



(b)The movement of smoke at the end of the simulation when the air curtain in the position of 8m in tunnel

(c)The movement of smoke at the end of the simulation when the air curtain in the position of 10m in tunnel

(d)The movement of smoke at the end of the simulation when the air curtain in the position of 20m in tunnel

(e)The movement of smoke at the end of the simulation when the air curtain in the position of 40m in tunnel

(f)The movement of smoke at the end of the simulation when the air curtain in the position of 80m in tunnel

Figure 2. Simulation results of smoke movement with air curtain placed in different positions.

Figure 2 shows the movement of the flue gas at the end of the simulation with the air curtain placed in different positions in the tunnel. When the air curtain is in the position of 5m and 80m in the tunnel, most of the flue gas spreads into the tunnel at the end of the simulation, the air curtains set in these two locations failed to contain the flue gas in the tunnel near the fire source, and the effect of blocking the smoke is poor. When the air curtain is in the position of 8m, 10m and 40m in the tunnel, the smoke can prevent the smoke from spreading to all parts of the tunnel. However, when the air curtain is set at 20m in the tunnel, the spread and accumulation of smoke are almost completely blocked, and the effect of smoke prevention is most obvious.

4.2The concentration of CO, visibility and temperature changes over time when the air curtain at different position in the tunnel

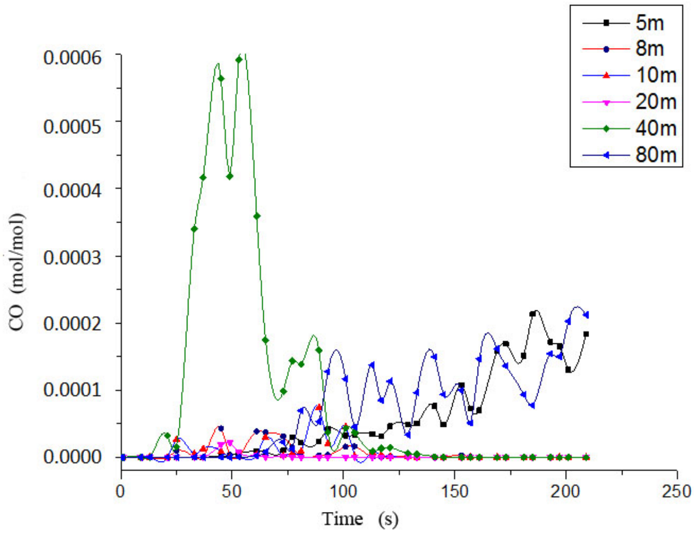


Figure 3. CO concentration curve under air curtain in different position.

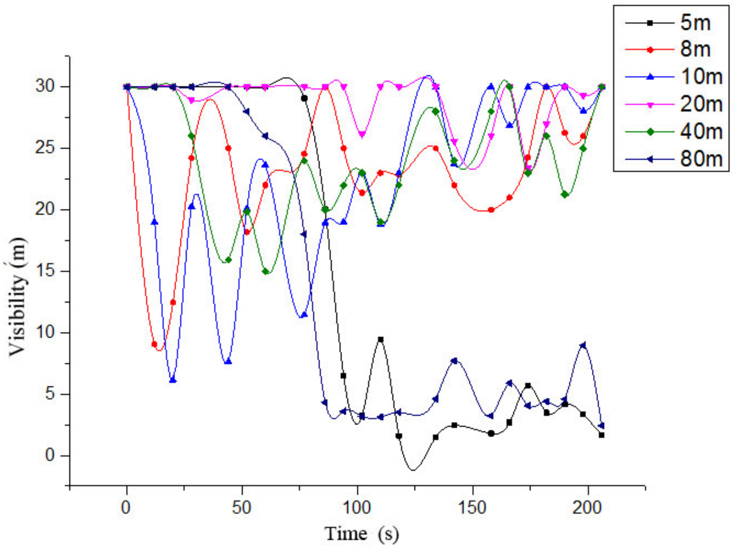


Figure 4. Visibility curve under air curtain in different position.

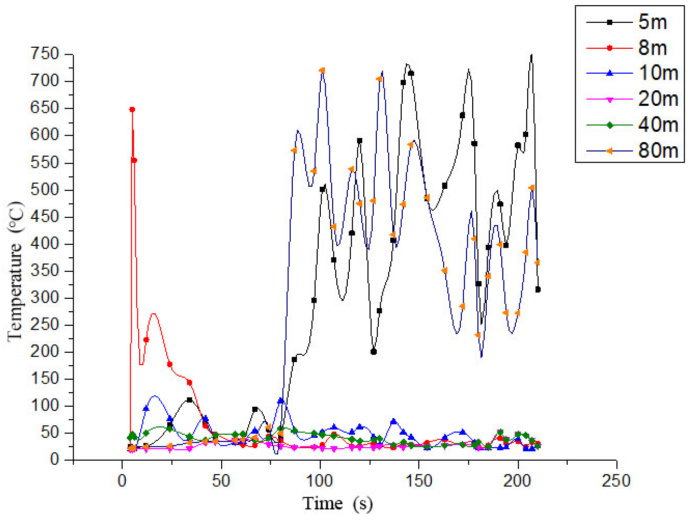


Figure 5. Temperature curve under air curtain in different position.

Figure 3, 4, 5 are the curves showing that the concentration of CO, visibility and temperature changes over time when the air curtain is at different position in the tunnel. From Figure 3, we can see that when the air curtain is located at a position of 40m in the tunnel, the concentration of CO is relatively high during the time between 25~70s, which exceeds the limit range of the human body and after that it gradually decreases. When the air curtain is located at a position of 5m and 80m in the tunnel, the concentration of CO is also at a high level after 75s, but within the acceptable range. When the position of the air curtain is set at 8m, 10m and 20m in the tunnel, the concentration of CO in the whole process is in a relatively low range, not exceeding 5×10^{-5}, far below the limit concentration range of 5×10^{-4}, it will not threaten the people in the tunnel. From the visibility curve of Figure 4, it can be seen that when the air curtain is located at the position of 5m and 80m in the tunnel, the visibility in the tunnel is less than 10m after 80s. When the air curtain is located at the position of 8m and 10m in the tunnel, the visibility in the tunnel is also lower than 10m at 20s and 40s. When the air curtain is located at the position of 20m and 40m in the tunnel, the visibility in the tunnel is higher than 10m in the whole process, and especially when the air curtain is located at 20m in the tunnel, the visibility in the tunnel is the highest, and the obstruction effect is the best. From the temperature graph in Figure 5, it can be seen that when the air curtain is at the position of 5m, 8m and 80m in the tunnel, the temperature of the flue gas in the tunnel is basically above 150°C, and the high temperature has a greater threat to the people in the tunnel. When the air curtain is at a position of 10m in the tunnel, the temperature also reaches 100°C at the peak time. When the air curtain is at a position of 20m and 40m in the tunnel, the temperature in the tunnel is basically in a relatively stable state and does not exceed 50°C. Especially when the air curtain is at 20m in the tunnel, the temperature in the tunnel is almost close to the room temperature, which is no threat to rescue and evacuation personnel.

5.Conclusion

This paper establishes a tunnel model to simulate the movement of smoke and the concentration of CO, visibility, and temperature changes over time. It can be seen that air curtains which are closer and farther to the fire source cannot effectively block the smoke and heat, such as the position of air curtain at 5m, 8m, 40m, 80m all have a bad effect on smoke control. Because when the position of the air curtain is close to the fire source, the air in the air curtain on the one hand acts as an oxidizer like a blower to encourage the fire and generate more smoke and heat. On the other hand, the jet of air curtain disturbs the smoke layer stratified by the plume near the fire source, causing the smoke layer to spread disorderly in the tunnel. When the position of the air curtain is far away from the fire source, it can't prevent the smoke and heat generated by the fire source at the initial stage. It is concluded that the air curtain has the best smoke prevention effect when the air curtain is set at about 10~20m in the tunnel (that is, 10~20m away from the fire source center).

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