The Field Model Construction and Analysis of Complex Mine Belt Fire Based on Personnel Evacuation Theory

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Abstract. In order to realize the visualization of the catastrophic law of mine belt fire on personnel evacuation theory, the complex roadway model is constructed by using the fire dynamic simulation software. The change of monitoring data such as temperature, smoke concentration and visibility is simulated in near-fire source of tape fire roadway. It is found that the main factors affecting the escape of personnel are smoke temperature, CO concentration and visibility in the mine tape fire. The first 100 s is a critical period for the smooth escape of the people on the wind side of the fire source after the tape fire. The high smoke temperature, high CO concentration and low visibility of the roadway seriously affect the escape of personnel after 150 s. At this time, the fire has developed into the flash-over stage. The parameters reach the critical value at 40 s with the 20% smoke concentration as the critical value in the roadway. It provides a reference for mine emergency rescue and fire escape.

1. Introduction

The belt conveyor has been widely used in coal mines because of its large transportation capacity, long transportation distance, low electromechanical accident rate and low energy consumption [1]. The flame retardant tape is used in China's coal mine underground belt conveyors. Since the material of the conveyor belt is mostly rubber, toxic gas will still be generated under high temperature and heat conditions. Especially the belt conveyor is generally located in the air inlet area of the mine. If it cannot be effectively controlled, it will spread within the large area with the ventilation system, causing huge personal injury and death. In recent years, the tape fire accidents have occurred in China, which seriously threatened the safety of underground workers and brought great impacts on mine safety production.

The process of fire disaster in the roadway has always been the research focus for researchers in various countries. A full-scale experimental study is carried out on the belt lane fire by US Mine Safety and Health Bureau. The influence of wind speed is analyzed on the detection of belt lane fire [2]. Thermal gravimetric analysis is carried out on the tape samples by Japan Jiuzhou Coal Mine Technology Research Center. It is found that the burning characteristics of the tape in the well lane have a qualitative relationship with the thermo gravimetric characteristics [3]. The research includes three aspects on the fire disaster process of the belt lane in China. Wang Deming and Ji Jingwei
studied the combustion performance and flame propagation speed of the flame retardant conveyor belt through the combustion test [4-5]. Su Mo and Qi Qingjie conducted numerical simulation analysis of the belt lane fire in the mine [6-7]. Li Cuiping and Zhang Jinggang research and develop the mine fire simulation software [8-11].

The previous research mainly focuses on the experimental and simulation research on the specific parameters and general rules of mine tape fire. In the actual production mine, the combustion characteristics of mine tape fire are not all the same with the different wind speed, tape material, fire source size, roadway inclination and other factors. In order to accurately grasp the burning characteristics of the belt transport lane fire, the fire spread process of tape transport lane is completely reproduced. In view of this, this paper applies the large eddy simulation method by the Fire Dynamics Simulator. The belt conveyor is the research objects in the roadway, combined with the burning characteristics of the tape. Combined the inquiring personnel, the fire characteristic parameters such as temperature distribution and smoke spread are simulated in the near-fire source area and the fire tunnel after the conveyor belt fire. The main factors affecting the escape of the personnel are analyzed. It provides a reference for mine emergency rescue and fire escape.

2. Construction of tape fire field quantity model
There are three types of field parameters included in the mine belt fire field. The spatial geometric field quantities are the physical equipment such as the well tunnel and the fire source where the underground ventilation and fire spread. The physical quantity fields are the air volume, wind resistance and wind speed. The amounts of meteorological properties are such as smoke flow concentration and fire pressure.

2.1. Spatial geometry of tape fire field
The main described volume includes the spatial position, spatial shape and spatial relationship of each roadway and its related entities in the roadway engineering. In the mine fire field, the spatial relationship between some geometrical fields is relatively independent, such as fire source, fan, damper and fire barrier. The relationship between some geometrical fields is relatively complicated, such as roadway space. Due to the complexity of the actual mine roadway, if the actual structure is modelled, the number of grids is too large, which is not conducive to modelling analysis. In order to facilitate the establishment of the model and the simulation analysis, this paper selects the local fire of the mine to carry out the movement state of the smoke. The geometric characteristic parameters of roadway 1 and roadway 2 are set to 100 m×4 m×4 m and roadway 3 are 50 m×4 m×4 m. The three-dimensional model of roadway and belt lane is shown in Figure 1. After several simulations, the grid is gradually encrypted, and the grid parameters are finally determined. The size of the lane 1 unit is 0.2 m×0.2 m×0.2m. The size of the tunnel 2 unit is 0.2 m×0.2 m×0.15 m. And the size of the lane 3 unit is 0.2 m×0.2 m×0.2 m. The grid has 1398,000 small units. According to the requirements of the anti-wind, smoke detectors and thermocouple are arranged at four locations on the downwind side near the fire source area. Considering the evacuation of adults, the average height of adults is 1.7 m. According to the most unfavourable conditions, The smoke detector and thermocouple are set to 1.8 m at y.

![Figure 1. Three-dimensional model of roadway](image-url)
2.2. Physical and meteorological attribute distribution characteristics

It is mainly the physical parameters such as wind volume, wind speed and wind resistance of various roadways in the fire field, as well as meteorological parameters such as fire smoke temperature, smoke flow concentration and fire pressure.

It is assumed that the conveyor roller jamming friction is heated, causing the burning of coal, and the tape is ignited to a spread fire. The fire source thermal release rate model uses the $t^2$ model. The maximum heat release rate in the fire development can be described the fire development process. It is shown in the equation (1).

$$Q = a \times t^2$$  \hspace{1cm} (1)

Where, $Q$ is the heat release rate of the fire source, kw; $a$ is the fire growth coefficient, kw/s$^2$; $t$ is the fire development time, s.

The fire source is located at 30 m from the entrance of Lane 1. The geometrical size of the fire source is 1×1. The upper surface property is set as the hot combustion surface. The maximum heat source release rate per unit area is 1.0 MW, and the fire growth coefficient is 0.0489. According to the formula (1), the time to achieve stable combustion is 143 s. The tape is set to 1cm thick, and the material is selected from the PVC in the database. Before the fire, the average temperature is 20 $^\circ$C in the roadway. The longitudinal wind speed is 2 m/s, ignoring all resistances such as natural wind resistance. The fire point is set to 380 $^\circ$C to simulate the spread of the tape fire with a simulation time of 180 s.

2.3. Vector directional characteristics

The information in the fire field is direction vector information such as wind field wind flow, smoke flow, and personnel movement. The wind flow is shown in Figure 2.

![Figure 2. Direction of wind flow](image)

2.4. Timing characteristics

The Mine fire field is a time-order dynamic quantity field. With the occurrence of fire and the continuous spread of smoke flow, the air flow temperature, smoke flow concentration and fire pressure of each roadway are changing with time. With the development of various field quantities with the passage of time, it is determined that the description of various fields must be simulated in time order in the mine fire field. Considering the danger of mine tape fire is mainly low toxicity and hypoxia caused by toxic and harmful gases, high temperature and smoke. This paper arranges CO detector, temperature detection slice, and smoke detection slice and visibility detection in the numerical simulation process. The following three aspects are studied the hazards of mine fires.
3. Simulation result analysis

After running analysis, the CO concentration, temperature and smoke layer are obtained at the 45 m and 60 m of roadway 1, 50 m at the outlet of roadway 2 and -50 m at the outlet of roadway 3. The analysis results are as follows.

3.1. Fire source temperature distribution analysis

High temperature smoke is a major cause of casualties in the roadway. The human body will increase heart rate, slow down the reaction, and distract the attention when the external temperature reaches 80 °C. In a hot environment of 80 °C, the human body can only survive for 30 minutes. The average height of male adults in China is 1.7 m. Considering the most unfavourable factors, the temperature of the fire source is monitored at 35 m from the lower side of the fire source, and the height is set 1.8 m, which is shown in Figure 3.

It can be seen that the temperature reaches 380 °C at the source of the fire in 18 s. At this time, the tape is ignited and the temperature is increasing. After the belt fire occurs in the roadway, the temperature of the roadway is gradually increasing. The monitoring point is about 80 °C in 10 s. It rises to 500 °C in 180 s, which poses a life threat to the underground personnel. Therefore, the person on the leeward side should stay away from the fire source as soon as possible within 180 s after the fire occurs.

![Temperature of fire source](image)

3.2. CO concentration analysis

The maximum concentration of CO is 50 ppm which the human body can withstand. When the CO concentration exceeds 50 ppm, the human body will have symptoms such as dizziness and fatigue. The higher of the concentration, the greater harm is to the human body. When the concentration exceeds 800 ppm, the human body is in danger. The CO1 and CO2 detectors are placed at 45 m, 60 m, and 1.8 m high on the downwind side of the fire source. The change of CO concentration is simulated in the smoke flow of the roadway fire at 2 m/s wind speed. It is shown in Fig. 4. It can be seen that the CO concentration reaches 50 ppm at about 100 s in the roadway 1. The CO concentration tends to be stable and higher than 50 ppm after 150 s. Therefore, people in 30 m on the downwind side will have symptoms of poisoning after tape fire in the roadway 1, which will affect the escape of personnel.
3.3. Smoke visibility analysis

The visibility of smoke affects the lives and the escape of underground personnel. Therefore, smoke visibility in fires is a key point of detection.

The smoke detection slice is set at $x=50$ m and $Z=50$ m in the roadway center. The spread of fire smoke can be observed in the roadway 1 and 2. It is shown in Figure 5. It can be seen that the smoke visibility has less influence at 50 m of the roadway 1 within 20 s. The visibility reaches 20% of the dangerous concentration at 20 s. The visibility reaches about 90% after 30 s. At the exit end of the roadway 2, the visibility reaches 20% of the dangerous concentration after 30 s, and the visibility reaches 90% after 90 s. Therefore, the walking and sight of the underground personnel will be affected by the smoke after 40 s, which will greatly affect the escape of the underground personnel.

4. Conclusion

Based on the fire dynamic simulation software and the evacuation theory, this paper constructs the field model of the belt fire in the complex roadway of coal mine. On the basis of it, the simulation analysis is carried out. The main conclusions are as follows:

1) The temperature of the fire source reaches 380 °C when the time is around 18 s. At this time, the belt is ignited. The height of 1.8 m is about 80 °C in the downwind side of the fire source in the roadway 1 at 10 s. It will greatly affect the escape of the underground personnel.
2) The CO concentration reaches 50 ppm at the monitor point after the roadway 1 tape fire occurs for 100 s. The underground personnel will have symptoms of CO poisoning, which will affect the escape of personnel.

3) In the early stage of fire in the roadway 1, the smoke concentration is low, and the visibility is less affected in the roadway. After the fire occurs for 30 s, the roadway is full of smoke. The personnel are difficult to escape in the roadway 1. The roadway 2 is full of smoke after 40 s, which has seriously affected people to escape.

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