Research on Numerical Simulation of Fire in Excavation Roadway of Te Li Coal Mine

Chengyu Li, Lili Zhang*
Xinjiang Institute of Engineering
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Abstract: based on the FDS fire simulation software, the temperature and gas concentration of the fire at the entrance of the tunnelling roadway in teli coal mine were numerically simulated. The simulation results show that, under the action of the fire wind pressure in the vertical direction, the high temperature flue gas floating makes the roadway temperature show a "low upper and lower level", and the roadway temperature decreases rapidly along the roadway due to the restricted air flow in the horizontal direction, and the temperature can drop to about 50 °C in the tunneling surface far from the fire source. The arrival of flue gas will rapidly reduce the concentration of O2 and increase the concentration of CO in the roadway.

1. the introduction
In recent years, the safety situation of coal mines in China has improved significantly, and the number of accidents caused by fire outside coal mines has decreased greatly, but it happens from time to time. External cause fire is still a major threat to mine safety and miners’ lives. The study of mine fire is an important link of prevention and control of serious and serious accidents. The mine roadway network is long and narrow, and the external causes of combustibles are distributed in a point-like manner. The types and quantities of them are still relatively large. The interaction between high temperature flue gas and ventilation system can cause airflow disorder. Its high toxicity and light reduction make it difficult to escape and rescue, and easy to cause death and injury. In this paper, a coal mine tunneling lane at the entrance of cable fire, the roadway drivage of FDS fire simulation software based on hanging cable fire numerical simulation studies of temperature, gas concentration, help to understand the law of fire accident, for the external cause of the fire warning technology research and development, optimize personnel escape behavior, provide a reference for accident rescue plan.

2. Mathematical and physical model of tunnel fire

2.1 introduction to FDS software
FDS is a fire dynamics numerical simulation software based on fluid dynamics and combustion theory. Fire behavior in the actual accident is extremely complex and difficult to restore. The software simplifies the simulated object:
(1) smoke flow generated by fire is regarded as multi-component ideal gas, and air flow and smoke flow follow ideal gas state equation;
(2) air flow temperature in the roadway before fire is uniform and in a turbulent state;
(3) the wall surface is dry and impermeable, and the roadway wall temperature is equal to the surrounding rock cooling zone temperature;
(4) the transport behavior of high-temperature smoke flow in fire is an unsteady three-dimensional turbulent flow field accompanied by the process of heat and mass transfer.
(5) radiation heat transfer and heat exchange with walls are not considered; Flue gas is incompressible and has the same thermal and physical properties as air. Excluding the influence of heat diffusion, viscosity dissipation and pressure work on flue gas flow;
(6) the fire simulation process follows the continuity equation, momentum conservation equation, energy conservation equation and component equation.

2.2 model establishment
According to the actual situation of the mine, the model is established, and the roadway is 4 meters wide and 3 meters high. In order to improve the calculation accuracy and efficiency, the model adopts the mesh precision of 0.25m × 0.25m × 0.25m.

Wind volume of lateral roadway is 4,800 m³/min and wind speed is 4 m/s. The driving air duct is a round air duct with a diameter of 800 mm. After the fire occurred, the local ventilator stopped working and there was no air flow in the tunneling roadway. According to the principle of ergonomics, the height of measuring points is set as the characteristic height of human eyes, 1.5m is taken, and 1#-12# 12 measuring points are uniformly arranged from the entrance to the heading face along the central axis of the roadway. Temperature, CO concentration and O₂ concentration are monitored at each measuring point, and the vertical temperature distribution is monitored at 2# and 5# measuring points.

The fire source is the PVC flame-retardant wall-mounted cable at the entrance of the roadway. The fire source is set to be 10 m long and located at the upper part of the wall on the right side of the roadway. In order to make the simulation close to the actual fire, the fire model is adopted in the setting of fire source to describe the change of heat release rate of fire source, and the heat release rate of fire source \( Q=bt^2 \)

Where \( b \) is fire development coefficient, kW/s²; \( T \) -- development time of fire, let \( t=20 \) s.

3. simulation results

3.1 characteristics of temperature change
The temperature distribution of roadway axes at 5 time points of 20, 50, 100, 200 and 300 s is shown in figure 1, and the vertical temperature distribution of monitoring points at # 2 and # 5 is shown in figure 2. The top temperature of roadway near the fire source is the highest, up to 500 °C. As can be seen from figure 2, when the fire source is far away from the longitudinal direction, the temperature drops rapidly. The temperature at 1/2 of the roadway height is about 120 °C, and the temperature at the bottom of the roadway is about 50 °C. With the continuous combustion of combustible materials and the continuous migration of high temperature to the tunneling working face along with the flue gas, the longitudinal temperature distribution of the roadway still shows the characteristics of "upper upper and lower lower". However, the difference of the longitudinal temperature of the roadway gradually decreases with the distance from the ignition source.
The change curve of temperature with time from the fire source to the measuring points 2#, 6#, 8#, 10# and 12# on the tunneling face is shown in figure 3. The temperature at the measuring point #2 fluctuates most violently, and its maximum temperature can reach more than 90 °C. The final temperature of the measuring points 8# and 10# is stable at about 55 °C, the temperature of the measuring
point 12# of the driving surface fluctuates from 45 °C to 50 °C, and the lowest temperature of the measuring point 6# is about 45 °C.

3.2 gas composition variation characteristics

The change curve of O$_2$ volume fraction with time from the fire source to the measuring points 2, 6, 8, 10 and 12 of the tunneling face is shown in figure 4. The initial O$_2$ volume fraction at each point in the model space is about 0.21, and the O$_2$ volume fraction at each measurement point starts to decline in sequence, and the peak rate of decline increases successively. By the time the simulation was completed, the O$_2$ volume fraction at each measurement point decreased successively and continued to decline. Among them, the O$_2$ volume fraction at the measuring points 2# and 6# has been reduced to about 0.195 and 0.175 at 360 s, and the O$_2$ volume fraction at 8#, 10# and 12# has been reduced to 0.16~0.165, which is relatively similar.

The change curve of CO volume fraction with time from the fire source to the measuring points 2, 6, 8, 10 and 12 of the tunneling face is shown in figure 5. The above measuring points have successively delayed rising time points of CO volume fraction, and the rising peak rate increases successively. Until the completion of simulation, the lowest CO volume fraction at the measuring point 2# is about 0.000, 3# is about 0.000, 8# is about 0.001, 2#, 10# and 12# are close to 0.001, 4, which is relatively close, and the CO volume fraction at each measuring point still shows an upward trend.

4. Analysis and discussion

(1) characteristics of roadway temperature distribution dominated by fire wind pressure

The simulated fire set at the entrance of the roadway drivage in upper wall, and near the fire source heat effect decreased density of smoke and air flow temperature rise, so the high temperature flue gas to rise up to produce the ceiling jet, part of the smoke flow with the alleys romantic walk, part of the roadway drivage smoke flow peak and to the inside of the migration, thus produce longitudinal and cross section of roadway in figure 2 "compete on low temperature distribution characteristics. In addition, due to the large amount of normal temperature air, small specific heat capacity and poor thermal conductivity, it is difficult to spread the high temperature of the fire source over a long distance, and the temperature drops rapidly after the flue gas mixes with normal temperature air. Therefore, only the upper part of the fire source is extremely hot, while the lower part of the tunneling roadway and the lower part of the roadway are relatively low. Smoke is the main heat propagation medium of fire source. The smoke is first perceived at the measuring point near the fire source, and the sensing time is relatively late along the measuring point. Therefore, the abrupt temperature rise at each measuring point in FIG. 4 is delayed successively. Affected by the fluctuation of heat release rate of the ignition source, the temperature fluctuation of the measuring point # 2 is the most severe.

In addition, due to the heat loss in the flue gas migration process, the temperature at each measurement point generally presents a downward trend. However, as the measurement point 6 of the tunneling face is a single roadway, the flue gas accumulates and even counterflows here, while the flue gas at the measurement point 3 is always in transit

Therefore, the temperature at the measuring point 3 is lower than that at the measuring point 6.

(2) fire gas distribution characteristics dominated by smoke flow migration

The coming of flue gas leads to the concentration change of O$_2$ and CO. As the measuring points of 2#, 3#, 4#, 5# and 6# are successively far away from the ignition source, the flue gas arrives successively, causing the concentration of O$_2$ and CO to decrease and increase successively. Moreover, due to the continuous decrease of smoke migration speed along the road, the smoke gradually accumulates in the tunnel. The farther the smoke is from the fire source, the greater the smoke quantity will be

The maximum change rate of O$_2$ and CO concentrations at each measurement point increases successively, O$_2$ concentration decreases successively, and CO concentration increases successively. Similarly, due to the cumulative effect of flue gas along the way, the values of each measuring point in the average distribution of space are closer to each other. Moreover, since there is no smoke exhaust
channel in the tunneling roadway, as long as the fire source is not extinguished, the concentration of O$_2$ and CO at each measurement point will continue to decline and rise.

5. Conclusion
(1) In the external fire at the entrance of the tunneling roadway, under the action of hot wind pressure from the fire source and under the action of fire wind pressure in the direct direction, the temperature of the roadway shows a "low upper and lower level" due to the rising of high temperature flue gas. Due to the limited air flow in the tunneling roadway in the horizontal direction, the temperature of the roadway decreases rapidly along the roadway. At the tunneling surface far from the fire source, the temperature can drop to about 50 °C.

(2) The law of temporal and spatial migration of flue gas dominates the concentration changes of O$_2$ and CO in the roadway in the ignition area, that is, the arrival of flue gas will make the O$_2$ concentration at this position drop rapidly and the CO concentration rise rapidly. In addition, the accumulation effect of flue gas along the way decreases the difference of gas concentration and increases the rate of change. If the fire source is not extinguished, the change of gas concentration in each position in the tunneling roadway will not be terminated.

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