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Numerical Simulation of The Effect of Opening Effect on The Propagation Characteristics of Gas Explosion in Roadway

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Abstract: In order to determine the effect of opening effect on numerical solutions of underground gas explosion and propagation, Fluent software was used to conduct relevant simulation research. Firstly, the reliability of the mathematical model is verified, and the simulated mesh size is 0.4m and the iterative step size is 0.5ms. By comparing the distribution of the peak value of shock wave parameters along different tunnel lengths with the calculation results of the model with a length of 260m, it is found that the effect of opening decreases significantly with the increase of distance, and the relative deviation of 20m from the opening is less than 0.05%. When the model length is taken with different values, the variation law of the parameter waveform and peak value at 120m from the explosion source with the roadway length is analyzed. The results show that when the roadway length is greater than or equal to 140m, the parameter waveform basically coincides and the variation amplitude of the parameter peak value is less than 0.02%, indicating that the distance affected by the opening effect is less than 20m. At the same time, in order to verify the above results, by changing the gas explosion equivalent and section size, the influence range of the opening effect is not affected by it. The numerical simulation of the propagation process of gas explosion in a mining face shows that the opening effect can be ignored when the selected roadway is extended by 20m.

Keywords: aperture effect, gas explosion, numerical simulation, shock wave propagation characteristics, coal mine underground roadway

1. Introduction

As the main energy source, coal is the cornerstone to ensure national energy security [1]. In China's energy resource endowment, coal is rich and widely distributed, accounting for more than 90% of the discovered resource reserves [2]. As fossil energy with the highest storage and production ratio, coal has played an extremely important role in the construction of our country for a long time due to its mature mining technology, low price and wide range of use [3]. However, the geological conditions of the mine and the occurrence conditions of the coal seam are complex and changeable, and various safety accidents occur from time to time [4], such as water permeation, gas or coal dust explosion, coal seam and gas outburst, roof, fire, etc. In all kinds of accidents, gas explosion, as one of the most serious disaster accidents in coal mine, is an important resistance affecting the safety of coal mine production, which accounts for the highest proportion of serious and serious accidents in coal mine, and is extremely destructive and sudden, often causing a large number of casualties and property losses, seriously threatening the safety of coal mine enterprises. According to statistics, since the founding of the People's Republic of China, the large gas explosion accidents in the roadway account for about 30.5% of the total number of large coal mine accidents, and the major gas explosion accidents account for about 27.1% of the total number of major coal mine accidents in China since 2000. The roadway is the place where serious and major gas explosion accidents occur most frequently [5]. Gas explosions instantly release huge energy, resulting in high temperature and high pressure shock wave spreading rapidly in the roadway, which has serious harm to underground workers, production equipment and roadway structure. For sustainable and safe production of coal mines, it is urgent to study and prevent gas explosion accidents.

At present, domestic and foreign scholars have carried out a lot of research on the characteristics and propagation process of underground gas explosion and achieved fruitful research results. Jinwei Qiu [6] used turbulence model and laminar velocity/vortex-dissipative combustion model to simulate shock wave propagation law in curved pipeline, bifurcated roadway and roadway with abrupt section change. Yifei Meng *et al*. [7] used RNG turbulence model and EDM combustion model to simulate and analyze the influence of obstacles in large-scale ventilation network on the propagation characteristics of gas explosion shock wave. Emami *et al*. [8], Blanchard *et al*. [9] and Xianhua Meng *et al*. [10] proved that the curved structure of L-shaped roadway could increase flame velocity and overpressure. Yunfei Zhu *et al*. [11] established a large-scale model with roadway section width × height =4m×4m and length of 200m and studied the law of flame propagation and pressure change, as well as the influence of premixed gas concentration and space blocking rate on gas explosion pressure. Xuebo Zhang *et al*. [12] proposed a piecewide relay numerical simulation method for shock wave propagation in order to solve the problem of studying the propagation law of gas explosion in a mine at a large scale. Huihui Liu *et al*. [13], Haiyan Wang *et al*. [14], Shuangshuang Liu *et al*. [15] studied the influence of different types of roadways, different turning angles and different fire source locations on the propagation law of gas explosion shock wave by Fluent simulation software. Weiguang Zhang *et al*. [16] used numerical simulation to analyze the relationship between flame propagation velocity, corner of roadway and gas filling length in roadway. Xingyan Cao *et al*. [17], Leilin Zhang *et al*. [18] and Jinwei Qiu *et al*. [19] found that bending structures with different angles have significantly different influences on the overpressure propagation law of gas explosion. Jianliang Gao *et al*. [20] carried out numerical simulation of gas explosion and propagation process of symmetrical Angle and parallel network roadway in combination with actual roadway dimensions.

When the gas explosion and propagation process in a certain section of the underground ventilation network (system) is studied, the section of the roadway is usually selected to establish a geometric model for numerical simulation. The open end and outlet end of the established geometric model are directly connected with the atmosphere, and the numerical simulation results are affected by the opening effect. Due to the influence of the opening effect, the numerical simulation results near the opening are different from the numerical settlement results under the condition that the roadway is connected to the underground ventilation network. In order to obtain reliable numerical simulation results, it is necessary (in this paper) to study the effect of opening effect on numerical simulation simulation results, the influence range of opening effect, and how to determine the opening position when building geometric models.

2. Model Building

2.1 Physical model

2.1.1 Basic assumption

The propagation process of gas explosion involves a series of flow, heat transfer, chemical reaction and other processes. In order to facilitate calculation and make simulation results reliable, appropriate assumptions on relevant issues need to be made before numerical simulation and simplified. 1) The chemical reaction of gas explosion mixed with air is a single-step irreversible reaction; 2) All gases in the flow field belong to ideal gases and conform to the ideal gas equation of state; 3) The wall surface in the flow field space is rigid and adiabatic and will not generate heat transfer with the external environment.

2.1.2 Physical model and grid division

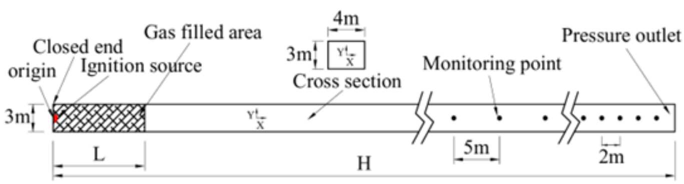


Figure 1: Schematic diagram of straight roadway model

In order to study the influence range of opening pressure on the change of related parameters of gas explosion shock wave propagation in roadway, the model as shown in Figure 1 was constructed. Straight roadway models with a rectangular cross-section of 4m×3m and lengths ***H*** of 120m, 130m, 140m, 150m, 160m and 260m were constructed. One end of the roadway is a closed end, and the other end is an open end. The center of the cross section of the closed end is taken as the coordinate origin, and the cross section is on the XOY plane. The methane gas is filled from the closed end with a filling length of ***L*** meters. The ignition source is located at the origin of coordinates; Monitoring points are set every 5m in the section from 80m away from the ignition source to 20m away from the opening section. And within 20m from the opening section of the roadway, a monitoring point is set every 2m. The monitoring points are set on the central axis of the roadway (that is, on the Z axis), and the data of overpressure, temperature, and velocity change over time at this point are simulated and recorded. Using the Mesh function of ANSYS simulation software, the tunnel model is divided into space grids, and hexahedron is used to mesh the entire physical model.

2.2 Mathematical model

The diffusion of gas explosion is a complex process involving the exchange and change of mass, momentum, energy and matter, as well as the change of pressure, temperature, density and substance amount. The conservation equation in fluid dynamics is the basis for solving and calculating the change of various parameters in this process. In this study, for the turbulence model, the unsteady Navier-Stokes (N-S) equation of large eddy simulation (LES) is selected, and for the combustion model, the eddy dissipation model (EDM) is selected to describe the propagation process of gas explosion. Other conservation equations followed in the explosion process are as follows:

(1) Mass conservation equation:

$$\frac{\partial\bar{\rho}}{\partial t}+\frac{\partial}{\partial x_i}\left(\bar{\rho}\tilde{u}_i\right)=0 \tag{1-1}$$

Where $\boldsymbol{\rho}$ is the fluid density, (kg·m^3); $\boldsymbol{t}$ is time, (s); $\boldsymbol{x_i}$ is the spatial coordinate in the direction of $\boldsymbol{i}$; $\boldsymbol{u_i}$ is the velocity in the direction $\boldsymbol{i}$, (m·s^1). Where "~" represents the density-weighted average; "¯" means three-dimensional space filtration, filtration size **Δ=(ΔxΔyΔz)$^{1/3}$**.

(2) Momentum conservation equation:

$$\frac{\partial}{\partial t}\left(\bar{\rho}\tilde{u}_i\right)+\frac{\partial}{\partial x_j}\left(\bar{\rho}\tilde{u}_j\tilde{u}_i\right)+\frac{\partial}{\partial x_j}\left[\bar{\rho}\left(\overline{u_iu_j}-\tilde{u}_i\tilde{u}_j\right)\right]=-\frac{\partial\bar{p}}{\partial x_i}+\frac{\partial\tilde{\tau}_{ij}}{\partial x_j}+\bar{\rho}\tilde{f}_i \tag{1-2}$$

Where $\boldsymbol{x_i}$ is the spatial coordinate of direction $\boldsymbol{i}$; $\boldsymbol{u_j}$ is the velocity in the $\boldsymbol{j}$ coordinate direction, (m·s^{-1}); p is the pressure, (pa); $\boldsymbol{\tau_{ij}}$ is the component of the viscous stress τ on the surface of the microelement due to the viscous action of the molecule, (N); $\boldsymbol{f_i}$ is the volume force component in the direction $\boldsymbol{i}$, (N).

(3) Energy conservation equation:

$$\frac{\partial}{\partial t}\left(\bar{\rho}\tilde{E}\right)+\frac{\partial}{\partial x_i}\left(\bar{\rho}\tilde{E}\tilde{u}_i\right)+\frac{\partial}{\partial x_i}\left[\bar{\rho}\left(\overline{u_iE}-\tilde{u}_i\tilde{E}\right)\right]=-\frac{\partial}{\partial x_i}\left(\bar{p}\tilde{u}_i\right)+\frac{\partial}{\partial x_i}\left(K\frac{\partial\tilde{T}}{\partial x_i}\right)+\frac{\partial}{\partial x_i}\left(\tilde{u}_j\tilde{\tau}_{ij}\right)+\bar{\rho}\tilde{f}_i\tilde{u}_i+\tilde{S}_h \tag{1-3}$$

Where $\boldsymbol{E}$ is the energy contained in the fluid per unit mass, $\boldsymbol{E=e+v^2\cdot 2^{-1}}$, (J·kg^{-1}); $\boldsymbol{K}$ is the thermal conductivity; **T** is the temperature, (k); $\boldsymbol{S_h}$ is the chemical reaction source term, (W·kg·m^{-3}·mol).

(4) Component conservation equation:

$$\frac{\partial}{\partial t}\left(\bar{\rho}\tilde{m}_l\right)+\frac{\partial}{\partial x_i}\left(\bar{\rho}\tilde{u}_i\tilde{m}_l\right)+\frac{\partial}{\partial x_j}\left[\bar{\rho}\left(\overline{u_im_l}-\tilde{u}_i\tilde{m}_l\right)\right]=\frac{\partial}{\partial x_i}\left(D_l\frac{\partial\tilde{m}_l}{\partial x_i}\right)+\tilde{R}_i+\tilde{S}_l \tag{1-4}$$

Where $\boldsymbol{m_l}$ is the mass fraction of each component; $\boldsymbol{D_l}$ is the diffusion coefficient; $\boldsymbol{R_i}$ is the net rate of chemical reaction forming component $\boldsymbol{i}$, (kg·m^{-3}·s); $\boldsymbol{S_l}$ is the formation rate of component l per unit volume, (kg·m^{-3}·s).

(5) Gas explosion chemical reaction equation:

$$CH_4+2\left(O_2+3.76N_2\right)\rightarrow CO_2+2H_2O+7.52N_2 \tag{1-5}$$

(6) Ideal gas equation of state:

$$\bar{p}=\bar{\rho}RT \tag{1-6}$$

Where $\boldsymbol{T}$ is temperature, (k); $\boldsymbol{R}$ is the gas constant.

2.3Initial conditions and boundary conditions

2.3.1 Initial condition

1) The filling length of the gas filling area is 10m, the dimension width × height × length of the filling area is 4m×3m×10m, and its concentration is 9.5% methane-air mixed gas; 2) Other areas are filled with air; 3) The initial pressure of the whole region is P_0, and the pressure relative to the atmosphere is set to P_0=0; 4) Calculate the initial velocity of gas in the area V_0=0; 5) Except the ignition source, the temperature in other areas is T_0=300k; 6) The ignition source temperature is 2000K, adopt a high temperature zone to trigger the explosion, and set the ignition source to a hemisphere with a radius of 0.1m (the center of the sphere is the origin).

2.3.2 Boundary condition

The outlet of the model is the pressure outlet, and the outlet group is divided into oxygen, whose mass fraction is $w(O_2)$=0.232. The outlet pressure is normal pressure and is set to 0 relative to atmospheric pressure. The other pipe walls are rigid adiabatic walls, and the heat exchange and loss between the fluid flow process and the wall surface are not considered, and the wall temperature is 300K.

2.4 Mathematical model verification

Before mathematical simulation research, the selected mathematical physics model needs to be verified to ensure its reliability. The simulation performance of mine roadway in the original scale was verified. According to the gas explosion test conducted by Shuzhao Yang *et al*. [21] in the experimental straight roadway with a section of 7.2m^2 and a length of 896m, the geometric model was constructed and the numerical simulation was carried out. The reliability of the mathematical and physical equations used was verified by comparing the simulation results with the experimental results. The geometric model is similar to section 2.1.2, its cross section is 2.68m×2.68m, and the length of the geometric model is set at 400m. The gas concentration in the experiment is 9.5% and the volume is 100m^3, so the length of gas filling is 14m. The initial air parameters are P_0=0.1MPa, P_0=1.25kg/m3, T_0=288K, V_0=0, which are consistent with the experimental conditions. The solution domain is meshed according to the meshing in Section 2.1.2. The Patch high temperature zone is adopted to achieve ignition, and the ignition conditions are the same as 2.3.1.

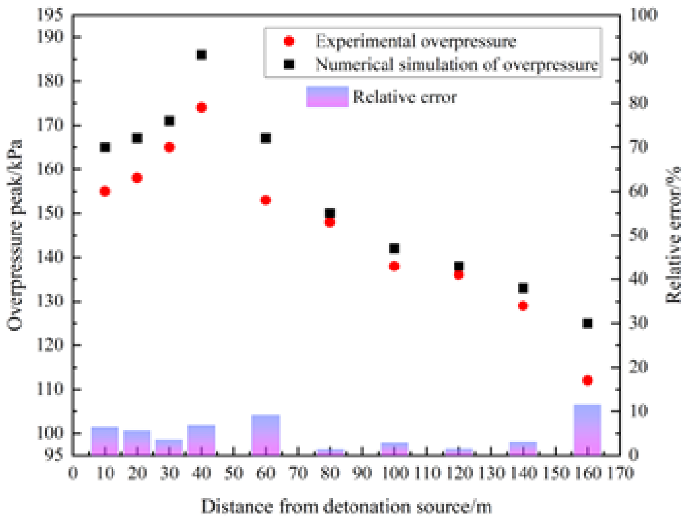


Figure 2: Plot of explosion overpressure simulation results against experimental result

Figure 2 shows the comparison between experimental data of explosion overpressure and numerical simulation results. The variation trend of gas explosion shock wave overpressure obtained by numerical simulation is basically the same as that obtained by experiment, and the numerical overpressure value is slightly larger than the experimental value. The maximum relative error between the numerical simulation results and the experimental results is 11.6%, and the minimum relative error is only 1.35%. The simulation results are in good agreement with the experimental results, the reliability of the mathematical model is verified, and the numerical simulation of gas explosion can be carried out.

3. Verification of the Independence of Key Parameters in Gas Explosion Simulation

3.1 Grid size independence verification

The key parameters of gas explosion simulation have a great influence on the simulation results. In order to make the simulation results more reliable, it is necessary to verify the independence of the key parameters of the simulation, such as grid size and iteration time step. According to the model shown in Figure 3, three monitoring points a, b and c are selected, and their coordinates are (0,0,15), (0,0,20) and (0,0,30) respectively. Initial conditions and boundary conditions are set as above. The Mesh function in ANSYS Workbench is used to mesh the whole physical model with different dimensions of hexahedral side lengths of 0.2, 0.3, 0.4, 0.5, 0.6 and 0.7m respectively.

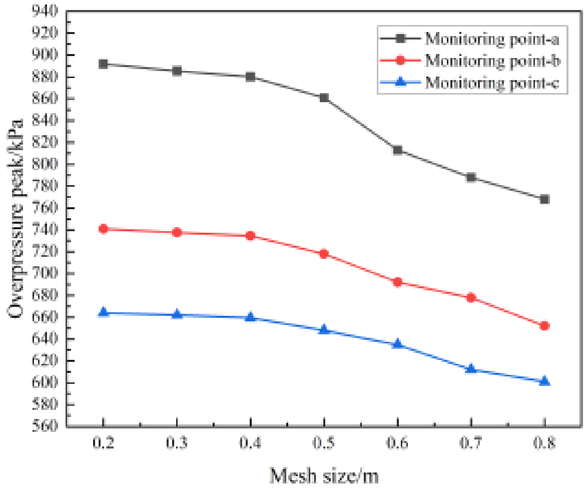


Figure 3: The variation of the peak overpressure with the grid size

By comparing and analyzing the variation law of the peak overpressure of each measuring point with the change of grid size, the reasonable grid size is determined, and the reliable simulation data is obtained. Figure 2-1 shows the variation law of the peak overpressure. It can be seen from the figure that the mesh size increases from 0.2m to 0.8m, and the peak overpressure of each monitoring point shows a decreasing trend. However, from 0.2m to 0.4m, the overpressure peak value decreased by a small margin and remained basically unchanged. When the mesh size increases from 0.4m to 0.8m, the peak overpressure drops sharply. Especially for the data at the monitoring point a, which is close to the explosion source, the change amplitude is extremely obvious, indicating that the mesh size of 0.4m is a node. Considering the reliability of the simulation data and the computer configuration, it can be seen that the mesh size of 0.4m is reasonable, reliable and economical without affecting the simulation results.

3.2 Iteration time step independence verification

On the basis of determining the mesh size of 0.4m, seven different iteration time steps of 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9ms were selected respectively. By comparing and analyzing the variation law of the peak overpressure of each measuring point under different iteration time steps, a reasonable iteration time step was determined. The result is shown in Figure 4. The iteration time step increases from 0.3ms to 0.5ms, but the overpressure peak value fluctuates slightly. However, when the iteration time step continues to increase from 0.5ms to 0.9ms, the overpressure peak value decreases rapidly, indicating that when the iteration time step grows larger than 0.5ms, it has a great impact on the numerical results, making the simulation results unreliable. In order to reduce the influence of iteration time step on the simulation results, and considering the configuration of the computer, the calculation is convenient, the computing pressure is reduced, and the time is saved, the iteration time step size of 0.5ms can be used for the numerical simulation of gas explosion propagation.

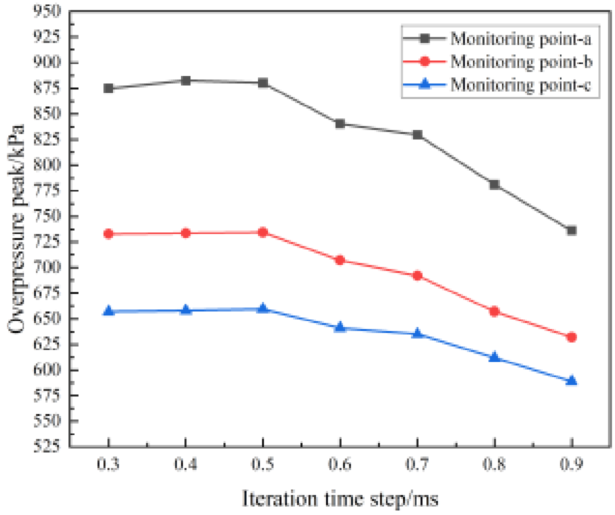
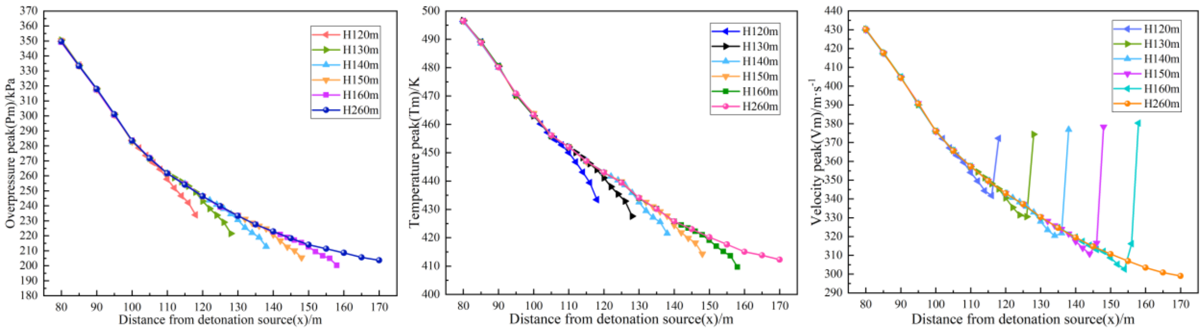


Figure 4: The variation of the peak overpressure with the time step

4. Result Analysis and Discussion

4.1 Study on the influence of opening effect on numerical simulation settlement results

Under the influence of the opening effect, the related parameters of shock wave propagation will deviate near the opening boundary. The influence range of the opening effect is determined by analyzing the deviation range. The distribution of relevant parameters of explosion shock wave along the roadway under the same gas explosion condition of different geometric model length $\boldsymbol{H_i}$ ($\boldsymbol{i}$=120m, 130m, 140m, 150m, 160m) was studied, and the attenuation of shock wave along the roadway was compared with that of simulated roadway length of 260m. To determine the influence range of opening effect on the change of related parameters of gas explosion propagation in roadway. When the length of the geometric model is 260m, the influence of the opening pressure boundary on the calculation of the relevant parameters in the tunnel 170m can be ignored. The changes of overpressure peak $\boldsymbol{P_m}$, temperature peak $\boldsymbol{T_m}$ and speed peak $\boldsymbol{V_m}$ along the path obtained by numerical simulation are shown in Figure 5.



(a) Overpressure peak. *(b) Temperature peak.* *(c) Velocity peak*

Figure 5: Shock wave overpressure peak, temperature peak, velocity peak along the distribution

As can be seen from the figure, the closer the distance to the opening pressure boundary, the greater the relative deviation between the calculated value of the geometric model with the length of 120m, 130m, 140m, 150m and 160m and the calculated value when the length of the simulated roadway is 260m, and the greater the deviation of the parameter variation curve along the path. The variation curves of gas explosion shock wave parameters along the roadway in the figure show that the curves of the geometric model with a length of 120m, 130m, 140m, 150m and 160m all deviate significantly within 20m of the pressure opening boundary, and the variation curves coincide when the distance is more than 20m.

Table 1 shows the length of the geometric model $\boldsymbol{H_i}$ ($\boldsymbol{i}$=120m, 130m, 140m, 150m, 160m). Relative deviation α(P,T,V) of calculated value $\boldsymbol{\theta_{mxHi}}$ ($\boldsymbol{\theta_m}$ is $\boldsymbol{P_m}$, $\boldsymbol{T_m}$, $\boldsymbol{V_m}$) from calculated value $\boldsymbol{\theta_{mxH260m}}$ from detonation source distance x under different simulated roadway lengths relative to geometric model length $\boldsymbol{H_{260m}}$.

$$\alpha_{(P,T,V)} = \frac{\left|\theta_{mxHi} - \theta_{mxH260m}\right|}{\theta_{mxH260m}} \times 100\% \qquad (3\text{-}1)$$

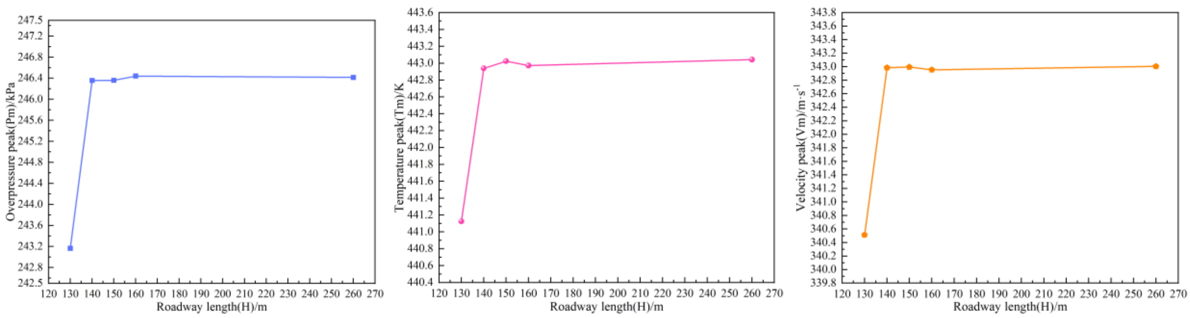
Table 1: Variation of shock wave overpressure, temperature and velocity peak relative deviation along the path

x/m	a_P/%					a_T/%					a_V/%				
	H_{120m}	H_{130m}	H_{140m}	H_{150m}	H_{160m}	H_{120m}	H_{130m}	H_{140m}	H_{150m}	H_{160m}	H_{120m}	H_{130m}	H_{140m}	H_{150m}	H_{160m}
80	0.04	0.03	0.03	0.02	0.01	0.02	0.03	0.02	0.01	0.01	0.04	0.02	0.02	0.03	0.02
90	0.02	0.01	0.02	0.04	0.02	0.03	0.01	0.03	0.01	0.02	0.02	0.02	0.01	0.02	0.02
100	0.03	0.05	0.03	0.04	0.01	0.03	0.02	0.01	0.02	0.02	0.02	0.01	0.03	0.02	0.01
110	2.60	0.01	0.02	0.03	0.02	1.96	0.02	0.02	0.02	0.01	2.01	0.02	0.01	0.03	0.02
120	42.90	2.30	0.02	0.02	0.01	22.56	1.68	0.03	0.04	0.01	37.91	1.82	0.02	0.02	0.02
130	-	42.29	1.80	0.04	0.02	-	22.13	1.51	0.03	0.02	-	35.38	1.65	0.03	0.01
140	-	-	38.49	1.60	0.03	-	-	20.64	1.32	0.03	-	-	40.94	1.50	0.03
150	-	-	-	32.55	1.20	-	-	-	21.35	1.21	-	-	-	49.93	1.31

The data in the table show that the relative deviation of explosion-related parameters is above 1% when the distance is 10m from the opening boundary, and the relative deviation of values calculated at the opening boundary is greater than 20%, while the deviation of values calculated at the opening boundary is less than 0.05% when the distance from the opening boundary is 20m or more. When the distance from the opening boundary is greater than 20m, the measured data is roughly the same. The relative deviations are all less than 0.05%, which indicates that the opening effect has a greater impact on the numerical simulation settlement results when it is within 20m of the opening boundary, while the impact when it is beyond this distance can be ignored.

4.2 Variation of the data at 120m from the explosion source with the length and time of the model

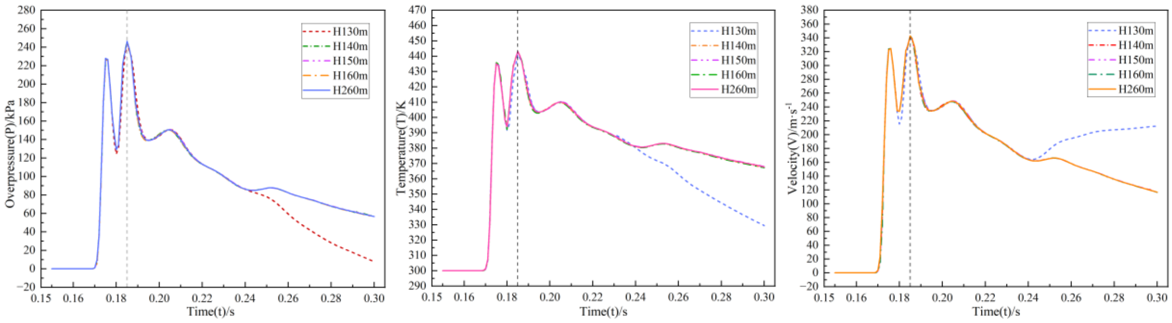
In order to determine the influence range of the opening effect, 120m away from the explosion center is taken as a fixed monitoring point, and the distance between the monitoring point and the opening pressure boundary is changed by changing the length of the geometric model $\boldsymbol{H}$ (130m, 140m, 150m, 160m, 260m). By comparing the variation of the peak $\boldsymbol{P_m}$ of overpressure, peak $\boldsymbol{T_m}$ of temperature and peak V_m of velocity at 120m away from the explosion source with the length of the geometric model and the waveform diagram of overpressure $\boldsymbol{P}$, temperature $\boldsymbol{T}$ and velocity $\boldsymbol{V}$ with time under the same explosion conditions, it can be concluded that the explosion-related parameters at 120m away from the explosion source no longer change when the roadway length increases to what number. To determine the influence range of opening effect on the change of related parameters of gas explosion propagation in roadway. As shown in the figure, Figure 6 shows the change of parameter peak value at 120m away from the explosion source with the length of the geometric model, and Figure 7 shows the change of parameter at 120m away from the explosion source with time under different simulated roadway lengths.



(a) Overpressure peak. (b) Temperature peak. (c) Velocity peak

Figure 6: Variation of the peak value of overpressure, temperature and velocity at 120m away from the explosion source with the model length

It can be seen in Figure 6 that the peak value of overpressure, temperature and velocity at 120m away from the explosion center increases from 130m to 140m with the length of the geometric model, in which the peak value of overpressure increases by 1.3%, the peak value of temperature increases by 0.4%, and the peak value of velocity increases by 0.7%, indicating that when the length of the simulated roadway is 130m, the peak value of the simulated roadway increases by 0.7%. The opening pressure has a great influence on the solution at 120m away from the explosion source. However, when the length of the geometric model is 140m, 150m, 160m and 260m, the numerical simulation results have little difference. With the length of the simulated roadway from 140m to 260m, the peak value of overpressure changes at about 246.4kPa, the peak value of temperature changes at about 443.0K, and the peak value of velocity changes at about 343.0m·s^{-1}. It can be seen that when the length of the geometric model is greater than or equal to 140m, the effect of the opening pressure boundary on the relevant parameters of the explosion propagation at 120m away from the explosion source can be ignored.



(a) Overpressure. *(b) Temperature.* *(c) Velocity*

Figure 7: Overpressure, temperature and velocity waveform at 120m away from the explosion source under different model lengths

As can be seen from the waveform diagram in Figure 7, when the length of the geometric model is 130m, the waveform diagram of relevant parameters of explosion propagation does not fully coincide with other waveform diagrams, and there is a significant deviation near 0.24s, indicating that the simulation tunnel of 130m will make the solution of explosion parameters at 120m away from the explosion source affected by the opening effect, and when the length of the tunnel is greater than or equal to 140m, the solution of explosion parameters will be affected by the opening effect. When the opening pressure boundary is at or above 20m, the waveform diagram of explosion parameters changing with time basically coincides, and the influence of the opening effect on it can be ignored. It can be concluded that the influence range of the opening effect on related parameters of gas explosion propagation in the roadway is less than 20m. When the monitoring point is at or above 20m from the opening boundary, it can be considered that it is no longer affected by the opening effect.

5. Verification of the Effect of Opening Effect on the Propagation Characteristics of Gas Explosion

5.1 Verification of the effect of different gas filling lengths on the opening effect

The longer the gas filling length ***L*** is, the larger the explosive gas equivalent is, the stronger the explosion power will be and the greater the explosion overpressure will be generated. The changed gas filling length ***L*** is 20m and 30m respectively. The geometric model and mathematical model are the same as those in chapters 2.1 and 2.2, and the initial and boundary conditions are similar to those in chapters 2.3 except the gas filling length. Through numerical simulation, the variation of the peak overpressure of the gas explosion shock wave in the roadway with the distance is shown in the figure.

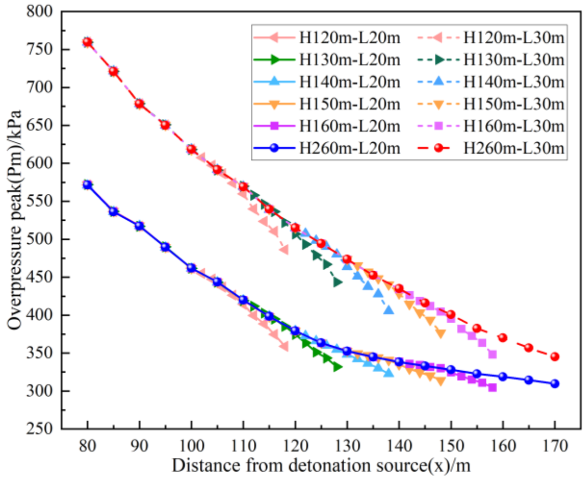


Figure 8: Variation diagram of overpressure peak value in different gas filling lengths

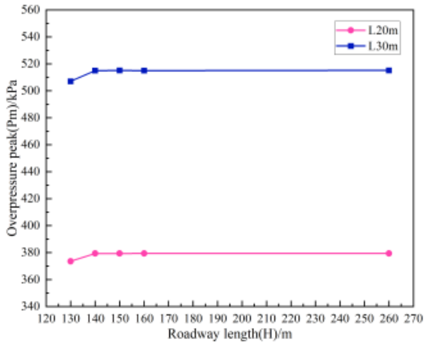


Figure 9: Variation of peak overpressure with model length under different gas filling lengths

As can be seen from Figure 8, when the gas filling length is 30m, the attenuation trend of overpressure in the roadway is much steeper than that of 20m gas filling length. This shows that the longer the gas filling area is, the greater the overpressure will be and the faster the overpressure will decay along the road. However, regardless of whether the gas filling length is 20m or 30m, there is a significant deviation from the opening boundary within 20m in general. Figure 9 shows the changes of the peak overpressure with the length of the geometric model (130m, 140m, 150m, 160m, 260m) under different gas filling conditions. When the length of the simulated roadway changes from 130m to 140m, the peak overpressure increases by 5.8kPa and 8.0kPa respectively, while the length of the roadway varies from 140m to 260m. The peak value of overpressure varies around 380kPa and 515kPa, respectively, and the amplitude is within ±0.02%, indicating that the influence of the opening effect is very small when the distance is 20m or later from the opening pressure boundary. The results show that when the gas explosion power is different, the influence range of the opening effect in the numerical simulation is still less than 20m.

5.2 Verification of the influence law of variable section short roadway on opening effect

When the gas filling length is 10m, the data at 120m is far away from the explosion center. In order to verify the universality of the influence rule of the opening effect, the geometric model is constructed with the length of 70m and 140m respectively. The rectangular roadway with a cross section of 6m×2.8m is a long straight roadway, and the roadway is filled with gas with dimensions of width × height × length 6m×2.8m×10m. The initial conditions and boundary conditions are the same as in section 2.3 except for the setting of the gas filling area; A monitoring point is set up 50m away from the explosion center in the roadway, and the monitoring overpressure changes with time under different roadway lengths respectively, as shown in Figure 10.

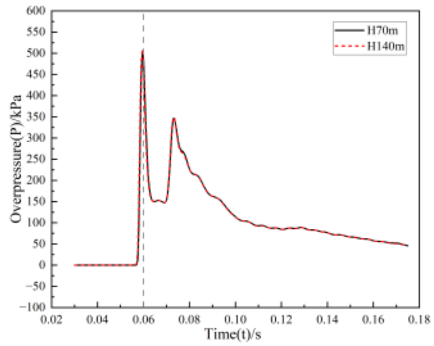


Figure 10: Overpressure waveform 50m from the explosion source

The numerical simulation results show that under the condition that the length of the simulated roadway is 70m and 140m respectively, the waveform diagram of the overpressure 50m away from the explosion center over time basically coincides. Because when the length of the roadway is 140m, the monitoring point 50m away from the explosion source is far away from the entrance boundary, and the influence of the opening effect on it can be ignored. When the length of the geometric model is 70m, the overpressure waveform at the monitoring point coincides with it, and the opening boundary is 20m away from the monitoring point, indicating that the relevant data is not affected by the opening effect when the opening boundary is set beyond 20m. Under the gas filling length of 10m, when the shock wave propagates to 50m away from the explosion source, the energy is large and the change is drastic, while the influence range of the opening effect on the shock wave propagation characteristics is still within 20m, indicating that the effect law of the opening effect is universal.

5.3 The effect of actual roadway size on opening effect is verified under complex roadway conditions

When the ventilation diagram of a coal mining face in a mine of China Pingcoal Group is taken to build a geometric model to study the propagation law of gas explosion shock wave along the return air roadway and the intake air roadway, how long can the roadway be taken to get the law of explosion propagation at the distance of 160m on the return air roadway and 100m on the intake air roadway when the gas explosion actually occurs on the underground coal mining face? Based on the above conclusion, the influence range of the opening effect is within 20m, and the length of the return air roadway is set as ***I*** (180m, 260m), and the length of the inlet air roadway is set as ***F*** (120m, 200m). The changes of overpressure at 160m on the return air roadway and 100m on the inlet air roadway with time are monitored. Thus, the feasibility of setting the length of the roadway as $\boldsymbol{I_{180m}}$ and $\boldsymbol{F_{120m}}$ is judged, and the feasibility of the influence rule of the opening effect is proved in turn.

As shown in Figure 11, the length of the mining roadway is 200m, the cross section of the intake roadway and return roadway is 4m×3m, and the cross section of the mining roadway is a rectangle of 6m×2.8m. The gas filling area is set up at the corner of the coal mining working surface. The gas area spans 15m (***A, B***) of the coal mining roadway and the return air roadway, and the total space length is 30m. Hexahedral mesh with side length of 0.1m was used for grid division. Monitoring points are set up at 160m on the return roadway and 100m on the inlet roadway respectively. The initial and boundary conditions are the same as in section 2.3 above.

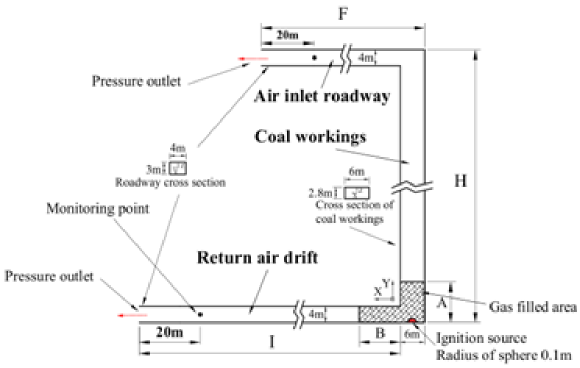


Figure 11: Schematic diagram of the geometric model of the coal mining face

The overpressure measured at 160m on the return air roadway and 100m on the inlet air roadway at fixed monitoring points varies with time under different simulated roadway lengths ***I*** (180m, 260m) and ***F*** (120m, 200m), respectively. The calculation results obtained through numerical simulation are shown in Figure 12 and 13. The overpressure waveform at the fixed monitoring point basically coincides and the peak value is the same. Therefore, it can be concluded that the position of the opening pressure boundary is set at 20m, which verifies that the influence range of the opening effect on the propagation characteristics of gas explosion shock wave is within 20m, and the data measured at the monitoring point where the length of the opening pressure boundary is greater than or equal to 20m is reliable. Not affected by the opening effect.

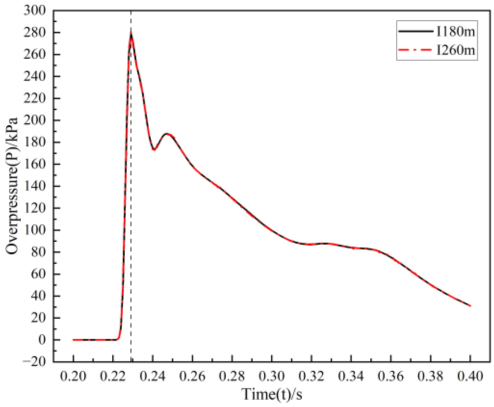


Figure 12: Overpressure waveform diagram at 160m on the return air roadway

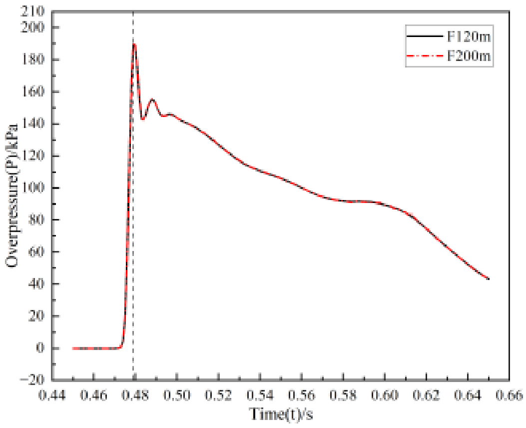


Figure 13: Overpressure waveform diagram at 100m on the inlet tunnel

6. Conclusion

(1) By comparing the experimental and simulated overpressure values of shock wave propagation, the overall error is small, the simulated values are highly consistent with the experimental values, and the selected mathematical model is reliable. The key parameters of the simulation were tested and optimized, and the reasonable mesh size of 0.4m and iteration time step of 0.5ms were determined

(2) By comparing the distribution of the peak value of shock wave parameters along different roadway lengths with the solution results of the model with a length of 260m, the variation of the curve along the change path and the relative deviation along the change path are analyzed. It is concluded that the explosion parameters deviate significantly within 20m from the opening boundary, and the relative deviation is only within 0.05% when the distance is 20m or more from the opening boundary.

(3) When the length of the geometric model is taken as 130m, 140m, 150m, 160m and 260m respectively, the variation law of the parameters at 120m distance from the explosion source with time and the variation law of the peak value with the roadway length obtained by numerical simulation show that when the roadway length is 140m or above, the numerical value has little change with the roadway length. The amplitude of

variation is within ±0.02%, which can be ignored, and the waveform diagram of the parameters basically coincides, indicating that the effect of opening effect can be ignored when the length of the geometric model is 140m for the numerical solution at 120m from the explosion source.

(4) The influence law of the opening effect is verified by changing the gas filling length and the cross-section size of the roadway. It is found that under the conditions of different gas filling lengths or different roadway cross sections, the opening pressure boundary condition is set at or above 20m, and the influence of the opening effect on the solution of the gas explosion shock wave propagation in the roadway can be ignored. For the problem of what the roadway size should be when the gas explosion propagation law is studied in a section of the actual roadway, combined with the above conclusions, it is found through verification that the impact of the opening effect can be ignored when the roadway to be studied is extended by 20m, that is, the opening boundary is set at 20m, and a practical and reliable solution can be obtained.

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