Simulations on two holes drainage for cleat coal gas

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Abstract. Gas drainage from seam is the main technical measure to prevent and control gas accident. The mathematical model and the numerical analysis method can be used to study the gas flow, and the more accurate results can be achieved. The LB method is a simplified computational model based on the microscopic scale and can be used for solving the problem of gas seepage. This paper based on LB method, simulated the gas pressure, flow track and speed vector diagram in terms of the topic for cleat coal gas drainage through symmetrical holes. It analyzed the depth of the holes influence the gas leakage; summarized and concluded the drainage performance under the controllable subjective factors during the cleat coal gas drainage process.

1. Introduction

Gas Disaster is one of the most serious hazards in coal mines. Gas is colorless and odorless, when it reaches a certain concentration, it can asphyxiate people because of oxygen and can be burned or exploded. The existence of gas are Free State and sorption state in coal or surrounding rock. But during coal mining, the high pressure gas in the coal seam will desorb and move to the low pressure when the mining work destroys the original gas balance state, then enter the mining space. Gas could occur dynamic phenomenon of coal and gas outburst in migration process and cause the gas disaster. Because of the low permeability of the coal seam and the complexity of ground terrain in china, drilling and setting out gas under the shaft is the main technical measure to prevent gas outburst. Therefore, it is important to study the law of coal seam gas seepage in coal seam gas drainage boreholes and be optimal layout of gas drainage boreholes, which is of great significance in effective gas drainage and ensuring the implementation effect of regional outburst prevention measures.

The LB method (Lattice Boltzmann Method) is a simplified computational model based on the microscopic scale at the end of the 1980s, it is not a direct discretization of the macroscopic continuous equation, but studying on the microscopic model and some microscopic kinetic equations. Under the coarse graining approximation, these microscopic kinetic equations can be reduced to the macroscopic fluid mechanics equations. This method can establish the model of porous media seepage theory and be numerically simulated. It has made great progress in parallel computing, boundary condition processing, analysis of accuracy and stability, comparison with typical numerical examples and traditional numerical methods and specific applications. The LB method provides a new way of thinking and method which simulate migration law of gas flow field.
2. Brief Introduction to LB Method

The LB method is developed and improved by the Lattice Gas Automata (LGA) [1-2] theory. In 1976, the HPP model [3] was proposed by Hardy et al. and the simple flow phenomenon was simulated. In 1986, Frisch et al. got the FHP model [4], and Hummers et al. put forward the HLF model [5] for three dimensional problems. Once we get the symmetry grid, the only remaining problem is to determine the rule of particle motion (evolution). There are two ways to deal with this problem, namely the LGA method and the LB method.

The main idea and calculation procedure of LB method is extremely similar to LGA. The main difference is that LB method uses the microscopic real number variables--- particle distribution function \( f(\alpha, x, t) \), instead of Boole type variables \( n_\alpha(x, t) \) of LGA. Here \( f(\alpha, x, t) \) represents the probability which there is one moving particle along the \( e_\alpha \) direction at t time in \( x \) node. That is:

\[
f(\alpha, x, t) = (n(\alpha, x, t))
\]

In this way, the LB method no longer needs to calculate the microscopic amount, but directly calculates the microscopic quantity according to the lattice Boltzmann equation.

\[
f(\bar{x} + c\hat{e}_\alpha \Delta t, t + \Delta t) - f(\bar{x}, t) = \Omega(f(\bar{x}, t)), (i = 0, 1, \cdots, b)
\]

Then use

\[
\begin{align*}
p(\alpha, x, t) &= \sum_{i=0}^{n} f(\bar{x}, t) \\
p(\alpha, x, t)u(\alpha, x, t) &= \sum_{i=0}^{n} \bar{e}_i f(\bar{x}, t) \\
p(\alpha, x, t)e(\alpha, x, t) &= \frac{1}{2} \sum_{i=0}^{n} (\bar{e}_i - \vec{u})^2 f(\bar{x}, t) \\
p &= c_s^2 \rho
\end{align*}
\]

To calculate macroscopic quantity. That is to say, the LB method uses the lattice Boltzmann equation to simulate the macroscopic phenomena.

The LB method represents the collision term as a function of the particle distribution function. Liguria, Sulci and Jimenez (1989) [6-7] to represent the collision term as a matrix by the linearization method. Elements in the matrix only depend on the angle between the colliding particles. These models effectively eliminate statistical noise, but other problems still exist because they still belong to the Fermi-Dirac distribution. In 1991, Chen S Y and Chen H D [8] abandoned F-D [9] distribution and used Maxwell-Boltzmann distribution, so that symmetry, invariance and pressure independent of velocity and other issues were met. In 1992, a very simple model D2Q9 [10] appeared, it makes collision matrix simplification. Lattice BGK (LBGK) model, which is proposed to use the relaxation time to make the distribution function approximate to the local equilibrium distribution function by Bhavnagar [11], gross [12] and Crook [13], is widely used at present. The corresponding LBGK equation is

\[
f(\alpha, \bar{x}, t + \Delta t) - f(\alpha, \bar{x}, t) = -\frac{1}{\tau}(f(\alpha, \bar{x}, t) - f(\alpha, \bar{x}, t)_{eq}), (\alpha = 0, 1, \cdots, b)
\]

The LB method is used to simulate the flow field, which is actually attributed to the iterative solution of the equation (2.2). After the particle distribution function of each grid point is obtained at every moment, the macromechanical quantity can be calculated by (1).
3. Building Gas Flow Field Model
An 80 x 80 grid is used to replace the flow area of the fractured coal body, and the gas is discharged by a double hole on the right side of the flow area. The air permeability of the coal seam roof and floor is much lower than that of the coal seam. Therefore, it is assumed that the surrounding rock of the coal seam roof and floor is an impermeable layer and does not contain gas. Gas flow field model as shown below:

![Figure 1. Gas flow field model](image)

There are various factors that affect gas drainage, the effect of gas drainage is different in different condition. The main factors affecting gas drainage include natural factors, equipment factors and technical factors. The main factors affecting gas drainage are natural factors, equipment factors and technical factors. This paper mainly discusses the influence of some technical factors on gas drainage without considering natural factors and equipment. Due to the fact that natural factors are not controllable, there is still no real efficient drilling rig in China at present. The efficiency of drilling rig widely used in coal mines is generally not up to the design requirements, which affects the quality of drilling holes and then affects the effect of gas drainage. Drilling parameters which influence on the effect of gas drainage are bore diameter, borehole angle, drilling length, the space between bores, drilling number, the negative pressure of suction, material and technology of whole sealing. Therefore, the parameter setting must be reasonable. In this paper, we mainly discuss the influence of whole depth on the effect of gas drainage.

4. Comparison and Analysis of the Model's Pressure Chart, Streamline Diagram and Velocity Vector Chart
When the opening position is 30 and 50, the pressure on the left side is 1.01, the free flow pressure on the right side is 1, and the drainage pressure at the opening is 0.96. With the increase of the whole depth, the pressure change of the model is shown in figure 2.

It can be seen from the above charts that the pressure fluctuation of gas entering the flow field increases, the pressure gradient in the flow field increases, and the pressure at the same horizontal coordinate decreases with the increase of the hole depth. The more obvious the pressure changes in the deepest hole of the gas, the more obvious change of gas pressure in the flow field. Similarly, as time goes by, when the change of gas pressure is closer to the distance of the hole, the pressure change is more obvious in the course of the gas near the hole. The deeper the depth of the hole is, the greater the pressure changes of the gas in the whole flow field. The shallower the whole depth is, the greater the pressure is in the center of the right boundary, the pressure gradient in the center of the exit boundary increases with the increase of the whole depth.
Figure 2. Pressure chart of different whole depth

Figure 3. Streamline diagram of different whole depth
The left side pressure is 1.01, the right side free seepage pressure is 1, and the right opening position is unchanged, which is 30 and 50. The velocity streamline diagrams of the different whole depth are shown in figure 3.

Figure 3 shows from the motion pattern about the different depth of the holes that the gas flow speed is higher around the trepanning spot. Meanwhile, it’s approaching to the radial flow as closer to the edge and deeper for the hole; and the gas flow direction is changing quickly around the porthole. Gas leaves intensive flow track at the trepanning spot means it’s quicker for the flow at the porthole. With the increasing of the depth, the gas flow may form into vortex at the edge of upper right and lower right side. The gas is flow as radial direction near the porthole and layer flow in the far area. The gas leaves intensive flow track at the trepanning spot means it’s quicker for the flow at the porthole. As deeper for the hole, the gas leakage amount is decreasing on the right side; and when the depth is above 30, vortex will appear on the top and bottom edge of the right side.

When the opening position is 30 and 50, the pressure on the left side is 1.01, the free flow pressure on the right side is 1, and the drainage pressure at the opening is 0.96. With the increase of the whole depth, the gas velocity vector is shown in figure 4.

![Velocity vector chart of different whole depth](image)

**Figure 4.** Velocity vector chart of different whole depth
Comparing the velocity vector of gas in different depth flow field, it is known that the velocity vector of gas flow is the almost same in the left boundary, and it is larger at the opening. The gas flow is radial flow around the hole. The gas velocity vector in the left border increases gradually when the whole depth is increased.

5. Conclusion
In this paper, the LB method is used to simulate the gas flow during the gas drainage in the fractured coal body according to the model of the gas seepage. The different whole depth gas flow is simulated in the condition of double whole symmetry. The simulation results mentioned above can be summarized as follows:

The deeper the hole depth is, the greater the pressure changes in the whole flow field, the pressure gradient in the center of the exit boundary increases with the increase of the hole depth.

With the increase of whole depth, the gas flow velocity becomes larger and the gas exudation of the right boundary is reduced. There is a swirl at the upper and lower boundary of the right when the hole depth is above 30.

With the increase of opening depth, the change of gas velocity vector of the left boundary increases. With the increase of hole depth, the pressure changes are more obvious, the gas flow is larger, the drainage effect is better in the whole flow field.

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