Flow field and gas concentration distribution in the coal mining face and mined-out area with J-Shape and U-Shape ventilation system using Comsol

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Abstract. Under different ventilation system, the flow field and gas concentration distribution characteristics of coal mining face are different. Taking U-Shaped and J-Shape ventilation as an example, the physical model of gas flow in coal mining face and mined-out area was established by COMSOL Multiphysics multi-physics coupled analysis software. The distribution of the flow field and gas concentration in the coal mining face and mined-out area are numerically simulated. The simulation results show that, under U-Shape ventilation, there are three gas accumulation sites in the coal mining face and only one in J-Shape ventilation. And in the J-Shape ventilation conditions, can change the upper corner of the flow field, thus effectively solving the J-Shaped ventilation conditions, the upper corner of the gas accumulation problem.

1. Introduction

With the gradual extension of coal mining from shallow to deep area, three "high" and one "disturbance" (high stress, high temperature and high content of gas, and dynamic disturbance) in deep mining have become the major problems influencing coal mining safety, and particularly, gas is the biggest killer of mine safety. During coal mining, due to coal uncovering in the working face, gas in the coal wall floods into the working face. Under the air current, part of gas leak in the mined-out area from the working face and is likely to cause gas accumulation in some zones of the mined-out area and the working face, thus leads an incident of transfinite gas especially in the upper corners. The major reason for excessive gas concentration is air infiltration in the mined-out area, so air current brings the gas in the mined-out area to pour out from the upper corner of the working face. Moreover, because the air current speed is rather small in the upper corner, the gas volume taken away by it is less than that poured in from the mined-out area, thus causing excessive gas concentration around the upper corner [1-3]. One of the major measures to solve the problem is to change the direction of the air leakage so as to increase sites for leaked air to reduce the concentration of gas in the upper corner poured in from the mined-out area.

There are many researches at home and abroad on the distribution law of discharged gas in the working face, and most of the researches combine with specific mines. However, no accurate
conclusions have been reached on the distribution law of gas in the working face and the mined-out area, especially on detailed gas concentration and flow field distribution, so far [6-9]. Therefore, this paper makes numerical analysis under U-shaped and J-shaped ventilation conditions to explore the distribution law of flow field and gas concentration in the working face and the mined-out area. The research result is expected to provide theoretical basis for predicting the distribution of gas in the working face and the mined-out area.

2. Gas flow model in the working face and the mined-out area

2.1 Gas Flow Equations of Coal Face

For gas flow laws in pipes, Navier-Stokes equations work best, which can be resorted for a solution to both breeze and turbulence [10-12]. As a coal face can be approximately seen as a pipe flow, this paper employs Navier-Stokes equations as the fluid flow equations for a coal face:

\[-\nabla \cdot \eta \left( \nabla u_{ns} + \left( \nabla u_{ns} \right)^\top \right) + \rho u_{ns} \cdot \nabla u_{ns} + \nabla p_{ns} = 0 \]

(1)

\[\nabla \cdot u_{ns} = 0 \]

(2)

Where:
- \( \eta \) = viscosity coefficient, kg/(m*s);
- \( u \) = velocity vector, m/s;
- \( \rho \) = liquid density, kg/m^3;
- \( p \) = pressure;

The dependent variables of Navier-Stokes equations are velocity (u) and pressure (p), respectively, with the suffixes expressed by “ns”.

2.2 Gas Flow Equations of Goaf

The goaf teems with falling gangue, which is abundant in pores and fractures in it. In the meantime, the falling gangue is the frame to form pores and fractures. Together the pores and fractures, the gangue can be regarded as a porous medium. As the falling gangue heaps up randomly, the goaf can be considered an isotropic inhomogeneous medium field. Mixed gas flowing in a goaf is non-linear filtration and mass transfer of diffusion in a porous medium. Based on the characteristics of gas flowing in a goaf and the theories of poromechanics, a goaf can be considered as a continuous filtration space, so that the law of conservation of mass and non-linear filtration equations can be directly used for porous media.

\[-\nabla \cdot \frac{\eta}{\varepsilon} \left( \nabla u_{br} + \left( \nabla u_{br} \right)^\top \right) - \frac{\eta}{\varepsilon} u_{br} + \nabla p_{br} \right) = 0 \]

(3)

Where:
- \( \varepsilon \) = porosity;
- \( k \) = permeability.

In carrying out simulation with COMSOL software, the selection of the goof permeability size has an important impact on the air flow field and gas distribution in the coal face and goaf. In practical production, as the coal face advances, the gangue in the goaf is continuously compacted, the permeability and gangue size reducing constantly in the opposite direction of the advance of the coal face. It can be assumed that the changes of the goaf porosity (n) and the gangue size (Dp) over distance comply with the parabola law when less than 100m distant from the coal face and no changes will take place when more than 100m distant.

The relations of the gob porosity (n) and the gangue size (Dp) with the distance from the coal face are as follows:

\[ n = \begin{cases} 0.000019x^2 - 0.0038x + 0.25 & x \leq 100 \\ 0.06 & x > 100 \end{cases} \]

(4)

\[ D_p = \begin{cases} 0.000005x^2 - 0.001x + 0.1 & x \leq 100 \\ 0.05 & x > 100 \end{cases} \]

(5)

According to the Carman formula,
\[ \alpha = \frac{D_p^2}{150} \frac{n^3}{(1-n)^2} \]  

Where:

\( \alpha \) = permeability, m\(^2\)

\( D_p \) = average size, m;

\( n \) = porosity of porous media.

3. Simulation result and analysis

During the simulation, the measuring points were added at several different locations to observe the change rules of gas concentration and wind speed at different times, the layout location of each measuring point is A (-2,159), B (-28, 151), C (-19.5, 11), D (-10,80), and the layout condition is shown in Fig. 1. These measuring points respectively monitor the four positions of upper corner, the return airflow roadway near the working face, the working face close to the intake airflow roadway and the middle of the working face, and the specific results are shown in Fig. 2 and Fig. 3.

![Figure 1. layout condition of each measuring point](image1)

![Figure 2. the wind speed of each of U-shaped and J-shaped measuring points](image2)
Figure 3. the gas concentration of each of U-shaped and J-shaped measuring points

It can be seen from Fig. 2 and Fig. 3 that under the condition of U-shaped ventilation, there are three points of gas accumulation, namely the upper corner, the return airflow roadway close to the working face and the working face close to the intake airflow roadway, especially in the first two positions, the gas concentrations exceeded the standard. However, under the condition of the J-shaped ventilation, there is only one area where gas accumulates, in particular, it can improve the gas concentration accumulation condition in the upper corner, it can also reduce the gas concentration at the working face close to the intake airflow roadway, but there is not much change in the gas concentration at the working face close to the return airflow roadway. The upper corner gas concentration of the U-shaped ventilation will decrease when it reaches the peak value, but it will take long time and cannot be realized in the actual production process, however, it can be well solved in J-shaped ventilation.

The analysis of the wind flow shows that the gas concentration in the working face is inversely proportional to the wind speed, and the increase of wind speed will decrease the gas concentration. Under the condition of U-shaped ventilation, the wind speed at the upper corner is very small, but the wind speed is very large under the J-shaped ventilation condition, which solved the problem of gas over limit in the upper corner from the perspective of “open flow”. When the wind flow in the working face, the wind speed close to the center line of the working face is large, while the flow speed of the airflow near the working face and the mined-out area is relatively small.

Figure 4. the gas concentration in the special return for gas discharge

In addition to the four measuring points arranged above, a measuring point E (220,151) is set up in the second half of the special return for gas discharge, and the result obtained is shown in Fig. 4. As can be seen from Fig. 4, the gas concentration at the E measuring point is high, which can produce the accumulation phenomenon, but with the development of time, the gas concentration will drop after it
reaches its peak and eventually fall to a very low level. This can explain that the gas at point E is mainly from the mined-out area, with the continuous air leakage, the gas in the mined-out area has been transferred to the special return for gas discharge, and the gas accumulates under the effect of the airflow, resulting in high gas concentration at the E measuring point, but with gas emissions from the mined-out area, the gas concentration will eventually fall, which is consistent with the previous analysis. Therefore, the J-shaped ventilation can reduce the gas accumulation in the upper corner from the angle of “save source and open flow”, but at the same time, it will cause excessive gas concentration in the special return for gas discharge. Therefore, in the practical application of the J-shaped ventilation technology, special attention needs to be paid to avoid the over limit of the gas concentration in the terminal segment of the special return for gas discharge, the draught fans can be added to the local area to increase the flow rate of the airflow to take away the accumulated gas.

4. Conclusion
(1) Under the condition of the U-shaped ventilation, the air leakage flow in the mined-out area is eventually going to the upper corner, causing the gas accumulation in the upper corner; under the condition of J-shaped ventilation, the airflow in the mined-out area is divided into two parts, a small portion goes to the upper corner, and most of it goes to the special return for gas discharge, reducing the emission of the gas in the upper corner, the problem of gas overlimit in the upper corner is effectively solved from the perspective of the “save source”.

(2) Under the condition of U-shaped ventilation, the wind speed in the upper corner of the working face is small, and the air current cannot take away the gas accumulated here. In the case of J-shaped ventilation, the flow rate of the air current obviously increases and can take away the gas here, which solved the problem of gas accumulation in the upper corner from the perspective of “open flow”.

(3) Under the J-shaped ventilation condition, most of the gas in the mined-out area has entered the special return for gas discharge with the wind, which makes the gas concentration in the whole mined-out area significantly lower than in the J-shaped ventilation. But since the air currents from the mined-out area begin to converge, and the wind is carrying a high concentration of gas, which makes the gas concentration rise rapidly in the second half of the special return for gas discharge, causing new accumulation, therefore, it is necessary to pay attention to the gas concentration overlimit problem in the second half of the special return for gas discharge.

(4) In the U-shaped ventilation, there are three places where the gas may accumulate, the gas accumulation can be formed at the working face close to the intake airflow roadway and the return airflow roadway near the coal wall in addition to the upper corner, but in the J-shaped ventilation, because of the change in ventilation conditions, the gas accumulation at the upper corner and the working face close to the intake airflow roadway will disappear, but there is still gas accumulated at the return airflow roadway close to the coal wall, which is the only place the gas may accumulate.

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