Study on Gas Field Optimization Distribution with Parameters Adjustment of the Air Duct Outlet for Mechanized Heading Face in Coal Mine

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Abstract. At present, as the increasingly drilling dimensions with cross-section expansion and distance prolong in coal mine, the situation of gas accumulation in mechanized heading face becomes severe. In this paper, optimization research of gas distribution was carried out by adjusting parameters of the air duct outlet, including angle, caliber and the front and rear distance of air duct outlet. Mechanized heading face of Ningtiaota coal mine was taken as the research object, simulated and analyzed the problems of original gas field, the reasonable parameters range of the air duct outlet was determined according to the allowable range of wind speed and the effect of gas dilution, the adjustment range of each parameter of the air duct outlet is preliminarily determined. Base on this, the distribution of gas field under different parameters adjustment of air duct outlet was simulated. The specific parameters under the different distance between the air duct outlet and the mechanized heading face were obtained, and a new method of optimizing the gas distribution by adjusting parameters of the air duct outlet was provided.

1. Introduction
The mechanized heading face is the critical casualty area of gas explosion [1]. At present, the air duct is installed on the side wall of roadway with finite room, and the angle, caliber and the front and rear distance of air duct outlet cannot be changed at any time [2], which resulting in the limited flow path of airflow and the serious gas accumulation in the heading face. The previous research showed that the caliber and the distance between the outlet and the heading face of air duct outlet have great influence on gas field transportation [3-5], reasonable velocity of airflow is not only beneficial to gas flow, but also saving ventilation cost [6]. Also, the size of the caliber of the air duct is good for the air jets coanda effect, which can effectively reduce the gas concentration in the heading face [7]. Author has found that changing the angle of the outlet has good effect on diluting gas accumulation in heading face, therefore, optimizing the distribution of the gas field by scientific adjusting the angle, caliber and distance from the end of the air duct is proposed in this paper. The gas field optimization simulation schemes are obtained, which provides the theoretical basis for dilution of the gas concentration and the optimization of gas field distribution.

2. Establishment of Numerical Simulation Method on Gas Field
2.1. Theoretical analysis
According to the actual working environment of Ningtiaota coal mine, the existence form of airflow in the heading face is turbulent, the air flow in the air outlet is circular air jets. In order to ensure the
accuracy of the results of numerical simulation, the Realizable k-ε model [8] is selected. In the process of airflow and gas simulation, assuming that the fluid is incompressible flow, the actual air flow meeting the continuous equation and momentum equation, the gas field simulation should also meet the species mass conservation equation, and the formula is shown as (1) and (2) [9].

\[
\frac{\partial (\rho c_s)}{\partial t} + \text{div}(\rho uc_s) = \text{div}(D_s \text{grad}(\rho c_s)) + S_s
\]  

The species mass conservation equation can be expanded, and the formula (1) can be rewritten as:

\[
\frac{\partial (\rho c_s)}{\partial t} + \frac{\partial (\rho c_u)}{\partial x} + \frac{\partial (\rho c_v)}{\partial y} + \frac{\partial (\rho c_w)}{\partial z} = \frac{\partial}{\partial x} \left( D_s \frac{\partial (\rho c_s)}{\partial x} \right) + \frac{\partial}{\partial y} \left( D_s \frac{\partial (\rho c_s)}{\partial y} \right) + \frac{\partial}{\partial z} \left( D_s \frac{\partial (\rho c_s)}{\partial z} \right) + S_s
\]  

Where \( \rho c_s \) is the species mass conservation equation, kg / m\(^3\); \( D_s \) is diffusion coefficient of components; \( u, v, w \) is the component of the velocity vector in the three directions of \( x, y, z \), m/s; \( S_s \) is quality source item of gas component; kg / m\(^3\)s.

2.2. Establishment the numerical simulation model

In order to make no effects on the calculation result, the drilling machine is simplified into two parts, the geometric model is shown in Figure 1. The velocity of outlet is 8.089 m/s, the hydraulic diameter is 1m, the turbulence intensity is 2.526 %, the wall roughness constant is 0.5, the wall roughness thickness is 0.05m, and the whole is divided by a tetrahedral mesh, the total number of meshes is 910880. In the scheme establishment of gas field, the porosity is 0.2, the quality source term is 0.001 kg/(m\(^3\)·s), the gas density is 0.6679 kg/m\(^3\), the viscosity coefficient is 1.087e-05, and the gas emission source is divided by hexahedral orthogonal grid. The other calculation domains are divided into tetrahedral mesh, and the total number of grid is 630262. Others parameters settlement are consistent with the airflow field scheme.

When the outlet is 7m far away from the heading face, the wind speed at the pedestrian respiration position of the duct side and the air return side are chosen as the observation object, the average wind speed is measured per meter, and the measured data of wind speed is compared with the data of numerical simulation, the result of comparing as shown in Figure 2.

It can be seen from Figure 2 that the numerical simulation data are in good consistence with the measured data, which indicates that the simulation distribution law of airflow is similar to actual situation. The simulation scheme is accurate and feasible.

3. Analysis on Existing Problems of Original Gas Field

In this paper, the distance between the air duct outlet and the heading face 5m, 6m, 7m, 8m, 9m, 10 m of the original gas field is simulated, and taking the distance between the outlet and the heading face 5m, 7m, 10m as examples, intercepted cross sections from the heading face ( \( z = 0.2m, 0.5m, 1m, 1.5m \) ), and the obtained contour map of original gas concentration at different cross sections is shown in Figure 3.
According to Figure 3 (a), the volume of gas accumulation is one third of total volume at the heading face, the gas concentration is as high as 0.218 %, indicating that the air flow impacts to the heading face when the distance between the outlet and the heading face is too close, and the airflow in the air return side is obstructed by the air duct, which lead to the gas cannot be effectively diluted; according to Figure 3 (b), the high concentration gas area is concentrated in the upper corner and the heading face because of the gas turbulent diffusion caused by convection funnels of air and gas flow, the maximum gas concentration in the upper corner is 0.287 %; according to figure 4 (c), the distance of airflow flow gets long, the air volume at the heading face is not sufficient to effectively remove the gas out basis on the law of conservation of energy, the maximum gas concentration is 0.218 %. according to the allowable concentration requirement of gas in the coal mine safety regulation, the actual gas concentration is beyond the limit of the allowable, therefore, gas distribution needs to be optimized, optimization thought of changing the parameters of duct outlet is proposed.

4. Simulation and Optimization of Gas Field under Variation Parameters of Outlet

4.1. Determination of the reasonable parameter range of outlet
The outlet parameters adjustment and simulation analysis for air-flow field have been carried out under the different distance from the outlet, in order to ensure that the wind speed can meet the allowable speed range under the coal mine safety regulations and the eddy flow is reasonable. The results of parameter range of outlet show that when the outlet is 5m away from heading face, distance is short, adjusting the caliber range of outlet is 1.1m to 1.3m and the angle to right 5° to 8°, to up 2° to 6°; when the outlet is 6m to 8m from heading face, just adjusting the angle to right 5° to 10°, to up 2° to 3°; when the outlet is 9m to 10m from heading face, adjusting the caliber 0.7m to 0.9m and the angle to right 5° to 12°, to up 2° to 3°.

In this paper, the numerical simulation schemes design of gas field under the actual condition with 5m, 6m, 7m, 8m, 9m and 10m drilling distances are carried out. In the adjustment parameters range of airflow field, the optimization range of gas field parameters with the different distances from outlet to the heading face are obtained, as shown in Table 1.
Table 1. Determined parameter range of air duct outlet

| Different distances from the heading face | Caliber range | Angle range       |
|------------------------------------------|---------------|------------------|
| 5m                                       | 1.1-1.2m      | Right 5°-8°, up 2°-6° |
| 6-8m                                     | 1m            | Right 5°-9°, up 2°-3° |
| 9-10m                                    | 0.7-0.9m      | Right 5°-10°, up 2°-3° |

4.2. Establishment of simulation scheme under the specific parameter of outlet

According to the location of gas accumulation and the reasons of gas concentration, the specific parameter of outlet adjustment scheme is obtained. Table 2 illustrates the design of specific parameter adjustment of gas field numerical simulation scheme when the outlet is 5m, 7m and 10m from heading face.

Table 2. Parameter adjustment scheme of air duct outlet in gas field

| Different distances from the heading face | 5m                               | 7m                               | 10m                              |
|------------------------------------------|----------------------------------|----------------------------------|----------------------------------|
| Scheme 1                                 | Caliber 1.1m, right 8°          | Caliber 1m, up 3°               | Caliber 0.8m, right 12°, up 3°   |
| Scheme 2                                 | Caliber 1.1m, right 5°, up 2°   | Caliber 1m, right 10°, up 2°    | Caliber 0.9m, right 7°, up 3°    |
| Scheme 3                                 | Caliber 1.2m, right 8°          | Caliber 1m, right 8°, up 3°     | Caliber 0.9m, right 7°, up 3°    |

4.3. Simulation and Optimization of Gas Field

According to Table 2, the different adjustment schemes are simulated. Considering the effective reduction of gas accumulation, the smaller the area of high gas concentration in each cross section is better, the optimization simulation schemes under the different distances from heading face is obtained. Figure 4 illustrates some of results of simulation under the distance from heading face is 5m, 7m, 10m, the numerical simulation results of the original and optimization schemes of gas field with cross section in z = 0.2m, 0.5m are shown in Figure 4.

Figure 4. Comparison of gas concentration area size before and after optimization

As shown in Figure 4, the gas distribution of the heading face is obviously improved, through the adjustment of the air outlet parameters, the gas concentration is effectively reduced. When the distance
between the outlet and heading face is 5m, the optimized scheme is to expand caliber to 1.1m, adjust angle to right 5 degrees, to upper 2 degrees, the gas concentration reduced by 15 %; when the distance from the heading face is 7m, the optimized scheme is to adjust angle to right 8 degrees, to upper 3 degrees, the gas concentration reduced by 20 %; when the distance from the heading face is 10m, the optimized scheme is to expand caliber to 0.9m, adjust angle to right 7 degrees, to upper 3 degrees, the gas concentration reduced by 18 %.

5. Conclusions
In this paper, mechanized heading face of Ningtiaota coal mine is taken as the research object, on the basis of the results of numerical simulation analysis of airflow field, the problems of gas field in the heading face are solved, and the gas distribution got optimizing by adjusting the parameters, including the caliber, angle and the front and rear distance of air duct outlet. The main conclusions are as follows:

(1) Numerical simulation and analysis of the original gas field at different driving distances are carried out and the high gas concentration is mainly located at the upper right corner of the mechanized heading face.

(2) When the air outlet is over near the heading face, expanding the caliber of the air outlet, to make the air flow fully develop in the limited space; when the air outlet is too far away from the heading face, the caliber should be narrowed, to prolong the effective distance of air flow and reduce the gas concentration; gas concentration at the upper corner is effectively diluted by changing the angle of the air outlet.

(3) From the simulation results of the optimization schemes, when the air outlet distance from the end of 7 m, the optimization scheme makes better effects on diluting gas, the gas concentration in the heading face is reduced by about 20% obviously. Therefore, it can be considered that under the different distance from air duct outlet the parameter can be adjusted to 7 m, adjust angle to right 8 degrees, which is more effective to dilute the gas.

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Reference
[1] Zhao Bo, Shen Xiangyang, Su Yanke., 2014, “Analysis of Ventilation Technology at Long Distance Driving Face”. Coal Technology, 33 (4) 158-160.
[2] Zan Jun, Zhao Yunsheng., 2010, “Coal Mine Heading Face Limit Attachment Jet Flow Numerical Value Calculation and Result Analysis”. Industrial Safety and Environmental Protection, 36 (01) 28-29.
[3] Zhou L, Goodman G, Martikainen A., 2013, “Computational fluid dynamics (CFD) investigation of impacts of an obstruction on airflow in underground mines”. Society for Mining, Metallurgy, and Exploration, 332 505-513.
[4] Zhou L, Pritchard C, Zheng Y., 2015, “CFD modeling of methane distribution at a continuous miner face with various curtain setback distances”. International Journal of Mining Science and Technology, 25 (4) 635-640.
[5] Zhou XinMing, Tang Minbo., 2014, “Numerical simulation of forced ventilation flow field in driving face”. China Mine Engineering, 43 (05) 58-61.
[6] Jia Junbao., 2015, “Numerical Simulation Study on Impact of Air Speed on Gas Migration Rule.” Zhongzhou Coal (6) 5-8.
[7] Zan Jun, Liu Zude, Zhao Yunsheng., 2010, “Influence of Characteristic Parameters of Restricted Attachment Jet on Flow Field in Blind Drift”. China Safety Science Journal, 20 (03) 24-28.
[8] Wang, F. (2004). Computational fluid dynamics analysis. Beijing: Tsinghua University.
[9] Bear, J. (2013). Dynamics of fluids in porous media. Courier Corporation.