Design of surface drainage system in Zhangbei coal mine and forecast of gas drainage

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Abstract. In order to optimize the design of the surface well extraction system at the 11418-working face of Zhangbei Mine, the gas drainage volume at the 11418 working face of Zhangbei Mine is predicted. Based on COSFLOW numerical analysis, this paper predicts the amount of gas drainage and gas emission from the borehole of the 11218 face in Zhangbei Mine. Through the CFD simulation of the gas distribution law in the goaf of the 11418 face, the layout position of the surface well is optimized. The gas drainage test showed the gas drainage volume of the borehole in the 11418 working face of Zhangbei Mine. The research shows that the use of ground-well extraction technology in the goaf can replace the high-drainage roadway in the roof and reduce the gas drainage intensity of other measures, thereby reducing the engineering cost.

1. Introduction

Ground drilling and drainage of goaf gas is one of the most successful methods used in foreign gas drainage technology in goaf [1, 2]. This method has been successfully applied in many mines in the United States, Australia, and other countries, as well as in my country’s Tiefa Bureau, Luling Mine in Huabei Bureau, Jinmei Coal, and Huabei [3-5]. This method is usually to drill a vertical borehole with a diameter of 300mm to 450mm from the ground to the working face. The borehole is generally drilled 5m~10m above the mining layer. When the roof collapses, the borehole can be used to directly eject from a large number of cracks. Dropping gas to drain. The upper part of the drill hole is completely reinforced with casing, while the bottom part is grooved, which can prevent the drilling hole from closing due to the falling of the top plate. The number and location of ground holes should be determined according to the parameters such as the length of the working face, gas emission from the goaf and mining speed [6, 7].

2. Principles of COSFLOW numerical analysis

The three-dimensional finite element computer program COSFLOW [8, 9] was developed specifically to simulate the state of layered rock masses. The program was developed on the basis of Cosserat's continuum theory and describes the state of rock formations (discontinuous) with a continuous structure. The main advantage of the Cosserat continuum formula over the traditional continuum model is that it can effectively simulate rock failure, sliding and delamination along the layer.
2.1. Cosserat model
For rock layers with flexural rigidity, this model can be successfully established based on Cosserat theory. This allows a large-scale (average) description of the layered medium. In this model, the interlayer interface (joint) is regarded as a thin slice in the rock mass. When selecting the stress-strain model formula, the joint effect is implicitly combined. An important feature of the Cosserat model is the combination of the bending stiffness of a single rock layer in its formula, which is different from other traditional implicit models. The Cosserat model allows joints and intact rocks (rock layers) to undergo plastic deformation. The yield of rock matrix and joints is defined by the Mohr-Coulomb criterion of tensile failure.

2.2. Flow model
In the COSFLOW flow model, porous media is regarded as an entity with two types of pores; one represents continuous pore rocks (primary pores) and the other represents fracture networks (secondary pores). Therefore, the flow characteristics are described by these basic groups, namely the interaction between the pore matrix and the surrounding fracture system. Fractures provide high-speed hydraulic connections and very little storage flow, while the pore matrix provides high storage flow and low-speed hydraulic connections.

The flow model in this study can be described by Darcy’s law. Assuming that the fluid (gas/water) flow complies with Darcy’s law; the continuity requirements of each fluid phase can be expressed by the following series of formulas:

\[ \nabla \cdot q_m + Q_m + \frac{\partial}{\partial t} \left( \eta S_m \right) = 0 \]  \hspace{0.5cm} (1)

\[ q_m = -k \frac{\partial P_m}{\partial B_m} k \left( \nabla P_m - \gamma \nabla d \right) \]  \hspace{0.5cm} (2)

Among them: \( \nabla \) is the divergence factor, \( q_m \) is the volume flux or flow rate, \( m^3/s \); \( \eta \) is the porosity; \( Q_m \) is the mass transport of gas between the secondary and primary pores, \( m^3 \); \( S_m \) is the fluid saturation; \( B_m \) is the rock formation Occurrence factor; \( k \) is the absolute permeability; \( k_{rm} \) is the relative permeability; \( P_m \) is the fluid pore pressure, MPa; \( \gamma \) is the fluid bulk density, N/m\(^3\); \( t \) is time; \( \mu_m \) is the viscosity coefficient; \( \nabla d \) is from a given base point Distance, m.

The volume of gas adsorbed in the coal matrix can be described by the Langmuir adsorption isotherm as follows:

\[ V = \frac{V_L P_m}{P_L + P_m} \]  \hspace{0.5cm} (3)

Among them: \( P_m \) is the pore pressure, MPa; \( V \) is the gas adsorption volume at \( P_m \) pressure, \( m^3 \); \( V_L \) is the Langmuir volume, the maximum gas volume that can be adsorbed, \( m^3 \); and \( P_L \) is the pressure when the adsorbed gas volume is half of \( V_L \).

Mass delivery can be expressed by Fick’s law:

\[ \frac{D}{r^2} \frac{\partial}{\partial r} \left( r^2 \frac{\partial c}{\partial r} \right) = \frac{\partial c}{\partial t} \]  \hspace{0.5cm} (4)

Among them: \( D \) is the diffusion coefficient of micropores; \( c \) is the gas concentration kg/m\(^3\); \( r \) is the radius distance from the center of the sphere, m.

2.3. Simulation of gas drainage in borehole of 11418 working face in Zhangbei Mine
(1) Coal seam geological conditions
The 11418 working face for the ground borehole extraction test this time is the first mining face of Zhangbei Mine, with a working face width of 240m and a length of 1320m. No. 8 coal seam mined is 3.2m thick. Coal seam is inclined upward by 2°~3°.

The overlying strata on the working face are mainly thick Quaternary sedimentary rocks. From the ground to the bedrock, they are 400m thick Quaternary sedimentary rocks, with developed aquifers,
faults and complex geological structures. Quaternary sedimentary new strata and aquifers are developed, which is not conducive to drilling holes, so in-depth analysis and optimization of drilling design are needed.

(2) Simulation conditions
The model aquifer is from the top of the 12th layer to the bottom of the 2nd layer. A pressure of 1.0 MPa was applied on the top of the 12th layer, so that the accumulated pressure of the mined No. 8 coal seam was 2.5 MPa. Similarly, the corresponding finite element is deleted every 40m to simulate the working face mining process. The model built simulates a 20-step longwall face with a total length of 800m.

(3) Analysis of simulation results
When the working face length is 180m, the predicted gas emission flow is about 20~30 m$^3$/min, and when the working face length is 240m, the flow rate increases to 40~50 m$^3$/min. The predicted total gas emission is between 40 and 50 m$^3$/min. The gas emission data observed during the mining of the working face is in good agreement with the predicted value.

The gas coming to the working surface predicted with COSFLOW. When the working face length is 180m, the predicted gas emission flow is about 20~30 m$^3$/min, and when the working face length is 240m, the flow rate increases to 40~50 m$^3$/min. The predicted total gas emission is between 40 and 50 m$^3$/min. The gas emission data observed during the mining of the working face is in good agreement with the predicted value. The initial gas extraction volume of the 14118-2 borehole predicted by the model fluctuates from 10 to 20 m$^3$/min. After the working face is pushed through the borehole by 100 m, the extraction volume increases to 40 m$^3$/min.

3. CFD simulation of gas distribution law in goaf of 11418 working face

3.1. Gas distribution in goaf of 11418 face
The main simulation parameters are shown in Table 1.

| Model parameters                          | Parameter value                         |
|------------------------------------------|-----------------------------------------|
| Working surface size                     | Length 580m, width 180m, height 3.0m   |
| Roadway size                             | 4m wide and 3.0m high (12m2)            |
| Coal seam tilt                           | 3°                                      |
| Ventilation system air volume            | "U" shaped ventilation, 2600 m$^3$/min  |
| Gas emission from mined-out area         | The whole mined-out area 45 m$^3$/min   |
| Gas composition                          | 100%CH$_4$                              |

The model was used to simulate and predict the gas distribution law of the mined-out area at the level of the mining layer. The results show that the amount of oxygen entering the mined-out area is very high, especially on the machine side of the working face. The results show that the oxygen concentration on the air inlet side 300m behind the working face can exceed 12%. On the return air lane side, there is oxygen accumulation 150m behind the working face, which is consistent with the data measured on site.

On this basis, the second section of the 11418 working face was simulated, and the results showed that the maximum gas concentration on the return air lane side of the goaf can reach 80%. This shows that if the ground goaf gas drainage holes are arranged 20 to 70 m away from the return air lane, high concentration goaf gas can be extracted. This understanding is very important for optimizing the design of gas drainage boreholes in the ground goaf and for designing the gas drainage system in the goaf and achieving a better drainage effect.
3.2. Gas distribution in the goaf of 11418 working face under the condition of borehole extraction

CFD was used to simulate a variety of different situations to analyze the ability of ground boreholes to extract goaf gas and the overall goaf gas distribution law[10, 11]. The boreholes in the mined-out area are opened separately, and a 40-60 kPa negative suction pressure is applied at the wellhead.

When the borehole in the mined-out area works at medium extraction negative pressure (40～60kPa), after the working face is pushed through the borehole, the available gas flow is 20～40m³/min, and the concentration is 80%. The extracted oxygen concentration is 2 to 7%, and it is expected to maintain a stable extraction flow rate.

When the two boreholes are working at the same time, more oxygen will enter the goaf and pumping system. The oxygen concentration of the goaf gas obtained by drilling the goaf close to the working face will be very high. The placement of boreholes in the mined-out area close to the working face is conducive to controlling gas overrun at the upper corner.

4. Gas drainage amount of borehole in 11418 working face of Zhangbei Mine

4.1. Design of ground drilling in 11418 working face of Zhangbei Mine

The design purpose of the ground goaf drilling is to obtain an efficient ground goaf drilling extraction system, which can extract more high-concentration gas. This requires optimized design of ground drilling according to design specifications, and careful construction and optimization of drilling [12].

(1) Drilling position

The results of numerical simulation show that, to a certain extent, it is beneficial to extract gas when the borehole is close to the upwind side of the goaf to prevent air from being drawn into the borehole. Considering that a large amount of oxygen enters the working face in Zhangbei Mine and it takes a long time to goaf extraction, the drill hole is arranged at a distance of 20-70m from the return air level roadway.

(2) Drilling diameter

The borehole diameter is designed based on the numerically predicted goaf area extraction volume, working face depth and extraction pumping station capacity. Therefore, the inner diameter of the borehole used is about 250mm, and the designed total drainage flow is 30m³/min.

(3) Drilling casing and forming holes

The length of the surface casing and the double casing should not be less than 400m, that is, penetrate the entire Quaternary system, so as to reduce the risk of groundwater influx into the borehole. Drill a hole 5m above the mining layer and keep the bottom of the hole open.

(4) Length of slot tube: Considering the weak layer in Zhangbei Mine, it was decided to extend the overall length of the casing and shorten the length of the slot tube to 40m.

(5) Number and spacing of drill holes: The number and spacing of drill holes depend on the specific location conditions, expected gas emission level, working face length and mining speed. Considering the amount of gas emission from the goaf, numerical simulation results, and the possibility of taking other extraction measures, arranging 3 to 4 ground boreholes with a borehole spacing of approximately 300m will be sufficient to ensure that the 14118 working face is effectively Gas drainage effect.

(6) Extraction negative pressure: The optimal extraction negative pressure should be determined through experiments and monitoring of gas flow, stability and purity in the extraction system. This requires detailed and careful monitoring of the gas concentration and the ability to quickly adjust the suction negative pressure. Numerical simulations show that the 40～60kPa extraction negative pressure will achieve the best results.

4.2. Investigation on borehole drainage effect in goaf of 11418 working face in Zhangbei Mine

(1) The effect of ground drilling and extraction in the goaf of 11418 working face

After the completion of the ground drilling construction and the formation of the extraction system, with the continuous advancement of the working face, we conducted a field inspection of the extraction situation of the two surface boreholes. The main investigation contents include: the extraction
concentration, the extraction flow rate, the total extraction amount and the extraction negative pressure (50 ~ 60kPa). Table 2 shows the results of borehole extraction.

### Table 2. Investigation results of ground drilling and extraction effect in 11418 face of Zhangbei Mine.

| Time (days) | 1# drilling | 2# drilling |
|-------------|-------------|-------------|
|             | Gas concentration (%) | Total low (m³/min) | Gas pure volume (m³/min) | Daily extraction volume (m³) | Gas concentration (%) | Total flow (m³/min) | Gas flow (m³/min) | daily extraction volume (m³) |
| 1           | 52          | 65          | 33.8          | 28392.0       | 32.0          | 63.0          | 20.2          | 29030.4       |
| 2           | 48          | 59          | 28.32         | 30585.6       | 60.0          | 54.9          | 32.9          | 47433.6       |
| 3           | 48          | 59          | 29            | 31104.0       | 83.0          | 38.0          | 31.5          | 45417.6       |
| 4           | 45          | 60          | 27            | 35640.0       | 85.0          | 8.9           | 7.6           | 10944.0       |
| 5           | 65.0        | 40.0        | 26.0          | 37440.0       | 83.0          | 11.0          | 9.1           | 13104.0       |
| 6           | 60.0        | 24.0        | 14.4          | 17280.0       | 68.0          | 17.0          | 11.6          | 6646.4        |
| 7           | 60          | 35          | 21.0          | 22680.0       | 75.0          | 13.4          | 10.1          | 14544.0       |
| 8           | 60          | 35          | 21.0          | 25200.0       | 45.0          | 14.9          | 6.7           | 9246.0        |
| 9           | 60          | 32          | 19.2          | 25344.0       | 45.0          | 14.9          | 6.7           | 9246.0        |

It can be seen from Table 2 that within 9 days of normal extraction of No. 1 borehole, the gas concentration of the borehole was 45 to 65%, the extraction flow rate was 14.4 to 33.8 m³/min, the total amount of gas extracted was 260114.5 m³, and the average gas extraction concentration was 55.3%, the average drainage flow rate was 24.4 m³/min, and the average daily extraction volume was 35136 m³. The extraction effect is very significant. 2# borehole gas drainage lasted for 8 days, the maximum gas drainage volume reached 32.9 m³/min, the concentration reached 85%, and a total of 176366 m³ gas was drilled.

(2) Effect of surface well extraction on gas concentration in top-draining roadway and gas concentration in return air flow

From Table 2, we can see the effect of the drainage of hole 1# in the ground goaf on other gas drainage methods and the gas concentration in the return air flow. In the process of ground drilling 14118-1, the gas concentration of the roof drilling and roof roadway has been reduced, especially the gas concentration of the roof drainage roadway fell to less than 6%. Drilling on the ground After the well is closed, its concentration rises again and increases to the peak again. At the same time, it can be seen that during the extraction process of surface well No. 1 borehole and for a period of time afterwards, the gas return air flow at the working face is significantly lower than before and after.

During the borehole test in the goaf, the extraction rate increased to 75%, which exceeded the target of 70%. During the normal work of drilling, the negative pressure is kept in a reasonable and stable range of 50 ~ 60kPa. Based on this observation, the negative pressure of extraction in this range can ensure that a single borehole reaches a stable extraction flow rate and concentration.

The test results show that during their work, both ground boreholes produced a large flow of gas, with an average of 10-15 m³/min, and the peak flow exceeded 20 m³/min. The gas concentration in the borehole is also quite stable, with an average of 60-75%, and the maximum value is 85%. Secondly, the use of ground drilling for gas extraction in the goaf has an important impact on the gas control of the working face, which can significantly reduce the dependence on other gas extraction methods.

### 5. Conclusion

(1) COSFLOW's predicted value of gas emission from the longwall face of Zhangbei Mine is 40-50 m³/min, which is consistent with the actual measurement results on site. The COSFLOW simulation results show that the single-hole gas drainage volume in the test face can reach more than 30 m³/min. Therefore, the optimal design drilling diameter is 250 mm.

(2) The results of CFD simulation show that the influence radius of extraction is 100-150 m, so the designed drilling interval is 200-300 m. A gas enrichment zone is formed on the return air lane side with a concentration of 70 to 80%. Therefore, it is designed to arrange surface drilling within a range of 20 to 70 m from the return air side to facilitate gas extraction.
(3) Under the test conditions, the single-well gas drainage pure volume is 10-25m3/min. After adopting ground drilling and drainage measures, the gas drainage rate of the mining face has reached 75%, and the gas concentration of the mining face has been reduced by more than half (0.2 to 0.3%), which has achieved obvious application results. Therefore, the use of ground extraction technology in the mined-out area can replace the roof high-drainage roadway, and reduce other measures of gas extraction intensity, thereby reducing engineering costs.

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