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Numerical Simulation Study of High-Level Directional Long Borehole

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Abstract: In order to extract gas from the working face, optimize the layout scheme of high-level gas extraction boreholes, and improve the efficiency of gas extraction in goaf and upper corner, taking Shoushan No.1 Mine as the research object, according to the ' O 'ring theory and the ' vertical three-zone ' theory of the working face, the appropriate extraction horizon is selected to arrange the extraction boreholes, and the fluid-solid coupling numerical model of gas extraction in coal-rock system is established for simulation verification. The research shows that the high-level directional long borehole is arranged in the upper three zones of the coal seam. The borehole is arranged at a vertical distance of 30 m from the roof of the coal seam and a horizontal distance of 60 m from the wind lane of the working face. The gas pressure in the mining area can be reduced to less than 0.6 MPa specified in Henan Province within 70 days, which can effectively extract the gas from the working face and ensure the safe production of the coal seam.

Keywords: Directional Long Drilling; Gas Extraction; Upper Three-band Height; Numerical Simulation.

1. Introduction

In recent years, with the continuous improvement of coal mining depth and intensity, the gas concentration and pressure in the working face and coal rock roadway have also increased. At present, the scene in order to solve the problem of upper corner gas overrun mainly has the following methods: install the corner windshield curtain, increase the mining face air volume, digging high measures such as lane, although this kind of technology can effectively control the gas overrun problem in the upper corner, it may increase the risk of coal spontaneous combustion due to the increase of air leakage in the goaf [1~2]. Therefore, the arrangement of the "three vertical belts" on the roof of the high gas mine is beneficial to alleviate the problem of gas overrun in the working face [3~4]. In view of the influence of the stability of large aperture directional drilling on gas extraction, [5] et al. revealed the negative correlation between the drilling aperture and the stability of surrounding rock, which can realize the stable gas extraction effect. Based on the evolution theory of overburden fissure, [6] et al. adopted the method of combining physical similarity simulation and field test to reveal the dynamic evolution law of mining overburden fracture zone and gas enrichment migration zone. Through theoretical prediction, numerical simulation and comprehensive measurement methods of drilling and water injection, [7] et al. revealed the relationship between the migration of overlying rock mass and the spatial development under the condition of large mining and width. Zhangcun [8] et al. used a multi-method fusion system combining empirical formula, numerical simulation and field measurement, revealing the coordinated development law of large height and wide rock; Liu Zhigao [9] et al. revealed the migration law of inclined coal seam covered rock, pointed out the stress concentration effect, and established a quantitative characterization model of the development height and water guide characteristics; Guo Ruirui [10] et al. analyzed the dynamic movement characteristics of covered rock and the evolution mechanism of multiple materials.

In order to improve the efficiency of coal system gas extraction, the author based on the "O" ring around the goaf theory, and the roof of mining face "vertical three zones" crack development theory and rock properties, choose the high directional long drilling layer, and use comsol numerical model to verify the extraction effect, provide reference for extraction drilling under similar conditions.

2. Overview of the Test Working Face

Henan Pingbao Coal Industry Co., Ltd. (hereinafter referred to as "Shoushan No.1 Mine") working face $_{15\text{-}17}$-12120 is located in the first section of the west wing, $_{15\text{-}17}$-12120 working face 1857m, 255m long coal seam, $_{15\text{-}17}$ coal structure is primary coal, $_{15\text{-}17}$ coal thickness of ~ 2.8 ~ 7.2m, 5.5m, average coal thickness is relatively stable, generally in 5°~ 12°, average 8°.

The measured maximum original gas pressure of the coal seam in $_{15\text{-}17}$ coal seam is 1.35MPa, and the measured maximum original gas content of the coal seam is 10.34m3/t. According to the outburst danger grade, it belongs to the coal and gas outburst working face. The $_{15\text{-}17}$-12120 working face is stratified coal in the left half of the working face, and the cutting end of the right half is stratified coal, with a small amount of sandstone in the middle. The pseudo top of $_{15\text{-}17}$-12120 working face is 0.8m thick dark gray mudstone, which is easy to break. The direct roof of coal seam is medium thick layered mudstone and sandy mudstone, and the lower part is gray mudstone, with a general thickness of 3.5m. The basic top is mainly large-occupied sandstone and sweet charcoal sandstone section, with a thickness of 34.3 ~ 57.8m, and the rock mass integrity is relatively complete. The direct floor is gray mudstone with a thickness of 4.2 ~ 5.6m, which is a soft floor.

The bar chart of working coal rock is shown in Fig 1:

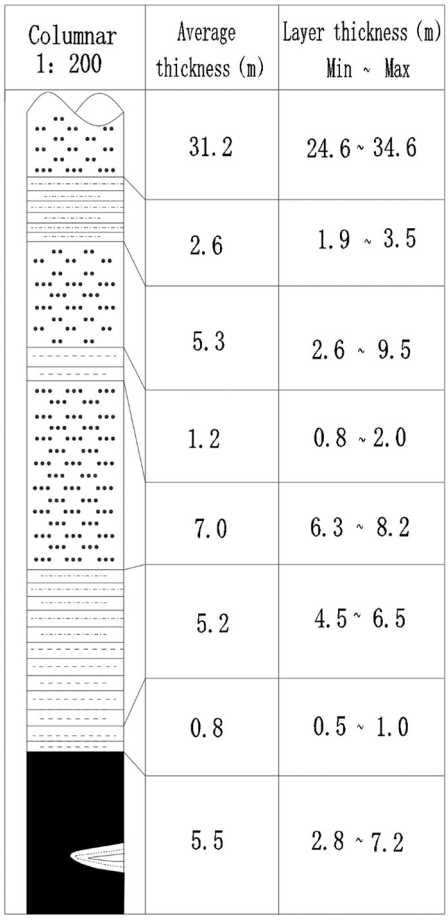


Figure 1. Column chart of coal rock of working face $_{15\text{-}17}$-12120

3. Level Selection

The thickness of coal seam in $_{15\text{-}17}$ is about 2.8~7.2m, and the average thickness of coal seam in $_{15\text{-}17}$-12120 working face is about 5.5m. Considering the lithology of 12120 in the roadway tunneling, the roof is mostly hard sandstone and hard mudstone. According to the Interim Provisions on the Design Management of Directional Long Borehole issued by Pingmei Group, the general layout of directional long borehole of high roof is 6~12 times of the mining height. According to the height of the height of hard lithology fracture zone and fracture zone (1) (2), the maximum height range of the roof fracture zone and fracture zone is calculated as follows:

Maximum height range of falling zone:

$$= H_{m1} = \frac{100\sum M}{4.7\sum M + 19} \pm 2.2 \ 6.86\text{~}11.2 \qquad (1)$$

Where: - H_{m1} falling band height

- M Meverage coal thickness

Maximum height range of the slit band:

$$= H_{m} = \frac{100\sum M}{1.6\sum M + 3.6} \pm 5.6 \ 30.1\text{~}41.31 \qquad (2)$$

Where: - H_{m2} fissure band height

In general, the high extraction drilling is selected at the upper part of the fall zone and the lower part of the crack zone. Meanwhile, considering the feasibility of directional long drilling construction, the inclination Angle of the directional drilling construction cannot be too large, so the vertical layer is selected at 30m vertical distance from the coal seam roof.

In addition to considering the layer layout of the directional long borehole in the vertical direction of the coal seam, the horizontal position of the borehole is arranged in the detached layer area inside the roof clad rock relief angle of the goaf according to the "O" ring theory. Combined with the actual situation of the working face, the working face tends to be too long, and the gas near the wind lane of the working face is preferentially extracted from the high directional long drilling hole of the wind lane. Therefore, the drilling hole is arranged in 1 / 4 of the working face, and the flat distance from the wind lane is set at 60m.

In summary, the high gas interception and extraction drilling hole is arranged at the lower level of the maximum height of the crack zone of the coal seam roof, 30m away from the coal seam roof and 60m away from the flat distance of the wind lane.

4. Gas Extraction Flow-Solid Coupling Model and Numerical Simulation

In the determination of the first mountain mine mining coal seam and the existing theoretical formula, establish the coal system gas extraction flow-solid coupling numerical model, combined with the characteristics of mine coal system structure, to select the layout of drilling gas extraction simulation, verify the rationality of drilling layout, guide and modify the field construction, for high directional long hole "to hole lane" gas extraction, has important guiding significance.

4.1. Gas Extraction Flow-solid Coupling Model

4.1.1. Gas Transport Equation

The equation for coal seam gas transport is:

$$\frac{\partial}{\partial t}\left[\frac{M_g p}{RT}\varphi+(1-\varphi)\rho_{ga}\rho_c V_{cg}\right]+\nabla\left(-\frac{M_g pk}{RT\mu}\nabla p\right)=0$$

Where: M_g - -the molar mass of the gas, the kg/mol;

- R -Gas mole constant, J / (mol · K);
- T -Coal seam temperature, K;
- p -Gas pressure, and Pa;
- — φ porosity;
- ρ_{ga} -Gas density in the standard state, and kg/m3;
- k The permeability, m3;
- μ -The dynamic viscosity coefficient of methane, Pa * s;
- V_{cg} -The volume of gas adsorbed by unit mass coal is m3/kg;

4.1.2. Seam Stress Field Equation of Coal Seam

The control equation of gas transport stress field in coal seam is:

$$Gu_{i,jj}+\frac{G}{1-2v}u_{j,ji}-\alpha p_i-K\varepsilon_{s,i}+F_i=0$$

Where: - $u_{i,jj}$ The $u_{j,ji}$ component of the coal in all directions

- K -Coal body volume modulus, Pa
- α -Coal body Biot coefficient
- $\varepsilon_{s,i}$ -The adsorption strain in the direction of the i
- — F_i body force, Pa
- v Coal body Poisson ratio

4.1.3. Coupled between Porosity and Permeability

Coal porosity:

$$\varphi=1-\frac{1-\varphi_0}{1+\mathrm{e}}\left(1-\frac{\partial}{K}\Delta p+\alpha_{sg}\Delta V_{cg}\right)$$

Coal body permeability:

$$\mathrm{k}=\mathrm{k}_0\left[\frac{1}{\varphi_0}-\frac{1-\varphi_0}{\varphi_0(1+\mathrm{e})}\left(1-\frac{\alpha}{K}\Delta\mathrm{p}+\alpha_{\mathrm{sg}}\Delta\mathrm{V}_{\mathrm{cg}}\right)\right]^3$$

4.2. Numerical Simulation

4.2.1. Geometrical Model and Simulation Parameters

Shoushan a mine for coal and gas outburst mine, mining geological conditions are relatively simple, has $_{15\text{-}17}$ main coal seam, coal seam thickness 2.8-7.5m, average thickness of 5.5m, the gas occurrence condition is complex, the original gas content is high, access to the first mine geological data, in $_{15\text{-}17}$-12120 working face goaf roof rock sample measurement related key physical parameters as shown in the following table:

Table 1. Parameter table of coal strata

stratum	Gas pressure is in MPa	Penetration / m^2	porosity
Mid-particle sandstone	0.45	2.91×10-16	0.015
mud stone	0.26	1.2×10-16	0.011
malmstone	0.35	2.1×10-16	0.018
mud stone	0.22	1.3×10-16	0.015
post stone	0.42	1.92×10-16	0.027
Direct top mudstone	0.49	0.67×10-16	0.013
$_{15\text{-}17}$ Coal seam	1.35	2.6×10-16	0.034

In order to optimize the efficiency and reliability of numerical simulations, we aim to simplify the actual 3 D structure to 2 D structure. With the coal seam data and the adsorption capacity of the coal sample, the flow-solid coupling gas extraction model of the $_{15\text{-}17}$-12110 and the nearby strata of Shoushan one mine was settled based on COMSOL Multiphysics software. The physical model of coal rock in Shoushan one mine is shown in the figure. The physical model size is length * width =80m * 50m, and the model boundary has no flow.

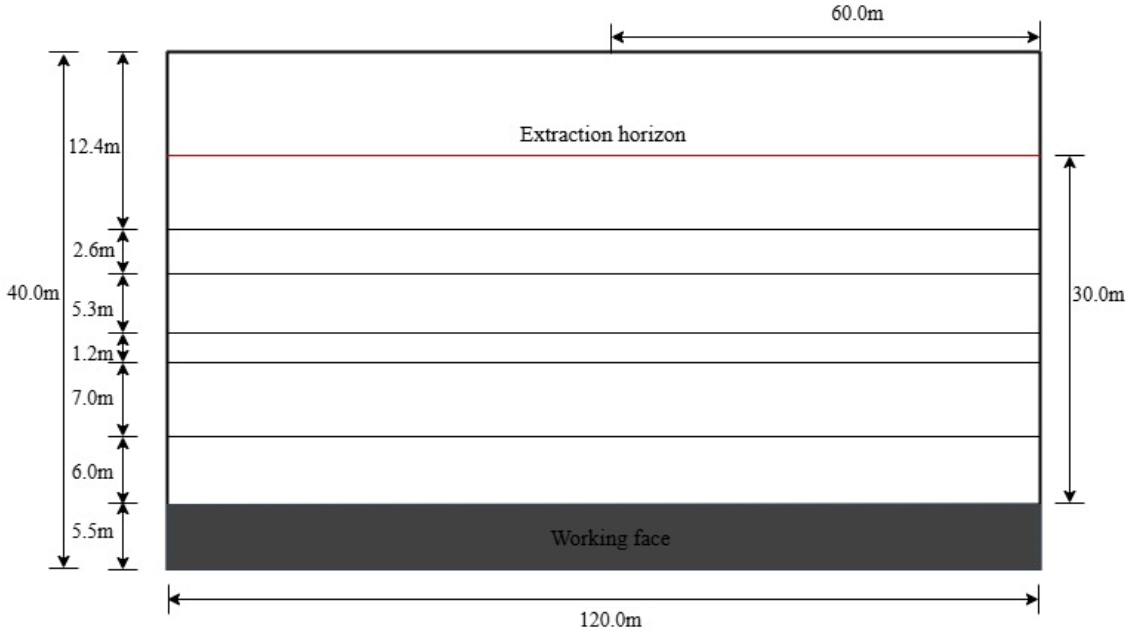


Figure 2. Physical model size diagram

Table 2. Table of simulated parameters

name	price	unit
Adsorption constant a	23.5	
The adsorption constant b	0.79	
Initial porosity	0.034	
Strong coefficient	0.45	
Initial gas pressure	0.74	MPa
Poisson ratio	0.32	
Draft negative pressure	-20	kPa
unit weight	1.4	t/m3

4.3. Analysis of the Simulation Results

In order to realize the efficient extraction of high-level extraction drilling and ensure the safe production of the mine, this paper is arranged according to the high-level directional drilling parameters designed in the second chapter, studies the gas extraction effect of this layer, and verifies the rationality of extraction to guide the design of high-level extraction drilling in the mine.

First mountain a coal gas extraction system numerical simulation as shown in Figure 3, figure 4, with the extraction activities, the coal seam gas pressure gradually decreased, in the gas extraction time of 30d, the coal seam gas gradually to the coal seam gas displacement, the extraction time reaches 70d, the drilling extraction influence area has reached the simulation area, as the overall gas pressure gradually smaller, and the gas flow speed is slow, achieve good pressure relief effect.

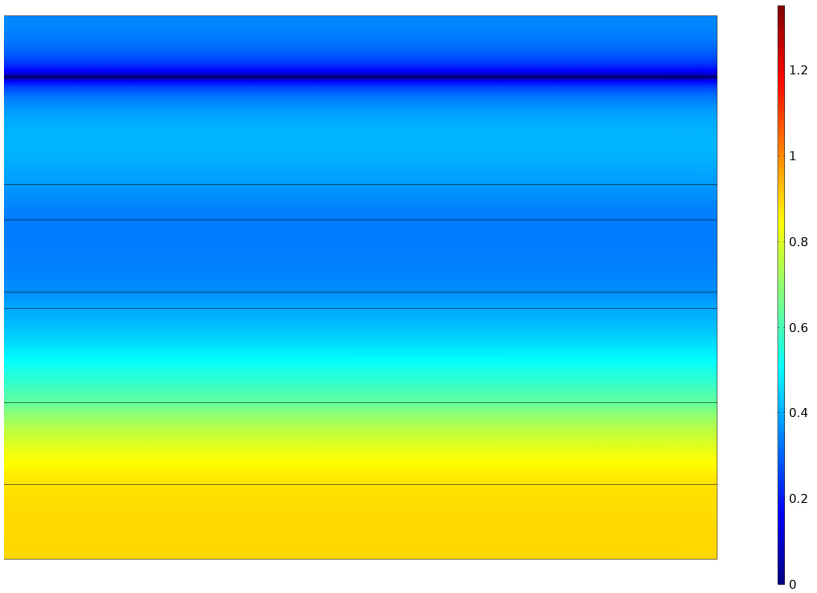


Figure 3. Gas pressure cloud drawing of 30 days

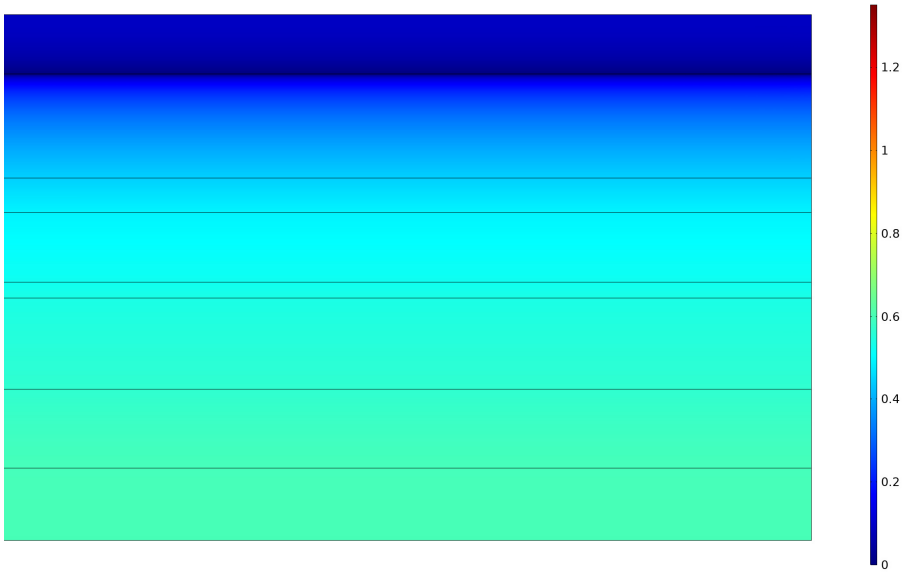


Figure 4. Cloud drawing of 70 gas days

Through the gas pressure cloud diagram, it can be concluded that after 10 days of extraction, the gas pressure of the coal seam is reduced to about 0.5 MPa, and after 70 days, the gas pressure of the coal seam is reduced to 0.32 MPa. The high-level directional long gas drainage borehole is designed at a distance of 30 m from the roof of the coal seam and a horizontal distance of 65 m. It can efficiently extract the gas of the coal seam in the early stage of the mining disturbance. With the advancement of the mining face, the mining area gradually advances outside the influence range of the borehole, the gas pressure drop rate of the coal seam gradually slows down, and the extraction speed and extraction amount

gradually decrease. Therefore, it is considered that the arrangement of extraction boreholes in the layer of 30 m from the roof of the coal seam and 65 m from the horizontal distance can effectively extract the gas from the working face and ensure the safe production of the mine. Considering the effect of coal and rock pressure relief and the total amount of gas extraction, multiple extraction boreholes should be arranged near the horizon to increase the extraction efficiency and avoid the influence of poor drilling quality on the extraction effect due to geological conditions, improper construction and other factors.

5. Conclusion

(1) In view of the high pressure of the return wind gas during the coal seam recovery, it is proposed to use high directional long drilling to arrange the three belts on the coal seam, and select the drilling hole 30m from the roof of the coal seam and 60m from the wind roadway, which can reduce the gas pressure in the mining area to below 0.6MPa stipulated in Henan Province within 70days.

(2) Based on the mining fracture, permeability evolution and gas seepage law of coal and rock in working face, the theoretical model of stress-gas seepage of coal and rock mass disturbed by mining is constructed. Based on this, the pre-simulation of extraction effect is carried out by comsol numerical simulation. The results are consistent with the empirical formula, which can effectively extract coal seam gas and provide reference for similar coal seam gas control.

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