Study on Optimal Parameters Optimization of High Drilling Field Based on the Theory of “Three Vertical Zones” of Overlying Strata

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Abstract. In order to make gas accumulation at the corner of 2106 working face safer, this paper analyzes the mechanism of high-level boreholes field when eliminating the gas accumulation of upper corner using theoretical analysis, numerical simulation and field measurement method, calculates the optimal position of high boreholes based on the theory of “three vertical zones” of overlying strata, and verifies the corresponding numbers using FLAC3D software. In this way, this paper optimizes the optimal layout parameters of the high-drilling field through on-site inspection and eliminates the danger caused by the gas accumulation in the upper corner.

1. Introduction
The present solution to the danger caused by the gas accumulation in the upper corner [1-2] in the fully mechanized mining face is to arrange high boreholes for gas drainage. However, many mines have low extraction rates due to unreasonable horizon selection and short drilling time. Therefore, it is a must to clarify the evolution law of the overburden fracture field and find the optimal layout of the high-drilling site in order to improve the gas drainage efficiency of high boreholes, maximize the drainage of unloading gas, and accurately control the risk of gas overrun in the working face, thus optimizing the layout parameters of high-drilling sites and make gas extraction in mines more efficient.

2. Overview of the mine
Please follow these instructions as carefully as possible so all articles within a conference have the same style to the title page. This paragraph follows a section title so it should not be indented[2-3].

The annual production capacity of a mine is 3 million tons, mainly including inclined shaft development and central side-by-side ventilation. It mainly mines 2# and 10# coal seams. It is now quarrying the 2# coal seam located at a mining level of +290 m, with an average depth of 6 m, a coal seam dip angle of 3-6°, and a depth of -560 m. It has been measured that the absolute gas emission of the mine is 59.67 m³/min, the relative gas emission is 8.43 m³/t, the absolute gas emission of the coal mining face is 19.58 m³/min, and the absolute gas emission of the driving face is 21.07 m³/min. Further measurement result of the parameters of the 2# coal seam is shown in Table 1.
Table 1. Coal seam gas parameters

| Coal seam number | Coal Seam Gas Content (m³/t) | Bulk density (t/m³) | Gas pressure (MPa) | Adsorption constanta (m³/t.r) | Adsorption constantb (MPa⁻¹) | Consistent coefficient | Permeability coefficient (m²/MPa²•d) |
|------------------|-------------------------------|---------------------|-------------------|-----------------------------|----------------------------|------------------------|------------------------------|
| 2#               | 7.53                          | 1.40                | 0.71              | 29.764                      | 0.681                      | 0.60                   | 0.023                         |

The 2106 working face being quarried is arranged along the 2# coal seam with an average dip angle of 5°, a strike length of 1160 m, and a propensity length of 205 m. It adopts the fully mechanized top coal caving method. As mining proceeds, the direct roof falling to the goaf, and the overlying fracture formed by mining becomes a channel for gas migration. When there is air leakage, part of it is mixed with the air flow in the goaf; in this way, the free gas in the goaf is taken out of the working surface and accumulates in the upper corner.

In addition, since the density of gas is lower than that of air, it produces the floating buoyancy as it flows, leading to the continuous upward movement of the gas in the goaf, thus resulting in an increase of gas emission in the upper corner.

The gas aggregation in the upper corner causes major safety concerns for the 2106 working face, thus it is imperative to adopt a high-level boreholes extraction process for controlling gas in the upper corner. However, in practical engineering, due to the differences in occurrence conditions of actual coal seams, problems such as inappropriate horizon selection, short drilling duration, and fast attenuation and inefficiency may occur.

3. Mechanism of high-level drilling and extraction

Influenced by quarrying of the 2106 working face, the overlying coal rock gradually broke, generating a large number of transverse and longitudinal cracks, which are divided into “horizontal three zones” and “vertical three zones” based on the movement of the overlying strata [3-5]. As shown in Figure 1, the overlying coal rock is divided into the affected area of coal wall supporting, the separated layer area and the re-compacting area along the direction of the working face while the vertical coal rock is divided into the bending zone, the fracture zone and the coving zone.

![Figure 1. Overburden zone and goaf zone of mining face](image)

The primary and secondary fissures caused by quarrying are not only the gathering place when the gas completes migration, but also the channel for gas movement. Mastering the distribution law of the fracture zone in Figure 1 will provide a theoretical basis for the layout parameters of the extraction drilling, thus improving the drilling and extraction efficiency. At present, based on the current situation of gas accumulation at the upper corner of the 2106 face and the space-time law of the distribution of the fracture zone, the directional roof-side high-drilling is selected for directional drainage to achieve effective interception and the relief of the large amount of gas released due to quarrying. The gas migration law changes because of the negative pressure of the borehole. As a result, a large amount of gas that is supposed to enter the working surface will enter the borehole, reducing the gas inflow pressure, thereby solving gas overrun problem of the upper corner in the working face, as shown in Figure 2. The layout principles of the high borehole are: 1) ensure strong permeability ability of the regional coal rock; 2) ensure that the borehole is less affected by quarrying.
Specifically, the longitudinal parameters of the high borehole are generally set based on the height of "three zones" the overlaying rock on the working face. The final borehole should be placed between the falling belt and the fracture belt, which can refer to the calculation formula as follows.

\[
\frac{m}{(R-1) \cos \alpha} < H_2 < \frac{100 \sum m}{2 \sum m + 16} \pm 2.5
\]

(1)

In the formula, \(m\), \(M\) are heights of the coal seam and the working face; \(m\), \(k\) is the average expansion coefficient of the fallen rock, which is 1.06 in this paper; \(\alpha\) is the dip angle of the coal seam.

Substitute the above parameters into Formula (1), it is obtained that the high borehole can be arranged within the region 51.3 m away from the 2# coal seam.

4. Numerical simulation of working face mining

Based on the above analysis of the mechanism of high-level boreholes [7-9] to control the gas in the upper corner, further analysis and calculation is conducted to decide the optimal position of the high borehole. However, in order to reflect the optimal three-dimensional horizon of the high borehole more clearly and comprehensively, this paper uses the FLAC3D numerical simulation software to dynamically simulate the distribution of stress of the overlying strata and the distribution law of the plastic zone during the quarrying of 2106 working face, thus providing the basis for the layout of high boreholes.

According to the actual occurrence condition of 2# coal seam and the layout characteristics of 2106 working face, the size of the model is set to 350 m × 1300 m × 70 m with the parameter SZZ of the topmost assignment of 13.25 MPa after eliminating the boundary influence range of working face. As shown in Figure 3, the longitudinal distance between the 2# coal seam and the top of the model is 59 m.

Figure 3. Model schematic

Reserve sufficient boundary conditions at the left and right sides of the 2# coal seam; Figure 4 shows the stress distribution when the 2106 working face is quarried for 300 m.

Figure 4. Stress nephogram of 2106 working face mining 300m

As shown in Figure 2, directional drainage of the upper corner gas is implemented in the high boreholes in the low-stress zone so that is will not be affected by quarrying. In addition, the coal rock in this area is still in the state of elastic deformation, so the final hole in the high drill field is still in the elastic zone, thus ensuring the intactness of the borehole. As shown in Figure 2, the low-stress zone of the overlying strata above the goaf of the 2108 working face is still a fissure development zone. When the high borehole is constructed in the low-stress zone, the porosity of the surrounding rock is greatly increased under the influence of quarrying. A large amount of free gas enters the borehole.
round due to the negative pressure, which reduces the gas inflow pressure of the working face, thereby solving the gas overrun problem of the working face and the upper corner.

The history function in FLAC3D software shows that the vertical distance between the 2# coal seam and the low-stress zone is 49.9-56.5 m, which indicates that the range of high borehole can be located in this region. Meantime, it shows that the result is basically the same as that of the formula (1).

5. On-site layout of high boreholes

The Φ94mm extraction and drilling is performed in the groove of the 2106 working surface. On-site sampling test shows that when the extracted negative pressure is 30 Kpa, the extraction radius is 2 m. Then, implement the high-level boreholes in the 2106 working face mining.

At the same time, place a high-level boreholes site with 4 boreholes every 10 m in the 2106 tape lane along the direction of the working face. The specific parameters of the boreholes are shown in Table 2 and the layout of the drilling field is shown in Figure 5. No extraction-blank area is placed between adjacent drill fields.

| number | inclination | Azimuth | Aperture/mm | length/m |
|--------|-------------|---------|-------------|----------|
| 1      | +32.4°      | -20.5°  | 94          | 50       |
| 2      | +31.5°      | -23.4°  | 94          | 53       |
| 3      | +30°        | -29°    | 94          | 58       |
| 4      | +28.9°      | -34°    | 94          | 62       |
| 5      | +27.2°      | -38.4°  | 94          | 68       |
| 6      | +26°        | -42.2°  | 94          | 63       |

6. Effect of gas drainage in the upper corner

Extract in the 1# and 2# drilling fields started from January 1 and lasted for one month. The gas concentration in each borehole in the 1# and 2# drilling fields were recorded every day with the gas concentration of the main pipe as the indicators, as shown in Figure 6. Same recording method is applied in the extraction of the 2# and 3# drill fields starting from February 1, 2010. The comparison between their gas concentration and that of main pipe in February 2017 is shown in Figure 7.

It can be seen from Figure 6 and Figure 7 that the gas concentration of the 1#, 2#, and 3# main pipes of the high-level boreholes field is about 40% at the initial stage of the extraction, indicating that affected by quarrying and the influence of negative pressure on the fracture development in the 2106...
working face, the gas gradually migrated into and accumulated in the drilling field. After nine months of continuous extraction, based on the above analysis method, the gas concentration curve of the 15# drilling field in October 2017 is shown in Figure 8. It was measured that the gas concentration of the main pipe of the high borehole in October 2017 was 8%.

![Figure 6 Gas concentration curve of main borehole pipeline in January 2017](image1)

![Figure 7 Gas concentration curve of main borehole pipeline in February 2017](image2)
7. Conclusions
(1) This paper put forward the mechanism of high borehole extraction under negative pressure for controlling gas accumulation in the upper corner, and points out that high boreholes should be arranged between the falling zone and the fracture zone.
(2) This paper calculates the optimal distance from the final borehole to the coal seam based on the distribution law of the “three vertical zones” influenced by fully mechanized mining.
(3) This paper verifies the correctness of the conclusions in (2) by numerically simulating the optimal position of the high boreholes.
(4) This paper improves the layout parameters of the high-drilling site. The gas concentration dropped from 40% to 8%, which proved the effect of extraction.

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