Research and application of pre-draining coal seam gas technology with three-dimensional cross drilling

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Abstract. In view of the current situation of low extraction efficiency and poor extraction efficiency of Yangquan No.5 mine 15# coal seam in, in order to ensure the daily safe and efficient production of coal mines, the three-dimensional cross-drilling technology was used to conduct field test on the drainage effect of the bedding in the 8401 working face, and compared with the gas drainage technology of traditional drilling arrangement methods such as plane cross hole and parallel hole arrangement. The result shows that after the gas extraction of the three-dimensional cross-drilled hole in the 8401 working face, the average extraction volume per 100 meters reaches 0.0097 m$^3$/min.hm, the attenuation coefficient is 0.0725 d$^{-1}$, and the extraction effect is better than that of the plane-intersecting holes and the parallel arrangement of holes, which effectively reduces the occurrence of coal mine accidents and opens up a new technical way for coal mine gas drainage.

1. Introduction
China's coal seam has large gas content and low gas permeability. With the development of coal mine intensive production and the significant increase in production efficiency, gas disasters are becoming more and more serious [1-3]. In a series of gas control measures, mine gas drainage is currently the most effective way to solve mine gas emission and prevent gas overrun [4]. For coal seams that are not up to standard, adopt active and effective gas extraction technology. The gas drainage effect of coal seam is affected by many factors, including the permeability of the coal seam to be drained, the type of drainage, the layout of the drilling, the drilling parameters, the sealing effect, and the negative pressure of drainage [5]. In recent years, domestic scholars have proposed cross-drilling pre-draining coal seam gas technology and achieved good development. Wang Kuijun et al. [6] used cross-drilling to pre-pump coal seam gas at the 13051 working face of Jiaozuo Jiulishan Coal Mine for the first time, and found that this method increased the gas drainage volume by 0.46 ~ 1.02 times compared with other conventional methods. Ren Zhongjiu et al [7] found that the gas extraction volume of the oblique cross-drilled 100-meter borehole was 2.72 times that of the parallel borehole, and the oblique cross-drilled gas was more practical. Zhang Wenyu et al [8] conducted a cross-drilling pre-draining coal seam gas technology test at the 13105 working face of a mine, which increased the gas drainage volume of the coal seam by 0.5 times and the pre-drainage rate by 10%. Zhang Yichun et al. [9] conducted gas pre-draining field test
on the No.2 coal seam of Shanxi Changda Coal Mine by using cross-drilling and drainage, and obtained the attenuation law of the gas extraction volume at 100m borehole with different hole distances. Xue Yanping [10], Zhu Xiaohui [11], Wang Yifan [12], et al. used cross-drilling gas pre-draining tests on different coal mine working faces, and achieved good results. Therefore, drawing on the experience of the predecessors, the three-dimensional cross-drilling was used to study the gas drainage along the layer in the 8401 working face in order to provide theoretical guidance for the gas control of other coal seams or working faces in the mine.

2. Engineering background
Yangmei Group Minmetals is located in Pingding County, Shanxi Province, with a total area of approximately 79.9km$^2$. There are two production mines and twelve wellheads. At present, the production wellheads are Wulin well and Guishigou well (referred to as Minmetals big well), and their design capacities are 0.9Mt/a and 4.00Mt/a respectively. The mine's recoverable reserves are 338.37Mt. The mine mainly mines 15# coal seam and 8# coal seam. The inclination angle of the coal seam is relatively gentle, generally the inclination angle is only 5°~7°, and the inclined long wall coal mining method is adopted. The average thickness of 15# coal is 6.8m, the gas content is 1.05~11.4m$^3$/t, and the gas pressure is 0.05~0.2MPa. Up to now, the absolute gas emission of the mine has reached 371.63m$^3$/min, and the relative gas emission is 60.62m$^3$/t. According to the mine gas grade and carbon dioxide identification, the Minmetals big well is a high gas mine. 15# coal seam permeability coefficient is 1.681m$^2$/MPa$^2$.d, and coal seam permeability coefficient is between 10 and 0.1. According to the investigation of the drainage parameters of this coal seam, the gas concentration is generally between 1% and 3%, the negative pressure of the borehole is below 3kPa, and the negative pressure of the mobile pump (2BEA-303) is about 13kPa. From the inspection and analysis of the drainage parameters, the sealing effect of the drill hole is poor (polyurethane 3m sealing), and the negative pressure of drainage, the drainage efficiency is very low, and the drainage effect is not good.

3. Investigation on the layout of the three-dimensional cross drilling and the effect of extraction

3.1. Three-dimensional cross drilling arrangement
The spacing of the three-dimensional cross drill holes is 3m, and 20 drill holes are constructed, and the drill holes are arranged in three holes. Drilling with the hole at a high position, the height of the hole is 1.5m, facing the working surface 85°, the drilling elevation angle is 3°. And drilling with the hole at a low position, the height of the hole is 1.3m, facing the working surface 75°, the drilling elevation angle is 3°. After completion, 10 boreholes were selected for the effect inspection. The layout of the three-dimensional cross borehole is shown in Figure 1. The borehole parameters are shown in Table 1. The length of the extraction borehole is about 16.5 to 69m, and the borehole diameter is 94mm. The hole sealing material is made of polyurethane, and the hole sealing pipe is made of double-anti-static (antistatic, flame-retardant) polyethylene pipe, and the length of the hole sealing section is 6m. After drilling and sealing, the DN50 serpentine pipe is used to connect the drilling and sealing pipe to the extraction pipe on the working face.
3.2. Investigation of the extraction effect of three-dimensional cross drilling

The single-hole extraction parameters (extraction amount, extraction concentration, extraction negative pressure) of 20 boreholes in the three-dimensional cross-drilled boreholes in 8401 working face were investigated. Typical drilling parameters (150#, 151#) are shown in Figure 2 ~ Figure 3.

It can be seen from Figures 2 to 3 that the negative pressure of the extraction is 2 to 3 kPa, the extraction concentration is 36% to 75%, and the single-hole extraction is 0.0056 to 0.015 m$^3$/min.hm. Through the inspection of the test boreholes, it is found that the average 100-meter drainage volume of the three-dimensional cross boreholes is 0.0097 m$^3$/min.hm, and the attenuation coefficient is 0.0725 d$^{-1}$. 

| Hole number | Angle with roadway(°) | Inclination(°) | Aperture (mm) | Design hole depth(m) | Completion hole depth(m) | Drilling distance(m) |
|--------------|------------------------|----------------|---------------|----------------------|-------------------------|----------------------|
| 145#         | 75                     | 3              | 94            | 50                   | 16.5                    | 3                    |
| 146#         | 85                     | 3              | 94            | 50                   | 30                      | 3                    |
| 147#         | 75                     | 3              | 94            | 50                   | 57                      | 3                    |
| 148#         | 85                     | 3              | 94            | 50                   | 69                      | 3                    |
| 149#         | 75                     | 3              | 94            | 50                   | 28.5                    | 3                    |
| 150#         | 85                     | 3              | 94            | 50                   | 67.5                    | 3                    |
| 151#         | 75                     | 3              | 94            | 50                   | 55                      | 3                    |
| 152#         | 85                     | 3              | 94            | 50                   | 59                      | 3                    |
| 153#         | 75                     | 3              | 94            | 50                   | 64                      | 3                    |
4. Comparison of extraction effects of different layouts
In order to investigate the impact of different drilling arrangements on the gas drainage effect, three pre-draining bedding holes were selected for parallel drilling, parallel cross drilling and three-dimensional cross drilling at 8401 working face 800m, 1200m and 1500m from the cut hole to carry out on-site gas drainage comparison test. The position of the drill hole is 100m away from the stop line of the test face, the hole depth is 100m, and the hole diameter is 113mm. At the same time, try to choose other geological structures that have no faults, collapse columns and other factors that affect the occurrence of coal gas. The coal gas content is basically the same and the area is evenly distributed. Three areas are distinguished in the experiment, as shown in Figure 4.
Figure 4. Schematic diagram of the drilling layout of the test face.

Table 2. The effect of different hole patterns.

| Arrangement            | The average 100-meter drainage volume(m³/min.hm) | The attenuation coefficient(d⁻¹) |
|------------------------|-----------------------------------------------|---------------------------------|
| Plane cross drilling   | 0.0081                                        | 0.0759                          |
| Parallel drilling      | 0.00765                                       | 0.0779                          |
| Three-dimensional      | 0.0097                                        | 0.0725                          |
| cross-drilled hole     |                                              |                                 |

From the Table 2, the average 100-meter drainage volume of the three-dimensional cross-drilled hole in the 8401 working face is 0.0097 m³/min.hm, and the attenuation coefficient is 0.0725 d⁻¹. The average 100-meter drainage volume of plane cross-drilled holes is 0.0081 m³/min.hm, and the attenuation coefficient is 0.0759 d⁻¹. The average drilling volume of parallel boreholes is 0.00765 m³/min.hm, and the attenuation coefficient is 0.0779 d⁻¹. Obviously, the average 100-meter flow rate of three-dimensional cross-drilled holes is 0.0097 m³/min.hm, which is greater than that of plane cross-drilled holes and parallel bedding holes. And the attenuation coefficient of 0.0725 d⁻¹ is lower than that of plane cross drilling and parallel bedding drilling. It can be seen from the above field practice that the extraction effect of the three-dimensional cross drilling arrangement is much better than that of the plane cross layout holes and parallel layout holes.

5. Conclusion

(1) Using the cross-drilling pre-draining and bedding drilling technology to conduct gas drainage research on 8401 working face, the average 100-meter drainage volume reached 0.0097 m³/min.hm and the attenuation coefficient was 0.0725 d⁻¹.

(2) A comparative analysis of the three pre-draining bedding borehole drilling techniques of parallel drilling, parallel crossing drilling and three-dimensional crossing drilling was performed on the 8401 working face, and it was found that the extraction effect of the three-dimensional crossing drilling arrangement is better than the arrangement of plane cross holes and parallel holes.

(3) Three-dimensional cross-drilling gas drainage technology opens up a new way for gas drainage in low-permeability coal seams, ensuring high-yield and efficient production of the mine and shortening the pre-drainage time, and it has very important guiding significance for the coal mine to ease the connection of pumping, mining and excavation.
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