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Research on Gas Extraction Effect of High Gas Mines Based on Stereoscopic Cross Directional Drilling Technology

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Abstract: Based on the advantages of three-dimensional cross drilling technology and directional drilling technology, a gas extraction technology of "three-dimensional cross + directional" drilling is proposed. The advantages, applicability, and key influencing factors of this technology are analyzed, and on-site gas extraction experiments are conducted at the 2210 working face of the No. 2 coal seam in a certain coal mine. The research results show that after adopting the stereoscopic cross directional drilling technology and extraction technology, the gas extraction effect of the 2210 working face has been significantly improved compared to using ordinary extraction drilling, and the stereoscopic cross directional drilling technology can effectively increase the gas extraction volume and concentration. This technology has obvious advantages in improving gas extraction rate and ensuring operational safety, providing a certain reference for solving gas control problems in high gas mines.

Keywords: High Gas Mine; Gas Extraction; Stereoscopic Cross Directional Drilling Technology; On Site Testing; Applicability; Influence Factor.

1. Introduction

Coal mine gas disasters are one of the main safety hazards in the process of coal mining [1]. The effective extraction of gas is of great significance for ensuring the safety of miners and improving mining efficiency [2-3]. Especially in high gas mines, the key to safe production lies in the application and innovation of gas extraction technology. However, in coal mines with complex geological conditions and low permeability of coal seams, gas extraction technology often fails to achieve ideal results.

In recent years, three-dimensional cross drilling technology [4-5] and directional drilling technology [6-8] have gradually become hot research directions for gas control in high gas mines. With the continuous advancement of engineering technology, the three-dimensional cross drilling technology has improved the efficiency and coverage of gas extraction by arranging cross drilling holes at different angles and depths in coal seams. The directional drilling technology improves the accuracy and reliability of gas extraction by precisely controlling the drilling direction, effectively solving the problem of long-distance displacement of drilling holes. Two technologies have shown unique advantages and application potential. The research and application of these two technologies provide new ideas and solutions for gas control in high gas mines, and have been widely applied in high gas mines. Therefore, based on the advantages of three-dimensional cross drilling technology and directional drilling technology, this article adopts a drilling method combining "three-dimensional cross + directional" for gas extraction, in order to provide more effective technical support for gas control in high gas mines.

2. Introduction to Stereoscopic Cross Directional Drilling Technology

2.1. Principle of Three-dimensional Cross Drilling Technology

Stereoscopic cross drilling technology is a method of arranging boreholes at specific angles and intervals in coal seams with the aim of improving the overall gas extraction effect of the boreholes [5,9]. This technology increases the flow channels and extraction area of gas in the coal seam by arranging boreholes of different heights, angles, and depths, thereby extracting more gas and reducing residual gas content, forming a three-dimensional intersecting drilling and extraction network. In order to ensure the effective flow of gas and reduce blind spots in extraction, three-dimensional cross drilling usually uses smaller drilling spacing. The three-dimensional cross drilling technology has also been widely studied by scholars at home and abroad. Wang Yifan [10] conducted an application study on the gas drainage effect of the 3rd parallel layer in Kaiyuan Coal Mine using the three-dimensional cross drilling technology, which confirmed the effectiveness of the three-dimensional cross drilling gas drainage technology. Xue Yanping [11] conducted a study on the pre pumping test of cross drilling in low-permeability coal seams. These studies provide a theoretical basis and practical guidance for the application of three-dimensional cross drilling technology.

2.2. Principle of Directional Drilling Technology

Directional drilling technology [12-14] refers to a technique that actively controls the drilling direction by precisely controlling the drilling direction and depth, ensuring that the drilling is always within the coal seam, achieving long-distance and large-scale gas extraction, and avoiding the drilling from deviating towards the rock layer. In addition, directional drilling technology can improve the continuity of gas extraction, enhance drilling construction efficiency, and thus bypass faults or structures. The research shows that directional drilling technology has significant advantages in improving gas extraction efficiency and safety.

2.3. Principle of Stereoscopic Cross Directional Drilling Technology

(1) Introduction to Technology

The combination of three-dimensional cross drilling technology and directional drilling technology can simultaneously leverage the strengths of both technologies, providing a more efficient and reliable solution for gas extraction in high gas mines, achieving more effective gas extraction [15]. The combination of two technologies can improve the accuracy and coverage of drilling while ensuring efficient gas extraction in coal mine gas control work. Stereoscopic cross drilling provides a foundation for creating multi-dimensional gas flow paths, while directional drilling ensures the accuracy and effectiveness of these paths, thereby achieving more efficient gas extraction.

After comprehensive analysis and comparison of the combination of the two technologies, it can be found that they have significant advantages in gas extraction efficiency and safety. The combination of three-dimensional cross drilling technology and directional drilling technology can significantly improve the efficiency of gas extraction. By increasing the flow path of gas and optimizing the drilling layout, the efficiency of gas flow can be improved. In addition, directional drilling technology can accurately control the coverage area of the borehole, ensuring effective extraction of key areas of the coal seam and further improving the efficiency of gas extraction. The combination of two techniques can to some extent reduce the risks of borehole displacement and gas accumulation, namely the precise control capability of directional drilling technology and the multi angle coverage of three-dimensional cross drilling technology. The former effectively avoids drilling displacement to rock formations or other non target areas, thereby reducing uncertainty and potential hazards in the gas extraction process; and the latter increases the coverage of extraction, thereby reducing the possibility of gas accumulation and promoting the safety production of mines.

In addition, combining the two technologies can improve the flexibility and adaptability of gas extraction work. When facing different geological conditions and gas occurrence conditions, flexible response to various situations can be achieved by adjusting the angle, depth, and spacing of drilling holes, thereby ensuring better continuity and stability of gas extraction work.

(2) Applicability analysis of technology

The three-dimensional cross drilling technology and directional drilling technology designed for different geological conditions and gas extraction needs have their own emphasis on applicability. The drilling arrangement of the three-dimensional cross drilling technology can significantly improve the flow efficiency of gas, especially in the case of poor coal seam permeability. By arranging multiple angles of drilling in the coal seam to form a three-dimensional cross extraction network, the gas extraction rate can be effectively improved [16]. The directional drilling technology focuses on precise control of drilling direction, adaptation to coal seam inclination and bending, and effective avoidance of drilling deviation towards rock layers, achieving long-distance gas extraction and improving gas extraction accuracy and efficiency. Due to its excellent performance in solving drilling offset, this technology is particularly suitable for mines with complex geological conditions and large variations in coal seam thickness [17].

(3) Analysis of influencing factors

As gas extraction technologies, the effects of three-dimensional cross drilling technology and directional drilling technology are influenced by multiple factors, including the permeability coefficient of coal seams, drilling layout, drilling parameters, sealing effect, and extraction negative pressure [4].

1) The permeability coefficient of coal seams. The permeability coefficient of coal seams directly affects the flow and extraction efficiency of gas [18]. Coal seams with low permeability have high gas flow resistance and low extraction efficiency. In this case, the three-dimensional cross drilling technology can improve efficiency by increasing the flow path.

2) Drilling arrangement. The arrangement of drilling holes, including the angle, depth, and spacing of the holes, has a significant impact on the effectiveness of gas extraction. The three-dimensional cross drilling technology can improve the efficiency of gas extraction by optimizing the drilling layout.

3) Drilling parameters. The diameter, length, quantity, and other parameters of the drilling hole that affect the gas extraction capacity and range can be accurately controlled using directional drilling technology to achieve more precise gas extraction work.

4) Sealing effect. The sealing material and method used will directly affect the efficiency and safety of gas extraction. Good sealing of drilling holes can prevent gas leakage and make gas extraction more efficient.

5) Extraction negative pressure. The magnitude of extraction negative pressure directly affects the flow velocity and extraction volume of gas. Appropriate negative pressure can improve gas extraction efficiency, but excessive negative pressure may affect mine safety and cause damage to coal seams.

3. Application of Stereoscopic Cross Directional Drilling Technology in High Gas Mines

3.1. Layout of Drilling Holes

(1) Location of the experiment

A coal mine located in Changzhi City, Shanxi Province, with an annual production capacity of 1.2Mt/a, is a high gas mine. Currently, the main coal seam being mined is the No. 2 coal seam, which is 0.8~2m thick (with an average thickness of 1.6m). The permeability coefficient of No. 2 coal seam is $0.1138m^2/MPa^2{\cdot}d$, and the natural gas flow attenuation coefficient of No. 2 coal seam drilling is 0.141/d·hm, with a permeability coefficient of less than 0.1. The No. 2 coal seam of a certain coal mine is difficult to extract and is classified as a challenging coal seam. A certain coal mine used to use ordinary drilling to extract coal seam gas, but due to the large variation in coal seam thickness, the dip angle of the coal seam changed. During construction, ordinary drilling frequently entered the rock layer and had to be supplemented frequently. Meanwhile, the gas concentration in ordinary boreholes is generally below 30%, and the pumping effect is not ideal.

To solve the problem of difficult gas control, a certain coal mine is now preparing to use three-dimensional cross directional drilling technology for application testing. The experimental area was determined from the underground site to be within a distance of 650m from the return airway of the 2210 working face in the second mining area of No. 2 coal seam. The original gas content of the 2210 working face is 11m^3/t, the length of the groove is 1195m, and the cutting length is 220m.

(2) Drilling layout parameters

A stereoscopic cross directional drilling was constructed in the transportation roadway of the 2210 working face, covering a range of 15m outside the return air roadway of the 2210 working face. The designed drilling length was 235m, the drilling hole diameter was 96mm, and the drilling spacing was 3m. A total of 10 drilling holes were constructed.

The drilling adopts a stereoscopic cross directional layout with upper and lower layers. The height of the high-level drilling hole is 1.5m, with an angle of 85 ° with the coal wall of the roadway. The inclination angle of the drilling hole varies with different coal seams. The low-level drilling hole has a height of 1m and an angle of 75 ° with the roadway coal wall. The inclination angle of the drilling hole varies with different coal seams. The drilling layout is shown in Figure 1, the drilling construction trajectory profile is shown in Figure 2, and the drilling completion parameters are shown in Table 1. The drilling and sealing process adopts parameters of grouting pressure of 1.5MPa and sealing length of 18m, and uses mining sealing bags and specialized expansion cement for grouting and sealing. After the drilling construction is completed, connect the manifold and gas extraction pipeline for drainage, with a negative pressure of 18kPa.

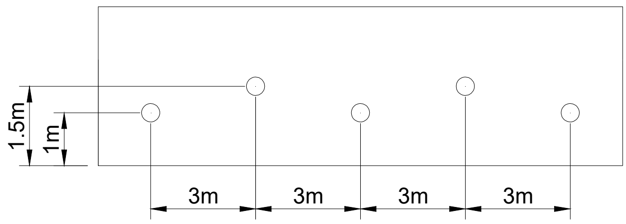

Figure 1. Layout of drilling holes

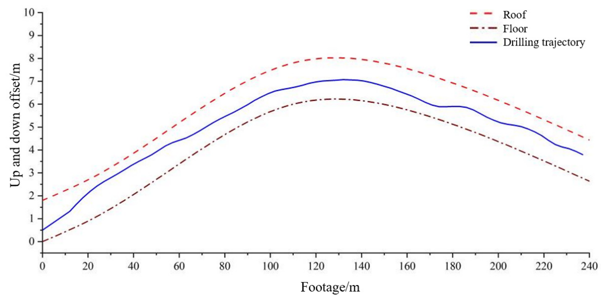

Figure 2. Sectional diagram of drilling construction trajectory

Table 1. Parameters of drilling completion status

Namber	Angle with coal wall /°	Drilling hole diameter /mm	Drilling length /m	Arrangement pitch /m	Hole height /m
1#	75	96	234	5	1.0
2#	85	96	236	5	1.5
3#	75	96	226	5	1.0
4#	85	96	238	5	1.5
5#	75	96	231	5	1.0
6#	85	96	228	5	1.5
7#	75	96	235	5	1.0
8#	85	96	233	5	1.5
9#	75	96	229	5	1.0
10#	85	96	231	5	1.5

3.2. Investigation of Gas Extraction Effect

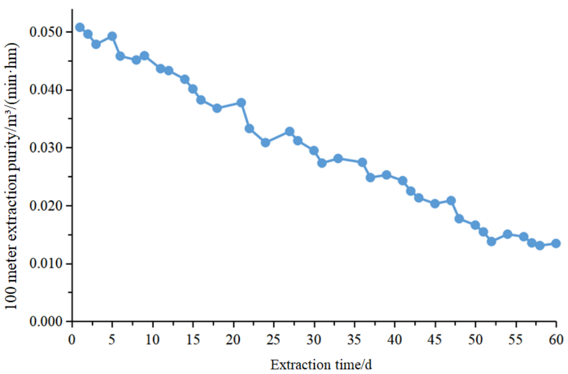

Figure 3. Changes in pure gas extraction from 100-meter directional drilling with stereoscopic cross directional drilling technology

Conduct an investigation on the pre extraction effect of 10 completed stereoscopic cross directional drilling holes, and calculate their daily gas extraction purity. Convert it into the average gas extraction purity per 100 meters of a single drilling hole based on the length of the drilling hole. Under a negative pressure of 18kPa, the extraction concentration ranges from 47% to 92%. The initial gas purity per 100 meters of extraction is 0.0507 m^3/(min·hm). After 60 days of extraction, the gas purity per 100 meters of drilling decreases steadily, and the gas purity per 100 meters of extraction drops to 0.0134 m^3/(min·hm). The variation of gas purity extracted from a hundred meter vertical directional drilling is shown in Figure 3. From Figure 3, it can be seen that the average net extraction volume per hundred meters of directional drilling in stereoscopic cross directional drilling reaches 0.0302 m^3/(min·hm) within 60 da.

3.3. Comparative Analysis of Gas Extraction Effects

In order to compare the extraction effects of a coal mine before and after using ordinary drilling and three-dimensional cross directional drilling technology, an area 800m away from the return airway in the transport roadway of the 2210 working face was selected as the ordinary drilling test area. The occurrence of coal gas is basically consistent, with gas content around 11m^3/t, which has good experimental conditions and comparability. Due to the unsuitable site conditions, ordinary boreholes are designed to be 100 meters long, with a total of 10 boreholes constructed. The boreholes are arranged at a spacing of 3 meters, with an inclination angle of+3° and a diameter of 94 mm. They are all constructed perpendicular to the coal wall, with a height of 1.5 meters. Under a negative pressure of 18kPa during gas extraction, the pre-extraction concentration of ordinary gas extraction boreholes is 16% to 28%. The initial pure gas extraction per hundred meters is 0.0182 m^3/(min·hm), and the average pure gas extraction per hundred meters within 60 days is 0.0107 m^3/(min·hm). The variation of gas purity extracted from a 100 meter ordinary borehole is shown in Figure 4.

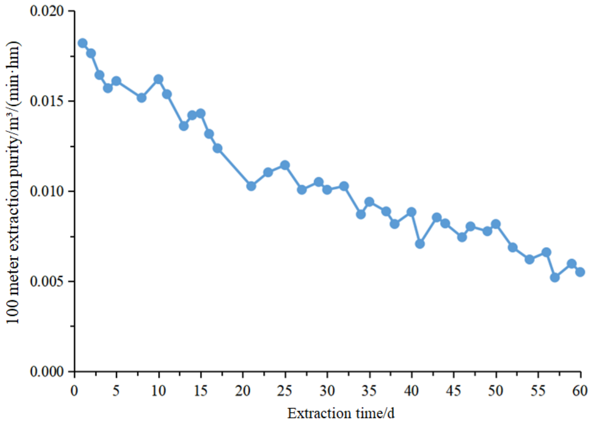

Figure 4. Changes in pure gas extraction from a 100 meter ordinary borehole

By comparison, it can be seen that after adopting the stereoscopic cross directional drilling technology and extraction technology, the gas extraction effect of the 2210 working face has been significantly improved compared to using ordinary extraction drilling. The experimental results show that the stereoscopic cross directional drilling technology can effectively improve the gas extraction volume and concentration.

4. Conclusion

(1) The gas extraction technology of "three-dimensional cross + directional" drilling has been proposed, which has the advantages of improving gas extraction efficiency, enhancing gas extraction safety, strong adaptability, and significant economic benefits.

(2) On site gas extraction experiments were conducted using stereoscopic cross directional drilling technology at the 2210 working face of coal seam 2 in a certain coal mine. On site practice has shown that after adopting the stereoscopic cross directional drilling technology and extraction technology, the gas extraction effect of the 2210 working face has been significantly improved compared to using ordinary extraction drilling. The stereoscopic cross directional drilling technology can effectively increase the gas extraction volume and concentration.

(3) The stereoscopic cross directional drilling technology can further optimize the gas extraction work in high gas mines, improve the safety production level of mines, and provide support for the sustainable development of mines.

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