

Optimization and Practice of the Efficient as Control Mode for Hard-to-Drain Coal Seam as in Sima Coal Industry

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Abstract: Due to the complex geological structure and poor permeability of the coal seam in Sima Coal Mine, the gas extraction concentration is low, the flow is small, the attenuation is fast, the efficiency is low, and the standard time is long. Based on the analysis of gas geological conditions, gas extraction parameters and current situation of Sima Coal Industry, the efficient gas control mode of return air corner buried pipe drainage, roof fracture zone drilling drainage technology, hydraulic slotting and hydraulic punching technology is designed, and the applicable conditions and key technical parameters are optimized. According to the practical effect, the design of buried pipe drainage in the return air corner of five trips, six parts and one cycle, as well as the hydraulic punching hole + bedding hole drainage solved the practical problem of gas difficulty in Sima Coal Industry, and effectively improved the concentration and purity of gas drainage.

Keywords: Difficult pumping coal seam; Gas control; Technical mode.

1. Introduction

Gas disasters pose a serious threat to the safe production of coal mines in China. Gas drainage is a fundamental technical measure for controlling gas disasters in coal mines [1]. Over the past few decades, China's coal mine gas drainage technology has made remarkable progress, playing a crucial role in controlling gas in coal mines and preventing gas accidents [2]. However, due to complex gas geological conditions and complex geological structures of coal seams with poor permeability [3], the gas drainage effect in many mines fails to meet expectations, affecting the safe mining of coal mines.

The Sima Coal Mine of Luan Group is a typical representative of low-gas and difficult-to-drain coal seams, mainly characterized by (1) low gas content in coal seams, weak gas desorption capacity, poor permeability, high difficulty in gas drainage, and low gas drainage concentration (the concentration in the working face branch pipes is generally between 0.5% and 2%) [4]; (2) large gas outflow from the coal mining face, with gas concentration in the upper corner increasing and even exceeding the limit; (3) the adopted "pre-drainage in the seam+ high extraction alley" gas control mode, which involves the construction of high extraction alleys, has large engineering volume, long cycle, and high cost.

Therefore, researching an efficient gas control model for low-gas and difficult-to-drain coal seams is an important technical support for improving the safety production level and comprehensive safety production benefits of coal mines.

2. Gas Geology Characteristics

2.1. Structural Characteristics

The Sima Coal Mine is located in the southeast of Shanxi Province, in the eastern part of the Qinshui Coalfield, 4 km

south of Changzhi, and is administratively under Changzhi County, Changzhi City [5]. The mine field is on the west side of the Changzhi major fault, the main structural trace of the southern section of the Jincheng-Huolu Fold-Overthrust Belt, and is adjacent to the Wuyang Depression-Fold Belt on the west. The structural traces are arranged in a (many) character pattern. The mine field generally has a monocline structure with a strike of NNE, a dip of NW, and a dip angle of about 4°, accompanied by gentle folds and a few faults, and there is no magmatic rock intrusion.

2.2. Coal Seam and Gas

The main coal-bearing strata in the mine field are the Taiyuan Formation of the Upper Carboniferous and the Shanxi Formation of the Lower Permian. There are five exploitable coal seams with an average total thickness of 15.03 m and a coal-bearing coefficient of 9.3%. The Shanxi Formation generally contains 1 to 3 coal seams, among which the No. 3 coal seam is located in the middle and lower part of the Shanxi Formation, with an average distance of 29.60 m above the K8 sandstone and 10.77 m below the K7 sandstone. The thickness of the No. 3 coal seam is 5.47 to 7.80 m, with an average of 6.62 m, and it is the current main exploitable coal seam. The maximum vitrinite reflectance of the No. 3 coal in the Sima Coal Mine is 1.67-1.83%, which belongs to lean coal-poor lean coal. The coal body structure is mainly fragmented coal, with a measured coal body firmness coefficient of 0.6-0.68, and a gas desorption initial velocity of 12.8-16. The gas adsorption constant a of the No. 3 coal seam is between 34.15-38.36 m³/t, and b is between 0.58-0.68 MPa⁻¹. The measured gas content in the 1208 transport roadway and 1303 return airway of the No. 3 coal seam in the mine is 4.38-6.02 m³/t, and the measured gas pressure is 0.2-0.43 MPa.

2.3. Gas extraction parameter testing

The coal seam permeability coefficient was measured

using gas pressure boreholes. The test site for the 3# coal seam was selected at the pressure measurement borehole in

the 1208 transportation roadway. The test results of permeability are shown in Tables 1 and 2.

Table 1. Original Data of Air Permeability Coefficient Test

Absolute gas pressure P0 (MPa)	Orifice pressure P1 (MPa)	Drilling hole radius r1 (m)	Time t (d)	Flow rate Q (m ³ /day)	Content (m ³ /t)
0.51	0.1	0.047	5	0.512	5.81

Table 2. Statistical Table of Permeability Coefficient

Gas content coefficient α (m ³ /m ³ •MPa ^{0.5})	q (m ³ /m ² •d)	A	B	F0	Air permeability coefficient λ (m ² /MPa ² •d)
11.064	0.3469	0.0652	298.0297	10~100	0.15

From the above table, it can be seen that the permeability coefficient of the 3# coal seam of Sima Coal Mine is 0.15 m² / MPa²•d.

Using the ZLD-2 multi-stage flowmeter, a 50-meter-long coal seam test borehole was drilled at the 530m position of the 1208 transportation alley of Sima Coal Mine to measure the natural gas outflow of the 3# coal seam in the borehole. The measured data were regressed using the least squares method to obtain the initial gas outflow per 100 meters of the borehole as 0.0427 m³/min•hm, and the natural gas flow attenuation coefficient of the borehole was 0.058 d⁻¹, as shown in Figure 1. In conclusion, the 3# coal seam of Sima Coal Mine is a difficult-to-extract coal seam.

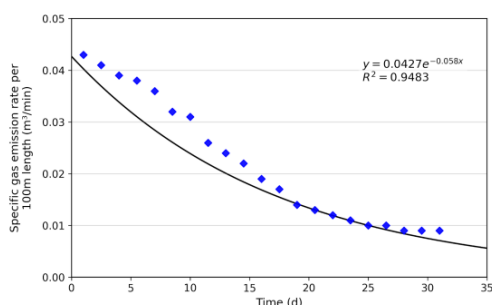


Figure 1. Curve of natural gas outflow attenuation

3. Optimization of High-Efficiency Gas Control Model in Low-Gas Mines

3.1. 3# Coal Seam Gas Efficient Governance Model Development

When choosing the method for extracting gas, the following principles should be followed: (1) It should be suitable for the coal seams occurrence conditions, the layout of mining tunnels, geological conditions and mining technical conditions; (2) According to the source of gas and the composition of gas outburst, it should adopt the comprehensive gas extraction method as much as possible to improve the gas extraction effect; (3) It is conducive to reducing the amount of underground engineering, achieving the combination of extraction tunnels and mining tunnels; (4) It is conducive to the layout and maintenance of extraction tunnels; (5) It is conducive to improving the gas extraction effect, increasing the gas extraction time and reducing the extraction cost; (6) It is conducive to the construction of drilling sites and boreholes, and the laying of gas extraction system pipelines.

Table 3. High-efficiency Gas Control Model for 3# Coal Seam

Serial Number	Burial Depth/m	Gas Content/m ³ /t	Gas Control Mode
1	≤160	≤3.5	In the gas weathering zone, no gas extraction measures need to be taken
2	160-280	3.5-4.5	Backside corner pipe extraction + roof fissure zone drilling extraction technology
3	280-460	4.5-6	Pre-extraction of this coal seam (pre-extraction before mining, extraction while mining, measures such as hydraulic drilling to create cavities for improved permeability can be considered) + backside corner pipe extraction + roof fissure zone drilling extraction technology
4	≥460	≥6	Pre-extraction of this coal seam (pre-extraction before mining, extraction while mining, measures such as hydraulic drilling to create cavities for improved permeability can be considered) + backside corner pipe extraction + high extraction alley (or increasing the number of drilling holes in the roof fissure zone to replace the high extraction alley)

The No. 3 coal seam of Siji Coal Mine has no risk of coal and gas outburst within the test area. The gas type is medium. The working face belongs to the general type of gas outburst to the general type of gas outburst. Considering the gas geological conditions of the No. 3 coal seam and the actual gas prevention and control priorities underground (the mining layer, the mined-out area and the return air corner of the working face), comprehensive application of targeted gas prevention methods is adopted to formulate an efficient gas

governance mode for the No. 3 coal seam, as shown in Table 3.

3.2. Test of pipe extraction for backflow air duct in the corner area of the air extraction alley

As the burial depth of the coal seam in the mine increases, the gas outflow during the mining of the working face also increases. In particular, the management of gas in the return

air corner directly affects the safety production of the mine. Taking the 1217 working face as an example, a buried pipe extraction scheme for the upper corner of the return air alley was designed. A steel pipe with a diameter of 457mm, which was hung along the northern side of the working faces return air alley, was used as the low negative pressure extraction pipeline. At the end of this pipeline, a specially designed blind plate was installed (the specially designed blind plate was welded with five 4-inch two-way valves, and all the two-way valves were opened).

Outside the 1217 tunnel, the external support team hung five 4-inch extraction hoses, each approximately 30 meters in length, along the coal wall and the roof of the tunnel, from top to bottom (the topmost hose was 0.2 meters away from the tunnel roof. All the extraction hoses were required to be hung using 8# iron wire in parallel). These five extraction hoses were connected to the 457-pipeline using specially made blind plates, as shown in Figure 2. After the working face advanced 5 meters, 7.5 meters, 10 meters, 12.5 meters, and 15 meters respectively, the first, second, third, fourth, and fifth extraction hoses were cut using tools (the cutting points were approximately 25 centimeters long), and the butterfly valves of these cut hoses were closed simultaneously. The other five extraction hoses were used to bury and extract gas in the return air corner.

Ultimately, the measured volume of gas extracted by the buried pipe in the upper corner of the 1217 return airway was 1.5 cubic meters per minute. The gas extraction through the buried pipe in the upper corner of the mining face effectively addressed the issue of excessive gas in the upper corner of the mining operation.

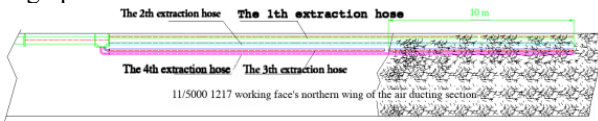


Figure 2. Diagram of Underground Pipe Extraction in the Upper Corners

3.3. High-altitude Drilling for Gas Extraction in the Roof Fracture Zone

When the gas concentration at the upper corner of the working face exceeds the limit during the gas drainage treatment of the abandoned area by using top plate drift drilling, the final position of the drilling hole must be within the top plate fracture zone. Due to the fracture space formed by the mining process, the fracture zone becomes a region where high-concentration gas accumulates [6]. Reasonably arranging the high-position drilling holes within the fracture zone, and through high negative pressure drainage, a negative pressure area is formed at the designed position within the fracture zone. This can enable the high-position drilling holes to extract high-concentration gas, effectively reducing the gas outflow volume of the working face and the gas concentration in the upper corner and the return airway of the working face.

High-position boreholes for gas extraction in the roof fissure zone are arranged every 50-70 meters along the inner side of the return airway of the working face. Each borehole field is equipped with 8-10 extraction boreholes. The borehole spacing is 0.4-0.5 meters, the borehole length is approximately 100 meters, and the final borehole is 22-32 meters above the coal seam roof. The borehole inclination is set at 5-10 degrees, and the azimuth is perpendicular to the coal wall. The specific construction diagram is shown in

Figure 3. After the experiment, the gas flow rate and purity of the boreholes have significantly improved.

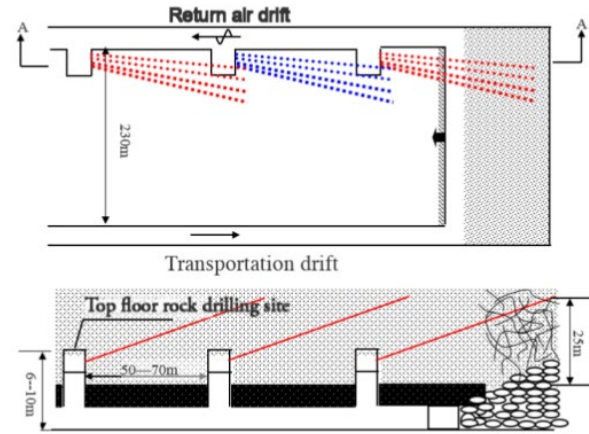
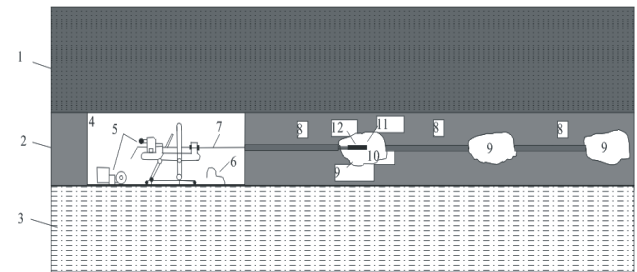


Figure 3. Schematic Diagram of Gas Drainage from Abandoned Areas through Drilling in the Roof Fracture Zone

3.4. Hydraulic Measures for Enhanced Permeability and Gas Extraction Test

For low-permeability and difficult-to-draw coal seams, taking necessary measures to enhance permeability is an effective way to improve the pre-drainage gas effect. Since the hardness coefficient f value of No. 3 coal is 0.60 - 0.68, its hardness is not high. To increase the permeability of the coal seam and enhance the drilling gas extraction flow rate, and quickly reduce the gas content in the coal body, the hydraulic hole-making and cavity-forming permeability enhancement measure was selected for on-site testing [7]. The technical diagram of hydraulic hole-making and cavity-forming permeability enhancement is shown in Figure 4.



(1 - Roof; 2 - Coal seam; 3 - Floor; 4 - Tunnel; 5 - Integrated drilling and flushing equipment; 6 - Anti-spill device; 7 - Drill pipe; 8 - Drill hole; 9 - Hole cavity; 10 - Diamond composite bit; 11 - High-pressure rotating tailpipe; 12 - High-low pressure water flow converter)

Figure 4. Schematic Diagram of Hydraulic Hole Formation Process in Parallel Strata

In this experiment, a hydraulic drilling test for creating cavities was conducted in the 1303 transportation tunnel of the third mining area of Siji Coal Mine, starting 200 meters before the initial mining. The depth of the cavity drilling holes was 60 meters; the spacing of the cavity drilling holes was 6 meters; the cavity pressure was 20 to 23 MPa; the time for cavity creation was 40 minutes; the cavity coal volume per hole was 0.7 tons; the cavity spacing was 6 meters; the cavity length was 1 meter; the diameter of the cavity drilling hole was 0.8 meters; the opening height of the cavity drilling hole was 1.7 meters or 2.3 meters; the number of cavity drilling holes per hole was 8; the inclination angle of the cavity drilling hole was calculated based on the coal seam inclination and various factors; the angle between the cavity drilling hole and the coal wall was 90 degrees; the opening

diameter of the cavity drilling hole was 115 mm, as shown in Figure 5.

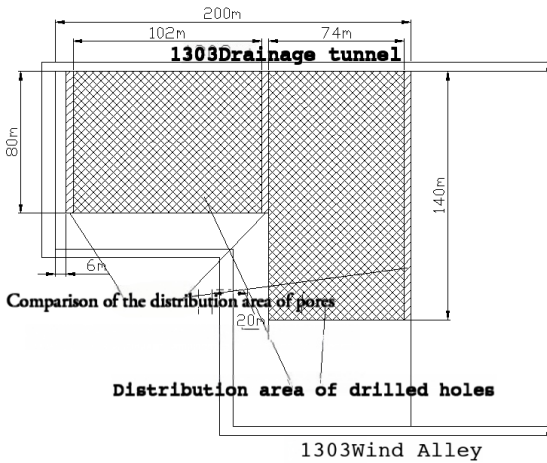


Figure 5. Layout Diagram of Drilling Holes for Hydraulic Hole-Cutting Test in 1303 Mining Road

After implementing the hydraulic hole-making and permeability-enhancing drilling measures, a comparison was made between the water-based hole-making drilling extraction flow and the ordinary drilling extraction flow, as shown in Figure 6. A total of 25 water-based hole-making drilling holes were completed, and a total of 301 holes were created. The analysis of the extraction effect indicated that after the implementation of hydraulic hole-making and permeability-enhancing drilling, the extraction effect was significantly improved. The average gas concentration was 39.8%. The single-hole extraction pure volume of the created holes reached 0.02 - 0.18 m³/min, with an average pure volume of 0.091 m³/min, which was 3 - 5 times that of the ordinary drilling holes. After the hydraulic hole-making and permeability-enhancing drilling, the surrounding coal body of the created holes was subjected to a large-scale pressure relief, and the coal seam fractures were significantly developed. The permeability enhancement effect was obvious, enabling the gas to be released rapidly, significantly improving the gas extraction efficiency and effectively shortening the time to reach the extraction standard.

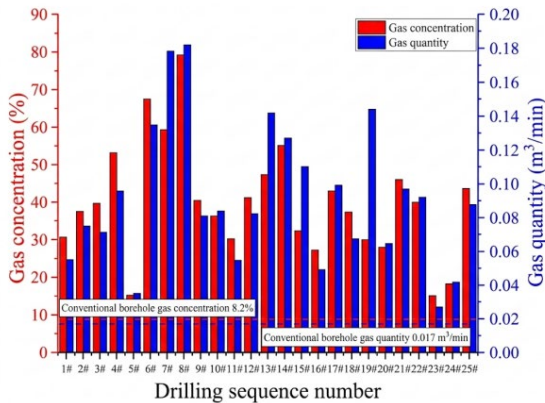


Figure 6. Statistical Chart of Gas Extraction Flow from Cavities Created by Hydraulic Drilling in the 1303 Mining Road

4. Conclusions

(1) To address the issue of excessive methane in the mining face, the Xiasi Coal Mine conducted an analysis and research on the technologies of pipe injection drainage in the return air corner and drilling for drainage in the roof fissure zone. A "five-pass, six-stages, one-cycle" design for pipe injection drainage in the return air corner was formulated, and the high-position drilling drainage scheme for the roof fissure zone was optimized.

(2) In the mining area, a hydraulic drilling hole cavity formation test was carried out, which significantly improved the drainage effect. The single-hole drainage volume of the cavity formation reached 0.02-0.18 m³/min, which was 3-5 times that of ordinary drilling holes. The permeability enhancement effect was obvious, enabling rapid release of methane and effectively shortening the time for reaching the drainage standard.

(3) Based on the methane geological conditions of the No. 3 coal seam and the actual methane prevention and control priorities in the underground (the mining layer, the subsidence area, and the return air corner of the mining face), targeted methane prevention and control methods were comprehensively applied, and a high-efficiency methane governance model for the No. 3 coal seam was formulated. This provided certain references for the efficient methane governance in this mining area and similar geological conditions mining areas.

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