

Gas Management in Coal-Gas Outburst Mines: Deep Analysis of Present Status and Future Tech Outlook

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Abstract

Pingdingshan Tian'an Coal Industry Co., Ltd. No.13 Mine is a typical coal and gas outburst mine, and gas disaster control is crucial to its safe and efficient production as well as sustainable development. Based on the mine's mining intensity assessment and production capacity confirmation report, this paper systematically and in-depth analyzes the characteristics of gas occurrence, gas control technology system, configuration of gas extraction system and current status of management and operation in the mine. The research shows that Pingmei No.13 Mine has established a three-dimensional comprehensive gas control model with "low drainage roadway cross-layer drilling pre-extraction" as the core and "soft rock protective layer mining + pressure relief extraction" as the auxiliary. The capacity of the gas extraction system fully meets the current production needs, the control effect is remarkable, and the residual gas content in the coal seam has been effectively controlled. On this basis, combined with the practical challenges faced by deep mining, this paper looks forward to the development direction of gas control technology in the future from four dimensions: precise extraction, intelligent monitoring, green emission reduction and multi-disaster coordinated control, aiming to provide practical reference and technical guidance for gas control in similar coal and gas outburst mines in China.

Keywords

Coal and Gas Outburst; Gas Control; Low Drainage Roadway Cross-Layer Pre-Extraction; Protective Layer Mining; Gas Extraction System.

1. Introduction

As the main energy source in China's energy security guarantee system, the safe production of coal is not only the core prerequisite for the high-quality development of the coal industry, but also an important foundation related to the stability of the national economy and social harmony[1]. Gas disasters, especially coal and gas outburst accidents, have long seriously restricted the safe and efficient mining of deep high-gas mines due to their strong suddenness, great destructiveness and serious disaster-causing consequences[2]. As a key production mine under Pingdingshan Coal Industry Group, Pingdingshan Tian'an Coal Industry Co., Ltd. No.13 Mine (hereinafter referred to as "Pingmei No.13 Mine") has extremely complex mining conditions. The current maximum mining depth has reached 836m, and the main mining No.2-1 coal seam has the "double high" characteristics of high gas content (up to 16.97 m³/t at maximum) and high gas pressure (up to 3.6 MPa at maximum), which is identified as a coal and gas outburst mine[3-4]. Establishing a scientific, efficient, safe and reliable comprehensive gas control system has become the core lifeline to ensure the mine's production succession and sustainable development. Based on this, this paper conducts an in-depth combing and analysis

of the existing gas control technical paths, engineering practice effects and system operation capabilities of Pingmei No.13 Mine, summarizes mature experience and control effects, and puts forward the optimization direction and technical prospect of future gas control in response to the new challenges faced by deep mining, so as to provide useful reference for improving the gas control level of similar mines.

2. Analysis of Current Status of Gas Control

The main mining coal seams of Pingmei No.13 Mine are the Ji Group coal seams, mainly including the Ji15-17 coal seam and Ji16, 17 coal seams. According to the measured data of mine gas emission in 2019, the absolute gas emission of the mine is 36.75 m³/min, the relative gas emission is 12.06 m³/t, and the absolute carbon dioxide emission is 16.51 m³/min. In addition, the main mining coal seams of the mine also have Grade II spontaneous combustion tendency and coal dust explosion hazard. The superposition of multiple disasters makes the gas occurrence conditions of the mine more complex, the outburst risk level is high, the difficulty of gas control is extremely great, and it brings severe challenges to the safe production of the mine[5-7].

2.1. Gas Control Technical Path

After long-term practice and technical iteration, Pingmei No.13 Mine has formed a three-dimensional gas control technical system with "regional control as the leading factor and local measures as the supplement", realizing comprehensive and multi-level prevention and control of gas disasters.

(1) Regional Control (Core Technology)

According to the gas occurrence characteristics of the Ji15-17 coal seam and Ji16, 17 coal seams, the "low drainage roadway cross-layer drilling pre-extraction" technology has been fully promoted and applied. The specific implementation method is: arrange the floor drainage roadway (i.e., low drainage roadway) in the stable rock stratum 8-13m below the coal seam floor, construct large-area and high-density cross-layer drilling from the low drainage roadway to the mining area to cover the entire mining face. To further improve the coal seam permeability and enhance the pre-extraction effect, hydraulic cavitation and hydraulic flushing and other permeability-increasing technologies are simultaneously adopted during the drilling construction, which effectively solves the problem of gas extraction in low-permeability coal seams. The effect inspection of regional control strictly takes the residual gas pressure and residual gas content as the core indicators. Only after the inspection confirms that the extraction meets the standards can the mining and excavation operations be carried out, thus eliminating the occurrence of coal and gas outburst accidents from the source.

(2) Protective Layer Mining (Innovation and Promotion Technology)

For areas with high gas enrichment and extremely high outburst risk such as the Ji15-17-13100 working face, the combined technology of "soft rock protective layer mining + low drainage roadway cross-layer pressure relief extraction" has been innovatively explored and promoted. The core logic of this technology is: first mine the soft rock stratum below the coal seam as the protective layer. Through the rock movement and pressure relief effect caused by the mining of the protective layer, the ground stress of the upper protected coal seam is released, the coal seam permeability is greatly improved (usually tens or even hundreds of times), and the gas desorption and migration channels are significantly increased. On this basis, the pressure-relieved gas is efficiently extracted through the cross-layer drilling arranged in the air roadway of the protective layer working face and the low drainage roadway of the protected coal seam. Practical data show that after the application of this technology, the gas content of the protected coal seam has decreased from the original 16.98 m³/t to 3-4 m³/t, the extraction rate has been

greatly improved, and the outburst elimination effect is extremely significant, providing an effective technical path for the safe mining of high gas enrichment areas.

(3) Local Supplementary Measures

To further strengthen the gas control during mining, on the basis of regional pre-extraction, in-seam drilling is constructed from the air roadway and machine roadway of the mining face to the interior of the coal seam to form a local gas extraction network, which effectively controls the peak gas emission during the mining of the working face, ensures that the gas concentration in the return air flow is always within a safe and controllable range, and provides double safety guarantee for mining and excavation operations.

2.2. Gas Extraction System and Capacity

Pingmei No.13 Mine attaches great importance to the construction and optimization of the gas extraction system, and has built a comprehensive extraction system combining "ground permanent extraction + underground mobile extraction", providing a solid hardware support for gas control.

(1) System Composition

The mine currently has two sets of ground permanent gas extraction systems, namely Dongfeng Well and Ji No.4 Air Shaft, and three sets of underground mobile gas extraction systems in Ji No.1, Ji No.3 and Ji No.4 mining areas. The total installed extraction capacity of the entire extraction system reaches 4575 m³/min, forming a gas extraction network covering all mining areas and mining faces of the mine, with strong gas extraction guarantee capacity.

(2) Capacity Verification

According to the mine's 2020 mining intensity assessment and production capacity confirmation report, the capacity of the extraction system is verified from multiple dimensions: the verified capacity according to the configuration of the extraction system is 2.965 million t/a; the verified capacity according to the actual extraction volume is 2.493 million t/a; the verified capacity according to the pre-extraction volume required for outburst prevention is 3.574 million t/a; the verified capacity according to the extraction rate is 3.269 million t/a. To ensure safety redundancy, the minimum value of 2.2629 million t/a is finally taken as the verified production capacity for gas extraction compliance. This verified capacity is higher than the designed production capacity of 2.1 million t/a of the mine, indicating that the overall capacity of the mine's gas extraction system is surplus, which can fully support the gas control needs under the current production scale and provide sufficient extraction guarantee for the safe and efficient production of the mine.

(3) Operation and Management

To ensure the efficient and stable operation of the extraction system, the mine implements the "Three Modernizations and One Project" management model for gas control, namely "drilling video recording, measurement precision, extraction standardization, and one drilling is a project". By installing a video monitoring system for drilling construction, real-time supervision of the entire drilling construction process is realized to ensure the quality of drilling construction; high-precision gas measurement equipment is adopted to accurately grasp the extraction parameters of each drilling and each area, providing data support for the evaluation of extraction effect; a standardized operation process for extraction is established to standardize the installation, maintenance, operation and other links of the extraction system; each drilling is managed as an independent project, the main responsibility is clarified, and the process control is strengthened, which comprehensively improves the standardized and refined management level of gas extraction.

2.3. Evaluation of Control Effect

Through the above comprehensive control model of "technology + management", Pingmei No.13 Mine has achieved remarkable results in gas control, effectively solving the safe production problem of high-gas outburst mines.

(1) Significant Outburst Elimination Effect

After the completion of regional control, it has been confirmed by third-party testing institutions and the mine's self-inspection that the residual gas content and residual gas pressure in the coal seam have been reduced below the critical values specified in the "Coal Mine Safety Regulations". During the excavation of the driving face and the mining of the mining face, all indicators of regional verification meet the safety regulations, which effectively eliminates the risk of coal and gas outburst and realizes the safe advancement of mining and excavation operations.

(2) Effective Control of Emission Volume

The efficient development of gas extraction has greatly reduced the absolute gas emission during mining, providing sufficient safe air volume guarantee for the mining and excavation faces. Monitoring data show that the gas concentration in the return air flow of each mining and excavation face is always stably controlled below 0.8%, which is much lower than the upper limit of 1.0% specified in the "Coal Mine Safety Regulations", ensuring the life safety of operators.

(3) Guarantee of Production Succession

The systematically improved regional pre-extraction technology has effectively shortened the preparation cycle of mining and excavation faces, creating favorable conditions for the safe and rapid excavation of coal roadways and the normal succession of mining faces. At present, the recoverable periods of the mine's developed coal reserves, prepared coal reserves and recoverable coal reserves all meet the relevant regulations of the coal industry, ensuring the continuity and stability of the mine's production.

3. Existing Problems and Future Technical Prospects

3.1. Main Existing Problems

Although Pingmei No.13 Mine has achieved remarkable results in gas control, combined with the current mining situation and future development trends of the mine, it still faces the following three prominent problems:

(1) Contradiction between Control Cost and Efficiency

The currently adopted low drainage roadway cross-layer drilling pre-extraction technology requires the construction of a large number of floor rock roadways and cross-layer drillings, which not only involves huge engineering volume and long construction cycle, but also occupies a large amount of human and material resources; at the same time, the hydraulic permeability-increasing process has high requirements for water resource supply and slag discharge system processing capacity, resulting in high overall gas control cost, which affects the speed of mining and excavation succession to a certain extent and restricts the further improvement of mine production efficiency.

(2) Technical Challenges of Deep Mining

With the extension of the mine's mining depth to the second level (-700m) and deeper, the ground stress, gas pressure and ground temperature underground will show an increasing trend, the coal seam permeability may be further reduced, the gas adsorption is enhanced, and the difficulty of desorption and extraction is greatly increased. The applicability and efficiency of the existing gas control technologies are facing severe tests, and there is an urgent need to develop new gas control technologies suitable for complex deep geological conditions.

(3) Room for Improvement in Extraction Concentration and Comprehensive Utilization Level
At present, the gas extraction concentration of some extraction drillings is relatively low due to factors such as changes in geological conditions and the quality of drilling sealing, which makes the comprehensive utilization of gas more difficult; at the same time, the comprehensive utilization of mine gas is mainly concentrated on the power generation of high-concentration gas on the ground, the resource utilization technology of low-concentration gas is not yet mature, and a large amount of low-concentration gas is directly discharged, which not only causes resource waste, but also brings environmental pressure of greenhouse gas emissions, failing to realize the organic unity of safety, environmental protection and economic benefits.

3.2. Prospect of Future Control Technology

In response to the above problems and combined with the development trend of coal industry technology, the future gas control of Pingmei No.13 Mine should transform and upgrade towards the direction of precision, intelligence, greenization and coordination, and build a modern gas control system with "advanced technology, controllable cost, safe and efficient, and green environmental protection".

(1) Precise Geological Exploration and Extraction Technology

Deepen the detailed exploration of coal seam gas occurrence laws, comprehensively use advanced geophysical exploration technologies such as geological radar, seismic wave exploration and microseismic monitoring to accurately delineate key areas such as gas enrichment areas, geological structural zones and gas-bearing abnormal bodies, providing accurate geological basis for gas control. Research, develop and promote directional long drilling construction technology to reduce the engineering volume of rock roadways and improve the coverage and construction efficiency of drillings; explore efficient permeability-increasing technologies such as ultra-high pressure hydraulic slotting, hydraulic fracturing and carbon dioxide fracturing, optimize permeability-increasing parameters for different geological conditions to improve coal seam permeability; optimize the drilling sealing process, adopt new and efficient sealing materials to improve the quality of drilling sealing, thereby increasing the gas extraction concentration and extraction efficiency of single drilling and reducing the unit gas control cost.

(2) Intelligent Monitoring and Regulation

Relying on "Internet of Things + big data + artificial intelligence" technology, build a full-process intelligent gas control system. In the drilling construction stage, install real-time monitoring equipment for drilling trajectory to realize dynamic regulation of drilling construction accuracy; in the extraction operation stage, deploy multi-parameter monitoring sensors covering the extraction pipeline network, drillings and mining faces to collect real-time data such as extraction flow rate, gas concentration, pressure, temperature, and gas concentration and ground stress of the working face; use big data analysis and artificial intelligence algorithms to establish a dynamic evaluation model of gas extraction effect, intelligently identify weak links in extraction, automatically warn of gas over-limit risks, and realize intelligent regulation of the operation parameters of extraction pump units and the opening of drilling valves through remote control technology, so as to realize the digital, visual and intelligent management and control of the gas control process and greatly improve the control efficiency and reliability.

(3) Green Emission Reduction and Resource Utilization

Increase the intensity of gas resource utilization, optimize the purification process of high-concentration gas on the ground, expand the ways of gas utilization, and actively explore diversified utilization modes such as civil gas supply, industrial heating and chemical raw materials in addition to power generation to improve the utilization rate of gas resources; research, develop and promote low-concentration gas oxidation utilization technologies, such as regenerative thermal oxidation (RTO) and catalytic oxidation, to convert low-concentration

gas into thermal energy for recycling and reduce the direct emission of greenhouse gases; explore the technical path combining gas extraction and carbon capture and storage (CCS) to realize the coordinated advancement of gas control and carbon neutrality goals, promote the transformation of gas control from a "cost center" to a "resource center", and achieve a win-win situation of safety, environmental protection and economic benefits.

(4) Multi-Disaster Coordinated Control

In-depth research shall be conducted on the coupled disaster-causing mechanism of multiple hazards such as gas, ground stress, geothermal temperature, and rock burst under deep mining conditions, so as to reveal the interaction laws and evolution paths among various disasters. Explore the integrated coordinated control technical route of "pressure relief - extraction - temperature reduction - rock burst prevention". For instance, optimize the mining parameters of the protective layer to achieve gas pressure relief extraction and outburst elimination while taking into account rock burst prevention and mine temperature reduction; develop new and efficient temperature reduction technologies, and realize the coordinated operation of gas extraction and mine cooling in combination with the gas extraction system; construct an integrated monitoring and early warning platform for multiple disasters to achieve synchronous monitoring, comprehensive analysis, and joint early warning of various disaster parameters. This will promote the transformation of gas control from single-hazard prevention to multi-disaster coordinated governance, providing comprehensive technical support for the safe and efficient mining of deep mines.

4. Conclusion

In response to the severe coal and gas outburst risks and complex geological conditions in its mining operations, Pingmei No.13 Mine has established a three-dimensional comprehensive gas control system through long-term technical innovation and practical exploration. This system takes "low drainage roadway cross-layer drilling pre-extraction" as the core, "soft rock protective layer mining + pressure relief extraction" as the auxiliary, and local measures as supplements. It is equipped with a well-improved efficient extraction system combining surface and underground operations, and implements the refined "Three Modernizations and One Project" management model. The gas control effect is remarkable, effectively ensuring the safe and stable operation of the mine's 2.1 million t/a production capacity, and forming a replicable and promotable "No.13 Mine Plan" for gas control.

Facing the challenges of the "three increases" (rising ground stress, gas pressure, and geothermal temperature) brought by deep mining, as well as issues related to control costs and efficiency, and comprehensive gas utilization, Pingmei No.13 Mine needs to continuously promote the transformation and upgrading of gas control technologies. It should focus on four key directions: precise extraction, intelligent monitoring, green emission reduction, and multi-disaster coordinated control. Through technical innovation, equipment upgrading, and management optimization, the scientificity, efficiency, and economy of gas control will be further improved. In the future, with the implementation and application of various new technologies and models, Pingmei No.13 Mine is expected to achieve a higher level of safe, efficient, and green mining, providing richer practical experience and technical reference for gas control in similar coal and gas outburst mines across China.

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