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Research on Prominent Early Warning Technology based on Dynamic Characteristics of Gas Emission

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Abstract

This paper elaborates in detail on the construction process and application effects of the prominent early warning technology and system based on the dynamic characteristics of gas emission in Xiayukou Coal Mine. In response to the frequent occurrence of coal and gas outburst disasters in Xiayukou Coal Mine, an early warning indicator system was constructed based on the dynamic characteristics of gas emission, and an early warning system was developed. This system enables real-time monitoring and early warning of coal and gas outburst hazards at the working face. Field applications have demonstrated that the system operates stably and reliably, with a high accuracy rate in early warning, thus providing a strong guarantee for the safe production of the coal mine.

Keywords

Gas Emission Characteristics; Prominent Early Warning Technology; Xiayukou Coal Mine; Real-Time Monitoring; Intelligent Early Warning.

1. Introduction

Xiayukou Coal Mine, serving as the core production mine of Shaanxi Coal and Chemical Industry Group Hancheng Mining Co., Ltd., holds a pivotal position within the regional coal energy supply framework [1-3]. As mining depths and intensities continue to escalate, the gas geological conditions encountered by the mine have become increasingly complex and challenging. The gas grade of the mine has shown a consistent upward trajectory, and the threat posed by coal and gas outburst disasters has become increasingly pronounced, posing a critical bottleneck to the safe production and sustainable development of the coal mine. Coal and gas outburst, a highly destructive dynamic phenomenon, often involves the sudden outburst of substantial quantities of coal and gas within an extremely short timeframe. This not only directly endangers the personal safety of underground personnel but also severely damages underground equipment and facilities, disrupts the ventilation system, and may even trigger secondary disasters such as gas explosions, resulting in more severe casualties and property losses [4-5]. According to authoritative statistical data, since its commissioning, Xiayukou Coal Mine has experienced over 20 coal and gas outburst incidents. Among these, the maximum amount of outburst coal reached as high as 1,100 tons, and the maximum gas emission volume was an astonishing 42,000 cubic meters. These alarming figures vividly illustrate the immense threat posed by coal and gas outburst disasters to the safe production of coal mines and underscore the urgency and importance of strengthening prevention and control efforts against coal and gas outbursts.

To effectively address this major safety hazard of coal and gas outbursts, Xiayukou Coal Mine has, through years of exploration and practice, gradually established a scientific and comprehensive "regional measures first, supplemented by local measures" dual "four-in-one"

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outburst prevention system. However, the current local outburst prediction methods primarily rely on contact-based point prediction techniques, which suffer from notable issues such as complex procedures and time-consuming operations. Contact-based point prediction methods can only obtain outburst danger information from localized areas of the coal seam and are unable to achieve comprehensive and continuous monitoring of the entire working face, resulting in certain monitoring blind spots that pose potential risks to the safe production of coal mines.

Therefore, the development of a non-contact, continuous outburst prediction method capable of real-time and uninterrupted prediction of coal and gas outburst danger holds significant practical and historical implications for breaking through the current technological bottlenecks in coal mine safety production and achieving safe and efficient coal mine operations [6-8]. The outburst early warning technology based on the dynamic characteristics of gas emission involves installing high-precision gas sensors at critical underground locations to monitor dynamic characteristic parameters such as gas emission volume and gas emission speed in real-time. By employing advanced data analysis and processing algorithms, these parameters are deeply mined and analyzed to detect precursor information of coal and gas outbursts in advance and accurately predict outburst danger. Compared with traditional contact-based point prediction methods, this technology offers notable advantages such as non-contact operation, continuous monitoring, and strong real-time performance, effectively compensating for the deficiencies of existing prediction methods and providing more reliable and efficient technical support for coal mine safety production. Consequently, in response to the frequent occurrence of coal and gas outburst disasters in Xiayukou Coal Mine, this study aims to construct an early warning indicator system based on the dynamic characteristics of gas emission, develop an early warning system, and achieve real-time monitoring and early warning of coal and gas outburst danger at the working face.

2. Principles of Outburst Early Warning Technology based on Gas Emission Characteristics

2.1. Analysis of Factors Influencing Gas Emission

Gas emission is influenced by multiple factors, primarily including gas content in coal, gas desorption characteristics of coal, coal permeability, and mining techniques and processes.

(1) Gas Content in Coal

The gas content in coal is the primary driving force behind gas emission. The higher the gas content in coal, the greater the potential for gas emission. Gas content in coal is influenced by various factors such as coal seam occurrence conditions, coalification degree, geological conditions, and mining techniques and processes. For example, an increase in coal seam burial depth leads to higher in-situ stress and poorer coal seam permeability, thereby increasing the gas content in coal. Additionally, a higher degree of coalification generates more gas, resulting in a larger gas content in coal.

(2) Gas Desorption Characteristics of Coal

The gas desorption characteristics of coal affect the rate of gas emission. The stronger the adsorption capacity of coal for gas, the slower the desorption rate, and the relatively smaller the amount of gas emission. Conversely, the weaker the adsorption capacity, the faster the desorption rate, and the relatively larger the amount of gas emission. Gas desorption characteristics of coal are influenced by various factors such as the physical and mechanical properties of coal, temperature, and moisture content in coal.

(3) Coal Permeability

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Coal permeability determines the flow capacity of gas within the coal. The better the coal permeability, the easier it is for gas to emanate from the coal. Conversely, the poorer the coal permeability, the more difficult it is for gas to emanate. Coal permeability is influenced by various factors such as the type of coal damage, coal porosity, and the permeability of the coal seam and its surrounding rock.

(4) Mining Techniques and Processes

Mining techniques and processes indirectly affect gas emission by altering the occurrence conditions and stress state of coal. For example, mining a protective seam can release the gas in the underlying coal seams, reducing the gas content in coal. Adopting reasonable drainage methods can effectively reduce the gas pressure in coal and decrease the amount of gas emission.

2.2. Principles for Constructing an Early Warning Indicator System

To construct a scientific and reasonable early warning indicator system, this paper adheres to the following principles:

(1) Principle of Singularity

The establishment of gas emission indicators should avoid having the same indicator reflect multiple influencing factors of outbursts, ensuring that each indicator can independently reflect changes in a specific factor. For example, gas volume indicators primarily reflect changes in gas content in coal, while gas desorption indicators primarily reflect changes in the physical and mechanical properties of coal.

(2) Principle of Independence

Various early warning indicators should remain relatively independent of each other to avoid mutual influence. Through mathematical statistics and data mining techniques, independence analysis of each indicator is conducted to ensure that each indicator can function independently during the early warning process.

(3) Principle of Sensitivity

Early warning indicators should possess high sensitivity, capable of promptly reflecting changes in gas emission. Through on-site investigations and data analysis, indicators sensitive to changes in gas emission are selected as early warning indicators.

(4) Principle of Reliability

Early warning indicators should exhibit high reliability, maintaining stable early warning performance under different geological conditions. Through on-site verification and data analysis, early warning indicators are optimized and adjusted to ensure their reliability in practical applications.

2.3. Construction of an Early Warning Indicator System

Based on the aforementioned principles, this paper constructs four categories of characteristic indicators: gas volume, gas desorption, gas fluctuation, and gas trend, totaling 16 specific early warning indicators, as illustrated in Figure 1. Through tracking investigations and data analysis of multiple heading faces in Xiayukou Coal Mine, combined with the actual conditions of the routine prediction indicator $\triangle h_2$, this paper has identified early warning sensitive indicators and their critical values suitable for Xiayukou Coal Mine. For instance, in the case of the 2# coal seam: When the gas indicator A is greater than or equal to 12 ($A \geq 12$), it is judged to be in a dangerous state. When A ranges from 9 to less than 12 ($9 \leq A < 12$), it is judged to be in a threatening state. When A is less than 9 ($A < 9$), it is judged to be in a normal state. For the gas desorption indicator B: When B is greater than or equal to 0.9 ($B \geq 0.9$), it is judged to be in a dangerous state. When B ranges from 0.6 to less than 0.9 ($0.6 \leq B < 0.9$), it is judged to be in a threatening state. When B is less than 0.6 ($B < 0.6$), it is judged to be in a normal state.

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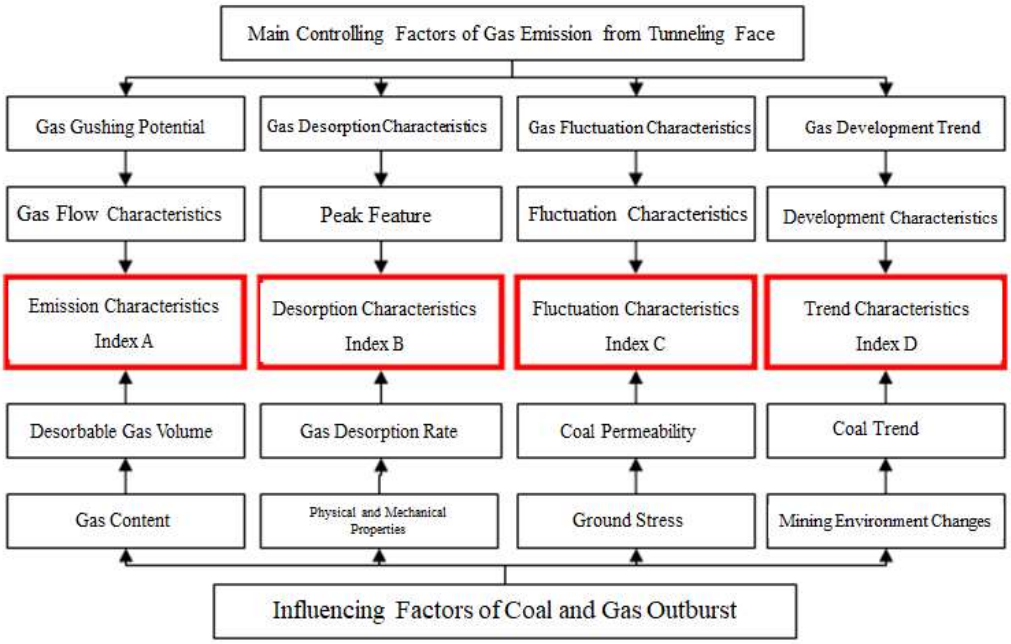

Figure 1. The relationship between gas emission characteristics and prominent influencing factors

3. Construction of Outburst Early Warning System based on Gas Emission Characteristics

The primary objective of system construction is to achieve online monitoring, early alerts, real-time early warnings, and timely dissemination of coal and gas outburst risks based on gas emission characteristics. The Outburst Early Warning System Based on Gas Emission Characteristics (referred to as the "KJA System") serves as the implementation tool for early warning technology. It primarily acquires gas concentration data from underground working faces through gas sensors installed underground or via existing integrated mine monitoring systems. Based on the tunnel parameters set in the control terminal, it automatically calculates the current outburst risk indicators for the working face based on the dynamic characteristics of gas emission and disseminates the results through early warning clients, SMS terminals, or web pages. The main functions of the KJA Outburst Early Warning System include analyzing the dynamic characteristics of gas emission, filtering out monitoring noise data, setting early warning indicators and rules for gas emission, managing early warning results, and system management. The early warning system also realizes intensive management of daily prediction parameters. Through information technology means, geological information, coal seam information, daily prediction indicators, and other relevant data are entered or imported into the system to cross-verify with early warning indicators, enabling centralized management of multi-source information on outburst risks. Additionally, the system provides convenient query and report generation functions, reducing the manual process of data retrieval and viewing, thereby improving work efficiency and the level of outburst prevention information management.

4. Evaluation of Application Effects

Since its operation in Xiayukou Coal Mine for four months, the early warning system has demonstrated overall stable and reliable performance. The system starts up and reaches normal operation within 5 seconds, with a slow database growth rate of approximately 5MB per month and a low error rate. When users operate and maintain the system in accordance

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with the "User Manual," the system can operate continuously and stably for no less than 6 months. Through tracking investigations of multiple heading faces, including the 21228 Inbound Roadway, 22206 Transport Roadway, 23202 Inbound Roadway, and 21314 Return Roadway, the early warning system has cumulatively issued over 800 early warnings, with a missed alarm rate of 0. In several cases, the early warning system issued early danger or threat alerts, providing strong support for the safe production of the coal mine.

(1) 23202 Inbound Roadway Working Face

On January 8, 2020, the prediction indicators for the 23202 Inbound Roadway working face exceeded the limits, with the maximum gas desorption indicator ($\triangle h_2$) from drill cuttings reaching 180Pa, indicating a certain degree of outburst risk ahead of the working face. The early warning system issued threat alerts for three consecutive shifts starting from the fourth shift on January 5, 2020, and continuous danger alerts for the first and fourth shifts on January 7, with the A indicator reaching a maximum of 12.95. The working face subsequently halted excavation, and after implementing local outburst prevention measures, the prediction indicators returned to normal. The early warning system issued a danger alert one day in advance and a threat alert three days earlier, demonstrating its foresight and reliability.

(2) 22206 Transport Roadway Working Face

From March 2 to March 10, 2020, the coal seam thickness at the 22206 Transport Roadway working face continuously increased, leading to the cessation of excavation on March 11 for regional drilling. During the drilling process, two instances of gas blowouts occurred on the midnight and fourth shifts on March 13, causing gas concentration to exceed the limits. The early warning system issued threat alerts for seven consecutive shifts starting from the fourth shift on March 10, followed by continuous danger alerts for three shifts starting from the midnight shift on March 13, with the A indicator reaching a maximum of 14.22. The early warning results were sent to relevant technical and management personnel through the SMS early warning platform, providing a basis for outburst prevention decision-making.

(3) 21314 Return Roadway Working Face

The coal seam being excavated at the 21314 Return Roadway heading face is the 3# coal seam, which is mined after the upper 2# coal seam protective layer has been extracted. After the extraction of the protective layer, the gas in the 3# coal seam has been released through pressure relief, significantly reducing its gas content. During the evaluation period of the 21314 Return Roadway working face, the daily prediction indicator ($\triangle h_2$) did not exceed the limits, with a maximum value of 120Pa, and the gas content remained below 8m^3/min, indicating a low outburst risk at the working face. The early warning system did not issue any threat or danger alerts during the evaluation phase of the 21314 Return Roadway, demonstrating the accuracy and reliability of the early warning threshold settings.

5. Conclusion

Through the construction of an early warning indicator system, the development of software systems, and the establishment of hardware systems, this paper has developed a comprehensive early warning method for coal and gas outbursts based on gas emission characteristics for Xiayukou Coal Mine. The main achievements are as follows:

(1) For the monitoring system employed at Xiayukou Coal Mine, a data acquisition and transmission port was developed to enable real-time collection of monitoring data by the early warning system without interfering with the monitoring database. Additionally, an SQL Server database was established to dynamically and comprehensively store relevant data information.

(2) A comprehensive early warning system integrating PC clients, Web browsing terminals, and SMS messaging platforms was established. This system enables multi-channel querying of early

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warning results and real-time dissemination of these results in various forms, facilitating online monitoring of gas disasters, advance alerts, and trend analysis.

(3) Through tracking investigations of heading faces such as the 21314 Return Roadway and 21228 Inbound Roadway, gas volume indicator A and gas desorption indicator B were selected as the most suitable early warning indicators for Xiayukou Coal Mine from among 16 indicators across four categories. Reasonable early warning critical values were also established.

(4) Since its operation at Xiayukou Coal Mine for four months, the early warning system has demonstrated stable and reliable performance in assessing and alerting to hazardous conditions and development trends at working faces. It has tracked over 500 meters of underground roadways, successfully capturing multiple instances of abnormal gas phenomena in advance, and achieving excellent application results.

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