Research on Regional Hazard Prediction Based on the Occurrence Law of Mine Gas

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Abstract. This study focuses on the occurrence law of mine gas and aims to predict the regional hazard of mine gas. Gas disasters are a prominent issue in coal mine safety, with significant impacts on the healthy and sustainable development of the coal industry and the overall production safety situation in the country. Understanding the occurrence state and flow pattern of gas is particularly crucial for gas prevention and control.

Keywords: mine gas; occurrence law; regional hazard

1 Introduction

Coal mines, as a crucial pillar of energy supply, play a pivotal role in global economic development. However, the issue of gas disasters accompanying coal mining has always been a significant challenge restricting mine safety and sustainable development. Gas disasters, particularly gas outbursts and explosions, not only pose severe threats to miners' lives but also may lead to substantial economic losses and environmental pollution[1]. Therefore, delving into the occurrence law of mine gas and conducting regional hazard predictions based on it is of great significance for enhancing coal mine safety management and reducing gas disaster accidents.

The state and distribution pattern of gas occurrence are influenced by various geological and mining conditions, making it a complex geological phenomenon. The gas content, pressure, occurrence forms (such as adsorbed and free states) of coal seams, and their spatial distribution are directly related to the risk of gas disasters in mines[2]. Geological structures, coal seam characteristics, hydrogeological conditions, mining depth, and methods, among other factors, all impact the generation, migration, and accumulation processes of gas to varying degrees. Therefore, unveiling the gas occurrence law is a prerequisite and foundation for understanding the mechanism of gas disaster occurrence and conducting regional hazard predictions.

Currently, domestic and international scholars have made some progress in researching gas occurrence laws. However, accurately predicting gas disaster risks based on the geological characteristics of specific mining areas or coal seams remains an urgent problem to be solved. Especially in complex geological structural zones, the occurrence

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and migration laws of gas are more intricate and variable, making it difficult for traditional prediction methods to accurately reflect the actual situation[3]. Therefore, combining modern geological, geophysical, mining engineering, and other multidisciplinary theories and methods to carry out research on regional hazard prediction based on the mine gas occurrence law is of urgent need and significant value for improving prediction accuracy and guiding coal mine safety production practices.

2 Occurrence Law of Mine Gas

The flow of coal mine methane gas is a complex process influenced by a multitude of factors. In specific situations, a comprehensive analysis must consider factors such as coal seam occurrence, geological conditions, mining intensity, ventilation conditions, and the physical and chemical properties of methane gas. Corresponding measures should be taken to control the flow of methane gas and ensure mine safety.

Methane gas, primarily composed of methane, has a high caloric value and is a clean energy source. During coal mining operations, an effective extraction and utilization system can be employed to collect methane gas for use as a gaseous fuel. This energy can not only meet the production and living needs of the coal mine, such as power generation and heating, but can also be supplied to surrounding areas, thereby reducing dependence on fossil fuels and lowering environmental pollution.

Power generation using methane gas is an important method of methane utilization. Utilizing methane gas for power generation not only improves resource utilization efficiency but also has a positive impact on the surrounding environment. In coal mines, methane gas is typically used for power generation through internal combustion engine technology, which converts the heat energy generated by methane combustion into electrical energy. This power generation method is characterized by stable operation, easy maintenance, and clean emissions.

Methane gas can also be used as a raw material for the production of chemical products such as carbon black. Under high temperatures, methane in the gas can be cracked to produce carbon black and hydrogen. Carbon black is an important chemical raw material widely used in industries such as rubber, plastics, paints, and inks. Additionally, the hydrogen in methane gas can be used for the synthesis of ammonia, methanol, and other chemical products.

Although methane gas may pose safety hazards in coal mines, through scientific and reasonable utilization and management, it can be transformed into a valuable resource. By establishing a comprehensive methane monitoring and extraction system, the methane concentration in the mine can be monitored in real-time to ensure it remains within a safe range. Furthermore, utilizing methane gas for power generation and the production of chemical products not only reduces direct methane emissions but also lowers environmental pollution, contributing positively to mitigating global climate change.

When a coal seam is exposed to the surface, forming an outcrop, or is covered by alluvial deposits, the gas within the coal seam exhibits distinct vertical zoning characteristics[4]. This is manifested in the natural division of gas into two main zones along the vertical direction: the gas weathering zone and the methane zone. Further subdivisions within the gas weathering zone, based on changes in gas composition, can be made into three sub-zones: firstly, the carbon dioxide-nitrogen zone, where the content of carbon dioxide and nitrogen is relatively high; secondly, the nitrogen zone, which is predominantly composed of nitrogen; and finally, the nitrogen-methane zone, where the proportions of nitrogen and methane gradually transition, with methane beginning to occupy a certain percentage. This zoning phenomenon reflects the complex distribution and evolution patterns of coal seam gas under different depths and geological conditions.

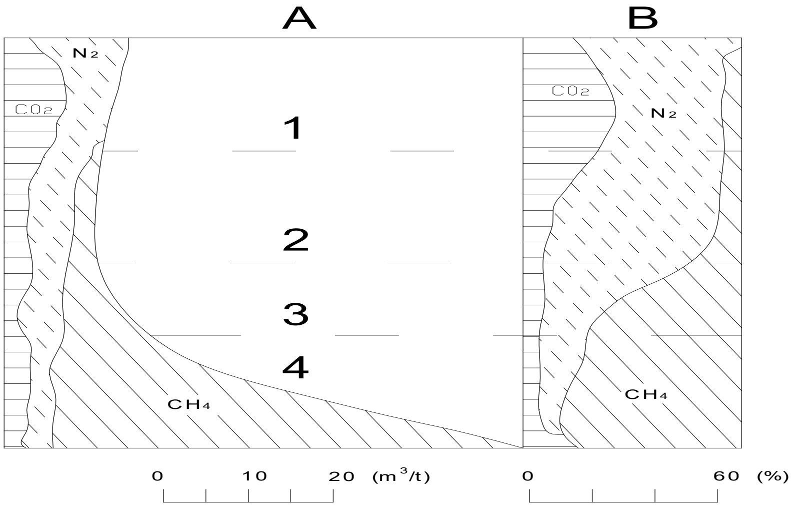

Fig. 1. Gas Zoning in Coal Seams and Their Sequence

A - Content, m³/t B - Percentage of total gas composition;

1 - Carbon Dioxide-Nitrogen Zone 2 - Nitrogen Zone 3 - Nitrogen-Methane Zone 4 - Methane Zone

Typically, the vertical zoning phenomenon of gas in coal seams presents a coherent layered structure as shown in Figure 1. Specifically, the carbon dioxide-nitrogen zone is often located at the outermost layer of the coal seam, followed by the nitrogen zone, then the nitrogen-methane zone, and finally the methane zone at the deepest level. This continuous distribution pattern reveals the variation in gas composition with coal seam depth. However, under certain specific geological conditions or environmental factors, the vertical zoning characteristics of coal seam gas may exhibit different patterns. One scenario is that the nitrogen zone is directly located at the shallowest part of the coal seam, followed by the nitrogen-methane zone, and then the methane zone at the deepest level; another scenario is that the nitrogen-methane zone occupies the shallowest part of the coal seam, followed by the methane zone. These special zoning patterns indicate that the vertical distribution of coal seam gas is not only influenced by depth but also by a complex interplay of various factors such as geological structures, groundwater activity, and coal seam permeability.

3 Distribution Law of Gas Content in Coal Seams

The gas content in coal seams is influenced by various geological factors, including coal quality characteristics, burial depth, geological structures, physicochemical properties of coal, and the lithology of the roof and floor rocks of the coal seams[5]. It is noteworthy that the extent to which these geological factors affect gas content may vary significantly among different mining areas. For a specific coal mine, there is usually a dominant factor that controls the overall trend of gas content variation, while other geological factors mainly influence gas content locally.

Taking the coal mine studied in this research as an example, its geological structure is relatively simple, mainly featuring a monoclinic structure. Only in the southern and southwestern parts are there gently undulating folds, and a small fault with a maximum drop of about 1 meter is exposed in the central area[6]. No collapse columns or magmatic rocks have been exposed. Additionally, this mine is adjacent to the Shangyuquan Mine and Madigou Mine, and there are no faults or other significant structures between the neighboring mines, which have a minor impact on the division of gas geological units in the mine and its neighbors.

For the No. 15 coal seam, which currently lacks gas data, since it belongs to the same coal type as the No. 16 coal seam, with similar coal quality and an average spacing of only 4.57 meters, the gas content distribution law of the No. 16 coal seam can be referred to in predictions.

Through the analysis of underground measured gas content data, the distribution law of gas content in the No. 11, 12, 13, and 14 coal seams has been revealed. Specifically, the gas content in these coal seams shows an increasing trend with burial depth. Through linear regression analysis, statistical relationships between gas content and burial depth have been derived, clearly demonstrating the law of gas content variation with depth.

Meanwhile, based on underground measurements and gas composition data from geological exploration boreholes, the gas zone distribution of each coal seam can be preliminarily determined. For example, the No. 13 and 14 coal seams are mainly located in the nitrogen zone and the nitrogen-methane zone, while the No. 16 coal seam is primarily in the nitrogen-methane zone. For the No. 18 coal seam, which lacks direct data, referring to the situation of the No. 16 coal seam, it is believed to also be in the nitrogen-methane zone.

Furthermore, the growth gradients of gas content in each coal seam have been calculated, which helps to gain a deeper understanding of the rate of gas content variation with burial depth. The results indicate that as the burial depth of the coal seams increases, the growth gradient of gas content also shows a gradual increasing trend.

Finally, by plotting gas content contour maps for each coal seam, the distribution of gas content within the coal mine area is visually presented. It can be seen from the maps that the gas content of each coal seam is lower at the southwestern outcrop boundary and higher in the central part of the mine. This distribution characteristic provides an important basis for gas disaster prevention and control.

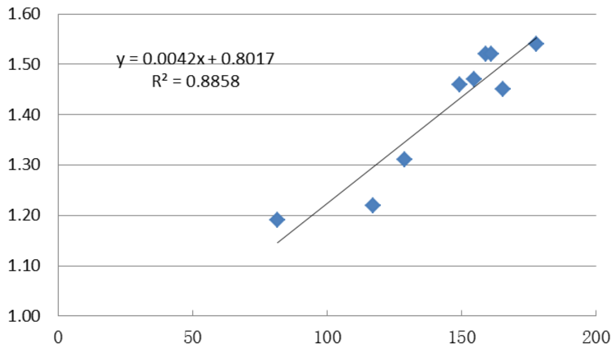

Fig. 2. Scatter Plot of Gas Content Versus Depth for the No. 12 Coal Seam

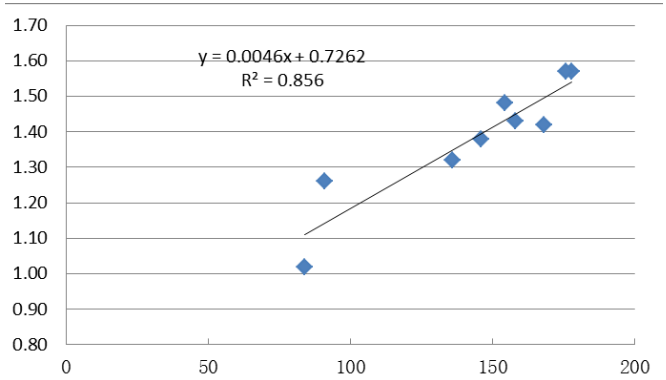

Fig. 3. Scatter Plot of Gas Content Versus Depth for the No. 13 Coal Seam

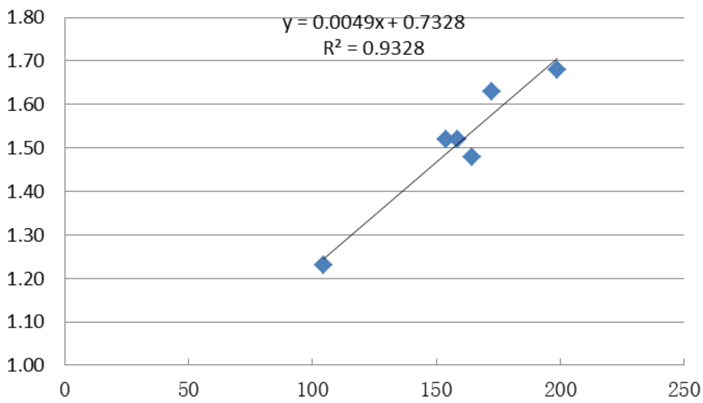

Fig. 4. Scatter Plot of Gas Content Versus Depth for the No. 14 Coal Seam

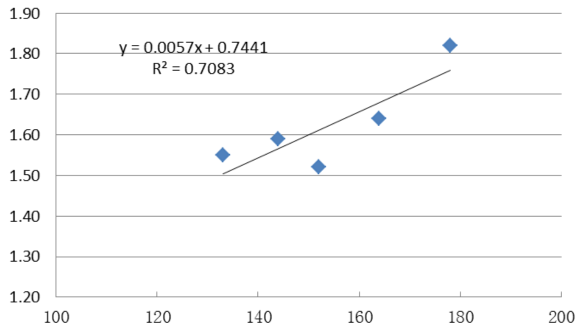

Fig. 5. Scatter Plot of Gas Content Versus Depth for the No. 15 Coal Seam

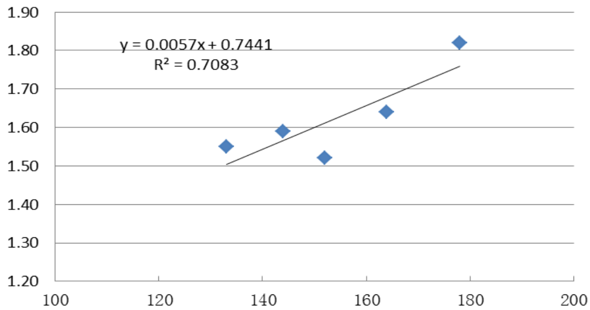

Fig. 6. Scatter Plot of Gas Content Versus Depth for the No. 16 Coal Seam

As shown in Figure 2-6. The research methods for coal mine gas include collection, analysis, and modeling. Collection mainly involves the coal mine gas extraction system, which uses equipment such as water ring vacuum pumps to safely and sealingly extract coal mine gas to the ground or collection system. The system includes ground pumping stations, main pipelines, branches, and drill holes. Analysis relies on tools such as gas chromatographs to conduct detailed component analysis of coal mine gas, providing data support for processing and utilization. In addition, establishing gas concentration prediction models can predict the distribution and trend of coal mine gas concentration based on mine ventilation, geological and mining conditions, enabling timely discovery of potential accumulation areas and guiding the adoption of effective measures, which is of great significance for preventing coal mine gas explosion accidents.

4 Prediction of Coal Seam Gas Emission

During the mining of different coal seams, the gas emission in the mine, as well as at the mining and tunneling faces, exhibits certain patterns and differences. Specifically:

When mining the No. 12 coal seam, the maximum absolute gas emission in the mine reached 13.59 cubic meters per minute, with a maximum relative gas emission of 1.43

cubic meters per ton. At the mining face, the maximum absolute gas emission was 2.56 cubic meters per minute; in contrast, the maximum absolute gas emission at the tunneling face was slightly lower, at 0.75 cubic meters per minute.

As the mining depth increased and mining shifted to the No. 13 coal seam, the maximum absolute gas emission in the mine rose slightly to 12.36 cubic meters per minute, with the maximum relative gas emission also increasing to 1.46 cubic meters per ton. The maximum absolute gas emission at the mining face increased to 2.73 cubic meters per minute, while the maximum absolute gas emission at the tunneling face decreased slightly to 0.56 cubic meters per minute.

Further mining into the No. 14 coal seam saw the maximum absolute gas emission in the mine continue to rise, reaching 12.62 cubic meters per minute, with the maximum relative gas emission also reaching 1.50 cubic meters per ton. The maximum absolute gas emission at the mining face increased to 3.14 cubic meters per minute, while the maximum absolute gas emission at the tunneling face further decreased to 0.45 cubic meters per minute.

When mining the deeper No. 15 coal seam, the maximum absolute gas emission in the mine significantly increased to 15.74 cubic meters per minute, with the maximum relative gas emission also substantially increasing to 1.87 cubic meters per ton. The maximum absolute gas emission at the mining face was as high as 4.32 cubic meters per minute, while the maximum absolute gas emission at the tunneling face remained at a lower level, at 0.36 cubic meters per minute.

Finally, during the mining of the deepest No. 16 coal seam, the maximum absolute gas emission in the mine reached the highest level of 16.69 cubic meters per minute, with the maximum relative gas emission also reaching the highest level of 1.98 cubic meters per ton. The maximum absolute gas emission at the mining face was 3.73 cubic meters per minute, while the maximum absolute gas emission at the tunneling face rebounded to 1.62 cubic meters per minute, which may be related to the geological conditions and mining methods of this coal seam.

In summary, during the mining of different coal seams, the gas emission in the mine, as well as at the mining and tunneling faces, exhibits different characteristics, providing an important basis for formulating targeted gas prevention and control measures.

5 Prediction of Regional Outburst Risk of Coal and Gas

The mine strictly follows relevant standards and conducts on-site measurements of gas content. Based on the actual distribution trend of gas content within the mine, a scientific prediction of the gas content in the coal mine is made. The prediction results indicate that the gas content in the coal mine is expected to be no more than 4 cubic meters per ton. This predicted value suggests that the risk of gas outbursts during coal mining is relatively low.

In specific cases, a detailed analysis of the flow of coal mine gas requires considering various factors collectively, including the state of coal seams, geological conditions, mining intensity, ventilation conditions, and the physical and chemical properties of gas. The following is a specific analysis of coal mine gas flow based on these factors:

Coal Thickness and Slope: The thickness and slope of the coal seam will affect the migration pattern of gas. In thick coal seams, the gas content is usually higher, and due to the inclination of the coal seam, gas may be more easily transported along the inclined direction.

Fractures and Porosity: The fractures and porosity structure of the coal body are the main channels for gas migration. The connectivity of the fractures and the size, distribution of pores will affect the speed and direction of gas flow.

Geological Structures: Geological structures such as faults and folds will affect the integrity and permeability of the coal seam, thereby affecting gas migration.

Mining Intensity: Increasing mining intensity will lead to an increase in the number of coal seam fractures and enhanced connectivity, thereby promoting gas migration. At the same time, increasing mining intensity will also increase the exposed surface area of the coal body, allowing more gas to be released.

Ventilation Conditions: Ventilation is an effective means of controlling gas concentrations. Good ventilation conditions can accelerate the diffusion and emission of gas, reducing the gas concentration in the mine. The design and operation of the ventilation system have a significant impact on the flow of gaseous substances.

Gas Pressure: Gas pressure is the main factor affecting the speed and range of gas migration. The greater the pressure difference, the faster the gas migration speed, and the greater the range of escape.

Gas Concentration: Gas concentration determines the explosiveness and toxicity of gas. Under certain conditions, high-concentration gas may cause an explosion, posing a threat to mine safety.

Gas Adsorption: The adsorption of gas in the coal body will affect its migration pattern. Physical adsorption is the most common form of gas existence in coal, and when the coal is affected by mining activities, the adsorbed gas will desorb and release into the fractures, thereby participating in migration.

In specific cases, such as coal seam mining, the flow of gas can be affected by a combination of various factors. For example, in the early stages of coal seam mining, due to the lack of fractures and poor connectivity in the coal body, gas migration is slow; as mining intensity increases and the number of fractures in the coal body increases, gas migration speed gradually increases. At the same time, the improvement of ventilation conditions can accelerate the diffusion and emission of gas, reducing the concentration of gas in the mine. In addition, changes in geological structures may also lead to changes in the migration patterns of gas.

6 Conclusion

In order to effectively control the flow of gas and prevent accidents such as coal gas explosions, a series of measures need to be taken, such as optimizing the ventilation system, strengthening coal gas extraction, treating fractures, and preventing water seepage. These measures should be designed and implemented based on the specific conditions of the mine and the flow patterns of gas.

In summary, the flow of coal mine gas is a complex process that is affected by multiple factors. When conducting specific analysis in a particular situation, it is necessary to consider various factors such as the state of coal seams, geological conditions, mining intensity, ventilation conditions, and the physical and chemical properties of gas, and take corresponding measures to control the flow of gas and ensure mine safety.

Furthermore, based on detailed measurement data of gas content in various coal seams of the mine, the following specific conclusions are drawn: the gas content of the No. 8 coal seam is 0.46 cubic meters per ton, the gas content of the No. 12 coal seam is 1.52 cubic meters per ton, the gas content of the No. 13 coal seam is 1.57 cubic meters per ton, and the gas content of the No. 14 coal seam is 1.68 cubic meters per ton. Additionally, referring to the gas content data of neighboring mines, it is found that the gas content of the No. 16 coal seam in neighboring mines is 3.02 cubic meters per ton. Based on these data, it is clear that the gas content of both the coal seams in this mine and the relevant coal seams in neighboring mines is far below the critical value of 4 cubic meters per ton.

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References

1. Packham R , Cinar Y , Moreby R .Simulation of an enhanced gas recovery field trial for coal mine gas management[J].International Journal of Coal Geology, 2011, 85(3-4):247-256.DOI:10.1016/j.coal.2010.11.013.
2. Wu A Y , Tian Y L , Song Y ,et al.Application of the grey system theory for predicting the amount of mine gas emission in coal mine[J].Journal of China Coal Society, 2005.
3. Shao L S , Fu G X .Disaster prediction of coal mine gas based on data mining[J].Journal of Coal Science and Engineering (China), 2008, 14(3):458-463.DOI:10.1007/s12404-008-0099-9.
4. Qin X , Fu M , Shen B .Coal Mine Gas Wireless Monitoring System Based on WSNs[C]//International Conference on Digital Manufacturing & Automation.IEEE, 2011.DOI:10.1109/ICDMA.2011.82.
5. Qian J S , Yin H S , Liu X R ,et al.Data Processing Model of Coalmine Gas Early-Warning System[J].Journal of China University of Mining and Technology: English edition, 2007, 17(1):5.DOI:10.1016/S1006-1266(07)60005-4.
6. Yang J , Huang J , Li X ,et al.High-sensitivity long-period fiber grating sensor with SAN/cryptophane A for coal mine gas detection[J].China Optical Express: English version, 2013, 11(008):14-17.DOI:10.3788/COL201311.080601.