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Research on Diversified Precision Prevention and Control System for Outburst Mine Gas Disaster

Guowen Tan[1, 2]

[1]State Key Laboratory of the Gas Disaster Detecting, Preventing and Emergency Controlling, Chongqing, 400037, China

[2]China Coal Technology and Engineering Group Chongqing Research Institute, Chongqing, 400037, China

Abstract

To prevent coal and gas outburst effectively and scientifically, guided by scientific connotation of precision coal mining, based on the cause and law of coal and gas outburst, the diversified and precision technology structure for gas disaster prevention and control is put forward, which includes "precise control of gas geology, reliable gas drainage, intelligent early warning of gas emission and daily management norm of gas outburst prevention", and the diversified precise prevention and control system of gas disaster has been constructed from three aspects of equipment, model and software, realizes the diversified and standardized analysis and management of prevention and control of gas disaster, and improves the precise prevention and control technology capability and level of mine gas disaster, the field application effect is good.

Keywords

Coal and Gas Outburst; Precision Prevention and Control; Diversified; Intelligence; Gas Geology; Gas Extraction.

1. Introduction

Coal and gas outburst disaster is one of the typical dynamic disasters in coal mines. It has the characteristics of sudden, sharp and violent. It not only has a large degree of harm and a wide range of influence, but also easily induces other major accidents. China's coal and gas outburst disasters are very serious and complex. Coal and gas outburst is the number one killer that threatens coal mine safety production, especially in southwestern regions such as Chongqing, Guizhou, and Sichuan, where gas outburst disasters are quite serious, and its control has always been the focus and difficulty of mine safety work [1-3]. After 40 years of innovation and development of reform and opening up, my country's coal mines have achieved a leap from general mechanization, comprehensive mechanization to automation, and began to move toward intelligence, providing a reliable energy guarantee for my country's economic and social development. Entering the new century, a new round of technological and energy revolution is being conceived, industrial informatization, automation and intelligence are developing strongly, and technology is becoming more and more mature. It provides new development opportunities and challenges for the transformation of coal mine typical and major disaster management from traditional qualitative and empirical prevention and control to modern quantitative and precise prevention and control [4-6]. According to the current development trend of science and technology, relying on these advanced science and technology and scientific management is an effective way to curb major accidents in coal mines. Then, the occurrence conditions of coal seams in my country's coal mines are complex and diverse, the foundation and level of intelligent construction of coal mine disaster prevention and control are uneven, and there are large differences in the safeguard measures for the intelligent

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construction of coal mines in different regions, resulting in the intelligent construction path and construction progress of coal mine disasters. Not the same, the intelligent development of coal mines in severe disaster areas lacks overall planning. Therefore, combined with the serious characteristics of gas disasters in mines in southwest my country and the limitations of actual prevention and control technologies, it is of great practical significance and value to research and apply diversified and precise prevention and control technologies and computer systems for gas disasters to comprehensively and accurately prevent and control gas disasters.

2. Diversified and Precise Prevention and Control Technology of Gas Disasters

2.1. Causes of Gas Disasters and Limitations of Existing Prevention and Control Techniques

The prominent dangers of the mine face generally change dynamically, which requires that the safety technology and measures should be adjusted in real time to adapt to these changes. Existing outburst disaster prevention technology and management methods are mostly static and manual analysis and management in the analysis of coal and rock outburst risk, prevention and control technical measures, construction management, etc. The level of automatic monitoring and informatization detection of hazard information is not high. It cannot adapt to the changing dynamics of the protruding danger of the working face, so that the fineness, comprehensiveness and reliability of mine gas geological analysis, gas drainage analysis, gas gushing analysis, and daily outburst prevention management are not enough, and the diversification of gas disasters cannot be realized. And the comprehensive and precise prevention and control of automation restricts the effectiveness and scientificity of prevention and control technology.

2.2. Technical Framework for Diversified and Precise Prevention and Control of Gas Disasters

The diversified and precise prevention and control technology of gas disaster is mainly based on the accurate detection of geology, structure and gas, based on the current information technology, Internet of Things, big data analysis and other technologies, guided by the scientific concept of precise coal mining, and based on the mine gas outburst disaster Based on the causes and occurrence laws, it is supported by multi-source information acquisition and sensing equipment, computers and multi-network integrated transmission equipment, and is based on diversified and accurate gas disaster prevention and control models and software as tools. Precise analysis and division of gas geology from the perspective of precise control of mine gas geology. From the intelligent evaluation of gas drainage compliance and the optimal design of drainage drilling holes are carried out from an accurate and reliable angle. From the perspective of gas gushing intelligent early warning, continuous monitoring and early warning of prominent anomalies, and daily outburst prevention management norms, formalized management and integrated analysis of "four-in-one" comprehensive outburst prevention measures information. In the end, it realizes the dynamic acquisition and comprehensive analysis of data in various links such as "gas geology → gas extraction → gas monitoring → daily outburst prevention" in the mine, and carries out diversified and precise prevention and control of gas disasters. The overall technical architecture is shown in Figure 1.

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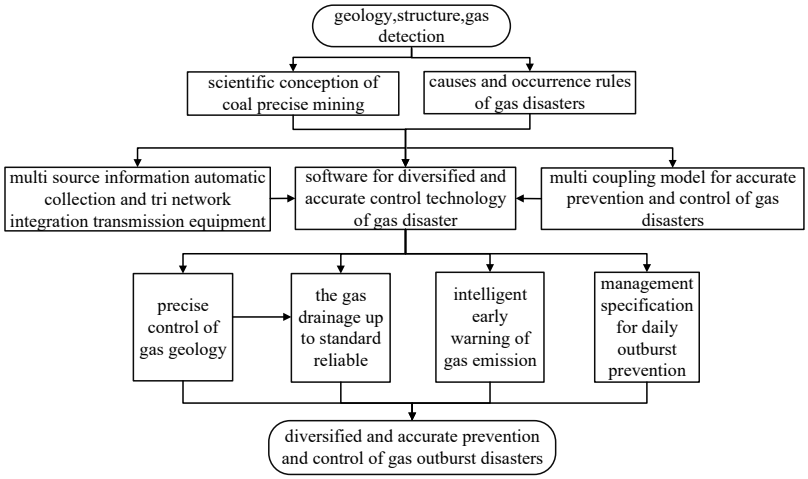

Figure 1. Technical framework of diversified and precise prevention and control of gas disasters

3. Diversified and Precise Prevention and Control System for Gas Disasters

According to the scientific connotation and key scientific issues of precise coal mining supported by the Internet of Things, big data, etc., the diversified and precise gas disaster prevention and control system is mainly researched and constructed from three aspects: automatic collection of multi-source information of gas disasters and three-network integration transmission equipment, multiple coupling models for precise prevention and control, and diversified precise prevention and control technology software.

3.1. Multi-source Information Automatic Collection and Triple Play Transmission Equipment

At present, the multi-source information collection of gas disasters has problems such as unreliability, incompleteness, insensitivity, and inability to integrate non-homogeneous data [4]. According to these problems, from the aspects of ventilation, gas, outburst parameters, etc., research and apply portable methane detection alarm instrument with uploading and self-checking functions, new gas outburst parameter instrument, high-precision anemometer, high-precision air pressure analyzer and gas surge early warning device, high-sensitivity laser methane sensor and wind speed and direction sensor. And through the establishment and integration of underground wireless WIFI, underground industrial ring network, surface local area network, surface Internet and other information transmission networks, the three networks of "underground network → local area network → Internet" for information transmission can be integrated and interconnected.

3.2. Multi-coupling Model for Precise Prevention and Control of Gas Disasters

According to the diversified and precise prevention and control thinking of "precise control of gas geology, reliable gas drainage, intelligent early warning of gas gushing, daily outburst prevention management specifications", from the combination and continuity of space and time, a multi-coupling model for precise prevention and control of gas disasters is constructed from the aspects of gas geology, gas drainage compliance, gas gushing, and daily outburst prevention.

(1) Gas geological control model

Gas outburst is the result of the combined effect of gas, coal structure and in-situ stress. Geological structure controls the distribution of outburst risk by controlling gas occurrence, coal seam occurrence and tectonic stress. More than 80% of outburst accidents occur near

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geological structures such as faults [7-9]. Therefore, the gas geological analysis control takes geological structure as the monitoring focus, and simultaneously analyzes gas occurrence and coal seam occurrence changes, and controls gas geological anomalies according to the factors shown in Table 1.

Table 1. Gas geological control factors

No.	Analysis class	Controlling factor
1	Geological structure	Compression-torsion faults, closed folds, magmatic intrusion zones, broom structure convergence
2	Gas occurrence	Gas content, gas pressure, prominent danger zone
3	Coal seam occurrence	Coal seam thickness change, soft layer thickness change, coal seam strike or dip change

According to the multi-level gas geological method, gas geological control first digitally integrates and categorizes multiple information such as mine gas parameters, coal seam parameters, geological exploration, geological structure, working face and roadway, etc. And it fits and analyzes the main controlling factors of gas occurrence, establish a multiple regression analysis model of gas parameters and various factors, automatically draws gas parameter contours, and generates standardized mine gas geological maps integrating gas, structure, coal seam, geology and other factors (such as shown in Figure 2). Then, based on the gas geological space identification and processing technology [7,9], according to the factors in Table 1, the gas geological map is accurately calculated, and the structure, gas and coal seam occurrence in the mining area of the working face can be identified, so that the accurate calculation can be generated. The gas geological map of the working face can finally accurately control and divide the abnormal area.

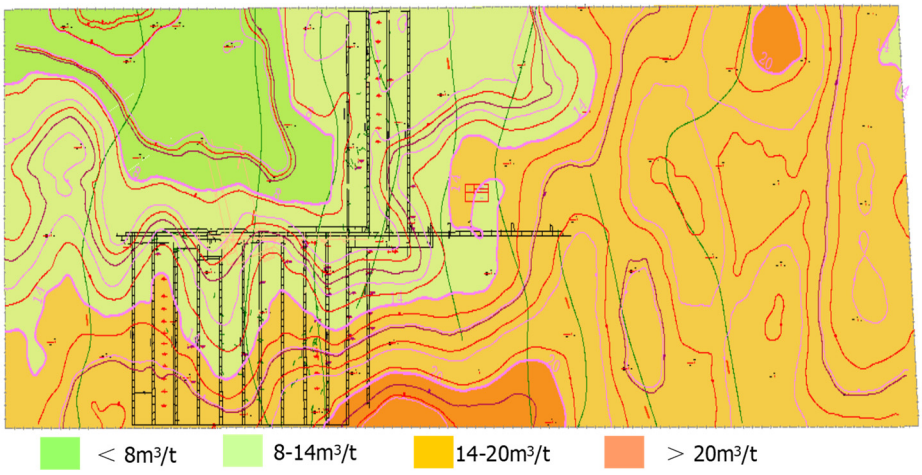

Figure 2. Standardized mine gas geological map

(2) Analysis model for gas extraction up to standard

"Drainage compliance" is the key to effectively preventing gas accidents. It is difficult to achieve the gas drainage compliance if the gas drainage holes do not meet the requirements, and the drainage effect and management during the extraction process are not in place [10,11]. Therefore, the sampling compliance is judged from the following two aspects.

1)Drainage drilling compliance analysis

According to the drilling defect analysis method of the measures, the automatically calculated drilling control distance and the blank zone of the drilling end hole meet the following requirements, and it is considered that the design or construction parameters of the extraction drilling hole are up to the standard.

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$$R \geq R_0 \tag{1}$$

$$K \leq K_0 \tag{2}$$

Where, R, R_0 are the actual control distance and the required control distance of the drilling respectively, m; K, K_0 are the actual blank tape ratio and the allowable maximum blank tape ratio, %, K is calculated as follows:

$$K = 100 \times (S_0 - \sum_{i=1}^{n} S_{1i} + \sum_{i=1}^{m} S_{2i}) / S_0 \tag{3}$$

Where, S_0, S_{1i} and S_{2i} are the total coal seam area in the pre-drainage area, the effective control area of the borehole and the overlapping area of two adjacent boreholes, respectively, m^2.

2)Drainage effect compliance analysis

By analyzing the main information such as manual measurement or monitoring of drainage data, gas occurrence law, gas drainage law, actual control range of drilling, actual engineering quantity of drilling, time when drilling is connected to the pipe network, air volume of working face and so on, the standard analysis of the extraction effect mainly calculates and evaluates whether the residual gas content of the working face and the gas pre-drainage rate meet the specified requirements.

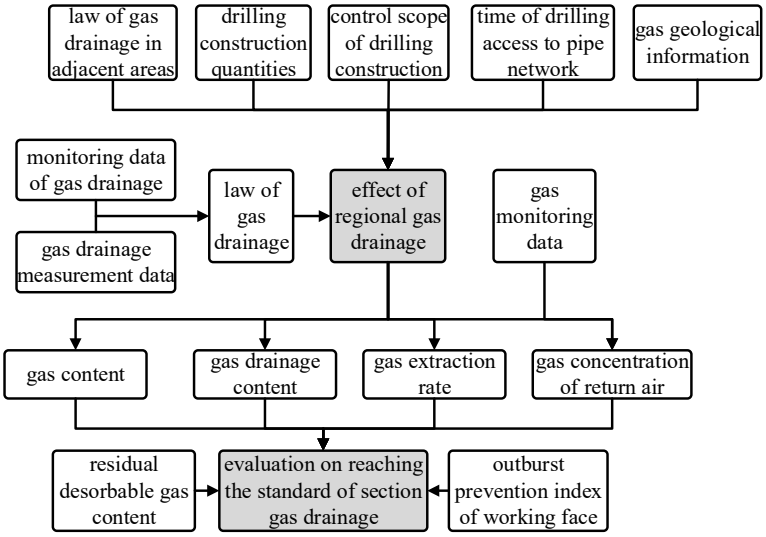

Figure 3. The analysis process of the extraction effect reaching the standard

The analysis process is shown in Figure 3, and the main calculation basis is:

$$W_C = \frac{WG - Q}{G} \tag{4}$$

$$\eta_m = \frac{Q_{mc}}{Q_{mc} + Q_{mf}} \tag{5}$$

Where, W_C and W are the residual gas content and the original gas content of the coal in the pre-drainage area, m^3/t; Q is the total amount of pre-drainage gas in the pre-drainage area (calculated based on the extraction measurement or monitoring data), m^3; G is the coal reserve in the pre-extraction area, t; η_m is the regional gas pre-extraction rate, %; Q_{mc} and Q_{mf} are average monthly gas extraction and wind discharge in the region, m^3/min.

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(3) Dynamic analysis model of gas gushing

Numerous outburst risk analyses and studies have shown that there are certain differences or abnormalities in gas gushing in areas with different outburst risk levels [12-13]. According to the hypothesis and occurrence mechanism of the comprehensive effect of coal and gas outburst, and based on the existing gas monitoring data, excavate and analyze the differences and characteristics of the gas volume, gas desorption characteristics, gas fluctuation characteristics, and gas trend characteristics of the working face. The dynamic analysis is based on the structure shown in Figure 4 to associate the prominent risk factors to carry out the prominent risk analysis. Specifically, according to the actual outstanding danger of different working faces of the mine, from more than 10 indicators in four aspects, comprehensively considering the result accuracy, false alarm rate, omission rate, etc., the computer selection method is used to optimize the mine suitable for gas gushing indicators, and determine the critical value of indicators.

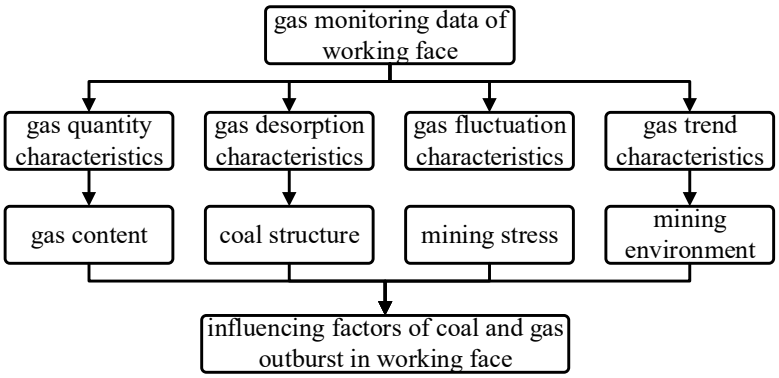

Figure 4. The structure of gas gushing and outstanding danger

(4) Standardized management model for daily outburst prevention

According to the requirements of local comprehensive outburst prevention measures, the daily outburst prevention standard management analysis is carried out from the following two aspects.

1)Regular analysis of local measures drilling

First of all, according to the analysis method of regional measure drilling up to standard, analyze the control effect of local measure drilling up to standard; Then, according to the comparison method, analyze whether the discharge time of the borehole meets the requirements; Finally, calculate the remaining safety distance for each shift of the working face as follows, and predict the remaining safety distance for the next shift. When the calculated or predicted number of remaining safety distances is insufficient, a reminder message is given.

$$l = L - \sum_{i=1}^{n} x_i \tag{6}$$

Where, l and L are the remaining safety distance of the working face and the front control distance of the drill hole, m; n is cycle inner shifts for drilling measures; x_i is footage for each shift, m.

2)Predictive index security analysis

According to the relationship between the daily prediction index and the prominent danger of the working face, the safety of the index is controlled from the relationship with the dangerous critical value and the drilling dynamic phenomenon. Specifically, the maximum value of the index exceeds the dangerous critical value or the dynamic phenomenon is predicted to exist in the borehole, and it is determined that the location is in outstanding danger, and a danger

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reminder is given. If the indicator is close to the dangerous critical value several times in a row, it is determined that there is a prominent abnormality in the location, and an abnormality reminder is given. At the same time, according to relevant requirements, monitor whether a certain range of daily forecasting execution densities meet the requirements, and if they do not meet the requirements, give danger reminders.

3.3. Diversified and Precise Prevention and Control Technology Software of Gas Disasters

The whole set of software is designed based on the mature "client/server, browser/server" combination of software architecture model, and reasonably allocates computing tasks, management tasks, query and analysis tasks to clients, browsers or servers, and realizes multi-source gas disasters. The distributed management, centralized storage and free-style query of information can improve the efficiency of system operation and user work [14-15].

Based on the principle of "less cross-maintenance, more cluster sharing", according to the work content and requirements of anti-sudden, the distributed software structure shown in Figure 5 is designed, and the corresponding software system is developed. Among them, 4 sets of subsystems have been developed into client software mode, which can perform standardized automatic drawing of two-level gas geological map of "mine → working face", step-by-step control of gas geological anomalies, auxiliary design of gas drainage drilling holes, intelligent evaluation of gas drainage compliance, automatic extraction and analysis of gas monitoring data, automatic monitoring of gas gushing anomalies, automatic generation of standardized outburst prevention forecast reports, and auxiliary generation and analysis of "one picture" for daily outburst prevention, etc., to realize multivariate analysis of gas disasters, standardized management and auxiliary decision-making. The integrated management and analysis system of safety information has been developed into a website mode, which automatically integrates, categorizes and displays the basic information and multivariate analysis results of the above four subsystems, so that the mine leadership and relevant personnel can easily grasp the mine safety dynamics.

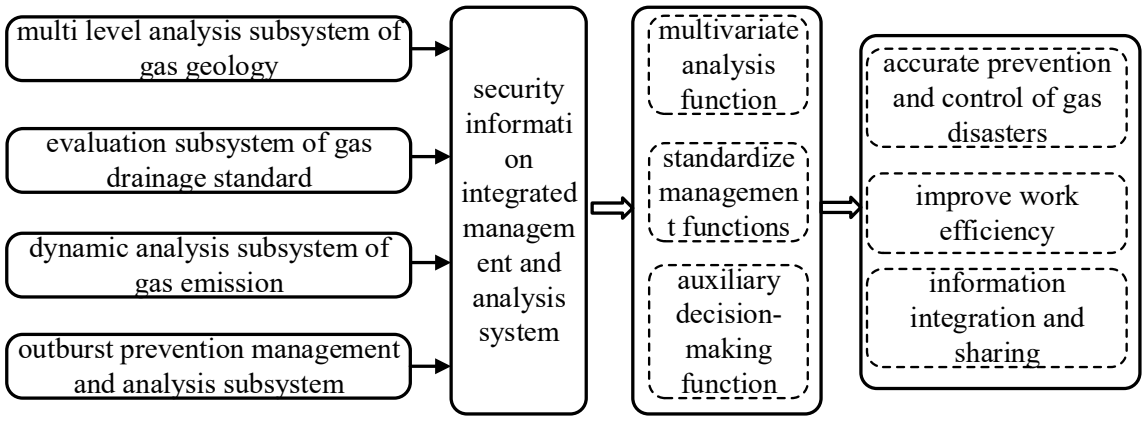

Figure 5. Composition of distributed software

4. Field Application

Chongqing Nengtou Yuxin Energy Co., Ltd. Shihao Coal Mine is located in the Songzao mining area with complex geological structure. It has the characteristics of high gas content, high gas pressure, low coal seam permeability, and multi-coal mining. It is a typical coal and gas outburst mine. According to the actual situation of the mine, a diversified and precise prevention and control system for gas disasters has been established.

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After the completion of the system, the precise control of gas disaster prevention and control in the working face has been realized from the aspects of precise control of gas geology, accurate analysis of gas drainage compliance, and standardized management of daily outburst prevention. technical and analytical level. For example, during the excavation process of N1643 return air liaison roadway from March to April 2020(starting from March 12, 2020), it encountered a geological structure belt and exposed a 0.8m normal fault. During this process, the thickness of the coal seam often became thinner and thicker. Since March 12, 2018, the gas gushing dynamic analysis system has continuously given orange and red early warning information (as shown in Figure 6). In Shihao Coal Mine, on the basis of gas pre-drainage in advance, according to the actual structure of the site, combined with the analysis results of gas gushing, the safety measures of shallow excavation and shallow advance and increased discharge holes were taken. In this way, the safe construction of the roadway is ensured and the occurrence of dangerous situations is controlled.

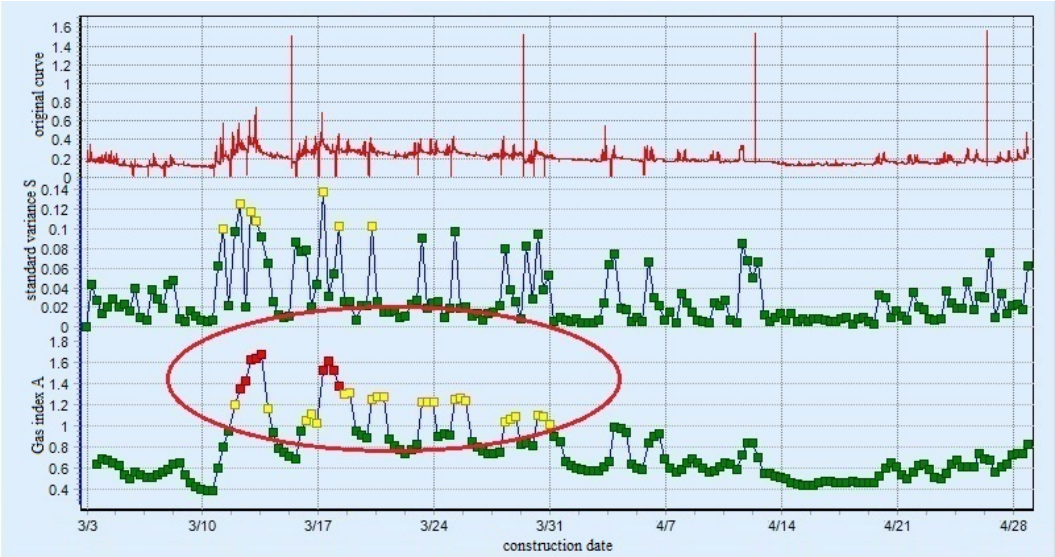

Figure 6. Example diagram of gas gushing warning

5. Conclusion

(1) Based on the scientific connotation of precise coal mining, the technical structure of diversified and precise prevention and control of gas disasters has been determined, and a diversified and precise prevention and control system of gas disasters including instruments, networks, models, and software has been researched and constructed. The system provides scientific means for gas disaster management.

(2) Combined with the specific conditions of the mine, the specific application of the gas disaster diversified and precise system has been carried out to realize the precise control of gas geology, the auxiliary design of drilling for drainage measures, the monitoring and intelligent evaluation of drainage compliance, and the automatic monitoring and early warning of abnormal gas gushing., automatic generation of standardized outburst prevention forecast report, integrated analysis of daily prediction indicators, analysis of compliance of outburst prevention measures, etc. In this way, the technical level of mine gas disaster prevention and control has been improved.

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