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Study on the Prediction Index of Outburst Risk in Working Face of Outburst Coal Seam Containing Carbon Dioxide

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Abstract: *Coal (rock) and gas (carbon dioxide) outburst is a rare special type of outburst in China. Compared with the traditional coal and gas outburst, there are both similarities and differences. The thickness of the main coal seam of Jinhe Coal Mine in the Yaojie mining area is more than 20 m. The prediction of the outburst risk of the working face is carried out according to the coal and gas outburst rules, but there is a lack of systematic research. Taking Jinhe Coal Mine in Yaojie Mining Area as the engineering background. The characteristics of coal seam gas disaster in the mining area are analyzed, the structural characteristics of coal seam outburst in the second layer of Jinhe Coal Mine are analyzed, and the parameters of coal seam outburst are tested. At the same time, a sensitive index investigation scheme for outburst risk prediction of working face was designed and field investigation was carried out. The critical value of K1 is 0.4mL/(g min1/2), and the critical value of S is 4kg/m.*

Keywords: *Carbon dioxide; Outburst coal seam; Prominent risk prediction; Prognostic indicators; Investigation*

1. INTRODUCTION

Coal and gas outburst (referred to as 'outburst ') is a complex dynamic phenomenon in underground coal mines, which is the result of the combined action of in-situ stress, gas and physical and mechanical properties of coal[1-2].Its occurrence may cause the destruction of underground safety production facilities, induce gas explosion and other major property losses and casualties. Outburst has become one of the main hidden dangers of coal mine safety production. The national coal industry regulations and standards have strengthened the management and supervision of mine outburst. The ' coal and gas outburst prevention and control rules ' clearly define that the outburst mine should establish a regional and local two 'four-in-one' comprehensive outburst prevention technology system. Coal (rock) and gas (carbon dioxide) outburst is a rare special type of outburst in China. Compared with traditional coal and gas outburst, it has both commonalities and differences[3-4]. At present, there are only two coal (rock) and carbon dioxide outburst mining areas in Yaojie and Yingcheng in China. There is a lack of systematic research on the mechanism of coal and carbon dioxide outburst and the comprehensive prevention and control system. The sensitive index and critical value of working face outburst prediction [5] are mainly based on the ' coal and gas outburst prevention and control rules '. It is not determined according to the actual situation of the mine, and needs to be continuously explored and tested.

Jinhe Coal Mine of Yaojie Coal and Electricity Group Co., Ltd. (referred to as ' Jinhe Coal Mine ') is one of the main production mines of Yaojie Coal and Electricity Group Co., Ltd., which is a coal and carbon dioxide outburst mine. The design production capacity is 1.2 million t / a. The main coal seam is the second layer of coal, and the current mining elevation is + 1340 ~ + 2085 m. The thickness of the second layer of coal mined in the mine is 0~45.71 m, with an average of 22.85 m. There have been four outburst accidents in the history of the second layer of coal in Jinhe Coal Mine, which have the danger of coal and gas (carbon dioxide) outburst[6]. At present, there is still a lack of research on the prediction method of outburst risk of working face related to extra-thick coal and carbon dioxide outburst coal seam in Yaojie mining area.

2. Analysis of Disaster Characteristics in Mining Area

The outburst and various dynamic phenomena in the history of Yaojie mining area are more serious. Through the statistical analysis of the outburst and dynamic phenomena in the history of Yaojie mining area, the following disaster characteristics are obtained.

(1) The location of outburst is mainly concentrated in roadway excavation, and there is no outburst in coal mining face at present. Combined with the historical outburst data of Haishiwan Coal Mine, Jinhe Coal Mine, No.3 Coal Mine, Zhangergou Coal Mine and Halagou Coal Mine, it is found that the coal and gas (carbon dioxide) outburst in the production process of Yaojie area almost occurs during the excavation of roadway.

(2) The location of outburst is mainly coal pillar area or geological structure zone, and the outburst increases with the increase of mining depth.

(3)Most of the outbursts in the mining area have obvious signs. The outburst omen is mainly manifested as the increase of gas (carbon dioxide) concentration, the change of gas (carbon dioxide), the drilling hole, the drill, the top drill, the coal wall slag and the outer drum, the coal drying, the coal dust flying, the coal wall gloss dim, the bedding disorder, the temperature reduction, the roof pressure, the support fracture, the coal gun sound in front of the working face and other abnormal phenomena.

(4)Coal (rock) and gas (carbon dioxide) outburst in the process of tunneling is mainly caused by blasting. More than 200 dynamic phenomena have occurred in Halagou Coal Mine, and more than 80 % of the dynamic phenomena are caused by blasting.

(5)Coal and gas (carbon dioxide) outburst in Yaojie area is mostly related to coal seam gas (carbon dioxide) content. The content of CH4 and CO2 in the second layer of western coal is low, and the outburst risk is small. The CO2 content of the second coal seam in the eastern part is high, and the danger of coal and carbon dioxide outburst is serious.

(6)The dynamic phenomena in the process of drilling construction are mostly related to the high gas (carbon dioxide) content and high pressure in this area. In the statistical data, there were four dynamic phenomena in the pressure measuring holes, three of which exceeded 0.74 MPa, accounting for 75 %.

3. Coal Seam Structure Investigation and Outburst Risk Parameter Test

3.1. Analysis of the Structural Characteristics of the Second Coal Seam

The average thickness of the second coal seam in Jinhe Coal Mine is 22.85 m. The coal seam is composed of vitrain, bright coal, dark coal and sericite, which is mainly composed of semi-bright and semi-dark coal and alternately appears and presents layered structure. There are also vitrain bands, sericite bands and lineation interspersed to show local banding and lineation structure. The structure of the second layer of coal is complex, and the gangue is up to 10 layers, with an average of 4 layers. The lithology of the gangue is mostly mudstone or carbonaceous mudstone. Due to the different composition and structure of coal rock, the proportion of solid lump coal, fragile lump coal and powder coal in different parts of the second layer of coal is different. The mining depth of the second layer of coal is more than 528 m, and the maximum is 903 m. According to the geological data and field sampling, the second layer of coal is generally hard and brittle, and there are local soft layers (fmin=0.47). It can be seen that the second layer of coal has the structural characteristics of outburst coal seam.

3.2. Laboratory Test Analysis of Coal Seam Outburst Parameters

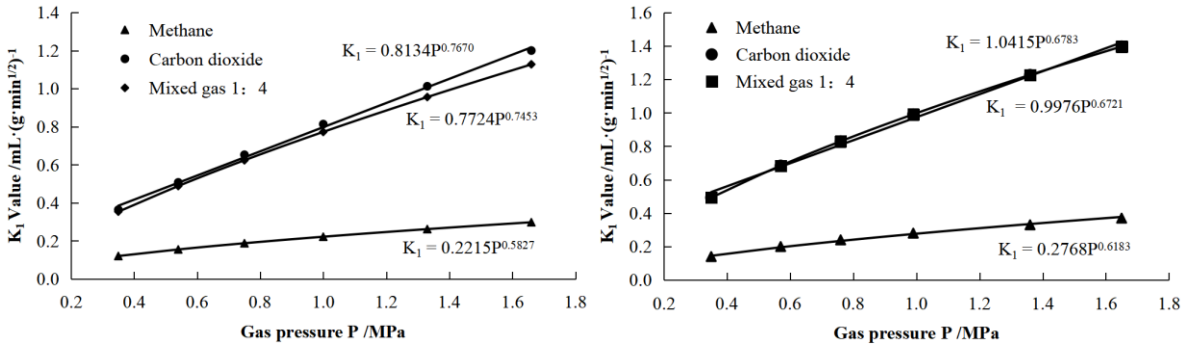
The whole section sampling was carried out in the exposed area of 16215 working face, 16215 air inlet crossheading and 16219^{-1} working face in the sixth mining area, and the relationship between coal seam firmness coefficient f, initial velocity of methane and carbon dioxide gas emission Δp and K_1-P was tested. The test results are shown in Table 1 and Fig.1.

Table1. *Test results of outburst risk parameters of coal second layer*

Sampling location	Category	**Δp**	***f***	**K_1=A*P^B**		**0.74 MPa corresponds to K_1 value**
				A	B	
16215 Working face	Methane	12	0.91	0.2215	0.5827	0.19
	Carbon dioxide	29		0.8134	0.7670	0.65
16215 Air inlet trough	Methane	11	0.78	0.2768	0.6183	0.23
	Carbon dioxide	13		1.0415	0.6783	0.85

It can be seen from Table 1 that the initial velocity Δp of methane and carbon dioxide gas in the second coal seam of Jinhe Coal Mine is 11~13 mmHg and 13~29 mmHg, respectively. The firmness coefficient f of coal seam is 0.68-0.99. The hardness of coal seam is large, and the emission capacity of carbon dioxide gas is greater than that of methane gas. According to the K_1-P curve of Fig.1, the K_1 value increases with the increase of gas (carbon dioxide) pressure P.When P = 0.74MPa, the K_1 values of methane and carbon dioxide gas are 0.18 ~ 0.24 mL/(g·min$^{1/2}$) and 0.65 ~ 0.85 mL/(g·min$^{1/2}$), respectively.

According to the relationship between methane and carbon dioxide emission ratio of 1:4 in mine mining face, combined with the K_1-P relationship model of pure methane and pure carbon dioxide gas of two coal samples shown in Fig.4.1 (a) ~ (d), without considering the interaction between molecules, the K_1-P relationship model of mixed gas under the condition of methane and carbon dioxide ratio of 1: 4 is obtained by theoretical calculation : K_1= 0.7724P$^{0.7453}$, K_1=0.9976P$^{0.6721}$, and the curves are shown in Figs.1 (a) and 1 (b).



(a) 16215 Working face coal sample (b) 16215 air inlet crossheading coal sample

Fig1. *K1-P curves of methane, carbon dioxide and mixed gas in coal seam*

According to the K_1-P relationship model of the mixed gas of the two coal samples shown in Fig.1 (a) and 1 (b), it can be seen that when P = 0.74 MPa, the K_1 values of the mixed gas are 0.62 mL/(g·min$^{1/2}$) and 0.81 mL/(g·min$^{1/2}$) respectively when the ratio of methane to carbon dioxide is 1:4, which is between pure methane and pure carbon dioxide gas.

4. INVESTIGATION SCHEME OF SENSITIVE INDEX CRITICAL VALUE OF OUTBURST RISK PREDICTION IN WORKING FACE

Firstly, the existing prediction data of outburst risk of working face are sorted out and analyzed, and then the representative mining working face is selected to carry out the investigation and test of outburst risk prediction index (the excavation length of coal roadway is not less than 500 m or the mining distance of working face is not less than 200 m). Combined with the theoretical research results of prediction index appearance characteristics of dynamic disaster attributes, the sensitive index of outburst risk prediction of working face is preliminarily determined. To judge whether an index is sensitive, two aspects are mainly considered. One is whether the index value will change significantly with the size of the prominent risk, and the other is whether the prominent risk factors affecting the index value are greater than the non-prominent risk factors such as measurement error. The scheme mainly compares and analyzes the sensitivity of screening indicators from the following two aspects:

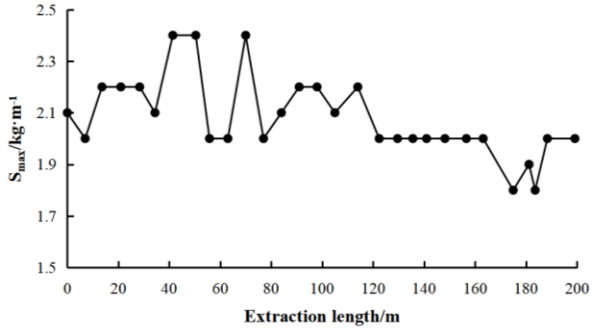
(1) The value of the index (or the experimental parameters reflecting the index) changes significantly with the size of the outburst risk, and the index value is predicted to change abruptly when there is a outburst risk.

(2) The index value can overcome the influence of measurement error. It is generally believed that the sensitivity is poor when the maximum prediction index of each circulation borehole is mostly less than 20 % of the reference critical value of the index.

5. ENGINEERING PRACTICE

5.1. 16215 Working Face Field Investigation and Analysis

From January 30,2022 to November 21,2022, the field test of outburst prediction index of 16215 working face was carried out. The cumulative time was 296 days, and the cumulative safe mining was 235.2 m. A total of 35 times and 342 boreholes were predicted. The prediction indexes did not exceed the critical value of the index, Smax=2.4kg/m, K1max=0.35mL/(g·min1/2), qmax=1.89L/min. There were no abnormal phenomena such as clamping and suction during drilling construction. Safe mining was realized without taking local outburst prevention technical measures. The distribution of the maximum value of the prediction index of 16215 working face is shown in Fig.2, Fig.3 and Fig.4.



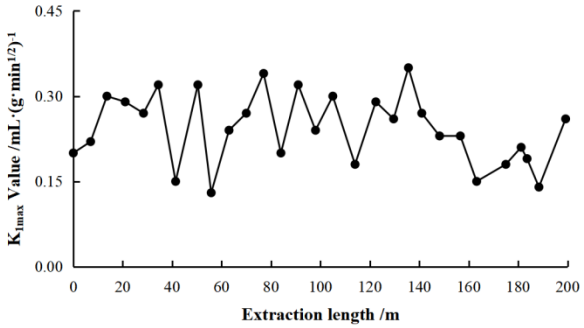


Fig2. *Smax variation trend of 16215 working face* **Fig3.** *K1max variation trend of 16215 working face*

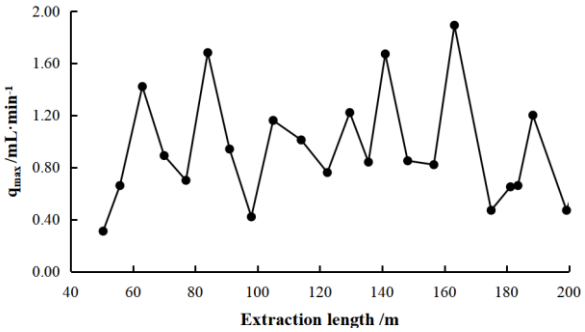


Fig4. *qmax variation trend of 16215 working face*

According to the geological data and outburst prediction data of 16215 working face, the outburst prediction index S value is 1.8 ~ 2.0 kg/m, K1 value is 0.15 ~ 0.25 mL/(g·min1/2), q value is 0.8 ~ 1.1 L/min in the normal area of coal seam during the mining period of the working face. Taking the open-off cut of 16215 working face as the starting point, when the working face is mined to the range of 40.8 ~ 50.4 m, according to the analysis of the dynamic disaster attribute of the second layer of 4.2 coal saving, the risk of coal seam outburst increases with the increase of mining and caving ratio in the initial mining period of fully mechanized caving face. The prediction index Smax increased from 2.1 kg/m to 2.4 kg/m, K1max increased from 0.15 mL/(g·min1/2) to 0.32 mL/(g·min1/2), while the q value did not change much in this area, and the prediction index did not exceed the standard. During the mining process of the working face, the maximum mixed concentration of methane and carbon dioxide in this round of prediction increased from 0.38% to 1.04% compared with the previous round of prediction T1 probe.

When the working face is mined to the range of 129.6 ~ 135 m, the part of the working face near the air inlet is affected by the structure. The prediction index K1max increases from 0.26 mL/(g·min1/2) to 0.35 mL/(g·min1/2), and the index does not exceed the standard. The prediction index K1max changes greatly compared with the normal area and increases to a certain extent, while the q value changes little in this area.

5.2. 16219-1 Construction Roadway Field Investigation and Analysis

From August 25,2022 to November 25,2022, the field test of the outburst prediction index was carried out in the 16219-1 construction roadway and the 16219-1 pre-intake crossheading tunneling face. A total of 39 times and 507 drilling cycles were predicted. The cumulative excavation amount was 203.7 m, the measured Smax=2.4kg/m, K1max=0.57mL/(g·min1/2), the S value index did not exceed the standard, and the K1 value index exceeded the standard once. After the local comprehensive outburst prevention measures were taken, the index was reduced to 0.4 mL/(g·min1/2). The distribution of the

maximum value of the prediction index of the 16219-1 construction roadway and the 16219-1 pre-intake air roadway heading face is shown in Figure 5 and Figure 6.

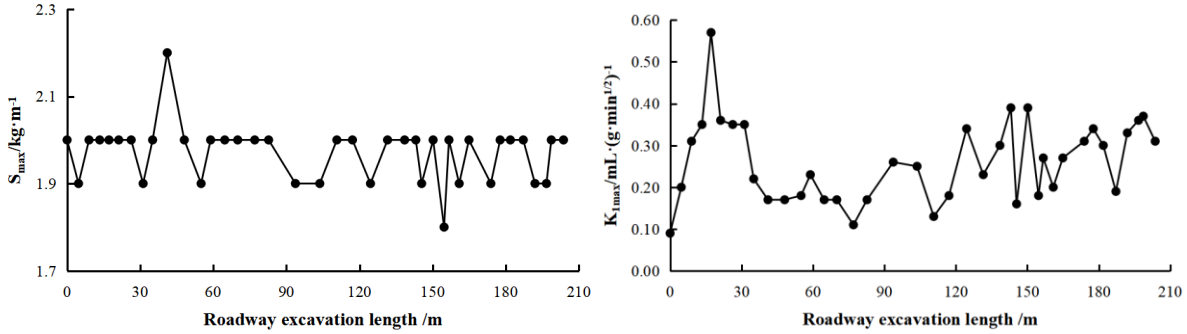


Fig5. *Smax variation trend of 16219-1 construction roadway Fig.6 K1max variation trend of 16219-1 construction*

The excavation of 16219-1 construction roadway is 0 ~ 10m and 37 ~ 92m within the protection range of overlying oil shale, and 10 ~ 37m is the stress concentration area of overlying oil shale rock pillar. When the coal roadway is excavated in the oil shale protection area, the prediction index does not exceed the standard. When the 16219-1 construction roadway is excavated to the stress concentration area of the rock pillar, the K1 value exceeds the standard once, and the K1max value exceeds the standard. The value is 0.57 mL/(g·min1/2), and there is no abnormal dynamic phenomenon. Then, local outburst prevention measures such as small-aperture dense borehole discharge, coal seam water injection, and blasting pressure relief were cyclically taken in the stress concentration area, and the K1max value was measured to decrease to 0.39 mL/(g·min1/2), and then the K1max value remained stable. After the stress concentration area of the rock column was excavated, the K1max value was generally less than 0.4 mL/(g·min1/2).

According to the statistical analysis of historical data and field investigation, there is no outburst and dynamic phenomenon in the process of outburst prediction of mining face. The investigation is carried out in the effective area of regional outburst prevention, and the critical value cannot be determined according to the index value of outburst and dynamic phenomenon. Combined with the above historical data analysis and field investigation, in the area where the single borehole pre-drainage is used as the outburst prevention measure, or in the abnormal areas such as coal thickness change, existing structure and coal pillar area, compared with the pressure relief protection area of the upper protective layer and the lateral pressure relief discharge area of the goaf, the outburst risk of the mining face will be relatively increased, and the outburst prediction index will be more sensitive. The outburst prediction index value of working face in the area with good outburst prevention effect and relatively small outburst danger is generally lower than 0.4 mL/(g·min1/2). In the area of outburst prevention measures in the strip coal seam gas (carbon dioxide) area of the coal roadway, considering the strong adsorption capacity of carbon dioxide gas in the coal body and the difficulty of extraction, the effect of strip gas (carbon dioxide) pre-extraction in the coal roadway is relatively poor. In this area, the proportion of outburst prediction index exceeding 0.4 mL/(g·min1/2) during mining is obviously more. The K1max before the index mutation under abnormal conditions during the mining period is generally 0.40 ~ 0.46 mL/(g·min1/2), and the critical value of the K1 value is 0.4 mL/(g·min1/2).Combined with the statistics of Smax value of coal seam drilling cuttings, the maximum Smax is 4.9kg/m, and 99.7 % of Smax value is concentrated between 1 ~ 4 kg/m. Considering a certain safety factor, the critical value of S value is determined to be 4 kg/m.

6. CONCLUSION

After the regional outburst prevention measures are taken in working face of Jinhe Coal Mine, the sensitive indexes of outburst risk prediction in the mining face are the amount of drilling cuttings S, the desorption index K1 of drilling cuttings gas (carbon dioxide) and the initial velocity q of borehole gas (carbon dioxide). It is recommended to use the amount of drilling cuttings S and the desorption index K1 of drilling cuttings gas (carbon dioxide) as the sensitive indexes of outburst risk prediction in the working face. The critical value of sensitive index of outburst risk prediction in working face is S=4kg/m, K1=0.4mL/(g·min1/2).

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