Research on the Regional Prediction Gas Content Critical Value of 3# Coal Seam in Sangshuping NO.2 Mine

Liu Jun1, 2, *  
1Chongqing Research Institute CO., Ltd of China Coal Technology Engineering Group, Chongqing, China  
2National Key Laboratory of Gas Disaster Monitoring and Emergency Technology, Chongqing, China  
*Corresponding author e-mail: liujuncaikuang@163.com

Abstract. In order to determine the regional prediction gas content critical value of 3# coal seam in Sangshuping NO.2 Mine, according to the mine’s gas geological conditions, the gas geological units in the investigation area was analyzed and determined. The minimum firmness coefficient $f_{min}$, the initial gas release rate $\Delta P$, and the volatility of coal $V_{daf}$ were measured. The outburst empirical formula was used to calculate the minimum gas pressure at which outburst occurred, and then the critical value of gas content was obtained. At the same time, the three-rate analysis method, the correlation analysis of gas content and prominent omen were used to comprehensively determine the critical value of gas content in the normal area of 3# coal seam is 9m$^3$/t in normal area, 8m$^3$/t in geological anomaly area, it provides a scientific basis for regional outburst prevention in the mine.

1. Forewords
Coal and gas outburst disaster is the first killer of coal mine safety in China, in recent years, for the progress of outburst disaster prevention and control technology and promulgated a series of laws and regulations by state, two four-in-one anti-penetration measures have been formed. Area prediction and the effectiveness test of regional outbreak prevention measures are important steps in the existing outbreak prevention technology process. The critical value of gas content is the technical key to determine whether it has outstanding danger. “Detailed Rules on Prevention and Control of Coal and Gas Outburst” is promulgated in 2019. It is recommended that the critical indexes of gas pressure and gas content are 0.74 MPa and 8.0 m$^3$/t respectively (6.0 m$^3$/t in geological structure area), at the same time, the inspection of the effectiveness of regional outburst prevention measures will preferentially use the residual gas content as an indicator, however, the prominent mines are required to be determined based on actual inspection during the production process. Because it is no consensus cognition about the mechanism of coal and gas outburst disaster yet, the influencing factors are also many, scholars at home and abroad have carried out a lot of research on the determination of the critical value of regional prediction. The "three-rate method", fuzzy mathematical method, and anti-bursting experience are mainly used to determine the critical value.[1-7] The existence conditions of coal mines in China are complex, and there are certain differences in the critical values of indicators used in prominent mines. The determination of reasonable critical values of indicators is the key to the prevention and treatment...
of prominent disasters. Therefore, it is of great significance for outburst mines to determine reasonable critical indexes based on gas geological conditions for outburst disaster prevention.

Most of the mines in Hancheng Mining Area are outburst mines. The initial outburst depth of No. 3 coal seam is 203m. When outburst occurs, the minimum gas content is 6.6 m³/t, the minimum gas pressure is 0.67 MPa. Sangshuping No. 2 mine is located in the low depth area in the northern part of the mining area. The deposit depth of 3# coal seam is about 230 to 460m, generally less than 350m. the main damage type of coal seam is type II, but it includes type I to V. The coal in this area is generally harder than other mines. Coal seam’s original gas content is 7.55~14.84 m³/t, the residual gas content of falling coal transported to the surface is 4.00~5.00 m³/t. By studying and examining the gas content threshold suitable for its own conditions, Sangshuping No. 2 mine can avoid the blindness of outbreak prevention work and improve the true certainty of outbreak prevention prediction.

2. Determine the research region

2.1. Influencing factors of outburst in the mine

There are 143 recorded coal and gas dynamic phenomena in 3# coal seam in the mining area, about 59 percent is coal and gas pressing out, and most of the outbursts occurred in geological structural areas. For example, the outbursts of Xiayukou Coal Mine are mainly concentrated in the Beishanzi syncline, the backbone structure in the central part of well-field system, as shown in figure 1. The small geological structures are development near outburst occurred spot, the damage types of coal seam are III, IV and V, no dynamic phenomenon occurred in hard coal seam. The frequency of the protrusion increases with the depth increasing, outbursts occurred in the low deposit depth area are mainly small and medium-sized, the proportion of the sub-large and large-scale outbursts increased gradually in deep area. According to the outburst features of the mining area, the outburst is in-situ stress-dominated outburst that’s controlled by geological structure and coal damage types. It should determine the different critical values of gas content at the geological structure area and the normal area.

![Figure 1. Outburst spots in Beishanzi syncline area of Xiayukou Coal Mine](image_url)

2.2. Determine the scope of investigation

The scope of inspection should be determined before the critical value of gas content is determined. The gas geological unit is an important basis for determining the critical value of regional prediction and its application range. Due to the differences in coal seam occurrence, geological structure, and gas in different geological units, the regional prediction thresholds should also be different. Therefore, the investigation of regional prediction thresholds should be based on the division of geological units. The damage type of coal seam in the northern part of the mine is mainly type II, and the soft stratified distribution is discontinuous, which only exists locally, as shown in figure 2.
As shown in figure 3, When the damage type of 3# coal seam is I and II, the firmness coefficient of coal is generally 0.42~0.56. When the damage type of 3# coal seam is III~VI, the firmness coefficient of coal is generally 0.20~0.40. Initial velocity of gas emission in 3# coal seam $\Delta P$ is 7~12, $\Delta P$ increases from south to north, outburst risk increases, this coincides with the actual outburst of the danger. Coal seam volatile is another factor reflecting coal seam outburst danger, it is 12.35~17.68%, there is no obvious difference between the values tested in geological exploration period and investigation. The volatiles is no obvious difference in investigated region. According to the geological structure, there is a gentle syncline and a gentle anticline in the area, small faults and folds locally, the continuity of gas flow has not been disturbed. Combining these factors, the investigated area can be considered as a gas geological unit.

3. Determine the critical value of gas content according to the experience of outburst prevention and control

At present, the empirical formula of minimum gas pressure $P_{\text{min}}$ for outburst prevention in coal seams is mainly obtained by analyzing the relationship among $P_{\text{min}}$, minimum firmness coefficient $f_{\text{min}}$, initial velocity of gas releasing $\Delta P$ and coal volatiles $V_{\text{daf}}$. For example, the Chongqing Research Institute of the Coal Research Institute of China found that $P_{\text{min}}$ has a linear relationship with the minimum solidity coefficient of soft seam [8, 9]. When carrying out critical value research in Sangshuping Coal Mine, it was found that the mine's $P_{\text{min}}$ was correlated with $f_{\text{min}}$, $\Delta P$ and $V_{\text{daf}}$ [10]. Yu Qixiang statistically analyzed the relevant initiation parameters of 26 mines and concluded that the minimum gas pressure at which an outburst occurs is related to the minimum solidity coefficient of coal and the volatile content of coal [11]. When the coal seam damage type is III, IV and V in Sangshuping No.2 mine, the $f_{\text{min}}$, $\Delta P$, $V_{\text{daf}}$ is 0.2, 11 and 14.28% respectively, when the coal seam damage type is I and II, the $f_{\text{min}}$, $\Delta P$, $V_{\text{daf}}$ is 0.42, 12 and 16.31% respectively. The minimum gas pressure $P_{\text{min}}$ of coal seam outburst is analyzed and calculated by empirical formula, the parameters required for calculating gas content critical value are
shown in table 1, then the Langmuir equation (1) is used to calculate the critical gas content, as shown in table 2.

\[
W = \frac{abp}{1 + bp} \frac{100 - A_{ad} - M_{ad}}{1 + 0.31M_{ad}} e^{c(t_s - t_p)} + \frac{10F_p}{ARD} \tag{1}
\]

In the formula: \(W\) - Gas content, m³/t. \(A, b\) - Adsorption constant. \(P\) - Absolute gas pressure, MPa. \(A_{ad}\) - Ash content, %. \(M_{ad}\) - Moisture content, %. \(n\) - Pressure correlation coefficient. \(t_s\) - Adsorption test temperature, ℃. \(t_p\) - coal seam temperature of underground, ℃. \(F\) - Porosity, %. \(ARD\) - Apparent density, t/m³.

### Table 1. Parameters required for calculating gas content critical value

| Damage type | A (m³/t) | B (MPa⁻¹) | A_{ad} (%) | M_{ad} (%) | n | Ts (℃) | T (℃) | F (%) | ARD (t/m³) |
|-------------|---------|----------|------------|-----------|---|---|---|---|---------|
| I,II        | 22.2086 | 1.4154   | 18.11      | 0.83      | 0.0175 | 30.0 | 25.0 | 3.95 | 1.46     |
| III,IV,V    | 21.2668 | 1.3213   | 17.98      | 0.86      | 0.0194 | 30.0 | 25.0 | 3.97 | 1.45     |

### Table 2. Regional Prediction Gas Content Critical Value in Different Damage Type Coal of 3# Coal Seam

| method | I, II | III~V |
|--------|-------|-------|
| \(P_{min}=2.2\times f_{min}\) | 0.92 | 0.44 |
| \(P_{min}=0.5+0.085V_{daf}\times f_{min}\) | 1.08 | 0.74 |
| \(P_{min}=0.028f_{min}^{0.33}\Delta P^{0.34}V_{daf}^{1.94}\) | 2.03 | 1.27 |

According to the analysis, when the coal seam damage type is III, IV and V in Sangshuping No.2 mine, the minimum outburst gas pressure is 0.44~2.03MPa and the minimum outburst gas content is 6.40~10.00m³/t. When the coal seam damage type is I and II, the minimum outburst gas pressure is 0.92~2.03MPa and the minimum outburst gas content is 9.57~12.31m³/t.

4. Determine the critical value of regional predicted gas content by statistical analysis

4.1. Investigate and determine by three-rate method

Apply three-rate method to determine the critical value of gas content in 3# coal seam. The range of the critical value is determined by the relationship among the prediction outburst rate \(\eta_1\), the prediction outburst accurate rate \(\eta_2\) and the prediction non-outburst accurate rate \(\eta_3\). \(\eta_1\) is generally considered to be less than 30%, \(\eta_2\) is the bigger, that is the better, \(\eta_2\) is generally considered to be more than 40%. The existing laws and regulations require that no outburst occurs in coal seam, the prediction non-outburst accurate rate \(\eta_3\) must be 100%. Therefore, the analysis must be based on ensuring the prediction non-outburst accurate rate, on the condition that guarantee \(\eta_3\) to be 100%, it can think about \(\eta_1, \eta_2\). The amount of investigate coal roadway engineering is about 18000m, the cumulative quantity of prediction and effectiveness test of regional prevention measure N is 252 cycles, the results of the analysis are shown in table 3.

### Table 3. Analysis table of three-rate method for determining the gas content critical value

| critical value (m³/t) | prediction outburst rate prediction outburst quantity n | \(\eta_1=n/N\) (%) | prediction outburst accurate rate prediction dangerous quantity n1 | \(\eta_1=n1/n\) (%) | prediction non-outburst accurate rate prediction non-outburst quantity n2 | \(\eta_1=n2/n\) (%) | prediction non-outburst accurate rate prediction non-outburst quantity n3 | \(\eta_1=n3/n\) (%) |
|-----------------------|---------------------------------------------------------|------------------|--------------------------------------------------------|------------------|--------------------------------------------------------|------------------|--------------------------------------------------------|------------------|
| 12                    | 17                                                      | 6.75             | 4                                                       | 23.53            | 222                                                   | 235              | 94.47                                                  |
| 11                    | 72                                                      | 28.57            | 7                                                       | 9.72             | 174                                                   | 180              | 96.67                                                  |
| 10                    | 120                                                     | 47.62            | 9                                                       | 7.50             | 128                                                   | 132              | 96.97                                                  |
| 9                     | 191                                                     | 75.79            | 13                                                      | 6.81             | 61                                                    | 61               | 100.00                                                 |
| 8                     | 216                                                     | 85.71            | 13                                                      | 6.02             | 36                                                    | 36               | 100.00                                                 |
There is no absolute critical value of gas content $W$ between outburst and non-outburst, just a critical range. When the critical value is $10m^3/t$, the prediction non-outburst accurate rate is 96.97%. When the critical value is $9m^3/t$, the prediction non-outburst accurate rate is 100%. The three-rate method analyze and conclude that the critical value is $9m^3/t$.

4.2. Correlation analysis between the gas content and the outburst omen
The amount of investigate coal roadway engineering is about 18000m, the cumulative quantity of prediction and effectiveness test of regional prevention measure N is 252 cycles. When the gas content is greater than $10m^3/t$, occasional drilling, ejection, and top drilling will occur, which indicates that the critical content of gas content cannot be greater than $10m^3/t$. Obvious prominent omen was found in 3303 cut-eye joint lane. There are obvious structures in this area and the type of coal seam damage type is III. There is a small fold trend on the side of the heading face. As shown in figure 4, the residual gas content for effectiveness test of regional prevention measure is $9.51m^3/t$. It verifies the characteristics of outburst occurring in geological structural belt in the mining area, therefore, when determining the critical value, it should be taken a small value. After take regional prevention measure, the critical value of the regional effect inspection is performed at $8m^3/t$. The continuous area verification has no indicators exceeding the limit and other anomalies, and safe excavation has been achieved, indicating that the critical value of the geological structural area can be determined as $8m^3/t$.

During the verification period, when spray holes or other abnormal phenomena occur during drilling, the measured gas content values are all greater than $10m^3/t$. The damage type of coal seam in the blast hole area is all type II, and there is no obvious geological structure, indicating that the critical value of predicted gas content in the geological structure area is less than the critical value in the normal area.

Based on the foregoing analysis, regional prediction(effectiveness test of regional prevention measure) gas content critical value is $8m^3/t$ in $3^\text{rd}$ coal seam III~V damage type area or 50m near geological structure belt, it’s $9m^3/t$ in coal seam I and II damage type area.

![Figure 4. The sketch of Roadway section](image)

5. Conclusion
Based on the coal seam occurrence conditions and gas geological units, the empirical formula, the "three-rate method", and the correlation analysis of prominent signs were used to determine the gas content threshold value index for the $3^\text{rd}$ coal seam regional prediction (effectiveness test of regional prevention measure). It provided the basis for the regional outbreak prevention work of Sangshuping No.2 Mine. However, the coal and gas outburst are relatively complicated, it is not only affected by the gas geological conditions, but also affected by the mining process and other factors. The mine also needs to correct and adjust the gas content threshold in time according to the change of conditions in order to be a regional defense. Suddenly provide scientific basis.

Acknowledgments
This work was financially supported by the National Key Research and Development Program of China (2017YFC0804209); the National Key Research and Development Program of China (2017YFC0804208); General project of Chongqing Research Institute Co., Ltd (2019YBXM31).
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