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Gas parameter characteristic and region prediction in Erdaoling coal mine area

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Abstract

In accordance with the large amount of test data, a systematic study of the coal body structure and gas parameter characteristic of Erdaoling coal mine area is carried out. With single index method, gas content method and comprehensive index method, region predictions of coal and gas outbursts are conducted in major coal seams of the mine, which offers reference and guidance in improving the efficiency and pertinence of preventing gas outbursts.

Keywords: coal mine; gas parameter; region prediction

Situated in the middle of Helan Mountain and Alxa Left Banner in Inner Mongolia, Erdaoling coal mine area develops along side Rujigou mine area of the Ningxia Hui Autonomous Region with Hulutai anticline in between. Shaped like an asymmetric north-east diamond, Erdaoling coal mine area marks its west and north boundary with Xiaosongshan reverse fault, its east and south with coal seam outcrops. Yan'an group of the area is comprised of 11 coal seams, labeled as No. I , first II\textsubscript{1}, first II\textsubscript{2}, second II\textsubscript{2}, II\textsubscript{3}, II\textsubscript{4}, III, IV, V, VII\textsubscript{1}, VII\textsubscript{2} from the top to the bottom. Within the exploration depth, the thickness of coal-bearing strata is 197.0m; the thickness of all coal seams is 26.42m with an average effective thickness of 18.07m, and coal-bearing coefficient is 13%. The geologic sketch map of the quality anthracite region in each seam is shown in Fig 1 [1, 2]. The prevention of coal and gas outbursts becomes more and more important with the increasing depth of exploration in the colliery. It offers reference and guidance in improving the efficiency and pertinence of preventing gas outbursts to study the gas parameters characteristic and region prediction of coal and gas outbursts in major coal seams of Erdaoling coal mine area.

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1. Coal body structure

1.1. Coal destruction modes

Coal destruction modes refer to the destruction degrees of coal body structure after tectonic stress, which comprise 5 modes: Mode I, non-destroyed coal; Mode II, destroyed coal; Mode III, fiercely destroyed coal; Mode IV, comminuting coal; Mode V, pulverized coal. The possibility of outbursts increases as well as destruction degree rises from Mode I to Mode V. According to Table 1, Douyagou and Hashatu mine have reached or surpassed Mode III.

1.2. Macroscopic depiction of coal body structure

Semibright and semidark coal dominates coalface 1800-1837 in No. I coal seam of Tuoligou mine, 2060 in No. II1 lower layer coal seam and 2097 in No. III Coal seam of Gulaben colliery No 1 mine, and 1750-1820 in No. II3 coal seam of Bieligou mine. Semibright coal is like a pie or an eyeball. Shaped like a tetrahedron and with columnar joint, semidark coal lacks clear stratification between coal seams and crampedly interpenetrated strips, with a sicken sided development. It is dense and hard with high gravity, and difficult to be broken with human hands. Semidark coal is mainly hard coal of Mode I (non-destroyed coal); in some regions Mode II exists, but no soft coal develops. The dense and hard coal body structure benefits greatly to resisting the destruction of high-energy gas.

The coalface 1840–1890 of No. II1 upper layer coal seam in Douyagou mine is mainly composed of glance and semibright coal, while the upper part mainly semibright and semidark coal, mingled with some dull coal. Soft coal does not develop in it, and its proto-structure is well reserved. Scratches are obvious, but polished faces are not. Ladder-like fractures interface and endocentric rifts are relatively developed in it. Coal destruction modes are primarily mode I and II, while in certain regions there exits mode III.

The coalface 1850-1900 of No. II1 upper layer coal seam in Hashatu mine is mainly occupied by glance and semibright coal. 0.7m in the lower part is mode III coal which is twisted into lamina form coals with flake and diamond shapes, and develops friction coalfaces and scratches, with 0.2m fractured coal in between. While the middle and upper parts are mode I, in which striped and sparse joint as well as scratches is visible; the middle part is the so-called “steel coal”, and 0.1m in the upper part exists crushing.
Soft coal witnesses an obvious increase in thickness around the tectonic zone, and the soft layers range from 0 to 0.8m in width, and mostly are 0.4m, with the destruction modes from mode III to IV.

The lower part of coalface 1850-1900 which belongs to No. II 1 coal seam in Hashatu mine consists of relatively developed mode I coal that is 1.5m long. In the middle, there is relatively developed fractured coal (0.4m thick) and with many joint groups, and mode III coal (0.4m thick) with flake and diamond shapes, in which scratches and coalfaces are relatively developed. The upper part possesses “steal coal” (0.3m thick). The top is Mode III coal (0.3m thick), flake and mirror forms.

The coalface 1850-1895 of No. II 1 coal seam and coalface 1885-1933 of No. V coal seam in No.2 mine of Xingtai colliery, coalface 1890-1932 of No. II 2 and II 3 coal seam of Baxian colliery, coalface 1940–1985 of No. II 3 and II 4 coal seam in Tanyaogou mine, and coalface 1900-1942 of No. V and VII 2 coal seam of No.1 mine of Xingtai colliery have similar characteristics in that the Macro-modes of coal rocks in the tunnels are, in general, glance and semibright coal with well-preserved proto-structures and relatively high hardness. modes I and II dominate the destruction modes of the coal.

2. Outburst risk index

Currently, the most frequently used region prediction indices are coal destruction modes, gas content $W$, consistent coefficient $f$, initial speed of diffusion $\Delta p$, gas pressure $P$, comprehensive index $D$, $K$ and so on [3].

2.1. Gas content method

Outburst region prediction is supposed to be based on the actual measured gas pressure of coal seams. While, there is no or lacking measured data of gas pressure, prediction can be carried out on the basis of gas content as well. The original gas content in the coal seams is crucial to the coal and gas outburst identification, region prediction and assessment. Gas content tested from direct method (desorption under mines) in each coal seam of Erdaoling coal mine area is shown in Table 1.

Table 1 [4-12] shows 76 groups of gas content value, in which the minimum is 1.75m$^3$/t, and the maximum 14.50m$^3$/t, with the average value 7.89m$^3$/t. Meanwhile, Table 2 manifests 32 groups of gas components [4-13], in which the lowest content of methane is 76.92%, the highest 98.01%, and the average 90.22%, with only 2 groups below 80%, from which it is concluded that the determination is carried out in the gas belts of coal seams. The coalface critical value of gas content for outburst risk prediction is 10m$^3$/t in Lanshan Coal Co. Ltd. of Erdaoling coal mine area, so that gas content is above 103/t of No. II 1 coal seam in Hashatu mine and Douyagou, No. II 3 coal seam in Bieligou mine and Baxian mine.

2.2. Initial speed of methane diffusion ($\Delta p$)

The initial speed of methane diffusion is one of the indices to judge the outburst risk in coal seams in that it manifests the ability of absorbing gas and the speed of diffusing gas of coal under ordinary pressure, displaying the micro-structure of coal. The bigger it is, the higher the outbursts will be. The initial speed of methane diffusion in each major coal seam is tested. The data is in Table 1, which demonstrates that $\Delta p$ of Bieligou and Tanyaogou mine surpass the critical index 10 mmHg.

2.3. Consistent coefficient of coal ($f$)

Consistent coefficient of coal is a comprehensive index of the ability to resist external destruction, determined by physic-mechanical properties of coal. It manifests the energy consumed in destroying coal
per unit mass, i.e. whether coal tends to be destroyed and causes outbursts. Test data is in Table 1, which shows that consistent coefficient of coal in Tuoligou mine, the No. II1 upper layer coal seam of Hashatu mine and Bieligou mine are above the critical index 0.5.

Table 1. Gas measurement & calculation in Erdaoling coal mine area

| No. of Coal seam | Colliery                  | Destruction mode | Single index method | Gas content | Comprehensive index |
|------------------|---------------------------|------------------|---------------------|-------------|---------------------|
|                  |                           |                  | $\Delta p$ (MPa)    | $f$         | $P$ (MPa)           | $W$ (m$^3$/t) | $K$  | $D$  |
| I                | Tuoligou mine of Bieligou colliery | Mode I to II | 9.5–21.5        | 0.25–1.01 | 0.13–0.55 | 1.75–9.70 | 25.0–86.0 | <0 |
|                  |                           |                  | 14.54            | 0.49      | 0.33      | 5.50      | 35.9    |    |
| II1 upper        | Douya mine of Douya colliery | Mode I to III | 10.0–12.0        | 0.48–1.00 | 0.34–1.42 | 6.23–14.05 | 10.5–25.0 | -   |
|                  |                           |                  | 11.20            | 0.83      | 0.76      | 10.37     | 14.6    |    |
|                  | Hashatu mine              | Mode III to IV | 9.5–21.0         | 0.19–0.82 | 0.50–1.09 | 6.80–8.68 | 11.6–110.5 | - |
|                  |                           |                  | 17.40            | 0.45      | 0.74      | 7.79      | 57.6    |    |
| II1              | No. 2 mine of Xingtai colliery | Mode I to II | 13.5–16.0        | 0.72–0.76 | 0.25–0.66 | 3.26–8.65 | 18.0–21.0 | <0 |
|                  |                           |                  | 14.38            | 0.75      | 0.38      | 5.11      | 19.2    |    |
| II2              | Baxian mine               | Mode I to II    | 10.0–18.0        | 0.61–0.82 | 0.35–0.44 | 6.71–7.74 | 11.9–29.5 | - |
|                  |                           |                  | 13.00            | 0.73      | 0.39      | 7.14      | 18.3    |    |
| II2 lower        | No. 1 mine of Gulaben colliery | Mode I to II | 11.5–18.5        | 1.02–1.41 | 0.18–0.55 | 4.86–8.57 | 8.2–13.9 | <0 |
|                  |                           |                  | 14.88            | 1.25      | 0.33      | 6.91      | 12.1    |    |
|                  | Bieligou mine of Bieligou colliery | Mode I to II | 8.0–11.0         | 0.38–0.53 | 0.39–1.82 | 7.44–14.50 | 15.7–27.6 | - |
|                  |                           |                  | 9.67             | 0.44      | 1.10      | 12.00     | 22.5    |    |
| II3              | Baxian mine               | Mode I to II    | 11.0–14.0        | 0.67–1.06 | 0.53–1.18 | 8.96–15.32 | 10.4–20.9 | - |
|                  |                           |                  | 11.63            | 0.88      | 0.88      | 12.40     | 13.8    |    |
|                  | Tanyaogou mine of Douyangou colliery | Mode I to II | 6.0–10.0         | 0.62–1.02 | 0.30–0.47 | 6.49–8.04 | 9.7–13.5 | <0 |
|                  |                           |                  | 8.4              | 0.79      | 0.36      | 7.42      | 10.7    |    |
| II4              | Tanyaogou mine of Douyangou colliery | Mode I to II | 8.0–9.0          | 0.92–1.15 | 0.31–0.51 | 6.81–9.23 | 7.3–9.8  | <0 |
|                  |                           |                  | 8.4              | 1.02      | 0.38      | 8.24      | 8.3     |    |
| III               | No.1 mine of Gulaben colliery | Mode I to II | 13.0–20.5        | 0.78–1.56 | 0.36–0.49 | 6.96–9.56 | 10.6–19.8 | <0 |
|                  | No. 2 mine of Xingtai colliery | Mode I to II | 16.1             | 1.13      | 0.42      | 8.01      | 14.9    |    |
|                  |                           |                  | 10.5–15.0        | 0.55–0.72 | 0.23–0.44 | 4.90–6.88 | 15.7–22.1 | <0 |
| IV                | No. 1 mine of Xingtai colliery | Mode I to II | 9.5–16.0         | 0.67–0.79 | 0.17–0.24 | 4.45–6.49 | 12.5–23.9 | <0 |
|                  |                           |                  | 12.75            | 0.75      | 0.21      | 5.47      | 17.2    |    |
| VII2              | No. 1 mine of Xingtai colliery | Mode I to II | 9.0–13.0         | 0.66–0.71 | 0.33–0.69 | 7.42–9.64 | 12.7–19.7 | <0 |
|                  |                           |                  | 11.25            | 0.68      | 0.53      | 7.78      | 16.6    |    |
|                  | Critical value            | Mode III to V    | ≥10              | ≤0.5      | ≥0.74     | ≥10       | ≥20     | ≥0.25 |

2.4. Gas adsorption constant

32 coal samples are collected from all the coalbed of different colliery. In the sampling process, different conditions in different mines and coal seams are considered to ensure their representiveness. High-pressure adsorption test is conducted under the temperature of 30°C in accordance with the standards in Isothermal Adsorption Testing Method of Coal under High Press-Capacity Method (GB/T19560-2008), in which testing parameters are such as adsorption constant $a$ and $b$, ash content, moisture, porosity of samples and so on. Testing results are shown in Table 2.

As is shown in Table 2, the range for gas adsorption constant $a$ is from 33.564 to 39.667 m$^3$/t, and the average is 35.632 m$^3$/t; the range for gas adsorption constant $b$ is from 0.586–1.480 MPa$^{-1}$, and the average is 1.054 MPa$^{-1}$. The conclusion is that there exists little difference in the coal adsorption quality in major coalbed mined, and the coal seams have comparatively high adsorption ability.
2.5 Gas pressure in coal seams

Gas pressure in coal seams is defined as the pressure of free gas included in the original pores of coals, i.e. the pressure imposed by gas on the pore walls. Gas pressure is one of the major indices to manifest the outburst risk in coal seams, and plays an important role in coal and gas outburst risk prediction.

Indirect method is employed to measure the gas pressure in coal seams. Based on the actual measured parameters of original gas content, gas adsorption constant and coal texture analysis, the Langmuir equation (1) as follows is applied to calculate the original gas pressure in coal seams.

\[
W = \frac{abP}{1 + bP} \cdot \frac{1}{1 + 0.31M_{ad}} \cdot \frac{100 - M_{ad} - A_{ad}}{100} + \frac{10\pi P}{\gamma}
\]

In which,
- \(W\) — gas content in coal seams, m\(^3\)/t;
- \(a\) — adsorption constant, the maximum adsorption amount in the testing temperature, m\(^3\)/t;
- \(b\) — adsorption constant, MPa\(^{-1}\);
- \(P\) — gas pressure of coal seams, MPa;
- \(A_{ad}\) — ash content of coal, %;
- \(M_{ad}\) — moisture of coal, %;
- \(\pi\) — porosity of coal, %;
- \(\gamma\) — volume weight of coal (bulk specific gravity), t/m\(^3\).

Gas pressure data measured in the prediction area by means of indirect method is recorded in Table 2, in which the maximum gas pressure of Douyagou mine reaches as high as 1.42MPa, with the average being 0.76 MPa. The maximum of No. II upper layer coal seam in Hashatu mine is 1.09MPa, the average being 0.74 MPa; the data of No. II coal seam are 0.97MPa and 0.76 MPa respectively. In Bieligou mine, they reach 1.82MPa and 1.10MPa. No. II coal seam of Baxian mine has the number of 1.18MPa and 0.88MPa. Just judging from the gas pressure in coal seams, there exists the possibility of outbursts.

3. Prediction of outburst risk area

3.1. Conclusions from gas content method

From Table 1, gas content of No. II upper layer coal seam in Douyagou mine, No. II coal seam in Hashatu mine, coal seams in Bieligou mine and Baxian mine is higher than the critical value 10m\(^3\)/t. Therefore, they are considered risk zone for outbursts if gas content is used as the only standard. Gas content in other mines does not reach the critical value, which implies the outburst risk need further test.

3.2. Conclusions from single index method

In Table 1, all the single indices of No. II coal seam in Hashatu mine reach or surpass the critical values listed in Table 1; therefore, the prediction area is categorized as risk zone for outbursts. Single indices of other mines do not reach or surpass the critical values entirely, so the outbursts risks need further test and verification.

3.3. Conclusions from comprehensive index prediction

Comprehensive index method is one of the important methods to conduct coal and gas prediction in coal seams at present, which directs the region prediction from qualitative to quantitative techniques of geological statistics.
### Table 2. Gas adsorption constants and industrial analysis and measurement results in Erdaoling coal mine area

| No. of Coal seam | Colliery                        | Adsorption constant \(a\) (m\(^3\)/t) | Moisture \(M_{ad}\) (%) | Ash content \(A_{ad}\) (%) | Methane \(\%\) | Porosity \(\%\) | Indirect calculation of gas pressure \(P\) (MPa) |
|------------------|---------------------------------|----------------------------------------|--------------------------|---------------------------|----------------|----------------|-----------------------------------------------|
| I Tuoligou mine  | Bieligou colliery               | 33.564                                 | 1.002                    | 0.58                      | 15.33          | 81.13          | 4.67                                           |
|                  |                                 | 34.738                                 | 1.110                    | 0.57                      | 14.94          | 86.50          | 4.79                                           |
|                  |                                 | 36.446                                 | 0.809                    | 0.72                      | 31.35          | 90.30          | 3.85                                           |
|                  | Douya mine                      | 35.752                                 | 1.082                    | 1.55                      | 5.63           | 98.01          | 4.83                                           |
|                  | Douya colliery                  | 36.653                                 | 1.134                    | 1.47                      | 6.17           | 85.86          | 4.73                                           |
| II 1 upper       | Hashatu mine                    | 34.310                                 | 0.880                    | 0.76                      | 34.01          | 92.61          | 4.55                                           |
|                  |                                 | 35.260                                 | 0.900                    | 0.89                      | 41.28          | 94.11          | 4.85                                           |
|                  |                                 | 36.210                                 | 0.930                    | 0.53                      | 13.61          | 84.27          | 5.14                                           |
| II 1             | Hashatu mine                    | 35.200                                 | 1.020                    | 0.55                      | 10.07          | 95.61          | 4.77                                           |
|                  |                                 | 38.130                                 | 0.920                    | 0.61                      | 4.41           | 88.55          | 4.86                                           |
|                  |                                 | 33.664                                 | 1.281                    | 1.85                      | 6.14           | 87.91          | 4.86                                           |
|                  |                                 | 35.746                                 | 0.959                    | 0.70                      | 9.07           | 82.14          | 4.47                                           |
|                  | No. 2 mine                      | 34.351                                 | 1.355                    | 0.53                      | 18.97          | 92.89          | 4.79                                           |
|                  | Xingtai colliery                | 34.718                                 | 1.212                    | 0.94                      | 8.61           | 95.91          | 4.86                                           |
| II 2             | Baxian mine                     | 34.682                                 | 1.291                    | 0.73                      | 5.94           | 94.49          | 4.79                                           |
|                  |                                 | 36.134                                 | 0.916                    | 0.65                      | 5.25           | 97.97          | 4.73                                           |
|                  |                                 | 34.663                                 | 0.910                    | 0.52                      | 5.77           | 92.98          | 4.26                                           |
|                  |                                 | 33.870                                 | 0.635                    | 0.63                      | 8.98           | 94.03          | 4.20                                           |
| II 3             | Baxian mine                     | 34.306                                 | 1.041                    | 1.21                      | 8.27           | 93.93          | 4.79                                           |
|                  |                                 | 36.999                                 | 0.991                    | 1.26                      | 5.60           | 90.57          | 4.83                                           |
|                  | Tanyaogou mine                  | 35.016                                 | 1.014                    | 1.21                      | 8.27           | 93.93          | 4.79                                           |
|                  | Douyagou mine                   | 35.520                                 | 1.116                    | 0.98                      | 4.10           | 93.58          | 4.20                                           |
| II 4             | Tanyaogou mine                  | 35.004                                 | 1.105                    | 1.34                      | 4.18           | 95.54          | 4.79                                           |
|                  | Douyagou colliery               | 35.520                                 | 1.116                    | 0.98                      | 4.10           | 93.58          | 4.20                                           |
| III No. 1 mine   | Gulaben colliery                | 38.713                                 | 1.210                    | 0.57                      | 7.68           | 92.62          | 4.73                                           |
|                  |                                 | 37.316                                 | 1.011                    | 0.87                      | 15.92          | 94.06          | 5.06                                           |
|                  | No. 2 mine                      | 34.945                                 | 1.085                    | 1.24                      | 11.13          | 83.69          | 4.73                                           |
|                  | Xingtai colliery                | 36.546                                 | 0.832                    | 1.63                      | 6.44           | 76.92          | 4.20                                           |
| IV No. 1 Xingtai | colliery                        | 35.239                                 | 1.285                    | 0.88                      | 8.61           | 92.85          | 4.73                                           |
|                  |                                 | 33.873                                 | 1.286                    | 0.98                      | 37.60          | 95.02          | 4.55                                           |
| II 2             | No. 1 Xingtai colliery          | 35.101                                 | 0.586                    | 0.7                       | 9.46           | 91.48          | 4.64                                           |
|                  |                                 | 35.240                                 | 0.763                    | 0.72                      | 9.53           | 70.97          | 4.70                                           |

In Table 1, judging from the single standard of comprehensive index method, the comprehensive indices \(D\) of the following coal seams are negative: No. I coal seam of Tuoligou mine, coal seam of No. II, and V in No. 2 mine in Xingtai colliery, coal seam of No. II in Baxian mine, coal seam of No. II 2 lower layer and III in No. 1 mine in Gulaben colliery, coal seam of No. II, and II 4 in Tanyaogou mine, coal seam of No. V and VII in No. 1 mine of Xingtai colliery. Therefore, the area is free from outbursts risk.

To sum up, coal seam of No. II 1 upper layer of Douyagou mine, coal seam of No. II 1 upper layer and II 1 in Hashatu mine, coal seam of No. II 3 in Bieligou and Baxian mine are regions with outburst risk; while the rest are safe from outbursts.
4. Conclusions

In light of the comparatively shorter length of coalfaces, outburst risk testing needs successive regional testing.

Single index method, gas content method and comprehensive index method are applied respectively to carry out area prediction of coal and gas outbursts in major coalfaces of Erdaoling coal mine area. It is predicted that such coal seam of No. II\textsubscript{1} upper layer in Douyagou mine, coal seam of No. II\textsubscript{1} upper layer and II\textsubscript{1} in Hashatu mine, coal seam of No. II\textsubscript{3} in Bieligou and Baxian mine have the risk of gas outbursts.

Making the best of the high gas osmosis of coal seams, and the direction and the comparatively short length of extracting coalfaces, equipped with high-power and large-torque drilling machines, enhancing the advance pre-drain and pre-emission in the mining and tunneling coalface by means of large-aperture boreholes, the remaining gas content and pressure in the coal seams is reduced under the critical value.

Importance should be attached to the testing and management of basic gas parameters so as to offer foundation to the risk prediction of gas discharge amount in deep mining and coal and gas outbursts.

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