Study on resource evaluation of coalbed methane in old gob area of Nanzhuang Coal mine

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Abstract. Nanzhuang coal mine in Yangquan mining area has entered the dry period of coal resources, founded the mine gas extraction to reduce gradually, need to find a new source for the mine to provide continuous heating, industrial district and coalbed methane in the old mined-out area is clean and precious resources, has a very high use value, and the old goaf coal bed methane development cost is higher, so within the mining area before mining goaf estimation of coalbed methane resources and the development and utilization is of great significance. Based on founded 15# coal seam in Nanzhuang coal mine based on geological and production data, explores the specific geological conditions in Yangquan mining area resources assessment technological applications, according to the situation of 15 # coal seam in the indirect method is chosen as the calculation model for the evaluation of mined-out area resources, calculated founded 15 # coal seam mine goaf largest recoverable CBM resources up to 86.9938 million m³, that founded in mined-out areas is recoverable CBM resources, which provides theoretical basis for subsequent resources development.

1. Project overview

In the 1990s, old gob (abandoned mine, mining stability area) CBM extraction as a new CBM (coal mine gas) development mode gradually developed. This technology is mainly used to extract the coalbed methane resources stored in the mining stability zone to the ground through negative pressure by using new surface Wells or existing underground tunnels in the ground [1-3]. In recent years, this technology has made great progress in Germany, Belgium, Britain and other countries [4-5]. At present, domestic research on the utilization of coalbed methane resources in old goaf has just started, with only field test projects in Shanxi, Chongqing, Liaoning, Ningxia and other places [6-7], and more theoretical research is focused on. Nanzhuang Mine in Yangquan mining area was built in 1952, with an annual output of 2 million tons after renovation and expansion. The test mine belongs to coal seam group mining. After more than 60 years of mining, the No.12 coal seam in the middle and east of the mine area has been mined out in a large area, while the No.15 coal seam in the north has been mined out in a large area. There are many old gob areas in the mine area, and a large amount of coalbed methane is left and accumulated inside. The test mine has entered the dry period of coal resources, and the gas extraction quantity is reduced accordingly, which is difficult to meet the daily heating demand of the mine.
Therefore, it is urgent to find new resources to provide continuous heat energy for the mine industrial site. Moreover, CBM in the old gob is a clean and precious resource, and the mining cost is relatively high. Therefore, based on the geology and production data of No.15 coal seam in Yangquan Nanzhuang Mine, resource assessment was conducted for the old gob area of No.15 coal seam in the test mine.

2. Assessment of coal seam profile
No.15 coal seam, located at the lower part of Taiyuan Formation, is about 44.26m above No.12 coal, 12.14m above K2 limestone, and 8.15m below K1 sandstone. It is the main coal seam available in this well field. The thickness of coal seam is 5.24~6.63m, with an average of 5.89m. Stable layer, whole area can be mined, complex structure, containing 1~2 layers of mixed stone, mixed stone thickness of 0.02~0.47m. According to the data of Nanzhuang mine, the accumulated resource reserves of no.15 coal seam are 76425KT, the resource reserves are 57699KT, and the resource reserves are 18726kt.

Physical characteristics of coal: the true density of coal is 1.5t/m³, the apparent density is 1.56t/m³, the porosity is 3.85%, the firming coefficient F value is 1.03, and the initial velocity of gas emission is $\Delta P = 9$. Industrial analysis of coal samples: Moisture (Mad) yield was 2.28%, ash (Aad) yield was 13.83% and volatile (Vdaf) yield was 9.59%. Gas adsorption constant: Adsorption constant A value is 41.2566, b value is 1.3596.

3. Method selection of coal seam resource quantity evaluation
Gas conservation subtraction, first of all, the original total CBM resources assessment area, then according to the actual test mine deducting the loss amount of coalbed methane production status, the remaining is the old goaf recoverable CBM resources, since the assessment of regional information evaluation methods need more, thus obtained is applicable to complete actual production data in underground mines. In Nanzhuang Mine, the mining period of coal seam evaluation is relatively short, and the coal mine geology and production materials are relatively complete. Therefore, indirect deduction method should be selected to estimate the resources of coalbed gas in old goaf. Therefore, indirect deduction method is adopted to estimate the situation of No.15 coal seam.

By analyzing the situation of No.15 coal seam in Nanzhuang Coal Mine, it is concluded that the original CBM resources in the evaluation area are mainly derived from three sources, namely, the original CBM in the evaluation area, the CBM in the vicinity of the pressure area in the evaluation area, and the CBM stored in the surrounding rock of the coal seam in the evaluation area, as shown in Figure 1.

![Figure 1. Schematic diagram of CBM source in mining area](image)

According to the investigation and evaluation area, the gas loss of No.15 coal seam mainly includes four parts: pre-extraction of coalbed methane by surface well before mining of working face, residual gas of coal produced on the surface, gas extraction of coal seam by drainage pipeline during mining of working face, and gas emission of goaf after mining closure of working face.
4. Calculation of No. 15 coal seam goaf resources

4.1. The delineation of the reserves assessment scope

1) Prediction of stope fracture zone

According to the geological data, the lithology of the overlying rocks in the coal seam in the
assessment area is mainly medium and hard rock. The common formulas for the calculation of fracture
zone are (1) and (2). According to the actual situation of No.15 coal seam, the calculation is carried out
according to Formula (1):

\[ H_i = \frac{100 \sum M}{1.6 \sum M + 3.6} \pm 5.6 \quad (1) \]

Or

\[ H_i = 20 \sqrt{\sum M + 10} \quad (2) \]

Where: \( H_i \) — height of fracture zone, m. \( M \) — cumulative thickness, m.

The calculation results are shown in Table 1.

| Number of coal seam | Mining thickness (m) | Height of fracture zone (M) |
|---------------------|----------------------|-----------------------------|
| 15#                 | 5.89                 | The minimum value 39.77     |
|                     |                      | The maximum value 50.15     |

According to the calculation results in Table 1, the maximum height of No.15 seam mining fracture
zone is 50.15m (including the height of caving zone). In order to ensure the accuracy of the calculation
results, the maximum height of fracture zone is taken for calculation.

2) Damage depth of stope floor

Formula (3) is used to calculate the maximum damage depth of stope floor rock:

\[ H_b = \frac{x_a \cos \phi}{2 \cos \left( \frac{\pi}{4} + \frac{\phi}{2} \right)} e^{\left( \frac{\pi}{4} + \frac{\phi}{2} \right) / 2} \quad (3) \]

Where: \( x_a \) — length of coal pillar yield zone, m; \( \phi \) — internal friction Angle of floor rock mass,

Given that the internal friction Angle of coal seam/rock layer is about 28°, the bulk density of floor
rock is 2,530kg/m³, the buried depth is 470m to 570m, the maximum stress concentration coefficient is
1, and 10 sets of different buried depth data are selected and inserted into the formula to calculate the
average floor failure depth of 12.98m.

4.2. Calculation of original gas volume

There is no coal seam within the damage range of No. 15 coal seam floor, so the amount of coalbed
methane above the stope roof is mainly considered when calculating the resource amount. The upper
adjacent layers of No.15 coal seam have No.12, No.13 and No.14 coal seams. The relationship between
each adjacent layer and the position of No.15 coal seam is shown in Table 2.

| Number of coal seam | Seam thickness /m | And 15# seam spacing /m | Spatial relations     |
|--------------------|-------------------|-------------------------|----------------------|
| 12#                | 1.22              | 50.1                    |                      |
| 13#                | 0.53              | 19.1                    | Upper adjacent coal   |
| 14#                | 0.31              | 46.1                    |                      |
Combined with the calculation results of the height of the roof rock fracture zone of the stope, it can be seen that the unloading adjacent layers of the overlying strata of No.15 coal seam are No.12, No.13 and No.14 coal seams. After working face exploitation, coalbed methane near the coal seam will flood into the goaf through cracks within the range of pressure relief in the evaluation area, and become a component of coalbed methane resources in the old goaf.

In order to ensure the accuracy of calculation, the maximum original gas content is taken as the gas content of No. 13 and No. 14 coal seams, namely 8.46m³/t, and the bulk density is 1.51t/m³. Since No.12 coal seam is far away from each other, the maximum original gas content is taken as the gas content of No. 12 coal seam, namely 5.94m³/t, at the edge of the royal pressure zone.

The original gas volume of coal resources in the evaluation area and the original gas volume of adjacent coal seams within the pressure-relief range of the evaluation area are shown in Equation (4) and (6) respectively.

\[ Q_{(c)} = M_{(c)} q_{(c)} L_{(c)} W_{(c)} H_{(c)} \gamma_{(c)} \]

(4)

Where:
\( Q_{(c)} \) —Evaluate the original gas volume of the coal seam in the area, m³.
\( M_{(c)} \) —To evaluate the total coal resources in the region, t.
\( q_{(c)} \) —Evaluate the gas content of coal seams in the area, m³/t.
\( L_{(c)} \) —Strike length of mining area, m.
\( W_{(c)} \) —Slope length of mining area, m.
\( H_{(c)} \) —True seam thickness, m.
\( \gamma_{(c)} \) —Bulk density of coal seam, t/m³.

\[ Q_{(j)} = \sum_i Q_{(j;i)} = \sum_i V_{(j;i)} \gamma_{(j;i)} q_{(j;i)} \]

(5)

Where:
\( Q_{(j)} \) —Evaluate the gas volume of adjacent coal seams within the pressure relief range of the area, m³.
\( Q_{(j;i)} \) —To assess the amount of CBM in the vicinity of layer I in the area, m³.
\( V_{(j;i)} \) —To evaluate the volume of adjacent coal seam in the zone I, m³.
\( \gamma_{(j;i)} \) —To evaluate the bulk density of the adjacent coal seam in the area's layer I, t/m³.
\( q_{(j;i)} \) —To evaluate CBM content in the adjacent coal seam of layer I in the area, m³/t.

\[ Q_{(c)} = 734.7859 \text{ million m}^3, \quad Q_{(j)} = 93.6293 \text{ million m}^3. \]

According to relevant geological data, the roof and floor of No.15 coal seam in Nanzhuang Mine are mostly mudstone, sandy mudstone and middle sandstone. Meanwhile, the amount of gas emission in the surrounding rock is assessed to be large. In summary, the gas reserve coefficient of the surrounding rock is taken as 0.3, and the gas reserve in the surrounding rock is obtained by substituting the formula: 193.9463 million m³.

By summing the calculation results of gas reserves in coal seams in the evaluation area, gas reserves in adjacent coal seams within the pressure-relief range of the evaluation area and gas reserves in surrounding rocks, the original gas reserves in the old gob of No.15 coal seam in the test mine can be obtained as follows: 1.0223614 billion m³.

4.3. Calculation of gas loss

According to the composition diagram of CBM emission loss in the mining area and combined with the actual production situation of Nanzhuang Mine, it can be concluded that the old gob emission loss mainly comes from the amount of gas contained in the mined surface coal, the amount of gas pumped underground during production, and the amount of gas emitted after the mining area is closed. According to the production data, the amount of gas from each source can be calculated respectively.

Total gas loss in goaf of No.15 coal seam: 720.6214 million m³.

By calculating the original reserves calculated above and the gas lost in each part, the gas reserved geological reserves in No. 15 coal seam goaf can be obtained: 301.74 million m³.
4.4. Calculation of recoverable reserves

The calculation formula of recovery factor of coal adsorption gas resource in old goaf is as follows:

\[ R_{fa} = \frac{(C_i - C_a)}{C_i} \]  

(6)

Where: \( R_{fa} \) — Adsorption gas recovery factor of coal seam, %. \( C_i \) — Current gas content of coal seam or residual coal in mining stable area, m³/t. \( C_a \) — Gas content at limit or waste pressure, m³/t.

According to Equation (7), coal seam adsorption gas recovery factor can be calculated \( R_{fa} = 77\% \). Therefore, gas recoverable resources in goaf of No.15 coal seam are as follows: 86.9938 million m³.

5. Conclusion

(1) The old goaf gas conservation subtraction of CBM resources assessment main train of thought for calculating original CBM resources assessment area, first test mine based on the actual production status again deduct loss amount of coalbed methane, evaluation results, the amount of goaf of coalbed methane is obtained due to the information needed for this method is more, thus obtained is applicable to complete actual production data in underground mines.

(2) According to the actual situation of Nanzhuang mine, the coal mine geology and production materials are relatively complete, so it is appropriate to use the deduction method to estimate the CBM resources in the old goaf. The original gas amount of coal resources in the evaluation area, the original coalbed methane in the adjacent coal seam and the free coalbed methane in the surrounding rock in the evaluation area are calculated. At the same time, the resource data of each component of the lost gas volume are calculated.

(3) The total gas loss in No.15 coal seam goaf of Nanzhuang Mine is 720,621,400 m³ by using the gas conservation and reduction method. The reserved geological reserve of goaf is 30,174 million m³, and the maximum exploitable resource reaches 86,938,800 m³. Therefore, the coal seam gas resource in the test mine has the exploitability, providing a theoretical basis for the resource utilization of the old goaf of Nanzhuang mine.

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