Study on prediction model of coalbed methane extraction production in goaf of Yuecheng Mine

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Abstract. A large number of mined-out areas are formed in the production of coal mines, which contain rich coalbed methane resources. If the coalbed methane resources in the mined-out areas are allowed to escape into the atmosphere, it will not only cause a waste of resources, but also pollute the environment and affect the underground production safety. Therefore, it is of great significance to the utilization of coalbed methane resources in the mined-out areas. However, due to the complex environment of mined-out area, the research on the prediction of coal bed methane extraction production in mined-out area has been few, and the coal bed methane extraction amount in mined-out area has a large randomness, so it can not be accurately predicted. Therefore, according to the actual pumping situation of YCCD-02 well in Yuecheng Mine, combined with the pumping curve of surface well, the prediction model of coalbed methane pumping production in goaf was calculated, and the accuracy was verified by the evaluation results of goaf resources.

1. Introduction
China's coal mining activities began to develop from the early 20th century, long-term coal production in China has formed tens of thousands of mining influence stability areas, commonly known as abandoned goaf. Due to the restriction of production conditions, there is still a large amount of coal remaining in the mine, among which a large amount of coalbed methane remains and accumulates [1-2]. Mined-out coalbed methane (CBM) resources escape into the atmosphere, which not only causes resource waste but also pollutes the environment and affects underground production safety [3-4], so it is necessary to extract and utilize the CBM resources in the goaf [5-6]. The development of coal bed methane in China is mainly based on the extraction of gas from unmined coal seams in production mines. The exploitation of coal seams in abandoned mines is still in the exploration stage. Mining-induced fissure is the basic condition for the seepage and occurrence of groundwater and coalbed methane in the mined-out area of abandoned mines. Since the 1950s, Liu Tianquan, Zhong Weilin, Qian Minggao, Song Zhenqi et al [7-8] have made a lot of measurement and theoretical research on rock strata failure and water-conducting fracture distribution in coal mining, and established a general understanding of "three horizontal zones" and "three vertical zones" of rock strata movement fracture and mining-induced fracture distribution in stope. However, at present, there are few researches on the prediction of goaf gas...
extraction amount. Therefore, based on the actual situation of Yuecheng Mine, the research is carried out on the basis of the coalbed methane extraction amount in the goaf of well YCCD-02, and the prediction model of goaf resource extraction amount is obtained.

2. Basic situation of surface well pumping

Experiment goaf formed in 2010 to 2018, the mining of coal seam 3# coal seam, located in the lower part of Shanxi group, YCCD-02 wells located in Yuecheng mine 1303 face, 1301 face ~ 1306 working face in the same panel, segregation of working face coal pillar of about 30 m, as after completion of the entire panel all working face mining, the working face goaf roof strata of the mining-induced fractures are likely to be well versed in each other, so well YCCD - 02 extraction from whole panel mined-out area.

YCCD-02 surface well began pumping operation on May 25, 2014. As of December 6, 2020, it has been running for 2388 days in total, with an average gas extraction volume of 15,300 m³/d, an average extraction concentration of 32.82%, and a cumulative extraction volume of 33,928,200 m³.

When YCCD-02 surface well starts pumping, the mining face is 1306 (above), and the replacement time of the subsequent working face is shown in Table 1.

| Name of working face | Start time of stoping | End time of stoping | Mining length/m |
|----------------------|-----------------------|---------------------|-----------------|
| 1306 (above)         | October 2014          | March 2015          | 623             |
| 1304 (below)         | November 2015         | July 2016           | 1035.7          |
| 1305 (below)         | March 2017            | December 2017       | 1060            |
| 1306 (below)         | September 2018        | March 2019          | 730             |

The ground well extraction volume and concentration of YCCD-02 are compressed as the start and stop working face in mining in up and down, namely when there are firstly, the ground well extraction data tend to rise, and with the working face, stop picking well with the decrease of data extraction on the ground, shows that when operating in the mining fissure and gob well versed in, new supplement source becomes the ground well, if there is no new surface pressure, the gas source supplement gradually reduce the ground well data. However, after the recovery of 1306 (below) surface was completed on March 26, 2019, there was no new production of production surface in the first block, and the extraction data of YCCD-02 surface well showed an obvious decrease trend.

3. Calculation model fitting of extraction volume

3.1. Computational model fitting

Through the analysis of Yuecheng ore in October 2018 to December 2020, data extraction, found that the phase extraction from higher gas quantity first, with the loss of the working face production gradually slow, so the gas extraction data fitting, calculation model of coalbed methane production change over time can be obtained Q, constant p1 and p4 for different extraction condition for the corresponding changes:

\[ Q = \frac{(p_1 + t)(p_2 + p_3 \times t) + p_4 \times \ln(t)^2}{(p_2 + p_3 \times t) + p_4 \times \ln(t)^2} \]

Where: Q is daily gas extraction volume, 10,000 m³; t is extraction days, t > 0; p1=11.244; p2=9.386; p3=0.181; p4=-0.105; Correlation coefficient R²=0.93.

Comparison between actual extraction data and fitting calculated data is shown in Figure 1.
3.2. Verification of accuracy of calculation model of extraction data

In order to verify the accuracy of the calculation model, the calculation data of the calculation model were compared with the goaf extraction data of Songzao Coal Mine and the other extraction data of Yuecheng Coal Mine.

(1) Compared with the goaf extraction data of Songzao Mine

The extraction time of surface well in goaf of Songzao Coal Mine is about 238 days, and the data is relatively stable. The average daily pure gas extraction volume is 0.169 million m$^3$. Due to the short measurement time of data, the fitting degree is low, and the correlation coefficient $R^2=0.69$. The fitting curve basically reflects the variation trend of the extraction data. Actual extraction data and fitting curves are shown in Figure 2.

(2) Compared with the extraction data of YCCD-02 well in Yuecheng Mine from 2015 to 2016

The extraction data of YCCD-02 well from October 2015 to March 2016 were compared. At this stage, the mining and stoping work of 1306 (above) working face were completed underground. According to the calculation, the correlation R2 between the fitting data and the actual extraction data was 0.8, showing a good correlation. Actual extraction data and fitting curves are shown in Figure 3.
Figure 3. Comparison of actual extraction data and fitting data of calculation model from 2015 to 2016 years in well YCCD-02

Among them: p1=-4.063, p2=-2.797, p3=-0.0253, p4=0.815.

(3) Compared with the pumping data of YCCD-02 well in Yuecheng Mine from 2016 to 2018
The extraction data of YCCD-02 well from February 2016 to August 2018 were compared. In this stage, the mining and stoping work of 1304 (lower) working face were completed. According to the calculation, the correlation R2 between the fitting data and the actual extraction data was 0.81, showing a good correlation. The actual extraction data and fitting curve are shown in Figure 4.

Figure 4. Comparison of actual extraction data and fitting data of calculation model from 2016 to 2018 years in well YCCD-02

Among them: p1=1.118, p2=6.304, p3=0.116, p4=-0.1604.

Through the analysis of the above three groups of data, we can see that the calculation model of extraction amount obtained through fitting has high reliability, so it can be used as the prediction model of the goaf extraction data in Yuecheng Mine.

3.3. Calculation of total amount of gas extracted from well YCCD-02
The calculation model was used to fit the extraction data of Well YCCD-02, as shown in Figure 5.
The cost of coalbed methane extraction in goaf includes workers' wages, equipment depreciation, fuel and power costs and other expenses. The direct income of coal extraction includes power generation sales (1 yuan/kWh) and financial subsidies for gas extraction (0.3 yuan/m³). Based on the premise of 1m³ pure gas power generation of 3.5°, according to the empirical calculation, when the produced gas is fully utilized for power generation, it is considered that when the daily average gas extraction of pure gas is less than 100m³, the surface well enters the operation stage of negative financial net cash flow, and the standard of daily gas production of less than 100m³/d is taken as the threshold value of surface well closure.

According to the calculation model analysis, the YCCD-02 well is expected to continue pumping for about 600 days, that is, it is expected to continue pumping until September 2022, and the gas extraction volume will continue to be 3.17 million m³, that is, it is predicted that the cumulative gas extraction volume of YCCD-02 well will reach 37.0982 million m³.

4. Comparison of prediction results of coalbed methane extraction
According to the volume of conservation subtraction to evaluate experiment area goaf resources, gas conservation of deducting the evaluation methods of overall thought is in the original based on the results of the gas resource evaluation, from the coal mine production before and after the loss of all gas quantity, finally get the gob gas quantity evaluation results, this method is applicable to certain mine actual production data of target can be obtained mining area, the evaluation result is accurate.

The maximum recoverable gas resource in the goaf of the test working face of Yuecheng Coal Mine is 38.0363 million m³, which is calculated according to the conservation subtraction method of gas volume. However, the cumulative gas extraction pure volume calculated by the prediction model in Well YCCD-02 is 37.0982 million m³, so the accuracy of the prediction model in calculating the CBM extraction volume in the experimental area is 97.5%, indicating the accuracy of the prediction model for CBM production.

5. Conclusion
(1) Aiming at the problem of less research on the prediction of coal bed methane extraction amount in goaf, the prediction model was selected based on the original extraction data of Yuecheng Mine, and the corresponding calculation formula was obtained.

(2) The extraction data of Songzao mine and YCCD-02 well in different time periods were analyzed to verify the high accuracy of the prediction model. Finally, the cumulative gas extraction pure volume of YCCD-02 well was predicted to be 37.0982 million m³.
(3) The maximum recoverable gas resource in the goaf in the experimental area is 38.03363 million m$^3$ by the conservation and subtraction method of gas volume, so the accuracy of the prediction model in calculating the extraction amount of coalbed methane in the experimental area is 97.5%, indicating the accuracy of the prediction model in predicting the production of coalbed methane.

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