Application of Directional Long Borehole Technology in Working Face of Thick Coal Seam Along Top Driving

Yongtao Shi
China Coal Technology and Engineering Group Chongqing Research Institute, Chongqing 400037, China

Abstract. With the increasing of gas content in a coal mine in Shanxi Province, when the coal seam roadway is driving along the top, the extraction effect of ordinary borehole is not good under the complicated geological condition of high gas content and thick coal seam. The traditional "step type" gas control method of ordinary borehole has seriously affected the mine excavation replacement and safety production. In view of the existing problems of gas control in mine heading face, this paper introduces the technology of long directional borehole extraction. Through the field test, investigation, comparison and analysis, the tunneling speed of the tunnel is increased from the original 150m / month to 240m / month; compared with the safe excavation of the 400m roadway, the directional long borehole extraction process was 37 days faster than the traditional ordinary borehole extraction process; the gas concentration in the working face and return air flow was reduced by about 0.3% on average, which greatly reduced the ventilation pressure during the excavation and ensured the safe excavation of the working face. Finally, the extraction technology and parameters of the long directional borehole along the heading face of the thick coal seam are investigated.

1. Introduction
A mine in Shanxi Province as the mining range extension of tunneling working face gas content increasing, take along the top driving tunneling faces at the same time, due to large thickness of coal seam, using common extraction extraction from drilling, drilling construction efficiency is low, the actual utilization rate is not high, and the construction precision is insufficient, the lower coal seam roadway extraction, downward drilling hole water seriously at the same time, the gas extraction effect is not good, can't meet the needs of the current gas control tunneling faces, seriously affects the normal mining of the mine and production safety [1-3]. Through the national major special projects, the performance and drilling technology of directional drilling in China have been greatly improved. The directional drilling technology can realize directional long distance drilling of coal seam drilling, controllable drilling trajectory and multi-branch hole construction, etc., and can realize long distance and full-coverage coal seam gas pre-extraction [4-6]. In recent years, directional long borehole extraction technology has gradually developed into an important measure for efficient gas extraction and regional gas control in underground coal mines. Based on the actual situation of the mine, this paper analyzes and studies the problems existing in the working face of the mine excavation, and introduces the technology of long directional borehole extraction [7-10]. This paper takes the application of the directional long borehole drainage technology in the main roadway of mine as an example, and through the comparative analysis of the field test, it investigates the technical parameters of the directional long borehole drainage suitable for the thick coal seam heading along the roof of the mine, so as to provide a reference for the gas treatment in the roadway under similar mine conditions.
2. Present situation and existing problems of gas management in tunneling face

2.1 The survey
A mine is located in Zhangzi County, Shanxi Province. It is approved to mine no. 3 coal seam, with an area of 71.3947 km² and a designed production capacity of 4.0 Mt/a. Since 2011, all identified is high-gas mines. There are many faults and collapse columns in the well field, and the geological conditions are complicated. The average thickness of no. 3 coal seam is 6m, and the original gas content of the mine is 7.3 m³/t to 15.8 m³/t.

2.2 Gas control method of heading face
At present, the gas treatment method of mine heading face is "front extraction + auricular drilling field". The horizontal projection length of the extraction borehole is 80m and the spacing between the end holes is 3m. At the same time, the two sides of the roadway were arranged as "striding" drill fields, and the area within 15m outside the roadway contour was evenly controlled. 20m lead distance was reserved for each cycle. The design diagram is shown in figure 1. The spacing of drilling sites and the number of boreholes are determined according to the actual gas emission and roadway conditions.

![Figure 1. Schematic drawing of head extraction + ear drill field (unit: m)](image)

2.3 Problems of gas management in tunneling face
Based on the current coal seam conditions of the mine and the actual problems of the mine, this paper analyzes the existing problems of gas control in the current heading face as follows:

(1) Due to the complicated regional geological structure in the deep of the mine, there are a large number of faults and collapse columns in the well field. Affected by geological structure, gas anomaly and other factors, the general drilling construction efficiency is not high, and the drilling extraction effect is difficult to achieve the desired effect.

(2) Due to the general drilling construction technology problems, the drilling trajectory cannot be controlled, the effective extraction length of the drilling is short, and the actual utilization rate of the extraction drilling is not high, especially in the drilling field when the stubble or the replacement of the drilling head, the extraction effect is not good.

(3) Due to many factors affecting the drilling effect, it is impossible to accurately quantify the number of drilling holes in the drilling field. The number of designed boreholes is large, which leads to the waste of engineering quantity. The number of designed boreholes is insufficient, and the extraction cannot achieve the desired effect.

(4) The coal seam roadway in the mine is driven along the top, the thickness of no. 3 coal seam in the well field is 6m, and the roadway height is 3.8m. The drainage borehole in the front part is downward, and the gas extraction effect in the lower part of the roadway is not good.

3. Design of technical parameters for long directional borehole extraction along the bedding
In view of the above problems, it is proposed to control the gas by adopting the technology of long directional borehole along the heading face of thick coal seam. The specific plan is as follows:
3.1 Basic information of test area
The location of the drainage process test of the directional drilling along the bed is located in the main roadway of the main haulage, and the roadway is arranged in the no.3 coal seam. The average thickness of the coal seam is 6m, the inclination Angle is 0° ~ 5°, and the average is 2.5°. Roadway tunneling along the roof of coal seam, roadway section 5.5m×3.8m. The content of raw coal gas in this area is 11m$^3$/t ~ 13 m$^3$/t, and the gas emission on the heading surface mainly comes from this coal seam. During normal roadway tunneling, gas concentration in the return flow is 0.63% ~ 0.96%, gas concentration in the working face is 0.53% ~ 0.79%, and the average gas emission is about 6.2m$^3$/min.

3.2 Borehole parameter design
According to the thickness of coal seam, gas content and roadway conditions of the mine, the chief engineer designed 6 boreholes, and designed two boreholes in the front to extract and dig the gas in the front; two boreholes are designed in the two side drill sites of the roadway to intercept the gas emission from the coal wall. The design length of the main borehole is 400m, the design length of the branch hole is 480m, and the diameter of the borehole is 96mm. The borehole is divergent.

Table 1. Drilling layout parameters

| Hole no. | Opening azimuth |
|----------|-----------------|
| 1        | 0°              |
| 2        | 0°              |
| 3        | 355°            |
| 4        | 351°            |
| 5        | 5°              |
| 6        | 9°              |

Figure 2. Schematic drawing of directional long borehole (unit: m)

4. Long directional drilling along the bed

4.1 Geologic structure survey
No.1 drill hole made two active roof tests of 130m and 280m, and the roof was drilled backward and the branch was drilled forward to 375m. Mudstone was found again. After the completion of drilling, the strike of coal seam within 375m in front of main haulage roadway was basically explored.

During the construction of the last branch hole of No.2 hole, the inclination gradually increased around 220m. When the borehole reached 399m, mudstone was found as the floor, but when the branch hole reached 330m, mudstone was found again, which was consistent with the direction of the roof and floor designed by the borehole.

Through the directional drilling construction of No. 1 ~ No. 2, the geological structure of this area is preliminarily found out, providing reference for gas control and tunneling in adjacent roadway.

4.2 Directional drilling along the bed
According to the precise positioning characteristics of directional drilling, combined with the geological structural conditions of the main roadway in the preliminary exploration, NO.1~NO.6 directional long drilling was constructed. NO.1~NO.6 drill hole construction total footage 4290m, total construction time 25.2 days, average daily footage 169m; see table 2.

Table 2. NO.1~NO.6 Drilling footage statistics table

| Hole no. | Main hole penetration /m | Branch penetration /m | Cumulative penetration /m | Construction time/day | Average daily footage /m |
|----------|--------------------------|-----------------------|---------------------------|-----------------------|-------------------------|

3
5. The effect analysis of borehole test along the bed

5.1 Extraction data analysis
After the completion of each drill, the negative pressure, concentration and flow of the extraction are observed every day. The actual observed data on site are shown in table 3.

Table 3. Drilling extraction parameters statistics table

| Hole no. | Negative pressure /Kpa | Concentration /% | Extraction scalar /m³/min | Extraction time /day | The total extraction /m³ |
|----------|------------------------|-----------------|--------------------------|----------------------|------------------------|
| 1        | 18.9~29.5              | 28.5~67.3       | 0.19~0.56                | 82                   | 44280                  |
| 2        | 17.3~30.8              | 29.3~69.9       | 0.21~0.68                | 74                   | 47419                  |
| 3        | 16.6~28.8              | 25.5~63.7       | 0.11~0.74                | 68                   | 41616                  |
| 4        | 17.4~29.8              | 20.6~70.3       | 0.24~0.77                | 65                   | 47268                  |
| 5        | 18.2~22.8              | 19.7~74.2       | 0.16~0.58                | 63                   | 33566                  |
| 6        | 17.4~28.6              | 23.5~66.8       | 0.08~0.83                | 61                   | 39967                  |

The No. 1 and No. 2 boreholes are evenly distributed about 400m in front of the tunneling face of main roadway through the main hole + branch hole layout, controlling the coal volume of about 16,500 tons. According to the prediction results of mine gas geological map, the maximum gas content in the control area of directional drilling is 13.41m³/t. According to this content, the coal seam gas reserves in the borehole control area are about 223,300 m³. After 74 days of drainage, the cumulative gas extraction capacity of the two directional boreholes in the main roadway driving face was about 91,700 m³, as shown in table 3. The extraction rate is about 41.44%, and it is expected that the coal seam gas content in this area will decrease by about 5.56m³/t, and the residual gas content will be about 7.85m³/t. The SDQ deep hole quick sampling device was adopted in the field for sampling verification, and the maximum residual gas content after extraction on the working face was actually measured at 7.8m³/t, and the extraction reached the standard.

5.2 Analysis of driving effect during stoping
The directional borehole in the main roadway has been fully pumped for nearly 2 months, and the head-on borehole has been pumped for about 70~80 days. Since the normal tunneling of the main yundajie roadway began on June 21, by collecting the gas concentration data of the return air flow and the tunneling surface during the tunneling of the main yundajie roadway, the analysis was focused on the maximum gas concentration and average gas concentration in the roadway, as shown in figure 3 according to the statistics of the field data.
As can be seen from figure 3, during the mining period, the gas concentration in the return air flow and the working face of the main transport roadway was stable on the whole, and the maximum gas concentration in the return air remained below 0.7%, with an average of 0.35%. The gas concentration of the working face is between 0.15%~0.4%, and most of them are kept below 0.3%. The local gas concentration is relatively high, but within the safe control range, it can be seen that the directional drilling in the two sides of the main transport roadway has a significant effect on reducing the gas emission from the coal wall of the working face and the roadway.

5.3 Analysis of tunneling efficiency

The tunneling efficiency of ordinary drilling and directional drilling after extraction is compared and analyzed. The 400m roadway is a cycle.

The conventional ordinary drill hole was used to extract the face and coal wall of the working face with a monthly feed of 150m. The gas concentration of the working face during tunneling was 0.53~0.79% and the gas concentration of the return air was 0.63~0.96%, which was in a high state. The total tunneling time of 400m was 175 days. The gas concentration on the working face during tunneling was 0.25~0.48%, and the gas concentration on the return air was 0.28~0.69%. The gas concentration on the working face and return air was significantly reduced. The total tunneling time of 400m was 138 days. The directional long drilling extraction process is 37 days faster than the ordinary drilling process. The specific comparison is shown in table 4.

| Way               | Drilling | Extraction | Tunneling | Total  | Monthly footage /m | Gas concentration/% |
|-------------------|----------|------------|-----------|--------|---------------------|---------------------|
| Ordinary drilling | 20       | 75         | 80        | 175    | 150                 | 0.53-0.79           | 0.63-0.96          |
| Directional drilling | 14       | 74         | 50        | 138    | 240                 | 0.25-0.48           | 0.28-0.69          |

6. Conclusion

In view of the problems existing in gas control in tunneling face, it is proposed to adopt a long borehole along the top of thick coal seam to control gas. In this paper, the main transport roadway is taken as the research object. After comparative analysis, the gas treatment effect of directional long boreholes in the bedding layer is remarkable. After adopting the extraction technology of the long directional borehole along the strata, the tunneling speed was increased from 150m/month to 240m/month, with an increase of 60%. Compared with the test of 400m roadway, the extraction time was shortened by 37 days and the range was reduced by 21%. The concentration of gas in working face and return air decreased by about 0.3% on average.
References
[1] Zhang, Q. Shi, Z.J. Yao, N.P. (2007) Analysis and suggestions on application of directional long boreholing technologies and drills in china. J. China Coalbed Methane, 4:8-11.
[2] WANG, Q. LIU, W.W. CUI, Y.B. (2017) Application of directional drilling technology in dredging and draining water of roof soft rock. J. Safety in Coal Mines. 47:152-154.
[3] WANG, Z.F. TIAN, F.C. ZHAO, B. (2010) The testing of gas drainage efficiency about feather-veined 1000m length drillhole. J. Journal of China Coal Society. 35:76-79.
[4] SHI, Z.J. XU, C. LI, Q.X. (2014) Application of MWD directional drilling technology in geologic exploration in underground coal mine. J. Safety in Coal Mines. 45: 137-140.
[5] SHI, Z.J. YAO, K. TIAN, H.L. (2019) Present situation and prospect of directional drilling technology and equipment while drilling measurement in underground coal mine. J. Coal Science and Technology. 47: 22-28.
[6] SHI, Z.J. LI, Q.X. XU, C. (2013) Directional drilling technology and application of measurement while drilling in coal mine. J. Equipment for Geotechnical Engineering. 14: 32-36.
[7] ZHU, X.P. CHEN, T. SI, J.H. (2016) Experimental Study on area gas pre-drainage via directional long borehole drilling in Huangling No. 2 mine. J. Coal Engineering. 48: 84-87.
[8] KONG, W. (2018) Application of directional drilling technology for coal roadway in Panchengling coal mine. J. Coal Engineering. 39: 135-137.
[9] ZHOU, J.L. DONG, H.K. LI, G.Q. (2013) Research on effect test method for regional gas pre-drainage measure against outburst by directional long boreholes along coal seam. J. Mining Safety & Environmental Protection. 40: 69-72.
[10] HUA, J.J. ZHANG, Y.B. WANG, X.J. (2014) Coal seam gas outburst prevention technology research and application of bedding directional drilling drainage long section. J. Coa. 23: 18.