A METHOD TO REMOVE GAS HAZARD AROUND UNDERGROUND THRUST FAULTS
Kilometer Directional Feathery Drilling

by

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In this paper, we take the W2303 working face in Sihe mine, Shanxi Province, China as a project case, where it has been met with three thrust faults. The occurrence regularity of coal gas near the faults are studied, and the gas content around the faults are measured. The comprehensive measures of gas extraction are carried out, including the wear layer and in-seam kilometer directional feathery drilling combined with multi-branch technique. The gas threat around underground thrust faults is effectively eliminated. This technical engineering practice has a good guiding significance to other similar mining areas.

Key words: *kilometer directional drilling, feathery boreholes, thrust fault, gas extraction, gas hazard*

Introduction

The occurrence of coal seam gas is restricted by many factors including hydrological conditions, geological structure, burial depth of coal seam, and roof and floor lithology and so on. Among them the geological structure is one of the most critical factors leading to the increase of gas pressure or content in local zones [1]. Coal-gas outburst accidents are very likely to occur near faults during mining [2]. Engineering practices show that more than 95% of significant coal-gas outburst accidents are because of unclear geological survey and improper control measures [3, 4]. For example, 71.8% of them occurred near small faults in stone gates and coal lanes in Huainan mining area, China [5, 6].

Due to the existence of faults and other geological structures, the coal is generally soft and mylonism along with low permeability. In addition, there are developed compression-torsional fault zones on the fault planes, resulting in different structural characteristics between the two fault plates. Good permeability and low gas content are on one side of the fault, while high energy gas is stored in the coal on the other side – known as impermeable fault [7-9]. Impermeable fault is the separation zone blocking the coal gas continuity between two faults [10, 11]. It was difficult to achieve drainage balance using regional pre-drained measures between the two coal seams of impermeable fault, where gas pressure and content differences were generated in [12, 13]. It was the control of geological structure that made the distribution of

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coal-gas outburst divide into zones and sections on the plane [14]. Based on the classification of the structures, some scholars believed that large structures controlled the regional distribution of gas in the well field, while medium structures determined the distribution of gas bands, and small, and micro-structures controlled the abnormal gas in local areas such as the mining face [5, 15, 16]. Others counted the geological tectonics in most mining areas, who believed that small structures at the end of the structures were the occurrence places of most gas disasters [17]. In this paper, the impermeable fracture zone induced by compressive-torsional thrust faults in the mining of outburst face will be detected and studied. The relationship between its structural form and gas occurrence will be analyzed, and the technology of outburst elimination using directional feathery long boreholes through layers will be proposed.

Fault profile

Overview of working face

The west well of Sihe colliery was a coal-gas outburst mine with an annual production capacity of 4.0 Mt. The mainly mined seam was No. 3, with the depth of 318-494 m and the formation pressure of 7.95-12.35 MPa. The average thickness of the coal seam was 5.5 m, the dip angle was 8°, the strike length of the working face was 1257.31 m, the inclination length was 220 m, and the original gas content of the working face was 21.8 m^3/t. In the delineation process of W2303 working face, two rock roadways were excavated to assist the tunneling of coal seam. During the excavation, gas abnormal emission was obvious.

Fault detection

Using WKT-E radio wave fluoroscopy instrument, it was found that there were three large (3-5#) pit penetration anomalous areas in the middle of the workface. The fault strike distribution and fault parameters showed in fig. 1 and tab. 1, respectively. Figure 2 showed thrust fault plane. It could be seen from the figs. 1 and 2, the directions of three thrust faults are consistent. The included angle between thrust and the working face was basically consistent. The main difference is only the drop. The influence scope of NO. 1 fault was biggest, which even had a certain

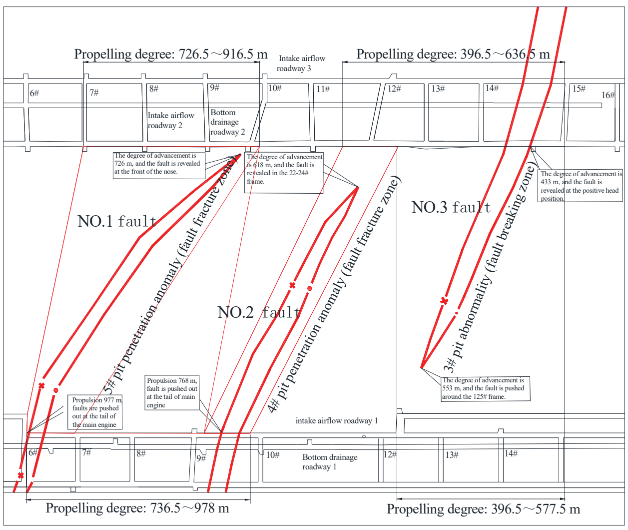

Figure 1. Diagram of abnormal penetration area

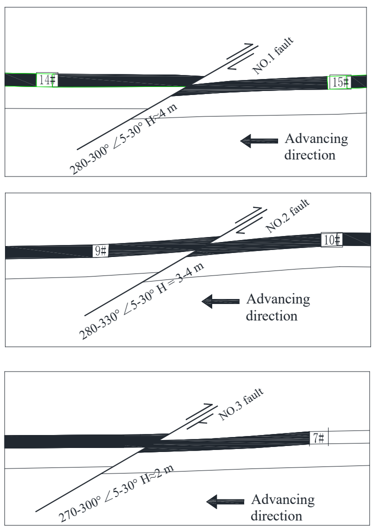

Figure 2. Thrust fault plane

Table 1. Structural parameters of fault

Fault	Tendency [°]	Trend [°]	Drop [m]	Coal thickness [m]	Influences on face/frame	Influencing advance distance [m]
NO.1	270-300	180-210	2	8	1#-Tail	251
NO.2	280-330	190-240	3-4	9-10	22-24#	170
NO.3	280-300	190-210	4	10	1-125#	120

degree of influence on the 251 m advance distance of workface. The main influence was severe coal fragmentation near fault, suddenly thickening of coal seam. There was an abnormal gas concentration area in the coal seam in the range of fault space and drop. If the effective extraction measures were not taken to reduce the coal gas content, it would bring huge safety risks to the prevention and control of coal-gas outburst during mining. The layout of measurement points (MP) and measurement results were shown in fig. 3 and tab. 2, respectively.

Distribution of coal gas content near faults

The gas content of coal near faults was larger than the normal value that did not affected by fault structure. Normal gas content was about 9.3 m^3/t, but gas content near the faults measured by 12 group were kept between 9.62 to 13.6 m^3/t. It was far more than the critical value 8.0 m^3/t of coal-gas outburst. So, it could be determined that the coal body near faults had coal-gas outburst risk. Furthermore, the content of the lower wall of the fault (MP 6) was higher than that of the upper wall (MP 7-9). The gas content at the rape end of the fault (MP 11 and 12) was higher than that of the other end of the fault. The gas content of coal among faults was higher than that of the single fault or normal coal. The gas content in the middle of

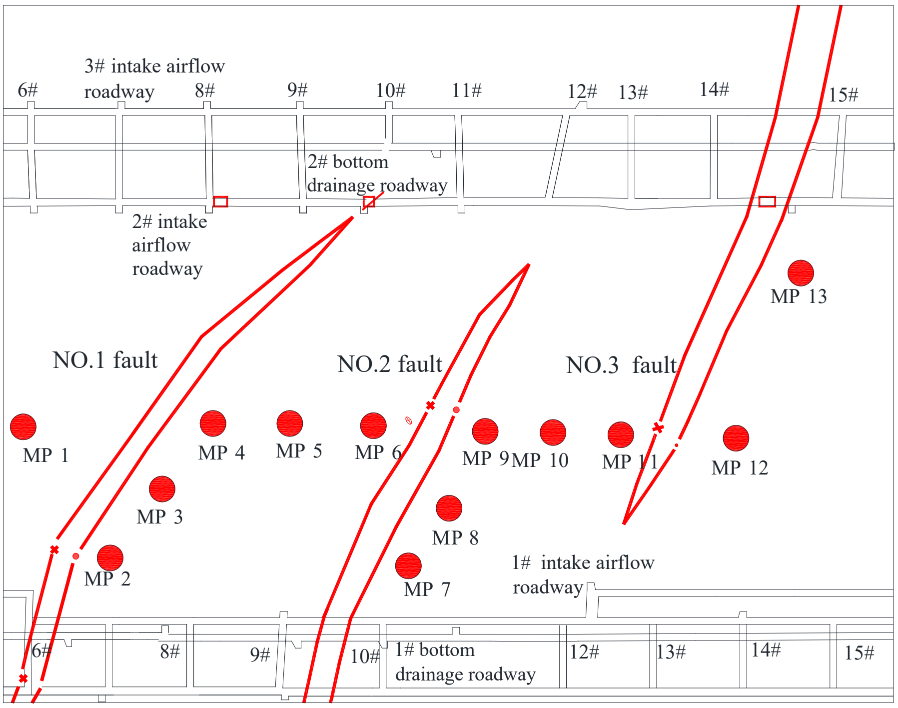

Figure 3. Distribution of MP

Table 2. Distribution of MP and measured gas content near faults

NO.	Gas content [m³/t]	NO.	Gas content [m³/t]	NO.	Gas content [m³/t]
MP 1	9.32	MP 6	10.44	MP 11	13.6
MP 2	10.16	MP 7	9.62	MP 12	9.8
MP 3	11.05	MP 8	10.11	MP 13	9.1
MP 4	11.38	MP 9	10.28		
MP 5	12.64	MP 10	13.24		

working face was generally higher than that in the side of working face along gateway. The main reasons were: due to the development of structural soft coal near the fault, the coal body was subjected to abnormal stress extrusion and rubbing; the fracture at the end of the fault was similar to the funnel-shaped gas flow channel, the gas and stress converge at the tip where the fault met the coal body, forming the phenomenon commonly known as *gas pocket,* and due to the superposition of tectonic stress, the coal between the faults formed a fault interaction area by mutual influence.

Anomaly gas area near faults relieved by kilometer directional feathery drilling

To fully cover the anomalous areas of high gas near different faults, 11 feathery long boreholes with the length of 45282 m were constructed in 1# and 2# intake roadways, and 1# drained bottom roadway. The drilling holes in 2# bottom drainage roadway were supplemented by infilling to eliminate coal-gas outburst near NO. 3 fault. A total of 752 boreholes were drilled in the area of 30 m before and after faults (a total of 90 m), with a cumulative engineering volume of 31500 m. The 11 feathery long boreholes in 2# bottom drainage roadway were constructed. To eliminate the outburst risk of NO. 1 fault, the cross-layer branches were constructed before and after the fault of 50 m. The spacing between the branches is 25-30 m. There were 11 cross-layer drilling holes constructed in 1# intake roadway, and the branche space was 30 m before and after the fault of 50 m, to strengthen the gas extraction of coal near NO. 2 fault. The 1# kilometer drilling site was constructed in 1# intake roadway to extract gas from the middle and tip of NO. 1 fault, while 2# kilometer drilling site was constructed in 1# intake roadway to extract gas from the middle and tail of NO. 1 and 2 faults simultaneously. The 4# kilometer drilling site was constructed in the 1# drained bottom roadway to extract gas from the tip of NO. 2 fault. The 5# kilometer drilling site was constructed in 2# drained bottom roadway to extract gas from NO. 2 and 3 fault tips simultaneously. Gas from the middle and tail of NO. 3 fault was extracted using 3# kilometer drilling site in 1# intake roadway. The trajectory diagram of the long feathery drilling hole through the stratum showed in fig. 4.

Result and discussion

Drainage effect of directional long borehole

Coal gas near the NO. 2 annihilate end and the NO. 3 fault was extracted through wear layer boreholes in 2# drained bottom roadway. The coal seam affected by the NO. 3 fault was basically covered through above boreholes, so the wear layer boreholes mainly dominated the coal gas near NO. 3 fault. We selected three wear layer boreholes to investigate the effect of gas extraction. The specific drilling track and fault strike plan showed in fig. 5. Figure 6 showed the evolution

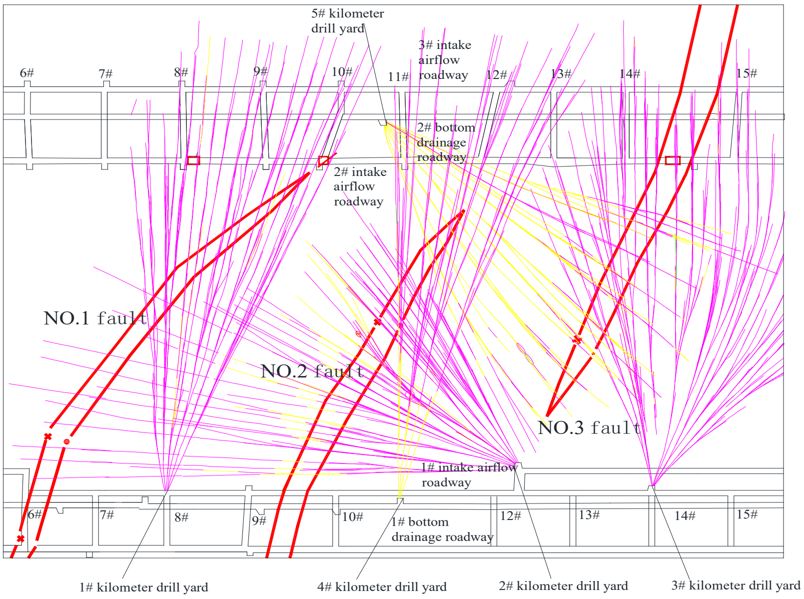

Figure 4. Trajectory of feathered long boreholes

results of extraction concentration and pure gas extraction quantity of 3-5 # directional feathery long boreholes at the 2# drained bottom roadway. After penetrating the upper and lower walls of the fault, the high-enriched gas area was organically linked together. The instantaneous emission of

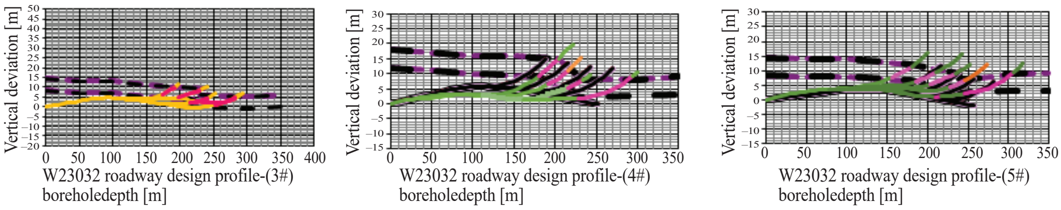

Figure 5. Trajectory of 3-5# wear layer boreholes in 2# drained bottom roadway

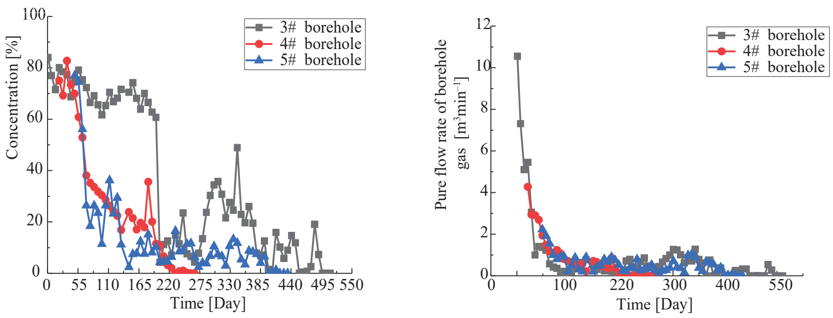

Figure 6. Extraction parameter changes in 3-5# wear layer holes in 2# drained bottom roadway

high-concentration gas can reach 85% of the maximum concentration and 10.55 m^3 per minute of the maximum gas pure quantity.

Extraction effect of kilometer directional long borehole in coal seam

The 11 kilometer directional long feathery boreholes for NO. 2 fault were constructed in 2# kilometer drilling field at 1# intake roadway. The 3 boreholes of 1-3# were selected to analyze. The trajectory and branch distribution of each borehole could be found in fig. 7. The 1-3# boreholes were constructed in the upper and lower walls of the fault with 4-5 main branches and 9-12 branch branches at the end of the hole in the fault. After drilling and during gas extraction, it could observe from fig. 8 that the evolution of gas concentration, flow and other related extraction parameters of each kilometer directional feathery long borehole in the coal seam.

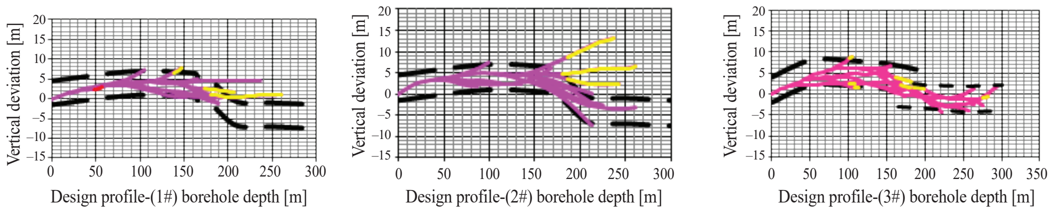

Figure 7. Trajectory of 1-3# kilometer directional feathery holes of 2# drilling field in 1# intake roadway

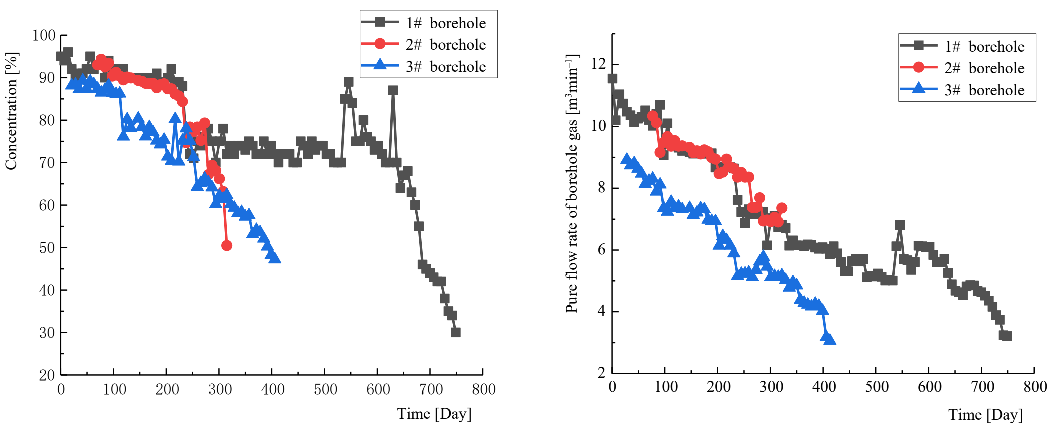

Figure 8. Extraction parameter changes in1-3# holes of 2# kilometer drilling field at 1# intake roadway

Compared with the kilometer long directional and pinnate boreholes of wear layer, the extraction concentration and quantity of NO. 2 fault using in-seam were obviously increased, the initial extraction concentration was maintained at more than 90%, and the initial gas extraction purity is generally maintained at about 10 m^3 per minute. In addition, the high concentration and high gas quantity were maintained for a longer time. The average pre-drained pure gas of a single borehole using in-seam and wear layer boreholes were 7.65 and 2.48 m^3 per minute for 20 days, respectively. Compared with wear layer boreholes, the pre-drained pure gas increment of the in-seam single borehole reached to 208%.

Evaluation of expected extraction standard in the workface

The gas content of 8 m^3/t was taken as the criterion to determine whether the mining surface met the expected standard or not. To accurately measure the gas content of the workface, three sections were divided into based on the measured gas content of 90 groups. Among them, NO. 1 fault area: Coring was carried out in the fault area of 8#-11# old lanes in the 1# intake roadway through the 1# drained bottom roadway, and 22 MP of gas content were measured. The maximum gas content was 7.0 m^3/t. NO. 2 fault area: Coring was carried out in the fault area of 8#-11# old lanes in the 1# intake roadway through the 1# drained bottom roadway, and 26 MP of gas content were measured. The maximum gas content was 7.7 m^3/t. NO. 3 fault area: Coring was carried out in the fault area of 13#-16# old lanes in 2# and 3# intake roadways through the 2# drained bottom roadway, and 17 MP of gas content were measured. The maximum gas content was 7.71m^3/t. The workface was divided into three zones: there was no faults in zone 1, zone 2 included NO. 1 and 2 faults, and NO. 3 was located in zone 3. From June 2015 to November 2017, after 29 months of pre-drainage, the gas extraction volume in the zones 1 and 2 was 37.3913 million m^3, the effective coverage area of boreholes was 85%, the residual gas content was 7.16-7.24 m^3/t, and the drainage rate was 67.02% in the workface. Because of the existence of NO. 1 and 2 faults in the zone 2, the gas reserves were larger compared with the zone 3. The total number of 100 m footage were 1389.73 m (the zone 2) and 972.24 m (the zone 3) using kilometer directional long boreholes, respectively. Under the same extraction time, the gas pre-drained volume of the zone 2 was larger and the extraction effect was more obvious. However, as far as the overall evaluation of the zones was concerned, we could judge that the effect of gas drainage in the zones 2 and 3 is up to the expected standard.

Determination of gas content during mining

In order to further confirm the mining safety of face, according to the relevant provisions of *the Regulations on Preventing and Controlling Coal and Gas Outbursts*, the effect of eliminating coal-gas outburst near faults was finally verified by the method of local prediction. When the distance from faults was 15-20 m, borehole sampling was carried out by short boreholes near the upper and lower walls of three faults along the mining direction. A total of 24 groups of gas content were measured near three faults by borehole sampling. The comparison results of gas content before and after extraction near faults showed in fig. 9. It could be seen that before extraction, the gas content of coal near faults varied greatly because of the existence of gas barrier zones in thrust faults. Gas content in some locations could reach to 13.6 m^3/t. After extraction by feathery directional long boreholes, the cracks between the upper and lower walls of faults run through, and the gas content of coal basically remained between 5.5-7.0 m^3/t. It also proves that the kilometer directional long borehole has a good effect on gas hazard relief for thrust faults.

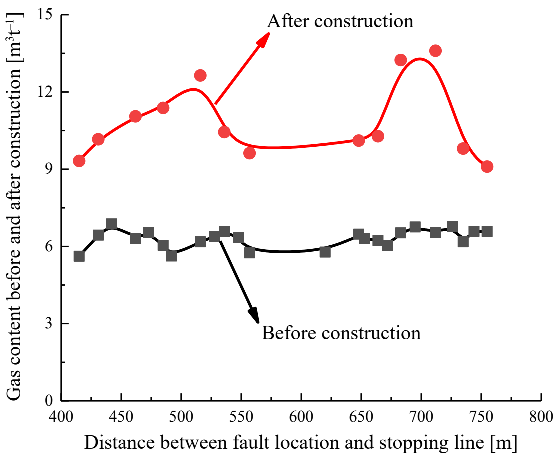

Figure 9. Comparison results of gas content before and after extraction near faults

Conclusion

In the present work, we take the W2303 working face in Sihe mine, Shanxi Province, China as a project case, where it has been met with three thrust faults. The feathery directional long borehole can cover the target area in a wide range, which can not only save the amount of borehole engineering, improve the gas extraction effect, but also eliminate the outburst danger of coal in a short time. It would provide theoretical and practical guidance for gas outburst elimination in other similar mines.

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