Experimental research on methane control of mining upper protective layers

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Abstract: In order to solve coal and gas outbursts during mining coal seam, studying on related problems were carried out. According to the theories of mining upper protective layer, proper mining plan were designed and performed through field experiment. By means of examining several parameters obtained from the field experiment, the protective effects were evaluated and the protective scope and related parameters were determined. The results of field experiment show that the danger of outbursts was evidently eliminated and the method of mining protective layers is effective and the safety and economic benefits are remarkable. The research has really applied worth and will give beneficial references to mining area with analogous conditions.

Key words: methane control; protective layer; coal and gas outburst; field experiment

1 Introduction

With the increase of mining and exploiting depths and mining scope, the safety problems in mining become more and more serious, especially in mining the coal seam with high gas content and low permeability, the coal and gas outbursts badly threaten the safety of regular production and restrict the survivorship and development of the mines. How to safely, economically and effectively prevent the outbursts from happening was studied by predecessors, and many countermeasures were developed[1], which contributed much for the relief of coal and gas outbursts.

Hitherto, mining protective layers is the most effective and economic means to prevent coal and methane outbursts. At home and abroad, when the coal seams which are prone to outburst were to be mined, the method of mining protective layers was adopted as long as the geological conditions are permitted[1]. At home, *The Safety Regulations of Mines* reads: when the coal seams which are prone to outburst are to be mined, the method of mining protective layers must be considered firstly. After the protective layers are mined, the protected zones in the protected seams can be excavated regularly, but the countermeasures against outburst must be taken before mining in the non-protected zones.

The experimental mine is a coal mine which has recoverable coal bed group. It has 5 recoverable coal seam in group B, i.e. the seams B_8, B_7, B_6, B_5 and B_4, in which seam B_4 is prone to outburst. In order to effectively prevent coal and methane outburst and comprehensively control the problem, a joint exploitation mode was arranged and the method of mining protective layer was adopted in the group B. Because the geological conditions of the mine are very complicated, different mining schemes are studied and applied in different zones of seam B_4.

The interlamellar spacing between seam B_5 and B_4 is only 8 m and even is zero in some zones. The interlamellar spacing between seams B_7 and B_4 is about 50 m and between seams B_6 and B_4 is about 40.42 m. According to *The Detailed Rules of Coal and Gas Outbursts Prevention* (shorten as *The Rules*), seam B_6 as the protective layer of seam B_4 is feasible. By taking into account all conditions, in order to excavate seam B_4 as early as possible, the measures adopted are as follows: reliable detections must be used before mining seam B_4 and methane of seam B_4 must be drained at the same time of mining the upper protective seam, i.e. seam B_6.

2 General conditions of the test district

The test zone, mining district B, which was 780 m along strike and 620 m along slope, its mining depth is $-330 \sim -530$ m. The recoverable seams of the mining district are B_8, B_6, B_5 and B_4, and its absolute volume of methane emission is 110.34 m^3/min and the relative is 32.11 m^3/t, the average slope angle is about 12° and Protodyakonov coefficient is $f = 0.8$.

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At present, seam B_8 was mined over −530 m, and others seams are not mined. Seam B_4 is prone to outburst and others are not.

3 Gas emission forecast and management scheme

3.1 Gas emission forecast

Because mining seam B_8 affected the lower adjacent seams inconsiderably, the effects were not taken into account in gas emission forecast. According to the geological materials of the mine and the corresponding predicted theories[1-4], the total amount of gas emission of the working face 12116 (the working face of seam B_6 in the mining district B) is 17.21 m^3/min, the gas emission amount of seam B_6 itself is only 27.3 % of the total amount, the amounts from seam B_4, B_5 and B_7 account for 44.2 %, 16.4 % and 12.1 % respectively, as shown in Table 1. Obviously, the gas management of seam B_6 itself and seam B_4 is the key of the scheme. Therefore, the drainage method of the stress-relief was adopted to drain the methane with long boreholes in the roof strata of seam B_6, the drainage method with cross-layered boreholes from the floor strata of seam B_4 was adopted to drain the methane of seam B_4.

Table 1 Forecast of methane flux of adjacent seams in mining upper protective layer

Coal seam	Seam thickness/m	Original methane content/($m^3 \cdot t^{-1}$)	Distance from B_6/m	Release coefficient	Methane flow amount /($m^3 \cdot min^{-1}$)	Ratio /%
B_7	2.55	5.0	11.50	0.90	2.09	12.1
B_6	2.20	6.5	Exploiting seam		2.83	27.3
B_{5-2}	0.98	6.5	22.38	0.86	1.34	7.8
B_{5-1}	1.10	6.5	26.86	0.84	1.47	8.6
B_{4-2}	0.96	8.0	40.42	0.82	1.79	10.4
B_{4-1}	3.2	8.0	43.12	0.80	5.82	33.8
Total					17.21	100.0

3.2 Solving methane flow by ventilation

As mentioned above, the predicted total amount of gas emission of working face 12116 is 17.21 m^3/min. The calculated methane amount by corresponding theory[1-4], which can be diluted effectively by ventilation, is 5.6 m^3/min and the remainder, i.e. 11.61 m^3/min, should be drained by combined drainage means. In addition, the predicted total amount of gas emission of the digging face of seam B_6 is only 2.0 m^3/min, so it can be diluted by ventilation according to *The Rules*.

3.3 The scheme of gas management

The return and inlet airways of working face 12116 are about 788 m and 760 m, respectively. The length of working face 12116 along slope is 153 m. The research scheme was designed according to *The Rules* and some references[2-4], the effective protective angles of raise and diphead after stress being relived are all seen as 75° and the effective protective angle along strike is seen as 56°. Because the interlamellar space between seams B_6 and B_4 is about 40.42 m, hence, in the research scheme designed, the horizontal distance of the return airways of working faces 12116 and 12114 is 2.2 m, the horizontal distance of the inlet airways of the two faces is 19 m and the horizontal distance of the beginning or terminal lines of them is 27.3 m.

3.3.1 The gas management of coal seam B_4

According to the predicted results, the gas management of seam B_6 itself and seam B_4, especially the latter, is the key of the scheme. In order to drain the gas of seam B_4 and test conveniently, a drainage roadway was excavated along strike in the sandstone of the floor of seam B_4, and its place is in the middle of the horizontal projection of working face 12114 designed. The vertical distance from the roadway to the floor of seam B_4 is 28 m and its designed length is 773 m.

In the drainage roadway, from the position under the beginning line of designed working face 12114, a drill site was constructed per 30 m from east to west, which called drill sites 1 ~ 24. The upward and cross-layered boreholes, which arranged fanwise were drilled to drain gas of seam B_4. In each drill site there are 5 boreholes, i.e. boreholes 1 ~ 5, which arranged fanwise, as shown in Fig. 1. The ends of them are in the seam B_4 and all the end spacing of adjacent boreholes along slope is 30 m, the distance between borehole 1 and the inlet airway (or between borehole 5 and return airway) is 7.8 m along slope.

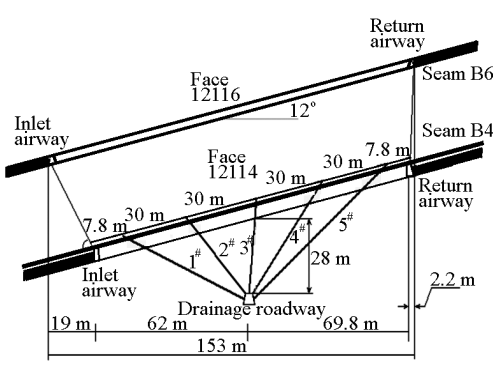

Fig. 1 Schematic of drainage boreholes in mining upper protective layers

3.3.2 The gas management of coal seam B_6

According to Professor Qian, in the direction of advancing, the affected rock by mining is composed of

three zones, i. e. the supporting and affected zones of coal rib, the zones of abscission layers and the zones of re-compaction[2]. In the upper side of gob, the overlying affected strata by mining is divided into three zones, i. e. caving zone, fractured zone and sagging zone.

Considering the viewpoint of methane flow, the methane of caving zone mixes with the gases of gob, so the methane is not applicable to drainage for its low concentration. The sagging zone is far away from gob, the entirety of the strata in the zone is not damaged and there is no fracture connecting with gob, so the gas of this zone cannot flow into the mining coal seam. The strata in fractured zone are layered and ruptured, so the gas of the zone can flow into the mining coal seam and can be drained effectively, that is to say, the ends of the long boreholes should be in the positions between the upper of caving zone and the lower of fractured zone[3,4].

According to the results of model simulation, theoretical calculation of parameters and field testing, as for the coal seam whose angle is 0° ~ 20°, if the vertical distance between the ends of long boreholes and the mining coal seam is proper, the horizontal distance between the long boreholes and the return airway is 0 ~ 25 m, the drainage effects in the upper of gob and the working face will be satisfactory[5,6].

According to the geological conditions of the mine, the theory of key strata and the analysis mentioned above, the ends of long boreholes in the roof of working face 12116, which drilled to drain the gas of the gob, are arranged 10 ~ 15 m above the roof of seam B_6. The horizontal distances between the ends of them and the return airway of working face 12116 are 10 ~ 25 m. There were 12 drill sites, which arranged in the roof of the return airway of working face 12116, the space between two adjacent drill sites was 60 m and there were 5 boreholes in each drill site. The distance between the former dill site and the ends of the boreholes of the latter drill site was not less than 20 m, as shown in Fig. 2.

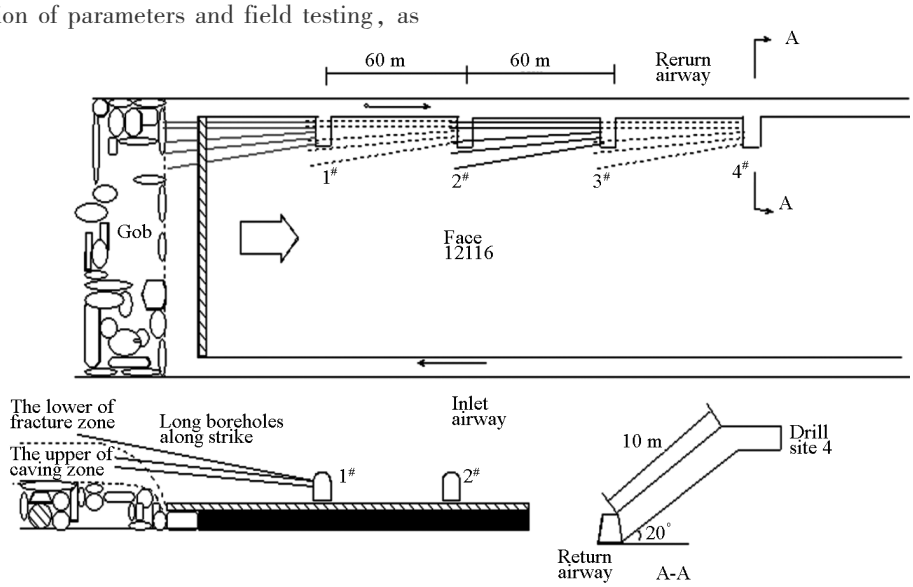

Fig. 2 Schematic of drainage boreholes along strike in roof of working face 12116

4 Test of protective zones

The studying key of the technique of mining protective layers and protective effects is how to ascertain the scope of protected zone. In order to ascertain the scope of protected zone, the gas pressure, gas release volume, seam deformation and their changes of the protected seam (B_4) must be measured during mining the protective seam (B_6), and then analyze comprehensively the change laws of the parameters mentioned above during mining the working face of the protective seam. According to the laws, the effective protected scope and angles after stress being relived along strike and slope can be obtained easily.

4.1 Experimental test along strike

In order to ascertain the protected scope in seam B_4 as soon as possible, some measured boreholes were drilled in the drainage roadway in the floor of seam B_4. Measured boreholes in drill site 5 (firstly in drill site 1) were planned to measure the gas pressure of seam B_4, measured boreholes in drill site 2 were planned to measure the release flux of methane from boreholes of seam B_4 and measured boreholes in drill site 3 were planned to measure the deformation of seam B_4, as shown in Fig. 3, all the measured boreholes were drilled at an obliquity angle of 60° and an azimuth angle of 47° .

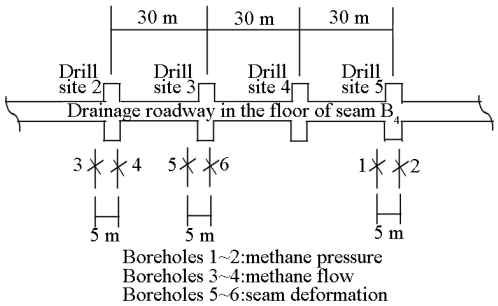

Fig. 3 Schematic of measuring boreholes along strike

4.2 Experimental test along slope

After taking into account all conditions, the measured drill sites along slope should be in the steady zone of the drainage roadway. According to the geological conditions of the mining district B, in the drill site 15, a measured roadway was excavated parallel to coal seam. There were 10 measured boreholes to test the protected scope along slope. The parallel boreholes 7 ~ 10 were drilled in the upper of the measured roadway, the end of borehole 9 was in the return airway of the designed working face 12114, the ends of borehole 7 and borehole 8 were inside the working face and the end of borehole 10 was outside it, the horizontal spacing of adjacent boreholes is 5 m. The parallel boreholes 1 ~ 6 were drilled in the lower of the roadway, the end of borehole 4 was in the inlet airway of working face 12114, the ends of boreholes 5 and 6 were inside the face and the ends of boreholes 1 ~ 3 were outside it, the horizontal spacing of adjacent boreholes is 7 m, as shown in Fig. 4.

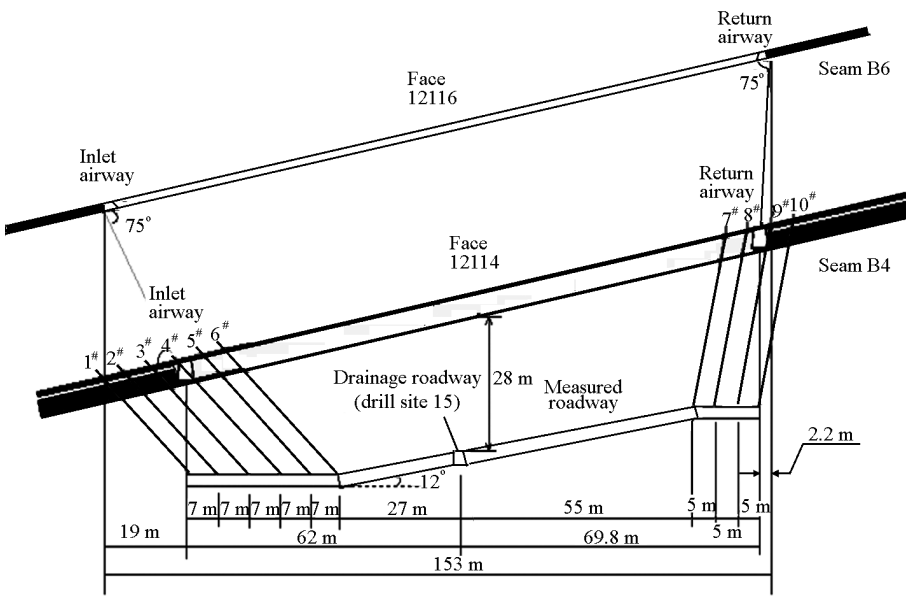

Fig. 4 Schematic of measuring boreholes along slope

5 Analysis of measured results

5.1 Protected effectiveness of coal seam B_4 along strike during mining coal seam B_6

The gas pressure of seam B_4 was measured three times during the test, but the results were unsatisfactory. In the first time, the measuring failed because the measuring range of the pressure gauge was too small, so the gas spouted from the sealed boreholes. In the second time, the pressure gauge reads 3.2 MPa but the gas spouted after one day. In the third time, the measuring failed again and the gas pressure was not measured ultimately.

The coefficient of gas permeability could be calculated by the radial non-stable method, which requires the parameters of gas pressure, gas release volume, seam deformation. Because the gas pressure was not measured, the coefficient of gas permeability cannot be calculated accordingly.

The horizontal distance between the beginning line of working face 12116 and the drill site 2, which was to measure the release flux of methane, is 57.3 m. The distance between the beginning line of working face 12116 and the drill site 3, which was to measure the deformation of coal seam, is 87.3 m. As shown in Fig. 5, when the distance between working face 12116 and the drill site 2 is 12 m, the release flux of methane began to increase obviously, when the distance is 27 m, the release flux of methane increased sharply till the maximum, i. e. 29 m^3/min, which is 4 times of the original value. As shown in Fig. 6, when working

face 12116 exceeded the drill site 3, the deformation of seam B_4 begin to increase obviously, when the distance between working face 12116 and the drill site 3 is about 30 m, the deformation increases to the maximum, i.e. 112 mm. That is to say, the maximal deformation of seam B_4 was 27×10^{-3}, the deformation remained about 20×10^{-3} after the methane pressure of seam B_4 was relieved, which greatly exceeds the set 0.6 % by *The Rules*. These show that protective effects of mining seam B_6 on seam B_4 is obvious. For the sake of production safety, the horizontal distance between working face 12116 and the digging face of 12114 was ascertained as 30 m according to the analyses above. That is to say, the horizontal distance of the beginning or terminal lines of working face 12116 and working face 12114 is 30 m, so the effective protected angles of seam B_4 along strike is 56° (the same as the designed value) according to the interlamellar spacing between seams B_6 and B_4, 40.42 m.

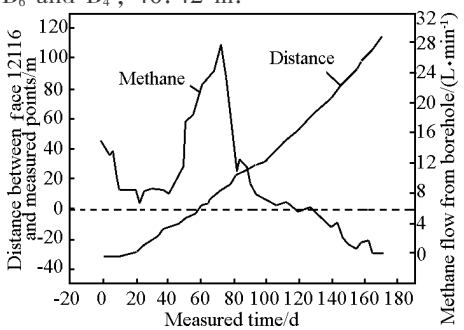

Fig. 5 Curve of methane flow of seam B_4 during mining working face 12116

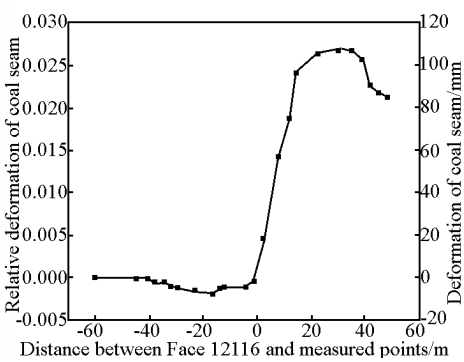

Fig. 6 Deformation of coal seam B_4 during mining working face 12116

5.2 Protected effectiveness of coal seam B_4 along slope during mining coal seam B_6

Because some testing instruments were invalidate in the course of measuring, only the gas pressure of seam B_4 was measured by the measuring boreholes along slope. As shown in Fig. 7, in the lower of the measured roadway, the gas pressures of boreholes 3 ~ 6 were obvious during mining working face 12116, but the gas pressures of boreholes 1 and 2 do not drop obviously. Hence, it can draw a conclusion that the place of the boreholes 3 ~ 6 in seam B_4 are protected effectively and the place of the boreholes 1 and 2 are not protected. In the same way, in the upper of the roadway, the place of the boreholes 7 ~ 9 are protected effectively and the place of the borehole 10 is not protected, as shown in Fig. 7. Obviously, the border of protected zone of seam B_4 is between borehole 3 and borehole 9. Compared with the designed scheme, the protected zone in the lower along slope increase by 7 m and the protected zone in the upper does not change. Hence, according to the interlamellar spacing between seams B_4 and B_6 and the seam angle, 12°, the protected angle of seam B_6 is determined to be 85° downward and 75° upward along slope after seam B_6 being mined. That is to say, the horizontal distance of the return airways and inlet airways of working face 12116 and working face 12114 are 2.2 m and 19 m, respectively.

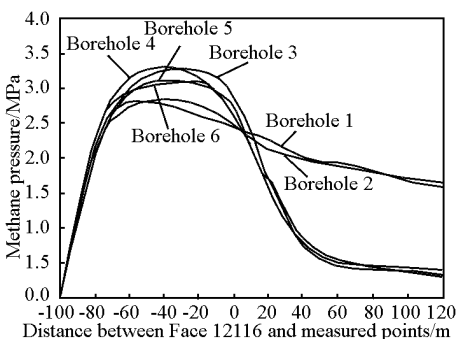

Fig. 7 Curve of methane pressure of boreholes in the lower part along slope

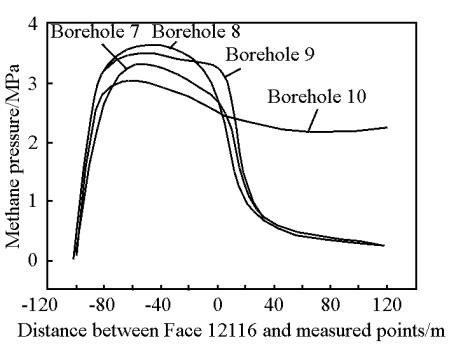

Fig. 8 Curve of methane pressure of boreholes in the upper part along slope

6 The digging and mining conditions of working face 12114 during mining protective layers

The outburst feasibility of digging face of seam B_4 was measured by following parameters: drill cuttings, methane desorption indexes of drill cuttings and the methane flow from boreholes, etc. According to *The Rules* the critical values of drill cuttings, methane flow from boreholes and methane desorption indexes of drill cuttings are 6.0 kg/m, 4 L/min and 0.8 ($m \cdot g^{-1} min^{-0.5}$), respectively.

According to applied results in job sites, there is not only no coal and methane outburst but also no omens of outburst during digging and mining in the protected zone of seam B_4, the measured parameters are in the limits, drill cuttings are all under 4 kg/m, methane desorption indexes of drill cuttings are all under 0.38 ($mL \cdot g^{-1} min^{-0.5}$), whereas outside protected zones, the measured parameters exceeds the limits three times during digging in seam B_4, the maximum of drill cuttings is 6.6 kg/m and the maximum of methane desorption indexes of drill cuttings is 0.56 ($mL \cdot g^{-1} min^{-0.5}$).

Outside protected zones of seam B_4, the digging velocity of coal roadway is only 30 m per month and the mining velocity is 45 m per month; however, the digging and the mining velocities are 90 m per month and 60 m per month in the protected zones, the two velocities are increased by 200 % and 33.3 %, respectively. In protected zones, the drainage amounts of methane from cross-layered boreholes in the floor of seam B_4 are increased by 4 times. So the economic and social performance is significant by means of mining upper protective layers.

7 Conclusions

1) The method of mining protective layers is effective. According to the theories of this method, in the same group, coal seam B_6 was exploited firstly which does not erupt methane, and then seam B_4 which is prone to outburst was exploited in sequence. The protected zones of seam B_4 were determined and the outburst risk in protected zones was eliminated. The safety and economic benefits are remarkable.

2) The research shows: in the course of mining working face 12116, the release flux of methane in seam B_4 where are 27 m behind working face 12116, increases to 29 m^3/min which is 4 times of the original value and the deformation of seam B_4 where is 30 m behind working face 12116 increases to the maximum (112 mm), the maximal deformation is 2.7 % and it remains about 2.0 % after the pressure of seam B_4 was relieved, which greatly exceeds the set 0.6 %.

3) After mining the upper protective layer, coal seam B_6, its protective effects on seam B_4 is remarkable. In the protected zones, the digging and the mining velocities are 90 m and 60 m which increased by 200 % and 33.3 %, respectively. The flux amount of methane from boreholes increases by 4 times after gas pressure was relieved, the outburst risk of seam B_4 in the protected zone was eliminated.

4) Obvious economic benefits are gained because of the success of this research. With the study results, the fully mechanized top-coal caving, which is the mining method of high-yield and high-efficiency, can be applied in medium and thick coal seams which are prone to outburst. It will give beneficial references to other mines with analogous conditions for controlling the outbursts.

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