TECHNICAL METHODS OF SAFE HIGH-EFFICIENT EXPLOITATION OF COAL AND GAS TOGETHER IN HIGH-GAS COAL SEAMS IN CHINA

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ABSTRACT

There are many coal seams in high-gas mining area of China. The permeability is low. The gas extraction from the original coal seam is difficult and the commercial value is little. The conception of the safe high-efficient exploitation of coal and gas is put forward in this article. It changes the conventional exploitation sequence that is from the upper to below. When we exploit coal seams, the initial coal seam with low gas content and without coal and gas outburst danger is exploited firstly. Then the permeability of the coal seams increases greatly making use of the exploiting effect. The gas effusion can be divided into short-distance gas emission, intermediate-distance gas emission and long-distance gas emission according to the difference of the comparative interval. The high-efficient gas extraction method is adopted to realize the high-efficient extraction of the gas resource. The high-efficient extraction of the gas resource affords advantageous condition to the safe high-efficient exploitation of the coal resource. Consequently the safe high-efficient exploitation of the coal and gas resources can be realized. The practice of the long-distance gas extraction and the safe high-efficient exploitation of coal and gas in the mining area of Huainan China proves that the safe high-efficient exploitation of coal and gas is the important technical method of the safe high-efficient exploitation of coal and gas together in high-gas coal seams.

KEYWORDS

high-gas; coal seams; safe high-efficient exploitation of coal and gas; low permeability

Coal is a major energy resource in China and represents seventy-four percent of China’s energy production and consumption. Typically, coal supplies seventy-eight percent of electricity production, seventy percent of chemical manufacture and sixty percent of urban heating and cooking in China[1]. Gas released from coal seams is potentially dangerous during coal mining, not only due to the explosive risk but also the risk of coal and gas outburst. There are many serious gas accidents resulting in numerous casualties every year in China. Fifty percent of national shafts have high gas content and coal and gas outburst danger. In process of mining, it not only wastes the energy resources but also pollutes the environment seriously when the gas is released directly to the air because the methane has serious greenhouse effect. The greenhouse effect of methane is above 20 times more than that of CO_2 and its destroying force to the ozone layer of the earth is as seven times as that of CO_2. At the same time the gas in coal seams is also a kind of clean energy resource, it can be used for urban heating and cooking, generating electricity, industrial material and so on. In China the gas in coal seams is abundant. The reserves of the gas in coal seams of which depth of burial is less than 2000 meters is

(32~ 35) × 10^{12} m^3,almost equaling to the reserves of the rock gas[2,3].
In China, most coal seams in high-gas draft have low permeability. The permeability parameters of most coal seams are only 10^{-3}~ 10 $m^2/(MPa^2.d)$. For example, the permeability of C13 coal seams in Huainan is only 0.011 $m^2/(MPa^2.d)$, the permeability of No3 coal seams in Beitouzuijing Yangquan is only 0.016 $m^2/(MPa^2.d)$ [4,5]. The experiments of gas extraction and compression fracture which increase the coal seams permeability and the gas exploitation in original coal seams indicate that the results of gas extraction is bad[2,5]. Currently, about 200 surface wells have been drilled by using of the ripe gas extraction technical methods of America in China. The TL-007 well of Qinshui basin is most distinguished, but the steady production of each well in short time is only 0.3 × 10^4 m^3/d after it was compressed to fracture. It is less than that(2 × 10^4 m^3/d) of the San Juan basin in America. So the commercial value is little[6,7].
The author brings forward a new technical method of realizing the safe high-efficient exploitation of coal and gas together in high-gas coal seams(the theoretical system of safe high-efficient exploitation of coal and gas together in high-gas coal seams) [8]. It proves that this theoretical system is feasible and can realize the safe high-efficient exploitation of coal and gas together by using it in the mining area of Huainan China[9].
We define three new terms which will be used in this article in order to narrate the question clearly and conveniently.
Initial coal seam: on the condition that we exploit the coal seams, we exploit the coal seam with low gas content, without outburst danger (or with little outburst danger) firstly. This coal seam is defined as initial coal seam.
Pressure relief coal seams: the pressure on the coal seams which are above or below the initial coal seam is relieved making use of the exploiting effect. These coal seams are defined as pressure relief coal seams.
Comparative interval: in order to describe the pressure relief degree, we define the ratio of the average distance of the pressure relief coal seams and the initial coal seam as comparative interval. Its unit is times which is denoted by B.

1. THE BASIC IDEA OF THE SAFE HIGH-EFFICIENT EXPLOITATION OF COAL AND GAS TOGETHER IN HIGH-GAS COAL SEAMS

For high-gas coal seams the necessary condition is the safe high-efficient gas extraction if we want to realize the safe high-efficient exploitation of coal. Thus we must make these goals come true: ? we must eliminate the outburst danger of coal and gas in order to adopt the high-efficient exploitation methods of coal; ? we must reduce the quantity of the gas effusing in process of the exploitation of coal in order to make the gas concentration of the returning air not exceed that of « safety regulation of coal mine» . The technical method of realizing these goals is to extract some gas from coal seams and to reduce the gas content of coal seams radically.
The stress distribution of the rock and coal seams above the exploited coal seams not only depends on the exploitation condition (such as the depth of the exploitation, the inclination length of the working face, stoping velocity, physical and mechanical property of the rock seams above the exploited coal seams and so on) but also depends on the key seam which controls the distortion and destruction of the wall rock[10,11].

While exploiting coal seams, the coal seam with low gas content and without (or with little) coal and gas outburst danger was exploited firstly. Then the pressure on the coal seams which are above or below the initial coal seam was relieved making use of the exploiting effect. The distortion and rupture of the coal and rock seams and the crannies will increase the permeability of the coal and rock greatly. So the domino effect of pressure relief, permeability increasing and flowage ability increasing comes into being and the active condition of desorption-diffusion-infiltration flow is formed. The desorption and flowage condition is different because the distribution of crannies is different in different areas. So the high-efficient exploitation of gas can be realized if we adopt reasonable and high-efficient method and system of gas extraction. The extraction of gas reduces the gas content of pressure relief coal seams, eliminates the coal and gas outburst danger of pressure relief coal seams and reduces the quantity of gas effusing to the working face air. Consequently the necessary condition of the safe high-efficient exploitation of coal is created. Fig.1 shows the safe and high-efficient exploitation system of coal and gas in high-gas coal seams.

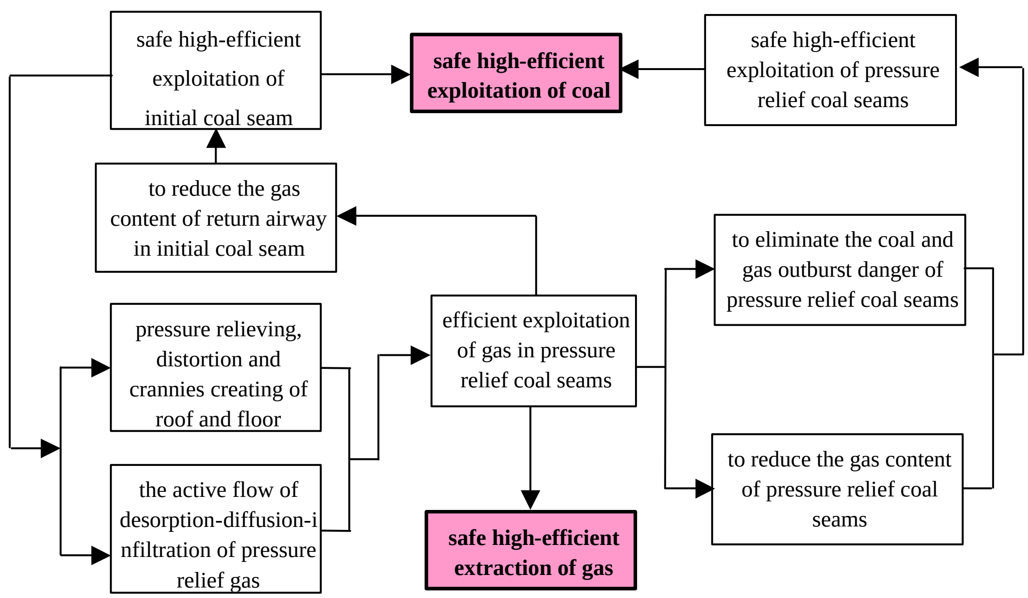


Fig.1 Safe High-efficient Exploitation System of Coal and Gas in High-Gas Coal Seams

2. ENGINEERING METHODS OF SAFE HIGH-EFFICIENT EXPLOITATION OF COAL AND GAS

This article uses the comparative interval to describe pressure relief degree of the pressure relief coal seams. The coal seams are low-angle dip in the mining area of Yangquan. The comparative interval of 6~ 8 B is the upper limit height of the caving zone and 10~ 30 B is the upper limit height of the fractured zone[7]. The average mining height of B11 coal seam is 2 meters in the mining area of Huainan. The comparative interval of 4~ 6 B is the upper limit height of the caving zone and 15~ 20 B is the upper limit height of the fractured zone. For example, in the drafts of Yangquan the average mining height of No 15 coal seam is 6 meters. The No 10 coal seam 50~70 meters away from the top of No 15 coal seam (the comparative interval is 8~12 B) is in the fractured zone[10]. But in the mining area of Huainan the average mining height of the B11 coal seam is 2 meters. The C13 coal seam about 70 meters away from the top of the B11 coal seam (the comparative interval is 35 B) is in the sagging zone. The pressure relief degree of the coal seams and the movement condition of the gas differs greatly because of the different comparative intervals after the initial coal seam is exploited. The gas effusion of the gob behind the working face can be divided into short-distance gas emission, intermediate-distance gas emission and long-distance gas emission. The gas of short-distance gas emission is most from the non-exploited separated layers of the initial coal seam, the lost coal in the gob, the coal seams in the caving zone, the lower coal seams of which floor heave greatly and some of the coal seams that are in the fractured zone. The gas of intermediate-distance gas emission is most from the fractured zone and some of the coal seams in the sagging zone. The gas of long-distance gas emission is most from the sagging zone.

2.1 EXTRACTION METHODS OF SHORT-DISTANCE GAS

The successful extraction methods of short-distance gas are the method of the strike boreholes in roof through coal and rock seams and the method of strike gas extraction drift in roof. The normal distance from the end of the strike boreholes in roof through coal and rock seams to the roof of the coal seam was not more than twenty meters in the mining area of Huainan. Five or six boreholes were constructed in every drill site. The length of the boreholes is 100~ 150 meters. The strike horizontal overlapping distance of boreholes in adjacent drill site was 30~40 meters. The horizontal distance from the acclivitous controlling area of the borehole to the upper air way was twenty meters. The best place of gas extraction was 6~13 meters above the roof of the coal seam. This method played an important role in controlling the short-distance gas emission in different working face of Huainan mining area. The gas flux of single extraction borehole was 1~ 2 m^3/min. The method of strike gas extraction drift in roof in Huainan mining area was that we tunneled a horizontal rock roadway of which cross-section was 3~ 4 m^2. The roadway was twenty meters away from the upper wind roadway and 10~14 meters at normal direction away from the roof of the coal seam. We extracted the gas in the caving arch which was above the gob making use of the roadway[12~ 14].

2.2 EXTRACTION METHODS OF INTERMIDIATE-DISTANCE GAS

The successful method of intermediate-distance gas extraction is the method of the strike gas drainage drift in roof in Yangquan mining area. The No.15 coal seam was exploited in Yangquan mining area. Its average exploitation height was 6.0 meters. A horizontal rock roadway was tunneled along the strike of the rock seam to drain the intermediate-distance gas. The cross-section area of the roadway was 4 m^2. The rock roadway was in the No.9 coal seam and about 60 meters away from the roof of the No.15 coal seam. The horizontal distance from the rock roadway to the air return roadway was 50 meters corresponding to the one third of the dip length of the working face. The statistics and the analysis of the intermediate-distance gas drainage of ten working faces indicated that the average gas flux was 17.1~ 60.6 m^3/min and the gas concentration was 60~ 80%[15]. We can adopt the method of shaft sinking from the ground to extract the intermediate-distance gas in principle. Gas extraction experiment was done in No.8103 and No.8104 working face of Yangquan mining area adopting the method of shaft sinking from the ground. We got some experience from it[5].

2.3 EXTRACTION METHODS OF LONG-DISTANCE GAS

Most of the long-distance gas comes from the coal seams in sagging zone. Pressure relief gas has the better condition of flowing in the open crannies along the rock and coal seams and less has the condition of flowing in the crannies through the rock and coal seams because most of the crannies in the sagging zone are open crannies along the rock and coal seams and few of the crannies are through the rock and coal seams. Little of the long-distance gas will effuse into the intermediate-distance area. So it has little effect on the safety of the initial seam. The pressure relief coal seam in the long-distance area upper the initial coal seam maybe the main exploited coal seam of the mine under the condition of safe exploitation of coal and gas together in high-gas coal seams. It is necessary for us to adopt an effective gas extraction method in order to make the main exploited coal seam have the safe and efficient exploitation condition.

At present, the successful method of long-distance gas extraction is the method of the gridding boreholes through coal and rock seams in the roadway below the floor of the pressure relief coal seams in Huainan mining area. This method will be narrated particularly in the section of the engineering practice of Huainan mining area.

The distribution characteristic of the rock stratum crannies was studied by experiments in the literature [16]. The shape of the crannies distribution like a “o” circle. The research results were applied to extract the long and intermediate-distance gas successfully by the method of shaft sinking from the ground. The gas extraction effect was very good[17].

3. ENGINEERING PRACTICE OF HUAINAN MINING AREA IN CHINA

3.1 GENERAL SITUATION OF THE EXPERIMENTAL ZONE

The experimental zone was in Dongyi and Donger mining section. The initial coal seam was B11 coal seam and the district was 2352(1) working face. The strike and dip length of the working face was 1640 and 190 meters separately. The thickness of the coal seam was 1.5~2.4 meters and the average thickness was 2 meters. The slope angle of the coal seam was 6~ 13 ° and the average angle was 9 ° . The gas content of B11 coal seam was 4~ 7.5 m^3/t, so it had no coal and gas outburst danger. The thickness of the B11 coal seam was even and the geological structure was simple. The intending yield from the working face was 2,000 tons everyday when adopting mechanized exploitation. The pressure relief coal seam was C13 coal seam and the district was 2121(3)/ 2322(3) working face. It was about 70 meters away from the roof of the B11 coal seam and the comparative interval was 35B. The strike and dip length of the working face was 1680 and 160 meters separately. The thickness of the coal seam was 5.57~6.25 meters and the average thickness was 6 meters. The slope angle of the coal seam was 6~ 13 ° and the average angle was 9 ° . The measured gas pressure of the C13 coal seam in this district was 4.4 MPa, the gas content was 13.0 m^3/t and the initial permeability coefficient was 0.011 $m^2/(MPa^2.d)$. Many coal and gas outburst and gas explosion accidents happened in the C13 coal seam. The thickness of the C13 coal seam was even and the geological structure was simple. After we adopted the methods to relieve pressure and eliminate the coal and gas outburst danger. The intending yield from the working face was 5,000 tons everyday when adopting integrated caving mechanized exploitation. Tab.1 shows the brief condition of coal seams in experimental zone.

Tab.1 Brief Condition of Coal Seams in Experimental Zone

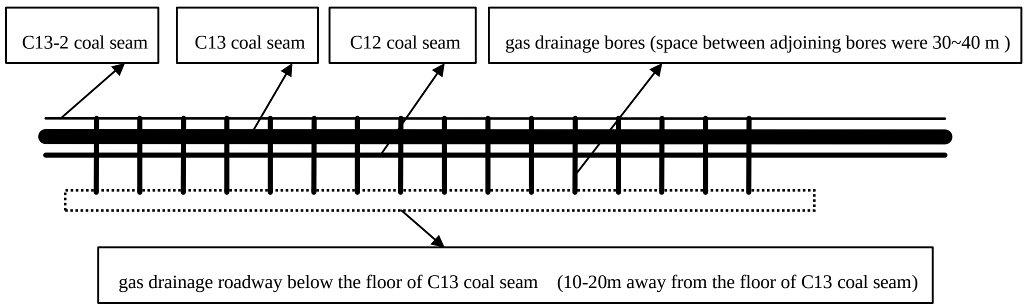
coal seam	thickness of coal seam/m	interval of coal seam /m	comparative interval of coal seam /B	gas content/m^3/t	horizon relation of the pressure relief coal seams
C13-2	0.9	77	38.5	13.0	long-distance pressure relief coal seam
C13	**6.0**	**70**	**35**	**13.0**	**long-distance pressure relief coal seam**
C12	0.8	66	33	13.0	long-distance pressure relief coal seam
B11-2	0.4	2	1	5.5	short-distance pressure relief coal seam
B11	**2**	**0**	**0**	**5.5**	**Initial coal seam**

3.2 TECHNICAL PROJECT OF SAFE HIGH-EFFICIENT EXPLOITATION OF COAL AND GAS

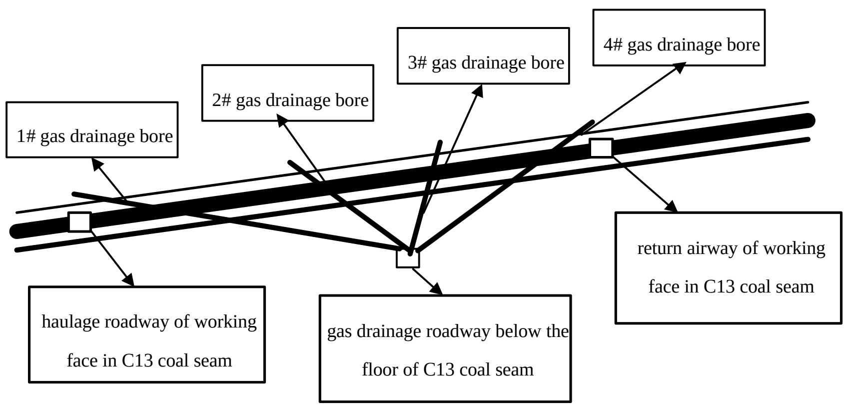
The B11 coal seam with low gas content and no coal and gas outburst danger was exploited firstly. Then the pressure on the C12 and C13 coal seams (in the sagging zone) that were 70 meters (comparative interval is 35B) above the B11 coal seam was relieved and some crannies were formed making use of the exploiting effect. So the active condition of desorption-diffusion-infiltration flow of pressure relief gas was formed. The gas effusion from the long-distance pressure relief coal seam had little effect on the production of the initial coal seam because most of the crannies in the sagging zone were open crannies along the rock and coal seams and few of the crannies were through the rock and coal seams. But because the C13 coal seam was the main exploited coal seam, so we adopted the high efficient method of long-distance gas extraction to reduce the gas content greatly in pressure relief zone, eliminate the outburst danger and achieve the technical demand of integrated caving mechanized exploitation.

3.3 TECHNICAL PROJECT OF LONG-DISTANCE GAS EXTRACTION

We chose the technical project of gridding boreholes through coal and rock seams in the roadway below the floor of the pressure relief coal seams to extract the long-distance gas by a detailed technical and economic comparison. It was illustrated in Fig.2. A gas extraction roadway was disposed along the strike direction of the rock seam in the middle of the projection of the haulage roadway and air return airway of the pressure relief coal seam working face. The gas extraction roadway was in the skewbald claystone and sandstone 10~20 meters away from the floor of the C13 coal seam. A five meters long horizontal gas extraction drill site was disposed every 30~40 meters in the effective pressure relief zone of the initial coal seam. A group of sector bores were drilled in every drill site through coal and rock seams. The diameter of the bore was 91 millimeters and the effective gas drainage radius was 15~20 meters. So the gridding bores through coal and rock seams in the roadway below the floor of the pressure relief coal seam were formed. The released and pressure relief gas in the C13 coal seam accumulated to the borehole along the open crannies under the action of residual gas pressure and extraction negative pressure and then went out to the ground through the gas extraction pipes.



(a)



(b)

Fig.2 Sketch Map of Method of Long-Distance Gas Extraction by Gridding Bores Through Coal and Rock Seams in the roadway below the floor of C13 coal seam
(a).map of strike section (b).map of dip section

3.4 EFFECT OF SAFE HIGH-EFFICIENT EXPLOITATION OF COAL AND GAS

GAS EXTRACTION EFFECT

The gas flux began to increase sharply when the working face of the initial exceeded the drill site 40 meters away. Fig.3 shows variation of gas flux vs time in one drill site. The figure reflects the relation between the stress change of coal seam and gas flux clearly. The first twenty days are gas extraction increase period. During this period the stress movement of pressure relieving in coal seam changed sharply and the gas extraction flux increased. From the twentieth to the eightieth day the gas drainage was active. During this period the stress movement of pressure relieving in coal seam were stable and the permeability was best. The permeability coefficient increased from 0.011

$m^2/(MPa^2.d)$ to 32.7 $m^2/(MPa^2.d)$. It increased nearly 3000 times. The average gas flux of one bore was more than 1.0 m^3/min and was stable. The attenuation period of gas extraction began from the eightieth day. During this period the coal seam was compressed tightly gradually, the permeability reduced, the residual gas pressure of coal seam descended and the gas extraction flux descended according to negative exponent. The flux of long-distance gas was 6.5~25.2 m^3/min and the average flux was 16.0 m^3/min. The flux of short-distance gas was 0.9~12.8 m^3/min and the average flux was 5.0 m^3/min. The high-efficient gas drainage period of the pressure relief coal seam was two months under the influence of the exploitation of the initial coal seam. The high-efficient gas extraction strike length was 160 meters. Four drill sites were useful and sixteen bores extracted gas simultaneously. The average gas flux was about 1.0 m^3/min every bore. The gas extraction ratio of the coal seam exceeded 60% after the gas was extracted continuously four months later. The residual gas pressure of the coal seam dropped to 0.5Mpa. The comparative distortion of the roof and roadway was 26.3‰. The parameter of coal and gas outburst during the process of tunneling in the coal roadway and open-off cut was smaller than the prescriptive critical value.

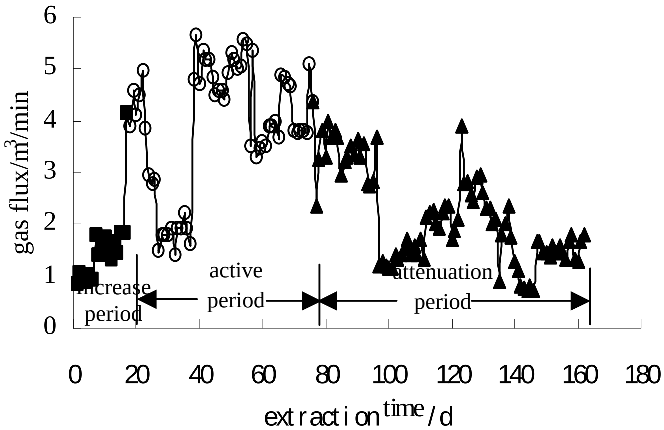


Fig.3 variation of gas flux vs time in one drill site

EFFECT OF THE INITIAL COAL SEAM EXPLOITATION

The wind supply flux of the 2352(1) working face in the initial coal seam during the mining period was 1100~ 1400 m^3/min. The gas flux along with the wind was 6~ 14 m^3/min and the average was 9~ 10 m^3/min. The gas extraction flux was 0.9~ 12.8 m^3/min and the average was 5.0 m^3/min. The total gas flux was 8.5~ 24.5 m^3/min and the average was 15.0 m^3/min. The output of working face was 1400~ 2000 t/d and the average was 1700 t/d. The gas concentration of the return air was 0.5~ 1.0% and the average was 0.8~ 0.9%. From the above we can conclude that the technical project can realize the safe exploitation of B11 coal seam.

EFFECT OF THE PRESSURE RELIEF COAL SEAM EXPLOITATION

The tunneling of 2121(3) working face in the pressure relief coal seam (C13 coal seam) was behind that of 2352(1) working face in the initial coal seam (B11 coal seam). The time difference between them was more than 4~ 5 months and the strike distance between them was 350~450 meters. During the tunneling the wind supply flux was 300~ 400 m^3/min, the gas concentration of the return air was 0.3~ 0.7% and the average was 0.5%. The speed of the tunneling in coal roadway exceeded 200 meters every month and there wasn't any dynamical phenomenon during the tunneling. During the coal roadway tunneling of the adjacent no pressure relief working face the index of the gas outburst exceeded the standard greatly. It was necessary to adopt preventing-outburst measures. The speed of the tunneling in coal roadway was only 40~60 meters every month. It was necessary to adopt the method of advance extraction to prevent coal and gas outburst and reduce the gas effusion of the working face.

The 2121(3) working face in pressure relief coal seam had no coal and gas outburst danger and the gas extraction ratio exceeded 60% because we adopted the methods of pressure relief and long-distance gas extraction. The yield from the working face increased from 1,700 t/d to 5,100 t/d.The comparative gas effusion reduced from 25 m^3/t to 5.0 m^3/t. The average gas concentration of the return air reduced from 1.15% to 0.5%. The average yield from the working face can achieve 7000 t/d according to the existing capability of gas extraction and ventilation of the 2121(3) working face in pressure relief coal seam.

4. CONCLUSION

(1) Gas released from coal seams is not only a potentially dangerous source during coal mining but also a kind of clean energy resource. In China, most coal seams in high-gas draft have low permeability. The commercial value is little. So we can increase the permeability making use of the exploitation of the initial coal seam to realize the high-efficient exploitation of gas.

(2) Under the condition of high-gas coal seams the safe high-efficient exploitation of coal and gas can be realized if we adopt a reasonable exploitation order and an efficient method of gas extraction. The exploitation of the coal resource resulted in the domino effect of pressure relief, permeability increasing and flowage ability increasing for the exploitation of the gas resource. The high-efficient extraction of the gas resource was the necessary condition of the high-efficient exploitation of the coal resource.

(3) The gas effusion could be divided into short-distance gas emission, intermediate-distance gas emission and long-distance gas emission according to the difference of the comparative interval. We adopted the gas extraction method of the long-distance, intermediate-distance and short-distance or the combination of different gas extraction methods.

(4) The practice of the safe high-efficient exploitation of coal and gas together in high-gas coal seams in Huainan mining area proves that the method of gridding boreholes through coal and rock seams in the roadway below the floor of the pressure relief coal seams to extract the long-distance gas can not only eliminate the coal and gas outburst danger of pressure relief coal seam but also reduce the gas content of pressure relief coal seam effectively, and at the same time it can realize the safe high-efficient exploitation of pressure relief coal seam and produce great economic and social benefit.

(5) There are many coal seams in high-gas mining area of China. For example, there are A, B and C coal seam (totaling to more than ten coal seams) within the range of 300 meters in the stratum of Huainan and Huaibei mining area. Though the condition of the coal seams is different in different coal mines, there are at least 3~5 main exploited coal seams. There are fifteen coal seams within the range of 200 meters in the stratum of Yangquan mining area. The main exploited coal seams are No.3, No.12 and No.15 coal seam. In the mining areas of high-gas coal seams the safe

high-efficient exploitation of coal and gas together in high-gas coal seams can be realized if we research the theory and engineering methods compatible with the condition of the mining area and then adjust the exploitation sequence successfully.

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