Safe strategy for coal and gas outburst prevention in deep-and-thick coal seams using a soft rock protective layer mining

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\textbf{A B S T R A C T}

Coal and gas outburst is one of the most harmful disasters in coal mine production. With the increase of mining depth, all the coal seams in the deep-and-thick coal seam group will be upgraded to outburst coal seams, resulting in no suitable first mining layer can be selected as the protective layer. In this case, coal and gas outburst disasters are more serious and outburst prevention and control is more difficult. In order to alleviate the gas disaster and eliminate the risk of gas outburst, a safe strategy was proposed in this study. In this strategy, a suitable soft rock layer adjacent to deep-and-thick coal seams in the Luling coal mine of Huaibei coalfield was selected as the first protective mining layer after safety, economic and technical feasibility argument. Meanwhile, the stereoscopic gas extraction and utilization system safety engineering was established. The effect in the mining process practice of the soft rock protective layer was investigated and verified. Practice shows that this safe strategy can effectively reduce the outburst risk of strong outburst deep-and-thick coal seams and a large amount of pressure relief gas can be extracted and utilized. It can provide a new safety idea for efficient exploitation of coal and gas resources in deep-and-thick coal seams in China.

\section{1. Introduction}

China has a much higher demand for coal than other energy sources (\textit{America}, 2012; \textit{Petroleum}, 2011). Although China's coal output has been limited to its production capacity under the pressures of environmental protection and energy structural reform, a large amount of coal resources is still needed every year. As a concomitant product of coal, gas (aka coaleded methane) is a valuable cheap and efficient source of energy source that is 21–25 times more effective than carbon dioxide (\textit{Al and Paasche}, 2007; \textit{Flores}, 1998; \textit{Karacan et al.}, 2011; \textit{Wang et al.}, 2012) and is attracting world-wide attention (\textit{Fan et al.}, 2019). The heat of 1 m\textsuperscript{3} of pure methane is 35.9 MJ, which is equal to 1.2 kg standard coal calorific value (\textit{Wang et al.}, 2014b). Commercial development of gas extraction has been carried out in many countries such as, U.S., Canada, China, Australia and India. China has rich coal seam methane resources with a shallow reserve of 2000 cubic meters at a density of 36.81 trillion cubic meters, which is almost the same as conventional natural gas (\textit{Cheng et al.}, 2011). However, the geological conditions of coal mines are complex and the permeability of coal seams is low in China, which makes it difficult to extract gas safely and efficiently. At the same time, gas is a major hazard in the mining industry leading to serious coal mine accidents (\textit{Xie and Xu}, 2017; \textit{Yu et al.}, 2016). Once coal and gas outburst or explosion occurs, it will cause heavy economic losses and casualties. China has suffered the most serious coal and gas outburst accident in the world. Therefore, it is necessary to strengthen the research and application of gas disaster prevention technology and achieve coal and gas co-mining while cooperating with safety mining. Safe and highly efficient mining of coal and gas have become the safety, economic, and environmental priorities (\textit{Wang et al.}, 2014a; \textit{Wang et al.}, 2017).

With the rapid development of coal mining technology and equipment in China, the shallow coal resources are gradually reduced or even depleted, and more and more coal mines are facing deep mining problems (\textit{Wang et al.}, 2012; \textit{Wang et al.}, 2017). As a result, the number of coal and gas outbursts in mines will increase and become more frequent. In order to reduce the risk of coal and gas outburst, improve the safety of coal production, and realize the high yield and high efficiency, many measures have been put forward, such as: drainage and wetting of...
Fig. 1. The location and regional structure of the Luling coal mine.

Fig. 2. Geological condition of the III11 soft rock working face.

Table 1

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Density (kg·m(^{-3}))</th>
<th>Bulk modulus (GPa)</th>
<th>Shear modulus (GPa)</th>
<th>Tensile strength (MPa)</th>
<th>Cohesion (MPa)</th>
<th>Internal friction angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone</td>
<td>2800</td>
<td>9.8</td>
<td>4.6</td>
<td>44.7</td>
<td>5.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Siltstone</td>
<td>2600</td>
<td>4.1</td>
<td>3.4</td>
<td>27.7</td>
<td>7.0</td>
<td>25.0</td>
</tr>
<tr>
<td>Fine sandstone</td>
<td>2700</td>
<td>7.6</td>
<td>5.5</td>
<td>41.6</td>
<td>6.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Mudstone</td>
<td>2500</td>
<td>4.0</td>
<td>3.3</td>
<td>28.9</td>
<td>5.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Coal</td>
<td>1400</td>
<td>5.0</td>
<td>2.1</td>
<td>8.0</td>
<td>4.5</td>
<td>16.0</td>
</tr>
<tr>
<td>Protective layer (soft rock)</td>
<td>2500</td>
<td>4.2</td>
<td>2.9</td>
<td>25.3</td>
<td>5.0</td>
<td>18.0</td>
</tr>
</tbody>
</table>
dangerous coal seams, protective layer mining, hydraulic flushing cavity, advanced drilling, and hydraulic blasting (Cheng et al., 2015; Xue et al., 2015; Yan et al., 2015). Among them, protective layer mining is currently the most effective method to prevent coal and gas outburst and has been used successfully in many countries in the world (Cheng et al., 2015; Dong, 2013; Wang et al., 2009b; Wang et al., 2013). The proved effective gas extraction methods include surface drilling extraction, protective seam pressure-relief extraction and underground gas extraction. On the ground, stimulation methods such as multi-gas replacement and directional horizontal pinnate drilling are always used to increase fractures in the original coal seam reservoir; Different underground gas extraction methods are adopted for coal seams of different deposit conditions in China. In general, cross-measure borehole combined with bedding borehole is used to extract gas for single seam. During the mining period, multi-source gas control methods such as roof high-level drilling and gob area pipeline burying are used (Liu and Cheng, 2014; Yu, 1992); For the protective seam pressure-relief extraction, the methods are as various as the gas sources are different and these gas extraction methods have been summarized by Cheng (Cheng et al., 2015). The factors affecting gas extraction effect are also very complex. Permeability of coal seams is the most important factor affecting gas extraction effect. With the increase of buried depth, stress, gas content and gas pressure increase, which lead to the permeability reduction of coal seams, thus making the gas more difficult to extract (Li et al., 2014; Yan et al., 2015; Yuan, 2008). During the mining process of the protective layer, change of the spacing has obvious influence on the gas extraction effect (Wang et al., 2009a). Extraction parameters such as arranging way of drill holes, drill holes interval, the depth of sealing holes, drainage negative pressure and drainage duration also have a great influence on the extraction effect (Wang et al., 2009b).

The mining of the protective layer combined with the pressure relief gas extraction was found to be the most effective and reasonable regional gas control technology (Cheng et al., 2015; Dong, 2013; Wang et al., 2013). Since the first trial of coal and gas outburst prevention in France in 1933 (Wang et al. 2013), almost all countries now with outburst coal seams have preferentially exploited the protective layer mining technology (Cheng and Yu 2003). China started its experiment in the Beipiao and Chongqing areas in 1958, then it promoted and applied the practice in nationwide well-qualified coal mines after achieving good results. In recent years, coal seam conditional protective layer mining and pressure relief gas extraction technology have been widely used in coal mining engineering. The combination of protective layer mining and pressure relief gas extraction can not only reduce the risk of gas accidents and achieve coal and gas co-mining while cooperating with safety mining, but also obtain significant economic benefits (Cheng et al., 2015; Sun et al., 2016; Yuan et al., 2013). The overall outburst of coal seams is closely related to the selection of the first mining layer, and the choice of the first coal seam is often the key to coal seam group gas control. Only by choosing a reasonable first mining layer and using its mining influence to relieve pressure and increase the permeability of the upper and lower adjacent coal seams and forming highly efficient pressure-relief gas drainage conditions, can we achieve totally safe and highly efficient exploitation of coal and gas (Cheng and Yu 2003; Cheng et al. 2015). Based on different engineering backgrounds, scholars conducted a large number of studies on the selection of the first protective layer. A study of choosing the mining sequence of coal seams as a protective layer was conducted in the Riosa-Olloniego coalfield in Spain (Aguado and Nicieza, 2007). The major coal-bearing basins in China consist of multi-period hydrocarbon accumulation, and 70% of the coal mines have group coal seam conditions (Yang and Han, 1980). The selection of key protected areas in Huainan was systematically studied and practiced (Wang et al., 2013). However, with the increase of mining depth, all the coal seams in groups will be upgraded to outburst seams, which makes it difficult to select the first mining protective layer and eliminate outburst in the whole coal seam group (Cheng et al., 2015; Wang et al., 2017). Therefore, in the case of no suitable or nondangerous outburst coal seam for a protective layer, some scholars turned to discuss the feasibility of mining rock as a protective layer according to the geological conditions. All rock as a protective layer were used in Pingdingshan (Sun et al., 2016), but this method did not get a widely promotion because of the economic deterioration and the lack of systemic feasibility studies on security, economics and technology before mining.

The Huabei mining area is one of the largest coal mining areas in China with an annual output of over 10 million tons. The formation of coal-bearing strata in the Huabei coalfield was affected by multiple tectonic movements resulting in the extremely complex geological formations of the coalfields and the serious disasters of coal and gas outburst (Wang et al., 2013; Wang et al., 2014a; Wang et al., 2014b). On April 7th, 2002, an extremely large coal and gas outburst accident occurred in the Nos.8/9 coal seams in the Luling coal mine, which threw out 10,500 tons of coal-rock masses and 1.23 Mm³ of gas (Wang et al., 2017). The Nos.8/9 coal seams of the Luling coal mine are extremely thick (9.70 m on average) and soft (consistent coefficient lower than 0.26) with low permeability (0.0007 mD) and high outburst risk. The measured gas pressure is 5.0 MPa and the gas content is more than 20 m³/t at the depth of 907 m (Wang et al., 2017; Zhou et al., 2015). After entering the third mining level (~900 m elevation or 925 m depth), the No. 10 coal seam which was originally a protective layer
Table 2

<table>
<thead>
<tr>
<th>Reservoir Parameters</th>
<th>Coal seam thickness (m)</th>
<th>Hardness coefficient (0-10)</th>
<th>Permeability coefficient (mD)</th>
<th>Spontaneous combustion tendency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nos. 8 and 9 Value</td>
<td>9.7 m on average</td>
<td>6.11-0.46, 0.26 on</td>
<td>Easy to spontaneous combustion</td>
<td>I</td>
</tr>
<tr>
<td>Characteristic</td>
<td>Extremely thick</td>
<td>Low permeability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nos. 10 Value</td>
<td>No. 10-1 is 1.4 m on average</td>
<td>No. 10-2 is 1.3 m on average</td>
<td>Hard</td>
<td>II</td>
</tr>
<tr>
<td>Characteristic</td>
<td>Medium-thick coal seam</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Gas pressure, gas content and \( p \) are the key factors dictating the outburst risk, which critical value are 0.74 MPa, 8 m³/t and 10 mmHg respectively.

was upgraded to an outburst coal seam. Therefore, the No.10 seam is not suitable to be the first mining protective layer, and an appropriate protective layer should be chosen.

Taking the Luling coal mine as an example, in order to reduce the risk of gas outburst and realize coal and gas co-mining while cooperating with safety mining, a safe strategy was proposed in this study. According to the characteristics of strata distribution, coal seam occurrence and gas disaster, the feasibility of the soft rock layer (55 m below the Nos.8/9 coal seams) as a protective mining layer is analyzed and demonstrated. In a recent project, the soft rock was chosen as a protective layer to eliminate the outburst danger of adjacent coal seams. The mudstone position, stable distribution, lithology and other aspects determine that the soft rock can be used as a protective layer. At the same time, the safe strategy for pressure relief gas extraction and utilization was established. The effect in the mining practice of the soft rock protective layer was investigated and verified. Practice shows that the project can effectively reduce the hazard risk of deep-and-thick coal seams and a large amount of pressure relief gas can be extracted and utilized. At home and abroad, there are few successful cases of mining with suitable soft rock as protective layer to eliminate the risk of gas outburst in deep-and-thick coal seams. In this paper, the mining of the soft rock protective layer provides “pressure relief and permeability enhancement” and “spatial-temporal guarantee” conditions for gas extraction, and gas extraction transforms high-gas outburst dangerous coal seams into low-gas non-outburst dangerous coal seams, so as to ensure safe and efficient coal and gas co-mining. It has innovative and practical significance and can provide a new idea for efficient exploitation of coal and gas resources in deep coal seams in China.

2. Risk analysis of deep-and-thick coal seam outburst

2.1. Geological characteristics

The Huaibei coalfield locates in the northern Anhui province, southeastern margin of the North China plate, and eastern of the depression of Yu-huai (Wang et al., 2014a). This area had a multicycle tectonic evolution of seven structural layers (Guo et al., 2014). The Huaibei coalfield is divided into four mining areas, namely the Suixiao, Suxian, Linhuan and Guoyang mining areas (Jiang et al., 2010). The Luling coal mine is located in the Suxian mining area, which area is mainly comprises the Sudong syncline and the Sunan syncline (Fig. 1). Because of the complex area, tectonic extrusion and shearing are strongly influenced. Thick coal layers are generally developed, and modern tectonic stress fields are characterized by the pressing effect.

There are abundant coal resources in the Luling coal mine, but the occurrence condition and fracture structure of coal seam are particularly complicated. The mine adopts the horizontal development method of vertical shaft stone gate. The mining methods are longwall collapse and caving coal mining. The ventilation method is extraction type, and the ventilation method is central boundary and two wings parallel type.

The Luling coal mine runs 8.2 km along the strike and 3.6 km along the trend. There are three primary mineable coal seams from top to bottom: Nos.8, 9 and 10 coal seams. The average thicknesses of the coal seams are 9.70 m (Nos.8/9 composited seams), 1.40 m (No.10–1 seasm) and 1.30 m (No.10–2 seam) respectively. The spacing between the Nos. 8/9 and No. 10 coal seams ranges from 60 to 110 m, with an average of 80 m. The lithologic components in the roof and floor of coal seams are mainly mudstone and siltstone. The location and coal strata histogram are shown in Fig. 2c.

The design layout of the III11 soft rock working face is shown in Fig. 2a. The working face is designed with approximately 850 m along the strike and 105 m wide along the trend at a buried depth of 630 m-710 m. According to the geological prospecting report, the basic characteristics of the lithology in the middle of the main coal seams are statistically analyzed and shown in Table 1.
2.2. Risk of gas outburst

The primary mineable coal seams in the Luling coal mine are all outburst-prone coal seams. Twenty-six coal and gas outburst accidents occurred in the Nos. 8/9 coal seams. The spraying holes phenomenon usually appears during the process of drilling, and the mean spraying coal amount is 15.0 tons (Wang et al., 2017). On April 7th, 2002, an extremely large coal and gas outburst accident occurred in the Nos. 8/9 coal seams in the Luling coal mine, which threw out 10,500 tons of coal-rock masses and 1.23 Mm³ of gas (Wang et al., 2017). The Nos. 8/9 coal seams of the Luling coal mine are extremely thick (9.70 m on average) and soft (consistent coefficient lower than 0.26) with low permeability (0.0007 mD) and high outburst risk. The measured gas pressure is 5.0 MPa and the gas content is more than 20 m³/t at the depth of 907 m (Wang et al., 2017; Zhou et al., 2015).

The gas pressure measurement results during mine production were statistically analyzed by the safety-line method in Fig. 3 (Wang et al. 2012) and the occurrence of coal seams is shown in Table 2. It is estimated that after entering the third level, the coal seam gas pressure and content increases. The maximum gas pressure in the Nos. 8/9 seams reaches 6.58 MPa and the maximum gas content reaches 25 m³/t. As shown in Table 2, the middle group coal seams (Nos. 8/9) are typical tectonic coal with characteristics of extremely soft and low permeability. It is also characterized by high gas pressure, high gas content and rapid diffusion rate. While the outburst risk of the No. 10 coal seam becomes more serious, the calculated maximum gas pressure reaches 5.31 MPa and the gas content reaches 18 m³/t. If chosen it as the first mining coal seam (protective seam) of the Nos. 8/9 coal seams, the No. 10 coal seam may become the first mining coal seam (protective seam).

### Table 3

<table>
<thead>
<tr>
<th>Seam category</th>
<th>Effective vertical distance (m)</th>
<th>Distance to the Kaolinite clay (Dip angle 22°) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The lower protected layer mining</td>
<td>The upper protected layer mining</td>
</tr>
<tr>
<td>Steep seam</td>
<td>&lt; 60</td>
<td>&lt; 80</td>
</tr>
<tr>
<td>Gentle dip or inclined seam</td>
<td>&lt; 50</td>
<td>&lt; 100</td>
</tr>
</tbody>
</table>

![Fig. 4. Schematic diagram of numerical geometric model.](image)

(a) Stress changes of protected layer during mining of the No. 10 coal seam; (b) Stress changes of protected layer during mining of the soft rock layer

![Fig. 5. Diagram of stress changes during the protective layer mining.](image)

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10 seam need to do a lot of gas control work. Because of the above-mentioned reasons, exploitation difficulty is further increased, resulting in the No. 10 seam being no longer suitable for mining as a protective layer. Therefore, a new appropriate protective layer needs to be re-selected.

3. Feasibility of the safe strategy using a soft rock protective layer mining

According to the results of mine prospecting data, the geological structure of the No. 10 coal seam is complex with large and medium-sized faults and their derived and associated structures (Fig. 2b). This surface exposes 20 faults in total, among which the fault throw of 7 faults are over 10 m with a 25° dip angle. In the strike of the 7 faults, there are approximately 260 m of rock to be excavated. In addition, there are 13 faults below 10 m, making the coal seam structure more complicated. Affected by the fault, the coal face needs to be exposed several times during the layout of the working face. Therefore, the construction time is long and the security threat is large. In the meantime, since the roof and floor of the No. 10 coal seam are very hard, blasting is required. Considering that the No. 10 coal seam is also a coal and gas outburst seam, if force to mine it as a protective layer requires regional gas treatment, which means large investment, and long construction time.

The orebody chosen for the protective layer is soft rock (Kaolinite clay) (Fig. 2c). The lithology is mudstone, and the thickness of the orebody is 3–7 m with average thickness of 5.1 m. The orebody is layered and laminar structures (Fig. 2b). They are nearly EW and have 15-52° dip angles with an average of 22°. The normal distance from the ore body to the floor of the No. 9 coal seam is 54–64 m, with an average distance of 55 m. The normal distance from the roof of the No. 10 coal seam is 20–27 m with an average distance of 23 m. The mined ore body is thinner along the upper part of the dip and its thickness is relatively stable (Fig. 2b). Both the roof and floor are fine sandstone (Fig. 2c). The hardness of the mudstone in this layer is between 1.9 and 4.6, the compressive strength of the rock is 25.3 MPa on average, and the tensile strength is 2.26 MPa. When it encounters water, it is easily disintegrated into pieces and was rubbed into muddy shapes by friction. The mudstone position, stable distribution, lithology and other aspects determine that the soft rock layer can be used as a protective layer.

Under the conditions of a coal seam group with deep horizontal outburst danger, the No. 10 seam cannot be used as the protective layer. The choice of soft rock mining also has certain economic benefits which are mainly reflected in the following aspects:

(1) **The economic value of soft rock:** According to the mineralogical
3.2. Theoretical analysis of mining validity for the soft rock protective layer

Coal seam mining will cause rock mass deformation and reduce rock strength, so the rock is considered to be an elastic-plastic material that shows strain softening characteristics after it is damaged. Therefore, the strain softening model was used in the numerical simulation (Jin et al., 2016). According to the distribution of strata shown in Table 2, the numerical model of this simulation is constructed as shown in Fig. 4. In this paper, two models under the protection of the soft rock protective layer and No.10 coal seam protective layer were established. The lower boundary of the model is 45 m below the floor of the 10th coal seam and the upper boundary is 47.2 m above the roof of the 8th coal seam. The longitudinal distance of the two models is 600 m, the width is 305 m and the height is 180 m. The model boundary conditions were set as: the left and right single restraints, the horizontal displacement is zero and the vertical displacement is not zero, and the horizontal and vertical displacements at the bottom are both zero. To simulate the overburden compressive stress, the load is applied to the roof (the protective layer is surface surcharge 14.9 MPa) stress constraints. The Moore-Coulomb failure criteria was selected for the simulation. The initial properties of the rock mass for the simulation based on the geological survey of the Luling coal mine are listed in Table 1.

The law of fracture development for overlying coal and rock masses on the protective face and the deformation characteristics of the protected layer are shown in Figs. 5 and 6. With the advancement of the working face during the mining process of the III11 soft rock face and the No.10 coal seam face of the lower protective seam.

Comparison of Figs. 5 and 6 shows that both mining methods have efficient and clean energy utilization and greenhouse gas emission reduction. Therefore, the strain softening model was used in the numerical simulation (Jin et al., 2016). When the soft rock is used as a protective layer, the maximum stress relief to the protected layer (Nos. 8/9 coal seam) can reach 6.44 MPa, which is much smaller than 9.55 MPa of the No. 10 coal seam. The maximum deformation of the protected layer (Nos. 8/9 coal seam) is up to 4.1‰, which is much larger than 3‰ of the 10th seam. The mining of the soft rock is in compliance with the requirements of the protective layer mining code that the deformation of the protective layer should reach 3‰ (SAWS, 2009). It can be seen that the relief from the soft rock protective layer mining is significantly better than from the No.10 coal seam mining.

4. Safe strategy for stereoscopic gas extraction and utilization

4.1. Gas extraction system safety engineering

The extraction of gas in the process of coal resources mining can not only guarantee the safety of coal mining, but also achieve the purpose of efficient and clean energy utilization and greenhouse gas emission reduction. According to Cheng’s (Cheng et al., 2015) summary of various gas drainage methods, when the pressure relief gas comes from the bending zone, as the whole coal and rock mass in the belt sinks and horizontal cracks often occur, pressure gas relatively easily flows in the parallel direction. More effective gas drainage methods are the roof or
### Table 4

<table>
<thead>
<tr>
<th>Gas drainage methods</th>
<th>Construction parameter</th>
<th>Concentration (%)</th>
<th>Pure volume (m³/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drainage system</strong></td>
<td><strong>Final hole spacing</strong></td>
<td><strong>Position</strong></td>
<td><strong>Quantity of drainage</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Distance</strong> (Km³)</td>
</tr>
<tr>
<td><strong>Surface well</strong></td>
<td>20 m above the soft rock working face</td>
<td>110.3 m</td>
<td>12.7-98</td>
</tr>
<tr>
<td><strong>Inclined interception boreholes</strong></td>
<td>20-20 m</td>
<td>113 mm</td>
<td>20.4</td>
</tr>
<tr>
<td><strong>High level interception boreholes</strong></td>
<td>1 m below the Nos. 8/9 coal seams</td>
<td>60</td>
<td>12.2</td>
</tr>
<tr>
<td><strong>Grid penetration bored pipes</strong></td>
<td>0.5 m drilling through the No. 10 coal seam</td>
<td>30</td>
<td>5.5</td>
</tr>
<tr>
<td><strong>Goaf burying pipe</strong></td>
<td>25 m, crossover step</td>
<td>Upper corner of the goaf</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>Tail road way</strong></td>
<td>25 m, crossover step</td>
<td>Upper corner of the goaf</td>
<td>2.5</td>
</tr>
</tbody>
</table>

In view of the strong outburst risk of the deep-and-thick coal seams in the Luling coal mine, the use of a single gas control method or several gas control methods can neither completely eliminate the mining risks and ensure safety, nor realize full utilization of gas. In this paper, a stereoscopic gas extraction system for coal and gas co-mining of deep-and-thick coal seams is proposed. As described above, the suitable soft rock was selected as a protective layer for mining. The mining of the protective layer provides “pressure relief and permeability enhancement” and “spatial-temporal guarantee” conditions for gas extraction. In this case, the establishment of the stereoscopic gas extraction system can more effectively and safely drainage the pressure relief gas of deep-and-thick coal seams.

The Nos. 8/9 coal seam lies in the bend zone of the soft rock working face (spacing is 55 m, 23 times of mining height) and the No. 10 coal seam is located in the deformation zone of the bottom drum (distance 23 m) in the soft rock working face. To cooperate with the safe and efficient gas drainage and pressure relief during the mining of the soft rock protective layer, a stereoscopic gas extraction safe strategy was designed, as shown in Fig. 7. Among them, the pressure relief gas drainage of the middle coal group mainly includes the surface well, grid penetration boles drilled in the bottom rock lane and the high intercept boreholes. For the No. 10 coal seam of the lower group, grid penetration boles drilled in the bottom rock lane are the main method. During the mining of the soft rock working face, the conventional goaf buried pipe and high level boreholes drilling are used for gas drainage.

Surface wells have a long service life, good drainage and extraction results, but the drilling holes are affected by mining breakage. The possibility for different forms of interception drilling can make up for this part of the defect. Therefore, the combination of ground drilling and interception drilling can effectively drain the pressure relief gas from the Nos. 8/9 coal seams. According to the characteristics of the roadway layout in the work face, in addition to the conventional high-level drilling of the working face, high-level interception drilling (intercept the gas of the Nos. 8/9 coal seams) should be carried out. For the No. 10 coal seam, gas is mainly drawn through the bottom hole rock network. During the mining face, the conventional goaf buried pipe and intubation high drilling are adopted. In the initial work surface, a tail lane is arranged to strengthen the initial gas extraction. After correcting the preliminary gas treatment plan in Fig. 7, the actual gas drainage layouts are shown in Fig. 8 and Table 4. The system in the coal mine is very complicated. In order to reflect the comprehensive stereoscopic extraction and facilitate the visual observation, the gas extraction methods are demonstrated in a three-dimensional way. The spatial distribution of gas extraction methods is shown in Fig. 9.

#### 4.2. Gas utilization system safety engineering

Gas (the main component is methane) is a clean and efficient source of energy, though it poses a serious threat to coal mine safety (Flores, 1998). If the extracted gas is directly discharged into the atmosphere, it not only wastes a lot of clean energy but also destroys the environment. To make full use of the extracted gas, two sets of permanent ground gas drainage systems have been built in the Luling coal mine. One is a 350-pumping system with two 2BEY-67 water ring vacuum pumps. The rated flow is 350 m³/min, and the motor power is 450 Kw. The other has two 2BEY-72 water ring vacuum pumps, the rated flow is 630 m³/min, and the motor power is 1000 Kw. Meanwhile, there are two sets of gas utilization power generation systems. The low concentration power plant is equipped with 10 generating units and the high concentration power plant is equipped with 18 generating units. When the drainage system gas concentration is greater than 30%, high-concentration power generating units will be used. When the concentration of the drainage system is < 30%, low-concentration gas generating units will be used. The Luling coal mine gas utilization model is shown in Fig. 10. Before reconstruction, the high-concentration gas drainage from the...
ground system is used as civil fuel and the low-concentration gas is used to generate electricity. Right now, all the gas drainage from the system is used to generate electricity. The underground moving drainage system drains the goaf burying pipe gas, where the gas concentration is low. Therefore, it is not yet considered for use and was discharged into the atmosphere through the return airway.

5. Effect analysis of deep-and-thick outburst dangerous coal seam safety mining

5.1. Effect analysis of eliminating outburst danger

The production test of the soft rock protective layer began in July 2015, with an effective method for pressure relief gas drainage, and no gas outburst accident occurred during the mining. The gas concentration of the return air flow was below 0.1% in the working face.
During the mining of the III11 soft rock working face, we carried out the inspection and verification of the relief of the protected layer. The investigation mainly includes measuring the original and residual gas pressure and content, the boundary of trend and tendency relief and the deformation of expansion. The relevant drilling design sketch map for this study is shown in Fig. 11. Different boreholes have different functions. Among them, 1# to 5#, 6# to 10#, 16# to 20# and 21# to 25#: Pressure relief boundary inspection boreholes; 11# to 13#: Raw original gas pressure and gas content measuring boreholes; 14# to 15#: Expansion deformation inspection boreholes.

From October 2015 to March 2017, the borehole construction was investigated as shown in Fig. 10 and the results of the data analysis were used to determine and calculate the effect of the pressure relief boundary (pressure relief angle) and the related protective layer evaluation index. Specific protective layer data of the inspection results is shown in Table 5.

It can be seen from Table 5 that the pressure relief of the Nos.8/9 coal seam is good after the end of III11 soft rock working face mining. The gas pressure decreased from the original 2.3 MPa to 0.25 MPa and the gas content decreased from 20 m³/t to 5.32 m³/t, both of which were below the critical value of 0.74 MPa and 8 m³/t. The propensity is towards a lower pressure relief boundary that relieves less than the theoretical value. The other pressure relief boundary can reach the theoretical value, and the pressure relief boundary reaches 90°. The pressure relief gas pumping rate is up to 88.6% and the calculated residual gas content is 2.27 m³/t. Based on the above survey data, the protective layer eliminates the danger of coal and gas outburst within the effective pressure relief range after gas drainage.

5.2. Effect analysis of extraction of pressure relief gas

Fig. 12 shows the statistical analysis of pumping for different gas treatment methods. It is found that the relief gas extraction effect is extremely obvious, especially for the strong outburst middle group coal
seam pressure relief gas. In the meantime, as the No.10 coal seam floor rock channel is not influenced at the late mining stage, the pressure relief gas can be extracted continuously and it will also play a good role in eliminating outburst gas. The statistics of gas drainage in the working face (Table 5) show that the total proportion of ground drilling and inclined interception drilling is approximately 90% and the pumping concentration is greater than 60%, effectively ensuring that no gas overrun accident occurs on the mining face and controlling the gas concentration on the working face to < 0.1%.

5.3. Effect analysis of gas utilization

Pressure relief gas drainage and utilization statistics for the Nos.8/9 coal seams during the mining of the III11 protective layer are shown in Fig. 13. It can be seen that during the mining of the soft rock protective layer a total of 19.8 million m3 of pressure relief gas (Nos. 8/9 and 10 seams) and an effective utilization of 14,523,900 m3 of gas were drained, with a gas utilization rate of 73.4%. The total generating capacity reached 36.332 million Kwh. The effective utilization of gas can not only bring economic benefits but also reduce atmospheric pollution. Calculated by 0.6 yuan/Kwh, the revenue can reach 21.8 million yuan.

6. Conclusions

Since all the deep coal seams were upgraded to outburst coal seams in China, it is necessary to conduct a comprehensive safety, economic and technical demonstration of selecting rocks with low-risk or economic value as the first mining protective layer. A safe strategy, which selected the soft rock as the first mining protective layer and developed a stereoscopic gas extraction and utilization system safety engineering for coal and gas outburst prevention, was implemented in Luling coal mine. The main conclusions are as follows:

(1) Through various discussions and verification, the safe strategy using a soft rock protective layer mining is feasible and reliable after safety, economic and technical feasibility studying. Theoretical analysis shows that the soft rock layer is located within the effective protection range of the Nos. 8/9 and 10 coal seams and can realize pressure relief on all the outburst coal seams at the same time. The numerical simulation shows that after the soft rock protective layer mined, the deformation of the protected layer can provide good relief and reach 4.1‰, meeting the requirement of 3‰.

(2) Based on the practice of protective layer mining and the characteristics of coal seams and gas occurrence in the Luling coal mine, the safe strategy for stereoscopic gas extraction and utilization was established. The pressure relief gas drainage in the middle group adopted a surface well, an inclined interception borehole and high level interception borehole. The low group coal of the No.10 coal seam was mainly drained by the grid penetration borehole. For the goaf gas of the soft rock working face, it was mainly drained by conventional goaf buried pipe, high level borehole and a tail roadway to strengthen the initial gas extraction in the early work face. The high-concentration and low-concentration extraction gas were both used to generate electricity after reconstruction.

(3) The statistical results show that this safe strategy has achieved good results. Based on the survey data, the soft rock protective layer eliminates the danger of coal and gas outburst within the effective pressure relief range after gas drainage. The gas pressure decreased from the original 2.3 MPa to 0.25 MPa and the gas content decreased from 20 m3/t to 5.32 m3/t. The pressure relief gas pumping rate is up to 88.6% and the calculated residual gas content is 2.27 m3/t, effectively ensuring that no gas overrun accident occurs on the mining face and controlling the gas concentration on the working face to < 0.1%. During the mining of the soft rock protective layer a total of 19.8 million m3 of pressure relief gas and an effective utilization of 14,523,900 m3 of gas were drained, with a gas utilization rate of 73.4%. Overall, it achieves significant safety, economic and environmental benefits.
(4) The safe strategy for coal and gas outburst prevention in deep-and-thick coal seams in the Luling coal mine can provide a feasible new safety idea for the efficient co-mining and utilization of deep coal seams and gas resources. In order to alleviate the gas disaster and eliminate the risk of gas outburst, the suitable soft rock was selected as the protective layer for pressure relief and safety mining. At the same time, the “surface - underground” stereoscopic gas extraction system was established. The integrated design and three-dimensional extraction of gas treatment in deep high-gas coal seam group were realized to ensure the safe and efficient co-mining of coal and gas in outburst mines. This safety strategy realizes the integrated design and stereoscopic extraction of gas treatment in deep-and-thick coal seam groups and ensures the safe and efficient co-mining of coal and gas in outburst mines. In the long run, China’s mining areas are mostly coal seam group mining conditions, with the increase of mining depth all the coal seams will be upgraded to outburst coal seams. In this case, the rock with low risk or economic value can be selected as an appropriate first protective layer for safe mining and a supporting stereoscopic gas extraction system can be established, so as to realize the safe and efficient co-mining system of coal and gas. This has a broad application prospect.

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