Study on simultaneous extraction of coal and gas and clean utilization in high-gas outburst mines

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Abstract: In order to solve the problem of gas overrun during the mining of large mining height working face in high process mine, based on the gas emission prediction, the source and composition of gas emission are analyzed, gas extraction method of combining the grossmeasures boreholes with borehole along the seam are put forwarded, the reasonable arrangement of the gas extraction parameter are designed, comprehensive control of gas in working face, heading face and goaf was carried out, and the new scheme of high concentration gas and low concentration gas clean utilization is proposed. It has been proved by practice that the coal and gas co-mining and clean utilization scheme of ‘gas pre-extraction + gas civil-oriented + gas power generation + waste heat utilization’ is of great significance to ensure coal mine safety production and environmental protection.

1. Introduction
Coal plays an important role in China’s energy structure. The number of high gas mines and coal and gas outburst mines keeps increasing, and gas accidents occur from time to time, which brings many problems to coal mine safety production [1-2]. With the increase of high yield, high efficiency and safe mining of coal and the demand for highly intensive production, technology of mining all height at one time has been rapidly popularized and applied in China [3]. In addition, as the mining depth extends to the deep region, the gas content and gas emission increase continuously, and the problem of gas overrun on the mining face becomes increasingly prominent, the difficulty of safe mining increases, and the safe mining of mines is seriously threatened [4-5]. In order to solve the problem of gas overrun, many mines use-and other ventilation systems, but also brought difficulties in safety management. Therefore, the only way to achieve comprehensive gas control, utilization and environmental protection is to co-mine coal and gas in high-gas outburst mines and extract and utilize low-concentration gas in goaf [6-8].

2. General situation
The mine adopts comprehensive exploitation of inclined shaft, and all caving methods to manage the roof. The mine adopts a centralized parallel exhaust ventilation system. Main inclined shaft and subsidiary shaft inlet air, return shaft exhaust air. The seam thickness of No.3 coal seam is 4.72–6.00m, and the average mining height is 5.35m. Five entry are arranged along the working face crossheading: belt crossheading, belt crossheading cooperating roadway, track crossheading, gas tail roadway, and
belt crossheading cooperating roadway of last working face. The belt crossheading and belt crossheading cooperating roadway are the main air inlet roadway. The track crossheading and gas tail roadway are the return air roadway, and the belt crossheading cooperating roadway of last working face is the auxiliary air inlet roadway, and the ventilation mode is "U + U" type ventilation mode. The working face adopts retreating type and the mining area adopts advancing type. The length of fully mechanized mining face is 175m.

The original gas pressure of the coal seam is 1.24~1.59MPa, which is a coal and gas outburst mine. The coal dust is not explosive, and the coal seam is not easy to spontaneous combustion. According to the prediction results of gas emission, the maximum absolute gas emission in the mine is 160.89m³/min, and the ventilation capacity of the mine is about 8000m³/min. The allowable CH₄ concentration in the total return air roadway is calculated at 0.70%, so the gas emission that can be solved by the mine air exhaust is about 56m³/min. The mine extraction volume is 136.32 m³/min, and the remaining 24.57 m³/min gas after extraction can be solved by air exhaust.

3. Analysis of source and composition of gas emission
According to the predicted results of gas emission, the mining working face, mining area and the source and composition of gas emission in no.3 coal seam of Chengzhuang coal mine are shown in table 1~3.

| Table 1. Prediction results of gas emission in working face |
|------------------------------------------------------------|
| Working face | Total emission quantity of working area (m³/min) | Emission quantity of working seams (m³/min) | Emission quantity of adjacent seams (m³/min) | Proportion of working seams (%) | Proportion of adjacent seams (%) |
|---------------|---------------------------------|---------------------------------|---------------------------------|----------------------------|-------------------------------|
| The first working area | 74.94 | 60.66 | 14.28 | 80.94 | 19.06 |
| The second working area | 73.89 | 59.82 | 14.07 | 80.96 | 19.04 |

| Table 2. Prediction results of gas emission in mining area |
|-----------------------------------------------------------|
| Producing area | Emission quantity of mining area (m³/min) | Working face (m³/min) | Heading face (m³/min) | Goaf (m³/min) | Proportion of Working face (%) | Proportion of Heading face (%) | Proportion of goaf (%) |
|----------------|---------------------------------|----------------|----------------|-------------|----------------------------|----------------------------|----------------|
| The first working area | 128.71 | 74.94 | 24.07 | 29.70 | 58.22 | 18.70 | 23.08 |
| The second working area | 126.97 | 73.89 | 23.78 | 29.30 | 58.20 | 18.72 | 23.08 |

| Table 3. Prediction results of the composition of the maximum gas emission in the mine |
|----------------------------------------------------------------------------------|
| Gas emission quantity of the mine | Working face (m³/min) | Heading face (m³/min) | Goaf (m³/min) | Proportion of Working face (%) | Proportion of Heading face (%) | Proportion of goaf (%) |
|---------------------------------|----------------|----------------|------------|----------------------------|----------------------------|----------------|
| 160.89 | 74.94 | 24.07 | 61.88 | 46.58 | 14.96 | 38.46 |

According to table 1~3 and mining conditions, it can be seen that: gas emission quantity is very large, gas emission is from many sources and widely distributed, and coal seam occurrence conditions are complex, so comprehensive control of gas should be carried out on working face, Heading face and goaf.

4. Scheme design of simultaneous extraction of coal and gas
The adjacent seams above No.3 coal seam in Chengzhuang coal mine is No.2 coal seam, with spacing of 19.92m and thickness of 0.40m. This coal seam is unstable and cannot be mined. The adjacent lower seam is No.5 coal seam, 13.35m apart from No.3 coal seam, with an average thickness of 0.30m,
but it is unstable and cannot be mined. Therefore, No.3 coal seam cannot adopt the method of mining protective layer to reduce the gas content.

4.1. Pre-extraction of coal seam gas by grossmeasures boreholes
Chengzhuang coal mine is arranged with three rock tunnels 40m apart, and the return air main roadway is arranged with a row of perforating boreholes 3m apart, bearing due north, with a depression Angle of 5~10° and a length of 70~150m. The boreholes in the link-roadway are located in the east, with a pitch of 3m, a length of 60~120m and a depression Angle of 7~15°. In the centralized air return roadway, the north and south wings were drilled along the seam at the coal top, with a spacing of 3m and a hole length of 120m.

4.2. Gas extraction in heading face
Two tunnels are used for alternate tunneling to reduce the number of coal stripping. According to the actual mining conditions, the gas extraction method of coal roadway tunneling working face is mainly to pre-extract coal seam gas by long borehole along the seam, as shown in figure 1. A row of pre-extraction boreholes were constructed in the vertical coal body in the link-roadway, with a spacing of 3m. There were 7 boreholes in total. Two rows of holes are arranged in the drill field, with the opening height of 1.0m and 1.30m respectively. The spacing between the bottom of the pre-extraction drill holes is 3m, showing a three presbyopia blast hole arrangement. The parameters are shown in table 4.

![Borehole layout diagram](image)

1- Drilling field; 2- Belt crossheading cooperating roadway; 3- Belt crossheading

Fig. 1. Schematic diagram of borehole layout of double tunneling face
Table 4. Parameters of borehole in coal heading face

| Serial number | Angle between borehole and heading direction (°) | Angle between borehole and direction of coal seam (°) | The hole depth (m) | The hole diameter (mm) |
|---------------|-----------------------------------------------|------------------------------------------------------|-------------------|----------------------|
| 1             | 3                                             | 2.5                                                  | 81                | 94                   |
| 2             | 6                                             | 0                                                    | 81                | 94                   |
| 3             | 9                                             | 2.5                                                  | 81                | 94                   |
| 4             | 13                                            | 0                                                    | 81                | 94                   |
| 5             | 18                                            | 2.5                                                  | 76                | 94                   |
| 6             | 24                                            | 0                                                    | 66                | 94                   |
| 7             | 29                                            | 2.5                                                  | 54                | 94                   |
| 8             | 35                                            | 0                                                    | 44                | 94                   |
| 9             | 42                                            | 2.5                                                  | 32                | 94                   |
| 10            | 49                                            | 0                                                    | 26                | 94                   |
| 11            | 57                                            | 2.5                                                  | 22                | 94                   |
| 12            | 0                                             | 90                                                   | 80                | 94                   |
| 13            | 0                                             | 90                                                   | 80                | 94                   |
| 14            | 0                                             | 90                                                   | 80                | 94                   |
| 15            | 0                                             | 90                                                   | 80                | 94                   |
| 16            | 0                                             | 90                                                   | 80                | 94                   |
| 17            | 0                                             | 90                                                   | 80                | 94                   |
| 18            | 0                                             | 90                                                   | 80                | 94                   |
| 19            | 57                                            | 2.5                                                  | 22                | 94                   |
| 20            | 49                                            | 0                                                    | 26                | 94                   |
| 21            | 42                                            | 2.5                                                  | 32                | 94                   |
| 22            | 35                                            | 0                                                    | 44                | 94                   |
| 23            | 29                                            | 2.5                                                  | 54                | 94                   |
| 24            | 24                                            | 0                                                    | 66                | 94                   |
| 25            | 18                                            | 2.5                                                  | 76                | 94                   |
| 26            | 13                                            | 0                                                    | 81                | 94                   |
| 27            | 9                                             | 2.5                                                  | 81                | 94                   |
| 28            | 6                                             | 0                                                    | 81                | 94                   |
| 29            | 3                                             | 2.5                                                  | 81                | 94                   |

4.3. Pre-extraction of coal seam gas by borehole along the mining face

The working face inclination length of No.3 coal seam in Chengzhuang coal mine is 175m. The coal body is drilled in the direction of belt crossheading to track crossheading on the working face, and the coal seam gas is pre-extraction before the working face is mined. The included Angle between the borehole and the roadway is 90°, the hole depth is 150m, the hole diameter is 94mm, and the spacing between the boreholes is 3m. The technical parameters of the borehole are shown in table 5, and the layout of the borehole is shown in figure 2.

Table 5. Technical parameters of parallel drilling along the working face

| Borehole categories                        | Angle between borehole and horizontal plane (°) | Opening height | Note               |
|--------------------------------------------|------------------------------------------------|----------------|--------------------|
| parallel boreholes alone seam of large mining height working face | Angle between borehole and coal seam 1.5° | 1.3            | Odd borehole      |
|                                            | Same as dip Angle of coal seam                 |                | Even borehole     |
4.4. Goaf gas extraction technology

4.4.1. Semi-closed goaf gas extraction. The goaf gas is extracted by intubation on the working face, and the drainage pipe is extended into the airtight 2~3 m. The layout of the roadway and pipeline is shown in figure 3. The drainage pipe should be as close as possible to the closed wall to extract high-concentration gas.

4.4.2. Completely closed goaf gas extraction. "U+U" type ventilation mode is adopted in the working face of Chengzhuang coal mine. After mining, cannula is inserted into the closed wall of the goaf area to extract gas in the goaf area, and the concentration of CO and CH₄ is detected. As shown in figure 4.
5. Clean utilization of gas

5.1. Gas civil-oriented
The gas extraction volume of Chengzhuang coal mine is 136.33m³/min, and the designed extraction concentration is high and the extraction volume is stable. It is close to the town and the surrounding residents are relatively concentrated. Therefore, this part of high concentration of gas can be used for residential use.

5.2. Gas power generation
1m³ of gas (equivalent to 100% CH₄) can generate 3.5kwꞏh of electricity. The gas extraction capacity of Chengzhuang coal mine is 136.33m³/min, and it can generate 28629.30kWꞏh of electricity every day, which can meet the installed capacity of about 10000kW. It can choose 20 500500GF1-3RW/3PW units, the power station investment is expected to be 3000~4000 yuan/kW, the unit guarantee continuous operation power 10000kW, the annual operation time is 330 days, the investment of 20 units is 30~40 million yuan. The waste heat after power generation can be used in steps again, which can be used for miners' bath and winter heating. The schematic diagram of gas utilization system is shown in figure 5.

![Flow chart of gas power generation process](image)

**Fig.5 Flow chart of gas power generation process**

Acknowledgements
This work was financially supported by Gansu youth science and technology fund plan (18JR3RM240) and innovation ability improvement project of colleges and universities in Gansu province (2019-154 B), Gansu safety production science and technology project (GAJ00011) and science and technology research project of china coal industry association(MTKJ2018-277,MTKJ 2018 -279).

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