Study on the application of ultra-high pressure hydraulic slotting in low permeability coal seam

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Abstract. In view of the difficulty in solving the problem of coalbed methane drainage and mining connection in Wangpo coal mine, a new layout method of slotted hole and common hole is put forward by adopting the ultra-high pressure hydraulic slotting technology and combining with the characteristics of coal seam. The drilling construction technology and construction process are optimized. The amount of coal discharged by slotted hole is statistically analyzed, and the gas drainage concentration and extraction of common hole in slotted hole are investigated. The results show that the ultra-high pressure hydraulic slotting radius is 1.60m ~ 2.26m, the average gas extraction concentration of slotted borehole is 54.88%, the pure gas extraction of slotted borehole is 51.4% higher than that of ordinary borehole, and the time of reaching the standard is 37.5% ~ 50%. Therefore, the ultra-high pressure hydraulic slotting technology can better solve the problem of increasing permeability of low permeability coal seam, and provide a new way for the prevention and control of coal mine gas disaster.

1. Introduction

China is one of the countries with the most serious coal and gas disasters in the world. With the continuous increase of mining depth and intensity, the in-situ stress, gas content, etc, also increase, the permeability of coal seam decreases, the pre drainage of coal seam gas becomes more and more difficult under the mining conditions without protective layer, the balance of "drainage, excavation and mining" is difficult to achieve, which seriously restricts the safe and efficient drainage of coal mine [1-3]. Ultra high pressure hydraulic slotting pressure relief and permeability enhancement technology, which takes water as the medium, scours and peels the coal body around the borehole, increases the cracks in the coal body, can greatly improve the gas flow state in the coal seam, create favorable conditions for gas emission, change the original stress and fracture state of the coal body, ease the stress tension state in the coal body and surrounding rock, and greatly change the things in the coal seam. The physical and mechanical properties play a role in releasing pressure, improving permeability and deflation capacity, improving gas drainage rate, saving gas drainage time to reach the standard, and effectively reducing the pressure of coal replacement, which is one of the development directions of the prevention and control measures of gas disasters in coal mines [4-6].

In recent years, with the development of high-pressure water jet technology, the method of using high-pressure water to cut the seam of coal body in the drilled holes has certain effect, increasing the
effect of drilling and drainage, but there are obvious deficiencies in the research and solution of drilling and slag drainage, and the effect of slag drainage directly affects the hole length, extraction efficiency and the promotion and application of the process [7-9]. At present, the hydraulic punching pressure is generally 3Mpa ~ 20MPa, the high-pressure hydraulic slotting pressure is 30MPa ~ 60MPa, the radius after the low-pressure reaming is 200mm ~ 400mm, and the depth of the high-pressure hydraulic slotting is 500mm ~ 800mm. The measures taken for the same drilling are relatively simple, and it is necessary to exit the drill pipe after the drilling construction is completed and then carry out the reaming and slotting, which can not achieve the function of the integration of drilling and slotting without the drill pipe retreating. There is no systematic There are some limitations in the effect of enhancing permeability and construction efficiency of low permeability coal seam, which affect the popularization and application of complete technology.

At present, Wangpo coal mine adopts the conventional drill hole in the bedding to pre exhaust the gas in the working face. The designed drill hole spacing is 2.5m, and the standard time of extraction is 8-10 months. The quantity of drilling work and the standard time of extraction are long. The existing technology is difficult to meet the needs of the connection of mining and extraction.

2. Overview of test working face

3314 working face is located in the south side of four concentrated roadways in the third mining area, which is perpendicular to the main transportation roadways. The stopping line is 225m to the south of the South concentrated return air lane, 1938m to the inside of the stopping line and 180m to the opening. The average thickness of coal seam is 5.5m.

According to the gas content measurement of 3314 working face in the laboratory, the gas content of 3314 working face is 7.2m³/t ~ 11.9m³/t.

In the process of 3314 return air tunnel excavation, the first drill hole shall be constructed from the intersection of 3314 return air tunnel and return bypass 20 m south to the direction of transportation tunnel. The drill holes shall be arranged in parallel with the height of 1.65 m, the spacing of the first 1102 m drill holes shall be 2.5 m, and the spacing of the last 1000 m drill holes shall be no more than 2.0 M. Gas pre drainage of the coal seam shall be carried out before the mining of the working face, and gas extraction shall be carried out at the same time during the mining of the working face.

The hole is sealed with Annette material. The hole sealing process is "two plugging and one injection". The designed sealing depth is more than 15m, and the grouting section is 13m. The hole sealing pipe is made of Φ75mm antistatic PVC pipe, which is connected to the Φ457mm (or Φ377mm) drainage branch pipe through the matching PVC connecting hose under the coal mine.

3. Design of test slotting and drilling

The construction of boreholes starts 10m to the west of No. 10 drilling field of 3314 return air chute. First, common boreholes are constructed at a spacing of 7m, with a hole height of 1.5m, a hole inclination of 0° ~ +1°, a hole depth of 120m, and then ten common boreholes are constructed at the middle of common boreholes, with a hole opening height of 1.5m, a hole inclination of + 3° ~ + 5°, a hole depth of 80m, and a cut is made at a spacing of 2m from the bottom of the hole to 20m from the hole, Each drill hole has 29-31 slits, and the drilling design is shown in Figure 1.
4. Analysis of slotting effect

4.1 Analysis of slotting radius

There are 9 construction slotted boreholes, with a total of 480 m of slotted boreholes, a total of 85 slotted boreholes, a total of 35.55t coal output, and an average of 0.42t coal output of a single knife. See Table 1 for slotting and drilling.

| Borehole Number | Borehole inclination /° | Borehole length /m | Number of slitting knives | Maximum slotting pressure /MPa | Coal output /t | Coal output per knife /t | Average cutting time of single knife /min |
|-----------------|--------------------------|-------------------|---------------------------|-------------------------------|----------------|--------------------------|------------------------------------------|
| G2-1            | +6                       | 50                | 7                         | 75                            | 3.5            | 0.5                      | 12                                       |
| G2-2            | +6                       | 51                | 9                         | 70                            | 4.5            | 0.5                      | 13                                       |
| G2-3            | +5                       | 73                | 15                        | 80                            | 7.5            | 0.5                      | 12                                       |
| G2-4            | +5                       | 61                | 10                        | 70                            | 4              | 0.4                      | 10                                       |
| G2-5            | +5                       | 60                | 9                         | 75                            | 3.6            | 0.45                     | 11                                       |
| G2-6            | +4                       | 77                | 12                        | 70                            | 3.6            | 0.3                      | 12                                       |
| G2-7            | 0                        | 70                | 13                        | 70                            | 5.85           | 0.45                     | 11                                       |
| G2-8            | -1                       | 80                |                           |                               |                |                          |                                          |
| G2-9            | 0                        | 64                | 10                        | 75                            | 3              | 0.3                      | 12                                       |

The equivalent slotting radius is calculated by using the coal output of a single knife as follows:

\[
M = \pi \times r^2 \times h \times K \times \gamma
\]  
(1)

\(\pi\)——PI, 3.14;
\(M\)——Amount of coal dust discharged after cutting, t;
\(K\)——Unbalanced coefficient of coal loss, 0.8–0.95, here take 0.9;
\(r\)——Equivalent radius of slit after cutting, m;
\(h\)——Width of gap after cutting, m, Considering that the slot is irregular in width and narrow in width, the average width of the slot after cutting is calculated as 2cm ~ 4cm;
\(\gamma\)——Density of coal, 1.45t/m³.

The slot formed by cutting is regarded as a cylinder. According to the formula (1), under the condition that the average amount of coal dust discharged from each knife is \(m = 0.42t\), the radius of the slit formed after cutting is calculated reversely: \(r = 1.60m ~ 2.26m\).
4.2 Analysis of pumping effect

(1) Comparative analysis of extraction concentration

As shown in Figure 2, the average concentration of slotted hole is between 44.12% and 73.90%, with an average of 54.88%. It is analyzed that the main reason for the decrease of the concentration of the slotted hole is that the slotted hole is constructed by water drilling, while the cracks of the 3 × coal seam in Wangpo coal mine are relatively developed, and it is easy to cross the hole when encountering water. The decrease of the concentration in the later stage of extraction is also due to the hole plugging caused by the collapse of the coal body in the hole during the extraction process.

![Fig. 2 extraction concentration of slotted drilling](image)

As shown in Figure 3, the extraction concentration of common borehole is relatively stable, ranging from 53.07% to 74.98%, with an average of 68.28%.

![Fig. 3 extraction concentration of common borehole](image)

(2) Comparative analysis of extraction volume in slotted area

As shown in Figure 4, the change of extraction purity of slotted hole in the connection time is between 0.080m³/min and 0.181m³/min, with an average of 0.106m³/min.

![Fig. 4 extraction concentration of slotted area](image)
As shown in Fig. 5, the change of extraction purity of common boreholes in the slotted area in the connection time is between 0.062m³/min and 0.130m³/min, with an average of 0.095m³/min.

(3) Analysis of gas drainage by ordinary drilling in uncut area

In Wangpo coal mine, the average extraction volume per hundred meters of the initial borehole is 0.166m³/min · HM; the attenuation coefficient of gas flow per hundred meters of borehole is 0.0067-0.1345d⁻¹, the average is 0.0412d⁻¹. Therefore, in Wangpo coal mine, the extraction volume of ordinary boreholes (the length of boreholes is calculated as 80m) in the uncut area should meet the formula:

$$q = 0.133e^{-0.0412t}$$  \( (2) \)

Through calculation, it can be seen that the average extraction purity of common drilling within 35 days of extraction is 0.070m³/min, and that of slotted drilling within 35 days of connection is 0.106m³/min. It can be concluded that the average extraction purity of slotted drilling is about 51.4% higher than that of non-slotted common drilling.

4.3 Analysis of extraction radius

Investigation on effective drainage radius of boreholes in the test area.

$$Q_{Total\ extraction} = L_1 \times L_2 \times h \times \gamma \times (W-8) = 31.5 \times 135 \times 5.27 \times 1.45 \times (11.9-8) = 126732m^3$$ \( (3) \)

In the formula, $$L_1$$ refers to the length of the control area of the extraction hole, and $$L_2$$ refers to the width of the area on both sides of the tunnel controlled by the extraction hole.

According to the negative index curve of the pure volume of gas drainage of slotted borehole, the extraction radius of different time can be obtained, as shown in Table 2.
Table 2 calculation results of drilling and extraction radius in test area

| Extraction time (d) | Total amount of single hole pumping (m³) | Number of boreholes | Extraction radius (m) |
|---------------------|----------------------------------------|---------------------|-----------------------|
| 30                  | 4473.2                                 | 28.33               | 0.56                  |
| 60                  | 7890.8                                 | 16.06               | 0.98                  |
| 90                  | 10501.8                                | 12.07               | 1.30                  |
| 120                 | 12496.7                                | 10.14               | 1.55                  |
| 150                 | 14020.8                                | 9.04                | 1.75                  |
| 180                 | 15185.2                                | 8.35                | 1.89                  |

The change curve of effective extraction radius in the test area is shown in Figure 6.

According to the design spacing of boreholes in the test area is 3.5m, and the effective radius of extraction needs to reach 1.75m when the extraction meets the standard. Therefore, the time of gas extraction in the test area is 150 days. Compared with the ordinary boreholes in the uncut area, the spacing of boreholes is 2.5m, and the time of gas extraction meets the standard is 8-10 months. After using the ultra-high pressure hydraulic slotting technology, the work amount of drilling is reduced by 29%, and the standard time of extraction is shortened by 37.5% ~ 50%.

5 Conclusion

(1) Through the underground test, 13 boreholes were slotted. The total length of the borehole slotting is 916.5m, the average coal output of a single drill is 0.42t, and the equivalent radius of the slotting slot is 1.60m ~ 2.26m.

(2) After ultra-high pressure hydraulic slotting, the gas extraction concentration of slotted borehole is between 44.12% and 73.90%, with an average of 54.88%.

(3) After using ultra-high pressure hydraulic slotting, the extraction volume of slotted drilling is between 0.080m³/min and 0.181m³/min, with an average of 0.106m³/min, which is about 51.4% higher than that of ordinary drilling in the area without slitting.

(4) By using the ultra-high pressure hydraulic slotting technology, the drilling work quantity can be reduced by 29%, the standard time of extraction can be shortened from 8-10 months to 5 months, and the standard time of extraction can be shortened by 37.5% ~ 50%.
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