Research on Segmented Hydraulic Fracturing and Enhanced Pumping Technology for Increasing Permeability in Coal Seams

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Abstract

In view of the characteristics of large quantity of pre-pumping gas by drilling along the seam, low efficiency of drilling and pumping, fast attenuation, etc. Staged hydraulic fracturing along the seam was adopted to increase the permeability of coal reservoir. By using the self-developed drag type double packer section sealing equipment and technology, the fracturing hole can be stably and rapidly sealed, and the whole hole section can be divided into three or more sections for fracturing. Compare the gas drainage effect of drilling in fracture zone and non fracture zone, the average concentration of fractured area is 41.5%, and that of non fractured area is 2.0%. The concentration of fractured area is 6.4 times of that of non fractured area. The pure flow rate of 100 holes in fractured area is 2.0 m3/min, and that in the non fractured area is 0.2 m3/min. The pure flow rate of 100 holes in the fractured are is 11.4 times of that in the non fractured area.

Keywords

Drainage Effect; Bedding Drilling Borehole; Staged Hydraulic Fracturing; Concentration Extraction; Enhanced Drainage.

1. Introduction

As the depth of underground mining increases, the difficulty of preventing and controlling gas disasters also increases, and the proportion of gas accidents in coal mine accidents is still relatively high [1-2]. There are many high gas and low permeability coal seams in our country, which restrict the effectiveness of gas extraction. Improving the permeability of coal reservoirs is a necessary way to increase extraction efficiency. Hydraulic fracturing, as a coal seam permeability enhancement measure, is increasingly widely used in high gas and low permeability mines. Domestic and foreign scholars have conducted extensive research on hydraulic fracturing permeability enhancement mechanism, fracturing technology, and crack propagation, providing theoretical basis for on-site practice [3] Domestic and foreign scholars have conducted extensive research on hydraulic fracturing permeability enhancement mechanism, fracturing technology, and crack propagation, providing theoretical basis for on-site practice [4-6].

At present, hydraulic fracturing is widely used in coal mine floor roadway through layer drilling, which has problems such as few coal seams, short effective fracturing sections, and small fracturing impact range. The pre drainage of gas in the layer by layer drilling of the mining face has a significant anti outburst effect on low permeability coal seams, with advantages such as flexible hole layout and convenient construction. The use of layered segmented hydraulic fracturing to enhance gas extraction in the mining face and achieve enhanced permeability of coal reservoirs is of great practical significance. For low permeability coal seams, conventional drilling arrangements often fail to

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achieve the required drainage effect. Communicate the existing fracture network within the coal seam or generate new fracture networks to increase the permeability of the coal body. The main purpose is to achieve enhanced permeability of coal reservoirs.

A certain mine in the northwest belongs to a high gas mine. A permanent high and low negative pressure gas extraction system has been built and put into use on the ground, which implements advanced pre extraction of the excavation face, layer by layer pre extraction of the mining face, and gas extraction of the goaf underground. At present, the 8 # coal seam is being mined with an average inclination angle of 4°, an average coal thickness of 6.8m, a permeability coefficient of 0.17-0.8 $m^2/(MPa.d)$, and a borehole attenuation coefficient of 0.0047-0.0491d^{-1}. The average spacing between pre drilled holes along the mining face is about 5m. The coal seam structure is relatively complex, with 3-4 layers of gangue, and the maximum thickness of a single layer of gangue is 0.6m. The single row of holes for extracting gangue plays a separating role and affects the extraction effect. By utilizing the segmented fracturing tool string jointly developed by Chongqing Institute and National Energy, rapid sealing is achieved. While pressing open the coal seam, it also penetrates through the gangue, playing a combined effect of horizontal and vertical permeability enhancement, forming a complete set of technical equipment and process suitable for segmented hydraulic fracturing of bedding holes in the mine.

2. Stratified Drilling and Segmented Fracturing Technology

2.1 Mechanism of Segmented Hydraulic Fracturing In Sequential Drilling

At present, hydraulic fracturing in underground layer drilling is mostly integrated fracturing, and the disadvantage of integrated fracturing is that as long as the crack extends on a weak surface, encountering structures inside the borehole will cause leakage of fracturing fluid, that is, fracturing is relatively weak.

The position continues, with the presence of blind spots in fracturing. In addition, overall fracturing requires a high flow rate of the fracturing pump group and requires a large amount of water.

The segmented fracturing of the coal seam is carried out by dividing the drilling holes of the coal seam into several sections through a packer, and the spacing and number of segmented fracturing can be adjusted according to the specific conditions of the coal reservoir. The step-by-step segmented fracturing can ensure uniform fracturing, eliminate blind spots in fracturing, avoid uneven overall fracturing and increase permeability, and ensure that high-pressure water pressure enters the target coal body.

2.2 Hydraulic Fracturing and Permeability Enhancement Equipment for Coal Seams

Figure 1. Fracturing pump set

The hydraulic fracturing equipment for underground coal seams mainly includes fracturing pump sets, fracturing packer tool strings, monitoring and safety assurance systems, etc. The fracturing pump set adopts the pump set developed by middling coal Science and Engineering Group Chongqing Research Institute, as shown in Figure 1. The pump set can be used for fracturing of coal seams, fracturing and pressure relief of roof and floor with severe impact tendency and hard coal seams, dust-proof water injection, slit cutting, hole digging and other processes. It is self-propelled, easy to transport, and easy to operate. Remote monitoring, data collection, quantitative processing and other functions.

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The layered segmented fracturing tool string developed by Chongqing Institute consists of guide shoes, packers, screen tubes, sealed drill rods, centralizers, and orifice pressure maintaining devices, as shown in Figure 3. The packer can withstand high pressure of 70MPa, has a large coefficient of expansion, reliable sealing, and can be reused.

Figure 2. Physical diagram of expansion segmented fracturing tool string

2.3 Fracturing Parameter Design

The essence of coal rock damage and failure is the result of continuous energy evolution, and studying fracturing pressure from the perspective of energy is more in line with the actual situation. Therefore, this section determines the magnitude of high-pressure fracturing pressure in coal seams through the principle of energy. The determination of fracturing pressure is crucial for the fracturing effect. If the fracturing pressure is too small, it will lead to poor wetting effect of water flow in the coal seam, which cannot achieve the desired effect; If the fracturing pressure is too high, not only does it increase the requirements for fracturing equipment, but the fracturing process is also prone to inducing coal and gas outbursts. For the convenience of analysis, the stress state model around the fracturing hole can be simplified as a plane strain problem for processing, as shown in Figure 3. The medium pressure stress in the model is positive, and the tensile stress is negative. According to the analysis in Figure 4, the yield failure of the coal body around the fracturing hole is the result of the combined action of high-pressure water and geostress. The force model of a certain unit of coal at the edge of the fracturing hole can be expressed as the following formula:

$$\begin{cases} \sigma_\theta = (1+\lambda) q_0 + 2(1-\lambda) q_0 \cos 2\theta - p \\ \sigma_r = p \\ \tau_{r\theta} = 0 \end{cases} \tag{1}$$

In the formula: is the fracturing pressure, MPa; Is the lateral stress coefficient; Is the vertical principal stress, MPa; The average bulk density of the overlying rock layer; The angle between a certain point on the edge of the fracturing hole and the horizontal direction.

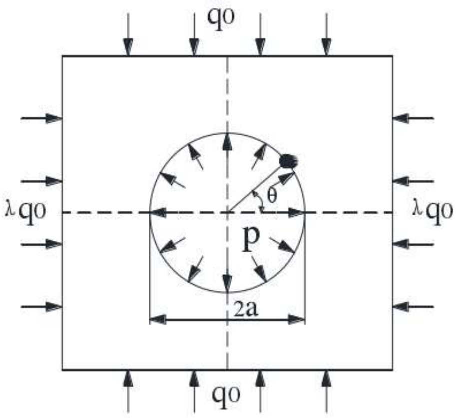

Figure 3. Stress state around coal seam fracturing holes

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$$\begin{cases} \sigma_1 = \frac{1}{2}(\sigma_r + \sigma_\theta)\sqrt{(\sigma_r + \sigma_\theta)^2 + \tau_{r\theta}^2} \\ \sigma_2 = \frac{1}{2}(\sigma_r + \sigma_\theta) \\ \tau_{r\theta} = \frac{1}{2}(\sigma_r + \sigma_\theta)\sqrt{(\sigma_r + \sigma_\theta)^2 + \tau_{r\theta}^2} \end{cases} \tag{2}$$

There exists the following relationship between the principal stress and each stress component, as shown in the above equation.

As the fracturing pressure increases, the minimum principal stress gradually decreases to tensile stress, while the maximum strain energy release rate will first occur in the direction of maximum tensile stress. Based on the actual situation of the mining face on site, the critical water pressure value for coal fracture during high-pressure fracturing can be calculated for different lateral pressure coefficients. The critical fracturing pressure value is calculated using the energy principle to be 25-40 MPa, and the relevant calculation parameters are shown in Table 1.

Table 1. Calculation Parameters

tensile strength σ_t /MPa	Unit weight $\gamma/(KN \cdot m^{-3})$	v	λ
1.4	25.3	0.3	0.8

3. On Site Industrial Testing

3.1 Investigation of the Scope of Fracturing Impact

The location of the fracturing impact radius test is the 81310 rubber transportation channel, the blank area between the extension of the main roadway and the retreat channel in the three panel area. The designed diameter of the fracturing drilling hole is 94mm, and the depth of the designed fracturing and inspection holes is 150m, with a sealing length greater than 40m. During the construction process, all boreholes should be inspected for coal seam gas content and coal seam attitude (whether there is gangue or soft stratification). During the fracturing process, the boreholes should be connected to the extraction pipeline and equipped with automatic water and slag discharge devices.

Experimental investigation was conducted on the fracturing time and fracturing impact radius in the experimental area. Figure 4 shows the design of the fracturing hole and inspection hole. The blue drill hole in the figure represents the fracturing hole. Before fracturing construction, fracturing inspection holes K1 and K0 were constructed at intervals of 20m and 30m on both sides of the fracturing hole to observe the water output during the fracturing process. During the construction inspection hole K1, coal samples were taken to test the original gas content and water content of the coal body. In addition, the lower pipe of hole K1 is inspected for 30m, and the "two plugs and one injection" cement mortar is used to seal the hole for 20m. A gate valve is installed at the hole opening (which is in the open state during fracturing). If the inspection hole produces water (indicating that the affected area of fracturing has covered a range of 20m between the inspection hole and the fracturing hole), the gate valve is closed to continue fracturing until the other side of the inspection hole produces water. Fracturing is stopped and the time from the beginning of fracturing to the inspection hole producing water is recorded. After the fracturing is completed, set up fracturing impact radius inspection holes (K2, K3, K4) at a distance of 35m, 40m, and 45m from the fracturing hole. Take samples to measure the gas content and water content, and compare them with the original coal body to further investigate the fracturing range (if the measured content is smaller than the original content, it indicates that it is within the fracturing impact radius).

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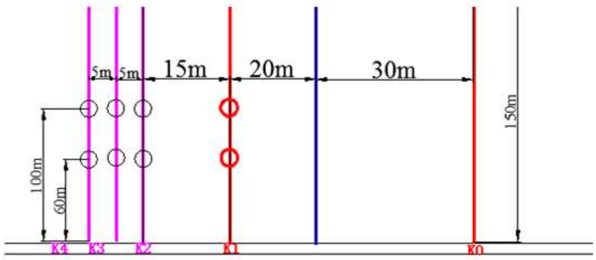

Figure 4. Layout diagram of drilling holes for inspection of fracturing radius in coal mining face

After conducting on-site fracturing tests to investigate the impact radius, it was found that after the water was released from hole K1, the orifice valve was closed to continue fracturing. After a period of time, the water was released from hole K0. Therefore, it was determined that the effective impact radius of the coal layer fracturing reached 30m.

3.2 Layered Segmented Fracturing Design

Based on the effective fracturing radius and fracturing time investigated, the fracturing spacing in the experimental area is comprehensively considered to improve fracturing construction efficiency and reduce construction workload. The proposed layout of fracturing holes and inspection holes is shown in Figure 5. Four holes (Y1~Y4) are compressed in the fracturing experimental area, and two fracturing inspection holes (K1~K5) are constructed with a spacing of 10m on both sides of the fracturing holes. The pumping effect of the 9 holes in the fracturing experimental area is compared with that of the 9 ordinary pumping holes (C1~C9). The design parameters are shown in Table 2, and the specific parameters can be adjusted according to the actual fracturing situation on site. If the radius of the fracturing impact is large, the fracturing spacing can be appropriately increased to reduce the fracturing constructionvolume.

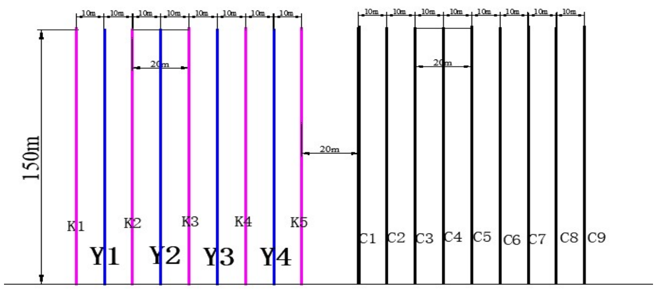

Figure 5. Layout of Fracturing Holes, Inspection Holes, and Comparison Holes in Coal Mining Face

Table 2. Drilling Design Parameters

Hole	Depth/m	Azimuth/°	Inclination /°	Aperture/mm
Y1~Y4	150	90	vertical Lane Gang	94
K1~K5	150	90	vertical Lane Gang	94
C1~C9	150	90	vertical Lane Gang	94

Figure 6. Stratified drilling and fracturing tool string

The area between two packers is the fracturing zone, and the length of the fracturing zone can be adjusted by the length of the fracturing steel pipe between the two packers. The implementation of segmentation is to lower the tool string with dual packers to the preset position at the bottom of the hole, and drag it from inside to outside for fracturing. This cycle achieves segmented fracturing in the set area of the borehole, as shown in Figure 6. This layer by layer fracturing test achieved fracturing in three stages or more.

3.3 Layered Drilling and Segmented Fracturing Construction

A segmented fracturing test was conducted on the 81311 working face, with a spacing of 10m between the two packers and 4 sections for fracturing. The spacing of 20m was designed to be 3 sections. Four fracturing operations were carried out in the fracturing area, with the Y4 # hole having the highest water injection volume. The entire hole section was divided into three sections, with a total of 40m^3 of water injection. The highest pump injection pressure for Y1 fracturing hole was 38MPa. The construction records are shown in Table 3.

Table 3. Fracturing Construction Record

Time	Hole	Water injection volume /m^3	waterflooding time /min	Maximum pumping pressure//MPa
2023-08-6	Y1	24	100	38
2023-8-7	Y2	30	120	36
2023-8-9	Y3	20	80	27
2023-8-12	Y4	40	150	35

4. Investigation on the Fracturing Effect of Layer by Layer Drilling

Use "two plugs and one injection" cement mortar to seal the hole, with a sealing length of 16m. In order to evaluate the fracturing effect, different pumping metering devices are connected between the fracturing area and the non fracturing area, and the pumping parameters such as pumping negative pressure are the same. The single hole concentration before and after fracturing of inspection holes K2 and K4 was statistically analyzed. On August 6th, the fracturing construction of Y1 fracturing hole was carried out. After fracturing, the nearby inspection hole K2 produced water as shown in Figure 7.

Figure 7. Physical photo of K2 inspection hole effluent

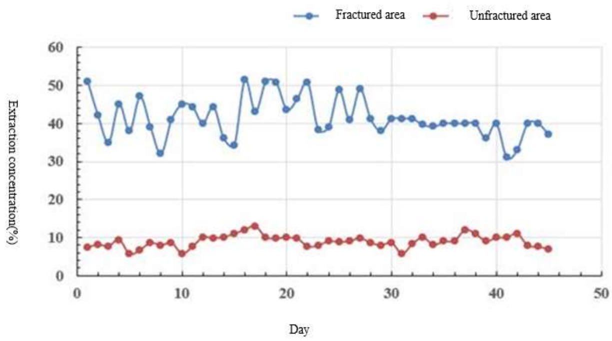

Figure 8. Comparison of Gas Extraction Concentration Changes between Fractured and Non Fractured Zones

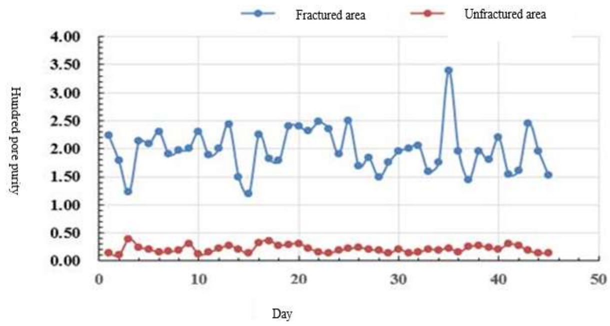

Figure 9. Comparison of Gas Extraction Pure Quantity Changes between Fractured and Non Fractured Zones

An investigation was conducted on the pumping effect in the fracturing test area and comparison area of the 81311 working face of the coal mine. From Figures 8 and 9, it can be seen that the pumping concentration and pure quantity in the fracturing area are significantly higher than those in the non fracturing area. The average concentration in the fracturing zone is 41.5, while in the non fracturing zone it is 2.0. The concentration in the fracturing zone is 6.4 times higher than that in the non fracturing zone. The pure volume of 100 holes in the fracturing area is 2.0m³/ Min. The pure amount of 100 holes in the fracturing area is 11.4 times higher than that in the non fracturing area.

5. Conclusion

(1) Developed segmented hydraulic fracturing equipment, construction technology, design schemes, etc. suitable for testing in layer drilling; According to the on-site fracturing test, the effective influence radius of bedding fracturing reaches 30m.

(2) After fracturing, the single hole concentration of K2 inspection hole increased from 10% to over 30%, and the single hole concentration of K4 inspection hole increased from 10% to 80%; The average gas extraction concentration and pure amount in the fracturing area are 6.4 times and 11.4 times higher than those in the non fracturing area, respectively. Prove that carrying out segmented hydraulic fracturing through layer by layer drilling in coal mines can effectively form uniform communication coal seams and achieve the goal of increasing coal seam permeability.

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References

[1] Yao Zhuangzhuang, Lin Fujin, Wu Wenbin, etc Segmented hydraulic fracturing and permeability enhancement test for coal mining face drilling along layers [J] Coal Mine Safety, 2021, 52 (3): 9-13.

[2] Zhou Xihua, Zhou Lijun, Fan Chaojun, etc Simulation and experimental research on hydraulic fracturing promoting gas extraction in low-permeability coal seams [J]. Chinese Journal of Safety Sciences, 2017, 27 (10): 81-86.

[3] Yao Zhuangzhuang. Experimental study on the time-varying law of coal particle gas desorption [J]. Industrial and Mining Automation, 2020, 46 (5): 94-98.

[4] Yuan Liang, Lin Baiquan, Yang Wei Research progress and development direction of gas control in coal mine hydraulic technology in China [J]. Coal Science and Technology, 2015, 43 (1): 45-49.

[5] Wu Xiuping Research on the Expansion Law and Mechanism of Fractures in Horizontal Wells of Fractured Soft and Low Permeability Coal Seams [D]. General Institute of Coal Science Research, 2017.

[6] Zhang Qun, Ge Chungui, Li Wei, et al. High efficiency extraction model for fractured and low-permeability coal seam roof horizontal well segmented fracturing coalbed methane [J]. Journal of Coal Science, 2018, 43 (01): 150-159.