Research on the Optimization of Coalbed Methane Utilization Based on Hydraulic Fracturing Enhanced Permeability Technology

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Abstract: This study presents the solution of the extraction and coal seam. Through the combination of numerical simulation study and field investigation, the fracturing radius is 12 meters after 30 days of hydraulic fracturing in the 6th coal seam, and the implementation measures of fracturing hole spacing of 20 meters and 5 meters were formulated. The results showed that the hydraulic fracturing technology significantly increased the gas concentration of drilling extraction to 93%, and the attenuation rate of gas concentration in 120 days was 14%. This technology has significantly increased the extraction flow, and effectively controlled the occurrence of coal seam fire. The methods and results of this study are instructive for coalbed methane utilization in other mines.

1. Introduction

As a kind of efficient and clean energy, the extraction and utilization of coalbed methane(CBM) can not only effectively reduce coal mine gas accidents and ensure the life safety of miners, but also increase the supply of clean energy, which is of great significance to reducing greenhouse gas emissions and protecting the environment and resources. However, in the actual process of coal mining, gas extraction measures such as pre-pumping and side extraction are often faced with the dilemma of low extraction efficiency due to the poor air permeability of coal seam, which makes coalbed methane cannot be effectively used, and then leads to a serious imbalance in the process of "extraction-excavation-mining".

In view of this problem, improving the air permeability of coal seam has become the key. In recent years, coal penetration technology has developed rapidly, including hydraulic fracturing technology, hydraulic cutting technology and CO_2 Crack-induced crack increase penetration technology, controllable pulse-induced crack increase penetration technology, etc. However, due to the complexity of stratigraphic and geological structure, all the applied technologies have some limitations.

In hydraulic fracturing technology, Chinese experts and scholars have conducted a lot of research, and accumulated rich research results. For example, Wang Zhichao made an in-depth study on the application of hydraulic fracturing technology in the withdrawal channel of large mining and high working face. Through the observation and analysis of the roof ore pressure data in the fracturing process, the stress distribution model of hydraulic fracturing technology was proposed, which provides a theoretical basis for the application of hydraulic fracturing technology in large mining and high working face[1]. Guo Longjiang made a systematic study on the gas extraction in the application process of hydraulic fracturing technology in the coal mining face roadway, and determined the technical method of hydraulic fracturing technology in the prevention and control of specific mine gas disaster[2]. According to the application of hydraulic fracturing technology in the 842 working face of Wobei Coal Mine, Zhou Xuebin studied the stress distribution deeply, and proposed the research method of hydraulic fracturing radius, which provided theoretical support for the investigation of the fracturing radius of similar mines[3].

In view of the above research background, in view of a coal seam high low permeability and gas extraction difficulty, coal seam easy spontaneous combustion, this research will focus on the application of hydraulic fracturing technology, in order to improve the permeability of coal seam through the technology, and improve the efficiency of gas extraction, realize the safe and efficient mining of coal mine.

2. Project Overview

A coal mine is a typical outburst mine, and its main mined coal seam is the 6th coal seam. The average thickness of the coal seam is 6m, and the average inclination is 6°, which has good mining conditions. The roof is mainly composed of mudstone and sandpaper mudstone with an average thickness of 12m; the floor is mainly siltstone and mudstone with an average thickness of 8m.

The maximum original gas pressure of the 6th coal seam is 2.12MPa, and the maximum gas content is

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13.89m³/t. The gas problem of the coal seam is rather severe, and effective gas extraction measures should be taken in the mining process to ensure safe production.

The standby mining face is S204 fully mechanized mining face, the direction length of the working face is 689m, and the cutting eye length is 200m. The advanced comprehensive mechanized mining method is adopted. In order to control the gas, the working face adopts the pre-pumping gas control measures along the coal seam. The design spacing of extraction holes is 3m and the estimated extraction radius is 1.5m. During extraction, use high negative pressure pump and ensure that the negative pressure is not less than 20 kPa.

After 5 months of continuous extraction, the K1 value and residual methane content of 20 points selected on the working face were investigated, and the results showed that the maximum K1 value of coal seam reached 0.8ml/g·min$^{1/2}$,The maximum value of the residual methane content is 10m^3/t。It shows that the coal seam has been extracted for a long time, but the residual methane content is still high, and the actual gas extraction volume is small, which cannot reach the target of continuous extraction for 6 months.

Further analysis of the data of extraction flow and extraction concentration found that the decay rate of gas extraction concentration is fast. After only one month of extraction, the extraction concentration of most boreholes has decreased to less than 20%.This phenomenon shows that the main reason for the substandard extraction is the poor permeability of coal seam, which leads to the difficulty of effective gas extraction. Therefore, in order to improve the efficiency of gas extraction, further penetration measures need to be taken. As show in figure 1.

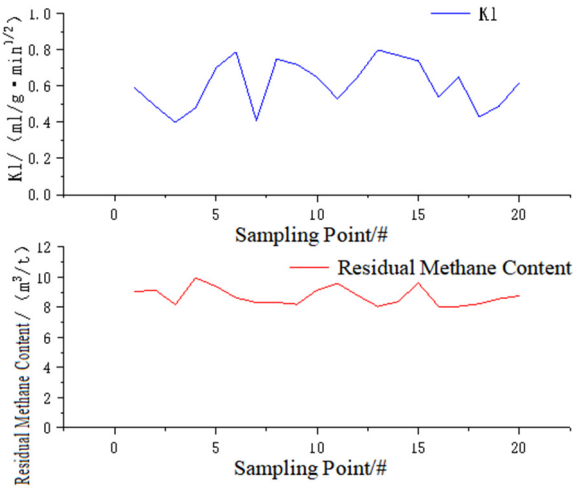

Figure 1. K1 value and residual methane content

3. Study on Cracking Radius of Hydraulic Fracturing Technology

In view of the poor gas extraction effect of S204 fully mechanized mining face, it is difficult to meet the needs of CBM utilization and safe production, so it is necessary to adopt the crack and penetration measures to improve the air permeability of coal seam in the 6th coal seam. Due to the characteristics of easy to spontaneous combustion, hydration measures can not only improve the permeability of coal seam, but also effectively prevent the occurrence of fire accidents. Therefore, this study decided to use hydraulic fracturing to treat the 6th coal seam.

To ensure the effectiveness of hydraulic fracturing technology, the cracking radius in no. This study uses a combination of numerical simulation and field investigation to comprehensively evaluate the effect of hydraulic fracturing technology.

3.1. Numerical Simulation Study

Currently applied hydraulic fracturing techniques can generate water injection pressure of up to 31MPa[4~6]. Since water is used as the fracturing medium, the pressure generated around the fracturing borehole is assumed to be linearly balanced, and the coal rock mass is considered as a homogeneous medium. Now simulation the simulation performed using COMSOL software.

The basic mechanical parameters were obtained by sampling the 6th coal seam, and the results are shown in Table 1.

Table 1. Basic mechanical parameters of coal rock mass

Lithology	The 6th coal seam
Density /(kg/m)	1700.18
Uniaxial compressive strength / MPa	13.38
Modulus of elasticity /GPa	1.81
Poisson ratio	0.8
Cohesive strength /MPa	1.18
Internal friction angle	20.18

Through the simulation, we obtained a cloud map of the gas pressure distribution around the borehole when the water injection pressure is 10d, 30d and 60d, as shown in Figure 2.

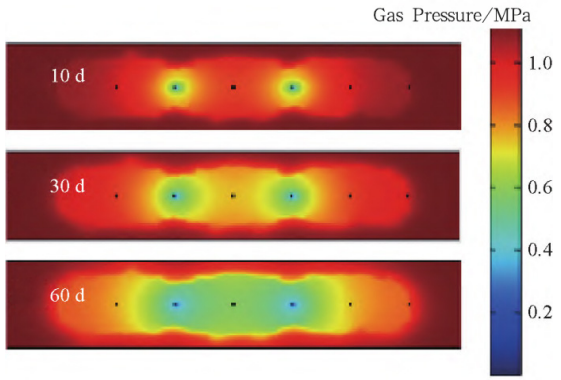

Figure 2. Cloud map of gas pressure distribution in different time periods

By analyzing Figure 2:

- After 10 days of the implementation of hydraulic fracturing technology, the stress within 3m around the fracture hole is significantly released, and the stress in the release area is less than 0.6MPa.
- After 30 days of hydraulic fracturing technology, the stress within 12m around the fracture hole is further released, and the stress in the release area is reduced to less than 0.5MPa.

- After 60 days of hydraulic fracturing technology, the stress within 20m around the fracture hole was released in a larger range, and the stress in the released area was maintained at less than 0.6MPa.
- When two hydraulic fracturing drilling holes are fractured at the same time, an energy coupling area is generated between them, which significantly expands the penetration range between the two drilling holes through the coupling action.

Based on the above simulation results, it can be concluded that in order to improve the penetration effect, we can shorten the fracturing hole spacing or increase the fracturing cycle. This will help to improve the permeability of the coal seam more effectively, and then improve the efficiency of gas extraction, to ensure the effective utilization of coalbed methane and the safe and efficient mining of coal mines.

3.2. Cracking Radius Investigation

In order to further investigate the gas cracking radius, the continuous hydraulic fracturing technique for a single borehole was performed for 30d, and the gas extraction concentration at different locations in different time periods was investigated respectively. The results are shown in Figure 3.

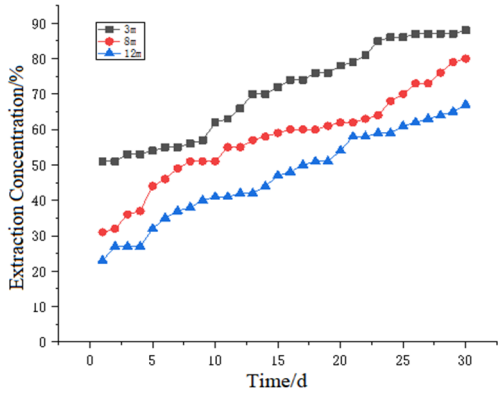

Figure 3. Concentration of extraction holes at different distances from the borehole

According to Figure 3, the initial extraction concentration is 3m is 51%, the gas extraction concentration is 88%; at 8m from the fracturing drilling hole is 31%, and 80%; at 12m, the initial extraction concentration of the fracturing drilling hole is 23%, and the gas extraction concentration reaches 67% at 30d.

3.3. Interpretation of Result

Based on the results of gas-induced crack radius, we can draw the following analysis and conclusions:

3.3.1. Relationship between gas extraction concentration and distance

With the increasing distance of gas extraction drilling hole from hydraulic fracturing drilling hole, the gas extraction concentration of gas extraction drilling hole shows a significant decreasing trend. This indicates that the fissure network formed by hydraulic fracturing drilling mainly affects the area close to the drilling hole, while the farther the distance, the weaker the effect of the fissure network.

3.3.2. Relationship between gas extraction concentration and time

At the fixed position point, the extraction concentration gradually increases with the fracturing time. Due to the continuous hydraulic fracturing of the fissure network, the permeability of the coal seam increases, making the gas easier to desorbe from the coal seam and flow to the extraction hole.

3.3.3. Investigation of gas-induced crack radius

It can be seen from the investigation results that the positions of 3m, 8m and 12m within 30d have good gas extraction effect, and it can be inferred that the maximum fracture radius of hydraulic fracturing technology is at least 12m. The specific fracture radius needs to be calculated accurately according to more data points.

3.3.4. Prediction of extraction concentration and flow rate

It can be seen from the investigation results that from the 24th day, the change of the gas extraction effect at 3m away from the hydraulic fracturing borehole tends to flatten out. Because of the distance from hydraulic, the fissure network of the closer the location of the fracturing hole is more active. With the extension of the fracturing time, the development of the fissure network first reaches the physical limit, and tends to be stable, the permeability of the coal seam reaches a relatively balanced state, and the rate of gas desorption and flow also tends to be stable. It is predicted that after 30d, the extraction concentration and flow at positions 8m and 12m from the hydraulic fracturing hole will be gradually stabilized with the development of the fissure network.

3.3.5. Prediction of the permeability-increasing effect of hydraulic fracturing technology

According to the above analysis, the coal seam permeability reached 3m from the hydraulic fracturing borehole until the 24th day. It can be inferred that the improvement of coal seam permeability by hydraulic fracturing technology is positively correlated with fracturing distance, fracturing time and basic mechanical parameters of coal seam within a certain range, and has an upper limit. It is predicted that after 30d, the air permeability of the coal seam at 8m and 12m away from the hydraulic fracturing borehole will also reach the maximum successively.

3.3.6. Comparison between actual observation and numerical simulation

The actual observation results are basically the same, which verifies the effectiveness of the numerical

simulation in predicting the effect of gas extraction. This provides an important theoretical basis for the further optimization of hydraulic fracturing technology and gas extraction scheme.

3.3.7. Analysis Results

Through the investigation of continuous hydraulic fracturing technology in a single borehole, it is found that the hydraulic fracturing technology can effectively improve the gas extraction efficiency of the 6th coal seam in a coal mine, and the extraction concentration and flow are affected by the distance and hydraulic fracturing time. The closer to the fracturing hole, the higher the extraction concentration; with the fracturing time, the extraction concentration gradually increases and eventually stabilizes. The hydraulic fracturing radius of 30 days in the 6th coal seam reaches at least 12m.

4. Technology application and effect investigation

Because the hydraulic fracturing measures should not be implemented for a too long cycle, the fracturing cycle of about 30d is relatively in line with the normal production demand of the mine, the 30d hydraulic fracturing radius is 10m, and the spacing between the two fracturing holes is 20m. The design of plain pre-extraction drilling and gas fracturing drilling is shown in Figure 4. The location of the construction drilling hole is as shown in Figure 4. The construction drilling hole is S204 transportation channel and return air channel, the fracturing drilling hole diameter is Φ 90mm, and the capsule sealing hole is adopted. The aperture of the extraction hole is Φ 50mm. After the completion of the construction, polyurethane and cement slurry are used to seal the hole. The hole sealing process is the traditional "two plugging and one note", and the length of the sealing hole is not less than 10m. After the completion of the construction, the continuous pumping was conducted, and the extraction concentration and flow rate were calculated for 120d. The statistical results are shown in Figure 5.

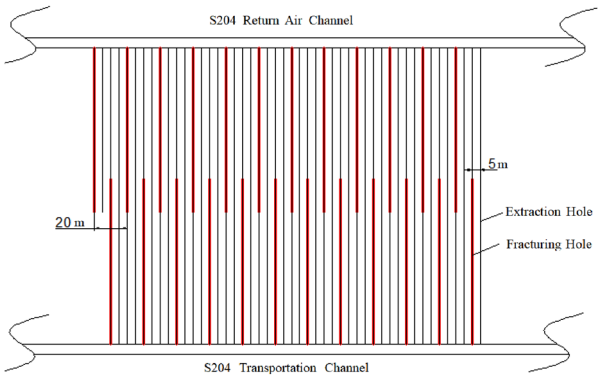

Figure 4. Construction measures of hydraulic fracturing drilling holes

According to the analysis of Figure 5, the maximum value of internal gas extraction concentration in 120d is 93%, the minimum value after attenuation is 80%, and the attenuation rate is 14%; the maximum value of extraction flow in 120d is 3.0m^3/min, lowest value 2.2m^3/min, with a decay rate of 27%. According to the statistics of the mining side, the hydraulic fracturing technology is not used, and the maximum extraction concentration of single hole of gas extraction hole is about 70%, and attenuated to about 14% after 38d. After comparing the area with hydraulic fracturing technology and the area without hydraulic fracturing technology, the gas extraction effect was significantly improved after increasing the permeability with hydraulic fracturing technology, which proved the effectiveness of hydraulic fracturing technology in improving the utilization of coalbed methane and showed significant advantages in mine gas extraction.

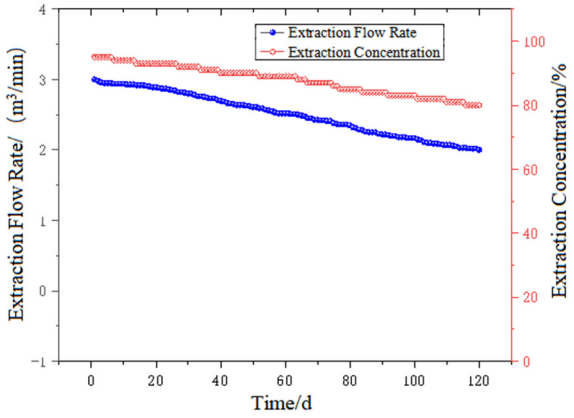

Figure 5. Investigation of the extraction concentration and flow rate after the implementation of the measures

Through the reasonable design and construction of hydraulic fracturing measures, this technical application effectively improves the extraction concentration and flow of gas extraction drilling hole in S204 fully mechanized mining face, extends the duration of effective extraction effect, and creates conditions for the effective utilization of coalbed methane. This technology is of great significance for ensuring the safe mine production and improving the utilization of CBM. In the subsequent study, the technical parameters of hydraulic fracturing need to be investigated and optimized in different areas of a coal mine, so as to make more efficient extraction and utilization of CBM.

5. Conclusion

A mine is a typical high outburst and low breathable coal seam, with low extraction concentration, fast attenuation speed and long extraction standard cycle. In order to solve the above problems and improve the utilization of CBM, the hydraulic fracturing technology is adopted to increase the penetration of the S204 working face, and the following conclusions are obtained:

(1) The air permeability of the 6th coal seam is poor, which cannot meet the needs of mine CBM utilization and gas control, so further penetration measures should be taken;

(2) Simulation study and comprehensive investigation, we can show that the maximum effective cracking radius after 30d hydraulic fracturing is 12m;

(3) After the use of hydraulic fracturing technology, the concentration of gas extraction is increased by 93% from the original single hole 70%, the attenuation rate of 120d concentration is reduced to 14%, the attenuation of extraction concentration is significantly reduced, and the effect of coal seam penetration is obvious.

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