Hydraulic Fracturing Application in Coal Seams of High Gas Content and Low Permeability

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Abstract
Hydraulic Fracturing is an important measure to relieve pressure and enhance permeability. In order to make the research of the effect of hydraulic fracturing application in coalmines, this text analyzes the theory of hydraulic fracturing technology used in coal breaking and high pressure ground water applied to relieve pressure and enhance permeability of coalmines, providing a theoretical basis to the application of hydraulic fracturing technology. It also obtains the pattern of crack propagation during the process of coalmine hydraulic fracturing by using numerical simulation software of geotechnical engineering FLAC3D to make a numerical simulation research of hydraulic fracturing. This text researches the technological parameter, fracture equipment and extraction system in the field trial of hydraulic fracturing and finished the hole sealing and fracture test. The theory, numerical simulation and the results of the field investigation suggest that after hydraulic fracturing, the concentration and scalar quantity of gas extraction is about twice as much as that before hydraulic fracturing. It has enormously improved gas extraction efficiency.
Keywords: LOW PERMEABILITY;COAL SEAM; HYDRAULIC FRACTURING; NUMERICAL SIMULATION; GAS DRAINAGE

0 Introduction

Coal seams in China possess the feature of high gas content and low permeability [1]. During the process of coal tunnel drilling and extraction, a large amount of gas will surge up to the tunnel that will bring about a frequent overrun of gas concentration in return airway. Furthermore, as mining depth is increasing, gas outburst potential and explosion risk is also magnified, which exposes a great threat to safety production in coalmines. If simply adopt the borehole method in extracting seams of high gas and low permeability, it will not only result in an immense construction capacity but also low extraction efficiency.

Nevertheless, hydraulic fracturing technology has an edgy of low cost, simple operation and high practical applicability as well as an obvious effect of enhancing permeability that can highly improve gas extraction efficiency.

According to the high gas content and low permeability characteristics of the trial coalmine, this text use numerical simulation software of geotechnical engineering FLAC3D to make a numerical simulation research of hydraulic fracturing, thus to analyze the pattern of crack propagation during the process of coalmine hydraulic fracturing. The field investigation suggests that after hydraulic fracturing, the permeability of the seams is increased and the gas extraction quantity is highly improved.

1 General survey of test mine

The seam of this mine is of high gas content and low permeability. Presently, the mine production is at second level and the main extraction seam is NO.14 seam. This seam has single structure: The dip angle of the seam is 10~15˚. The thickness is 1.8~2.15m. Permeability coefficient is 0.023~0.026m^2/MPa^2.d. Borehole flowing attenuation coefficient is 0.0243~0.1306d^{-1}. Pore volume is 0.083 m^3/m^3. The difficulty degree of the seam gas drainage is very high. The gas pressure of the seam is 7.1MPa. The gas content of the seam is 25.1m^3/t. The thickness of the soft seam is 0.1m and the firmness coefficient is 0.31. The gas identification result in 2014 is as follows, absolute magnitude: 119.2 m^3/min, relative magnitude: 46.8 m^3/t, seam explosion coefficient: 19.1~53.1%.

Since the main extraction seam is of low permeability, gas pre-drainage is very difficult and the extraction efficiency is quite low. During the working face mining, the gas emission quantity reaches up to 40m^3/min that brings about a frequent overrun of gas concentration in return airway. However, the current gas control measure cannot efficiently deal with gas emission at such a high level. Therefore, adopt an appropriate measure to increase the seam permeability and gas extraction efficiency. The hydraulic fracturing technology is thus applied to increase the seam permeability and gas extraction efficiency.

2 The analysis of hydraulic fracturing and permeability improvement theory

Coal seam hydraulic fracturing breaking aims to divide the coal seam internally with the help of high-pressure ground water's supporting in the two sides of the weak surface among various weak surfaces in the coal seam and expanding and extending those weak surfaces. On one side, the stretch and expansion of the weak surfaces increases the space volume of the crevice etc. On the other side, the extension of the crevice increases of the connection between the crevices, thus to form an intertwined connected network of many crevices. This kind of connected network of crevices highly improves the permeability rate of the coal seam.

Hydraulic fracturing and permeability improvement technology mainly relieve pressure and improve permeability from the following aspects:

(1) Relieve pressure from coal mass and improve the air permeability of the seam

When high-pressure ground water penetrates into the seam, it ceaselessly connects and expands pores and fissures to cause an intense change and re-distribution of the internal stress of the seam which thus formulates stress concentration and radially transfer towards outside around the gap caused by stress along with the extension and expansion of the gap and eventually forms a stress-relaxed zone around the drill hole. The connection and expansion of the pores and fissures that will form a gap and enhance the displacement of the coal body will increase the tunnel that gas flows and reduce the obstruction that the gas faces when it flows and penetrate in the coal body. The air permeability in the seam is increased and thus speeds up the process of desorbing absorbed gas, releasing free gas and also increasing flow rate and quantity of gas in the coal body.

(2) Fully moisten the coal body and increase its plastic property

The injected high-pressure water is ceaselessly cracking and breaking the coal body at depth and extending and expanding the gap in it. The equilibrium state of gas in the seam is destroyed for a great amount of absorbed gas turning into free gas is brought away by water. The plastic property of the coal body that is moistened is increased and its elasticity potential is lowered. Once the basic condition that the coal body accumulates its energy was destroyed, the diffusing speed of gas in the coal would be diminished.

(3) Improve the drainage effect of gas

After high-pressure ground water penetrating into the seam during hydraulic fracturing, it will create a great amount of pores and fissures and increase the tunnel that gas flows and the air permeability in the seam which thus speeds up the process of releasing and transporting free gas. More absorbed gas will turn into free gas and then boost the intensity and time of duration of gas emission.

3 The numerical simulation of hydraulic fracturing and permeability improvement theory

Since it is very difficult to observe the breaking process of coal-rock mass at the site or during the experiment, therefore, usually apply numerical analysis method to investigate the breaking process. FLAC^{3D} numerical simulation software was based on Lagrange algorithm and mingling-dispersing partition technology. It can compile Seepage-stress connection equation through embedded scripting FISH program language, hence to carry out numerical analysis on the pattern of crack propagation during the process of hydraulic fracturing. Therefore, this article applies FLAC^{3D} numerical simulation software to simulate the pattern of crack propagation.

3.1 Set up a computation model

The computation model that mainly focuses on deformation and damage of the seam during hydraulic fracturing possesses a limited dividing elements. Therefore, those computation model units should be divided unevenly and the surrounding area of breaking holes will be divided into small units and units divided in exterior zone will be gradually amplified. As is shown in the Fig.1, a 20×40×20 hydraulic fracturing physics computation model set according to the physical and mechanical parameter of the coal body in the main extraction seam. Table 1 is about the physical and mechanical parameter of the coal body in the main extraction seam.

Table 1. Physical and mechanical parameter of coal body in the main extraction seam

Bulk B/Pa	Shear S/Pa	Friction F/°	Cohesion C/Pa	Tension T/Pa	Density D/kg.m^{-3}
1.19×e^8	0.368×e^8	20	1×e^6	0.035×e^6	1400

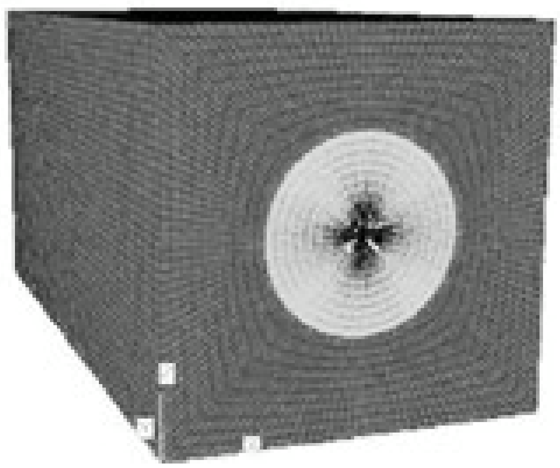

Figure 1. Hydraulic fracturing physics computation model

Subsurface and side of the model are supposed to restrict horizontal and vertical shift. The upper face of the mode is imposed by weight stress and the tectonic stress at horizontal direction from overlying strata. As breaking process is conducted during extraction at the working face, the most released stress during extraction process is the horizontal stress at the direction of seam strike, and the second is the horizontal stress at the direction of fall while little at the vertical direction. Therefore, according to the extraction depth, the horizontal stress at the direction of seam strike is settled at 10Mpa, and stress at the direction of fall is 15Mpa while the stress at vertical direction is 20Mpa. The computation adopts the Mohr-Coulomb Yield Criterion.

During deep engineering, the original stress field is the composition of the structural stress field and weight stress field. In $FLAC^{3D}$, definition of the boundary conditions does not include usual boundary conditions but the speed boundary conditions. That is to say, the control of boundary conditions is realized by the speed at pitch point of model boundaries. To solve this problem, high-speed S-B was employed to imitate the original stress field. Concrete thoughts: During the formation of original stress field, speed boundary conditions won't be set in numerical model. It just impose stress boundary conditions and keep them stable in accordance with distribution of ground stress field at model surface. The stress boundary imposed on model surface can be regarded as the stress on the outermost layer of the model, and this stress will be acted on the pitch point of the outermost layer of the model by transforming into node force[5].

3.2 Simulation results

Hydraulic pressure during hydraulic fracturing process was 10Mpa, 20Mpa and 30Mpa. The length of the fracturing hole during the simulation is 20m and the length of the hole sealing is 10m. After the initialization of the model by ground stress, compressive stress was imposed on the inner surface of circular cylinder of the drilling hole. As is shown in Fig.2, calculation method of seeking explicit solution was adopted, and time step was established as 5000. Due to the length of the article, this text only provide simulation results in the following Fig.3- Fig.5 when hydraulic pressure was 10MPa, 20Mpa and 30MPa.

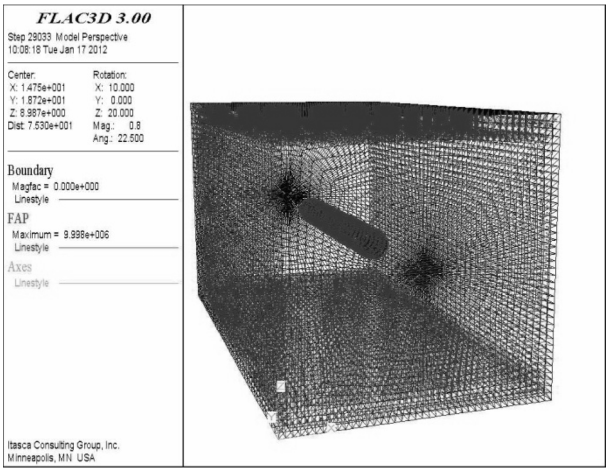

Figure 2. Pressure state of hydraulic fracturing holes

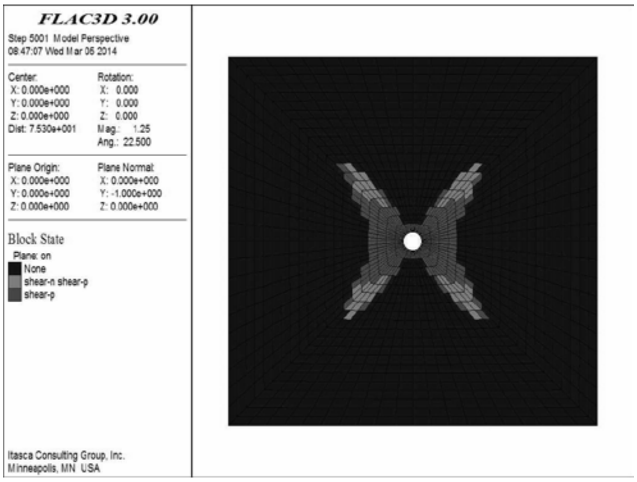

Figure 3. 10Mpa state of vertical fracture surface of the borehole after hydraulic fracturing

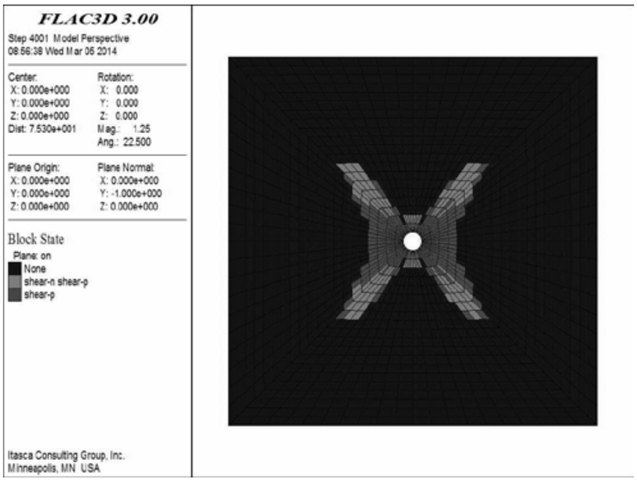

Figure 4. 20Mpa State of Vertical Fracture Surface of the Borehole after Hydraulic Fracturing

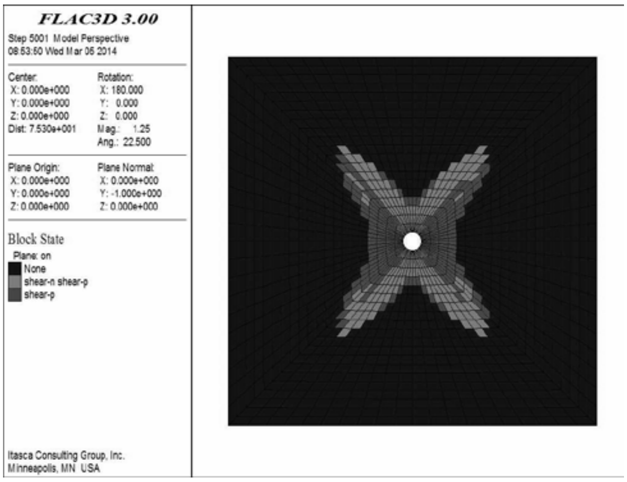

Figure 5. 30Mpa State of Vertical Fracture Surface of the Borehole after Hydraulic Fracturing

3.3 Analysis of the simulation results

Conclusions can be drawn from the state of vertical fracture surface of the borehole after hydraulic fracturing that the main breaking type of the coal body during hydraulic fracturing is shear breakdown. The expansion boundary and angle of the fracture at different orientations can be calculated according to Fig.3 to Fig.5. The following Fig.6.

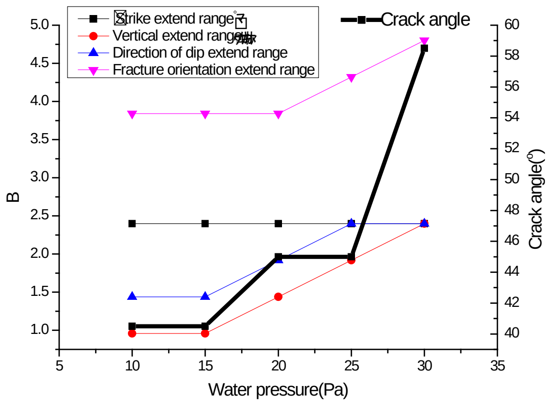

Figure 6. Hydraulic fracturing simulation result

From Fig.6, it can provides that during hydraulic fracturing, the fastest growing scope of breaking sections lies in the main direction of fractures. Secondly, growing speed of the fracture radius at trending direction and breaking sections at inclination direction is in the middle, while as growing speed of the fracture radius at orientation direction is the slowest. At the direction of fractures, as the pressure increases, the angle of fracture expansion increased gradually. That is to say, scope of fracture is expanded.

4 The on-site application of hydraulic fracturing and permeability improvement technology

4.1 Fracturing equipment and process flow

As is shown in Fig.7, hydraulic fracturing equipment includes water injection pump, water block, pressure gage, pressure regulating valve, high-voltage tube etc [6].

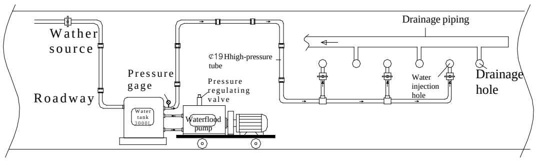

Figure 7. Water flooding and fracturing equipment and drainage system

Before hydraulic fracturing, drainage borehole should be under construction at the first step and collect coal samples of all investigated holes. Those samples should be sent for testing gas content of the seam, void content of the coal body, moisture content, water saturation etc. Finally, Discharge gas after sealing all the investigated holes and inspect gas flow rate and concentration at every single hole until they are stable. Then the fracture hole could be constructed. Hydraulic fracturing special hole-packer will be used in sealing the hole after construction and then fracturing will be begun. Gas flow rate and concentration of the drainage hole should be inspected after the hydraulic fracturing experiment and compared with the data collected before fracturing [7].

On the basis of the FLAC^{3D} numerical simulation results, when the water injection pressure of the seam is 30MPa, fracturing radius at the inclination surface of the seam is 2.4m. Therefore, the shortest distance between the water injection hole and the extraction hole can be set at 5m during on-site experiment and the actual numerical figure of the fracture radius will be ultimately decided by field test. The arrangement of the water injection hole and extraction hole can refer to Fig.8:

Figure 8. The arrangement of the water injection hole and extraction Hole

The extraction hole should be under construction at first and the aperture is 113mm. Extraction can be conducted after sealing the hole and gas extraction quantity and concentration of the drainage hole should be recorded until they are stable so that the data can be compared and analyzed with the extraction effect after hydraulic fracturing.

The original water injection pressure was settled at 10MPa and it should be increased gradually at 1MPa every five minutes. When the water pressure rises up to a certain figure and after a period of stability, it will fall rapidly and not rise obviously even if under continuous pressure increasing which means that the coal body of the water injection hole was fractured and it is the time to finish water injection. The extraction effect before and after water injection will be then compared and analyzed. Hydraulic fracture index of the experimented drilling hole is shown in Table 2.

Table 2. Hydraulic fracture index of the drilling hole

Mode	Depth /m	Diameter /m	Length /m	Time /min	Yield /m^3	Pressure /MPa
Water Injection Hole	150	113	20	150	31	26
Gas Drainage Hole	150	113	6			

4.2 Analysis of the on-site experiment results

On the basis of the variation of the gas drainage concentration and purity in the extraction hole before and after water injection, data accumulated are: after water injection and fracturing, the gas drainage concentration of 1# extraction hole reached to 68.6%; the gas drainage concentration of the 2# extraction hole reached to 63.6%, which was 1.8times and 2.1 times of the concentration before water injection and fracturing respectively. The gas drainage purity of the first extraction hole reached to 0.31m^3/min; the drainage concentration of the second extraction hole reached to 0.26m^3/min, which was 2.6times and 1.8 times of the purity before water injection and fracturing respectively. Thus, the hydraulic fracturing and permeability improvement technology applied in the test block has achieved tremendous effects in increasing gas extraction quantity.

5 Conclusions

(1) When hydraulic fracturing numerical simulation was conducted to the coal body, conclusion can be drawn from the state of vertical fracture surface of the borehole after hydraulic fracturing is that the main breaking type of the coal body during hydraulic fracturing is shear demage.

(2) When hydraulic fracturing numerical simulation was conducted to the coal body, conclusion can be drawn that growing speed of the fracture radius at trending direction and breaking sections at inclination direction is in the middle, while as growing speed of the fracture radius at orientation direction is the slowest. At

the direction of fractures, as the pressure increases, the angle of fracture expansion increased gradually. That is to say, scope of fracture is expanded.

(3) After water injection and fracturing, the gas drainage concentration of the extraction hole reached over 60% and the gas drainage purity of the extraction hole reached around 0.3m^3/min that was 2times before water injection and fracturing. Hydraulic fracturing and permeability improvement technology applied in the test block has achieved tremendous effects in increasing gas extraction quantity.

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