Influence of water injection parameters on fracturing effect in coal seam hydraulic fracturing

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Abstract. According to the basic parameters of Yangquan mining area, based on the determined meso physical and mechanical parameters and geological parameters, several groups of numerical calculation models considering different fracturing parameters (water injection flow and water injection time) are established. Then, the numerical simulation test of water injection fracturing is carried out by using the particle discrete element program, and the influence effect of related parameters of coal seam hydraulic fracturing is analyzed numerically, the influence of flow rate, pressure, time and other parameters on water injection flow is obtained.

1. Introduction

Water injection pressure is also an important parameter to control fracturing effect[1,2]. In the actual process of hydraulic fracturing, an initial value of water injection pressure is usually set first, and then the water injection pressure is gradually increased on the basis of the initial value; when the water injection pressure exceeds the initial fracture pressure of coal, the fracture occurs. When the hydraulic fracturing reaches the predetermined effect, the water injection pump stops injecting water[3,4].

It should be noted that each water injection pump has a rated injection pressure, which can only work within the rated water injection pressure range, so the injection pressure cannot be increased indefinitely. In the actual water injection process, the injection pressure is not a constant value, but a curve that changes with the time of water injection. Previous studies have shown that the peak water injection pressure corresponding to the curve can be approximately regarded as the fracture initiation pressure[5,6]. Since the water injection pressure is directly related to other fracturing parameters, the influence of other fracturing parameters (water injection flow rate and water injection time) on fracturing effect is mainly studied. Based on this, the following two parameters of water injection flow and water injection time are used to optimize the hydraulic fracturing process parameters of soft and low permeability coal seam.

2. Analysis of the influence of water injection flow rate and injection time on fracturing effect

2.1. Water injection flow

Water injection flow is an important parameter to control fracturing effect, and its value will directly determine the quality of fracturing effect and the economy of hydraulic fracturing operation. If the construction water injection flow is too large, fracturing is mainly to create new fractures, but
effect of fracture length and width is weak. The new cracks are generated too fast. Before the original cracks can be widened and extended, the new and old cracks can not communicate to form a fracture channel network of gas migration, which will affect the effect of gas drainage. At the same time, if the water injection flow is too large, the injection pressure should be increased accordingly It is necessary to prepare for it, which will undoubtedly increase the construction cost. However, if the water injection flow rate is too low, it is bound to increase the water injection time to reach the predetermined total water injection volume, which will lead to the extension of water injection operation period and is not conducive to the progress control. At the same time, when the water injection flow is low, the corresponding water injection pressure should also be reduced, which may affect the fracturing, so as to not play the expected fracturing effect.

2.2. Water flooding time
Water injection time is an important parameter that affects fracturing operation quantity, construction progress and fracturing effect control. If the water injection time is too short, in order to achieve the predetermined fracturing effect, it is necessary to increase the injection pressure and increase the water injection flow rate, which will have higher requirements for the fracturing equipment, which will correspondingly increase the fracturing cost. However, if the injection time is too long, although the corresponding water injection pressure and water injection flow can be appropriately reduced, thus reducing the requirements for water injection equipment, but the construction time will be extended, which will affect the construction quantity and construction progress.

3. Model establishment and parameter selection

3.1. Establishment of model
Because the displacement of coal seam in the whole hydraulic fracturing process is limited by the overlying strata, the deformation in the vertical direction is very small relative to the horizontal direction, so the model can be regarded as a plane strain model. A plane with a size of 50m × 50m is taken as the calculation area along the horizontal direction. A small diameter circular hole is set in the middle of the calculation area to represent the fracturing hole. The maximum horizontal stress $\sigma_1$ and the minimum horizontal stress $\sigma_3$ in the model are kept at predetermined values through the servo system control. Based on the above conditions, the discrete element model can be established. The model includes 2345 particles, the minimum particle size is 0.42 m, and the ratio of maximum and minimum particle size is 1.66. The method of water injection and pressure control is adopted.

3.2. Selection of geomechanical parameters of coal
The selection of coal physical and mechanical parameters has an important impact on the results of numerical simulation, so it is very important to select these parameters correctly and reasonably. In order to simulate the actual situation more truly, the physical and mechanical parameters of soft and low permeability coal and rock are basically used, combined with relevant literature and engineering experience, the data are selected on the basis of repeated comparison, analysis and simulation test.

4. Numerical calculation and analysis
Based on the determined meso physical and mechanical parameters and geological parameters, several groups of numerical calculation models considering different fracturing parameters (water injection flow rate and water injection time) are established, and then the numerical simulation test of water injection fracturing is carried out by using particle discrete element program. The specific scheme is as follows:
(1) In order to study the variation law of fracture initiation pressure, fracture opening and crack number under different water injection flow conditions, 8 groups of different flow rates were set, which were 5.076m$^3$/h, 6.876m$^3$/h, 8.676m$^3$/h, 10.476m$^3$/h, 12.276m$^3$/h, 15.876m$^3$/h and 17.676m$^3$/h respectively.
(2) In order to study the variation law of fracture initiation pressure, fracture opening and crack number under different fracturing time conditions, seven groups of different fracturing time were set up: 400s, 450s, 500s, 550s, 600s, 650s and 700s. By selecting different flow rate and different fracturing time, 56 groups of calculation schemes can be obtained, and the influence of fracturing parameters on fracture formation and propagation can be analyzed.

4.1. Establishment of model

(a) Influence of fracturing time on fracture radius:
The numerical simulation results of injection radius with fracturing time can be obtained as shown in figure 1.

![Figure 1](image1.png)

It can be seen from figure 1 that when the water injection flow rate is controlled to a certain value, the hydraulic fracturing radius of soft and low permeability coal rock increases steadily with the increase of water injection time, and there is a good nonlinear positive proportional relationship between the two. At the same time, corresponding to the same water injection time, when the flow rate is different, the fracture radius also has a big difference, which shows that the longer the water injection time, the larger the corresponding hydraulic fracturing radius. At the same time, the water injection flow also has a great influence on the fracture crack propagation radius. The general trend is that for the same injection time, the greater the injection flow, the larger the fracture radius.

(b) Influence of flow rate on fracture radius:
Figure 2 shows the fitting curve of hydraulic fracturing radius and flow rate of soft and low permeability coal body corresponding to a certain fracturing time.
Figure 2. Fitting curve of fracture radius with water injection flow under different fracturing time

The relationship curve between fracture radius and water injection flow in figure 2, which shows that dependent variable increases with independent variable, and there is a good nonlinear positive relationship between them. The rule reflected in figure 2 is: when the water injection time is controlled to a certain value, the hydraulic fracturing radius of soft and low permeability coal body increases nonlinearly with the injection time, and the water injection flow has a great influence on the fracture radius, and the two are positively correlated.

4.2 Influence of fracturing parameters on maximum fracture opening

(1) Study on the influence of water injection time on the maximum opening of fracturing crack:

By analyzing the results of numerical simulation experiment, figure 3 can obtain the curve of maximum crack opening varying with water injection time corresponding to a certain flow rate, as shown in figure 3. It can be seen from figure 3 that there is a strong power function positive proportion relationship between the maximum opening of hydraulic fracturing fracture and water injection time in soft and low permeability coal body, and the maximum opening is positively related to water injection time. When the control water injection flow is a constant value, with the increase of water injection time, the maximum opening of coal rock hydraulic fracturing, that is, the maximum width of fracture around the fractured hole, increases steadily; at the same time, the maximum opening of coal rock fracturing also changes with the change of water injection flow. The general rule is: when the water injection time remains constant, the greater the water injection flow, the greater the maximum fracture opening.
(2) Influence of water injection flow rate on the maximum opening of fracturing crack:

As shown in figure 4, the fitting curve and scatter diagram of the relationship between the maximum fracture opening and water injection flow corresponding to a certain water injection time are respectively shown.

It can be seen that when the injection time is a certain value, there is a good nonlinear power function relationship between the maximum fracture opening and the water injection flow. With the increase of water injection flow, the fracture opening increases gradually. At the same time, the maximum fracture opening has a positive correlation with water injection time; the longer the water injection time, the greater the maximum fracture opening.
5. Conclusions

(1) The hydraulic fracturing radius of soft and low permeability coal rock increases steadily with the increase of water injection time, and there is a good nonlinear positive proportional relationship between them. When the injection time is controlled to a certain value, the hydraulic fracturing radius of soft and low permeability coal increases nonlinearly with the injection time.

(2) There is a strong power function positive proportion relationship between the maximum opening of hydraulic fracture and water injection time in soft and low permeability coal body. There is a good nonlinear power function correlation with water injection flow.

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