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APPROACH TO HALTING FRACTURE PROPAGATION FOR USE IN CONFINED AREAS

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Abstract. Hydrostatic fracturing has become more common, which has led to a quick development of numerical modelling methodologies and a thorough comprehension of the propagation trajectory of fractures during this process. Nevertheless, there is still a lack of adequate understanding of the process of fracture interference during hydraulic fracturing. A simulation model was developed to describe the propagation of fractures using the boundary element approach, taking into account linear elastic fracture mechanics and applicable fracture criteria. Fracture interaction processes are investigated. The results demonstrate that when hydraulic fractures propagate, the direction of distribution of formation stresses changes, and that asymmetric fractures have a tendency to combine. Although it is common in numerical simulations, the real formation almost never exhibits the reverse propagation phenomena between two cracks.Later on, hydraulic crack trajectory control may be theoretically grounded on investigations into the mechanisms of fracture propagation and interaction.

1. Introduction

With the rapid development of science and technology, our country's demand for oil and gas resources is increasing seriously. At present, hydraulic fracturing technology is an important way to improve oil and gas well recovery.

In recent years, scholars at home and abroad have carried out a lot of research on hydraulic fracturing. When hydraulic fractures and hydraulic fractures or hydraulic fractures and natural fractures are in contact with each other, with the continuous injection of fracturing fluid, there are three types of interactions between hydraulic fractures and natural fractures: stop propagation near natural fractures, penetrate natural fractures and extend along natural fractures. The greater the crack approach angle and horizontal stress difference, and the higher the strength of the natural crack and parent rock bond, the easier the hydraulic crack penetrates the natural crack and vice versa [3,4]. At the same time, scholars have introduced fracture criteria into the determination of intersecting fractures, such as fracture shear strength theory [5,6], stress intensity factor theory [7], Griffth energy principle [8]. Based on these criteria, different numerical simulation models were established, some of which considered the distribution of random natural fractures [9], some extended their simulation models to three-dimensional conditions [10]. When there is no contact between fractures, such as simultaneous fracturing and multi-cluster fracturing, the fracture tip will depart or approach each other[11]. In the actual hydraulic fracturing process, especially when there are other fractures near the hydraulic fracture, it is still unknown that the tip of hydraulic fracture will tend to be closer to other fractures or deviate from other fractures. At present, the analysis of this problem and the study of the internal interaction mechanism are still relatively lacking.

In this paper, the basic mechanical model is established based on the theory of elastic mechanics and fracture mechanics. After the boundary element calculation method is used to discretize the boundary and fracture, a simulation calculation model that can simulate the fracture propagation of hydraulic fracturing was established. The remainder of this paper is organized as follows. The construction of the computational model and relevant validation are described in Section 2. The interaction mechanism between fractures been analysed in Section 3. The paper ends with some conclusions in Section 4. In this paper, for simplicity, our numerical model incorporates some assumptions in the calculation process: (1) isothermal conditions, (2) two dimensions, and (3) homogeneous rock, with isotropy of the rock porosity and mechanical properties.

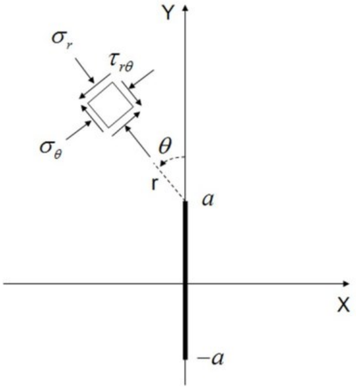
2. Simulation model

2.1 Fracture criterion

During the hydraulic fracturing, the damage of rock under complex stress fields mainly performs as shear failure and tension failure, which is respectively denoted by $K_I$and K_{II}. In this place, we put the maximum circumferential stress criterion as the fracture criterion which is proposed by Erdogan and Sih[12] in 1963. As is shown in Figure 1, the stress distribution at the tip of fracture in the polar coordinate can be expressed as the equations below:

$$\begin{cases} \sigma_r = \frac{1}{2\sqrt{2\pi r}}\left[K_I(3-\cos\theta)\cos\frac{\theta}{2} + K_{II}(3\cos\theta-1)\sin\frac{\theta}{2}\right] \\ \sigma_\theta = \frac{1}{2\sqrt{2\pi r}}\cos\frac{\theta}{2}\left[K_I(1+\cos\theta) - 3K_{II}\sin\theta\right] \\ \tau_{r\theta} = \frac{1}{2\sqrt{2\pi r}}\cos\frac{\theta}{2}\left[K_I\sin\theta + K_{II}(3\cos\theta-1)\right] \end{cases} \tag{1}$$

Where σ_r is the radial stress near the fracture tip, σ_θ is the circumferential stress near the fracture tip, $\tau_{r\theta}$ is the shear stress near the fracture tip, *MPa*, *r* is the distance between any unit to fracture tip, *m*, and θ is the fracture opening angle, °.



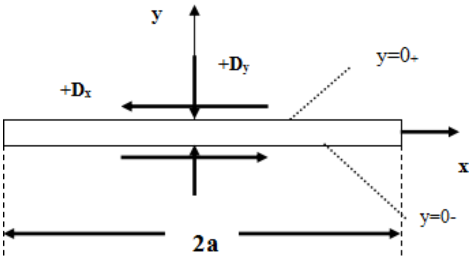


Figure 1. Stress around a fracture tip. Figure 2. Fracture plane.

Based on the maximum circumferential stress criterion, the opening angle must satisfy two conditions:

$$\frac{\partial\sigma_\theta}{\partial\theta} = 0 \text{ and } \frac{\partial^2\sigma_\theta}{\partial\theta^2} < 0 \tag{2}$$

By calculating the derivative of θ from Equation (1), we can obtain the relationship between the I-II mixed stress intensity factor and the opening angle (Equation (2)), the relationship is as follow:

$$K_I\sin\theta + K_{II}\left(3\cos\theta - 1\right) = 0 \tag{3}$$

2.2 Boundary element method

Boundary element method was first proposed by Crouch[13] in 1976. And now this method is divided in two aspects: displacement discontinuity method and stress discontinuity method. According to displacement discontinuity method, a fracture can be divided into small elements with two discontinuity planes. In the x-y coordinate system shown in Figure 2, the planes can be expressed as y=0+ and y=0-.

The displacements of the two sides are symbolized by $u(x, 0_+)$ and $u(x, 0_-)$, respectively. D is defined as the tangential and perpendicular difference in displacement between two sides of the element. D_x and D_y are the definition of D in x- and y-direction.

$$\left\{\begin{array}{l} D_x = u_x(x, 0_-) - u_x(x, 0_+) \\ D_y = u_y(y, 0_-) - u_y(y, 0_+) \end{array}\right. \tag{4}$$

The solution for displacements and stresses caused by the fracture-relative movement (D_x, D_y) can expressed as [14]:

$$\left\{\begin{array}{l} u_x = D_x[2(1-\nu)f'_{y} - yf'_{xx}] + D_y[-(1-2\nu)f'_{x} - yf'_{xy}] \\ u_y = D_x[2(1-\nu)f'_{x} - yf'_{xy}] + D_y[2(1-\nu)f'_{y} - yf'_{yy}] \end{array}\right. \tag{5}$$

$$\left\{\begin{array}{l} \sigma_{xx} = 2GD_x(2f'_{xy} + yf'_{xyy}) + 2GD_y(f'_{yy} + yf'_{yyy}) \\ \sigma_{yy} = 2GD_x(-yf'_{xyy}) + 2GD_y(f'_{yy} + yf'_{yyy}) \\ \sigma_{xy} = 2GD_x(f'_{yy} + yf'_{xyy}) + 2GD_y(-yf'_{yyy}) \end{array}\right. \tag{6}$$

2.3 Simulated flowchart

During simulation process, the fracture tip propagation and in-situ stress variation are obtained. The detailed calculation flow chart is shown in Figure 3.

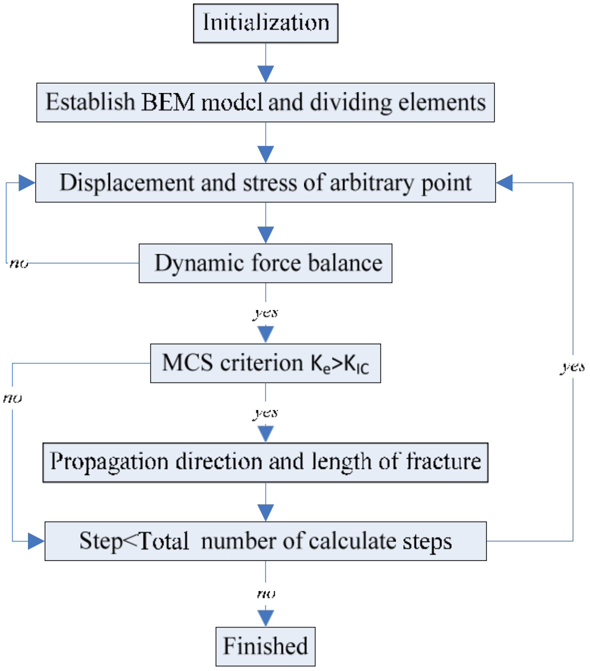


Figure 3. Computer program flow chart. Using the maximum circumferential stress criterion, the opening angle and propagation path of the fracture were calculated. If the tip of the fracture does not satisfy the opening requirement, the calculation stops, otherwise, the fracture extends in the direction of the opening angle and repeat the aforementioned calculation until get a planned fracture length.

3. Simulation results

Before numerical simulation, it is necessary to confirm in-situ stress parameters, rock mechanics parameters and construction parameters, these parameters are determined from field and laboratory tests performed on samples[15-16] and is shown in Table 1. The Model size is about100m•100m. In this chapter, we will conduct numerical simulation on multi-cluster fracturing and synchronous fracturing. Therefore, physical model diagrams under different fracturing methods are established, as shown in Figure 4 and Figure 5. σ_H and σ_h are respectively the maximum and minimum horizontal stress.

Table 1. Initial values in numerical simulation

Reservoir geologic data		Fracturing design parameters	
Young's modulus /MPa	32860.38		
Poisson's ratio	0.221	Fracturing pressure /MPa	35
Maximum horizontal stress /MPa	35		
Minimum horizontal stress /MPa	30	Perforation depth /m	5
Fracture toughness /MPa•m$^{1/2}$	2.5		
Rock density /kg•m^{-3}	2600	Fracture spacing/m	10

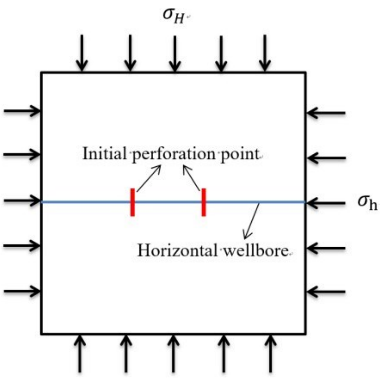


Figure 4. Multiple clusters fracturing

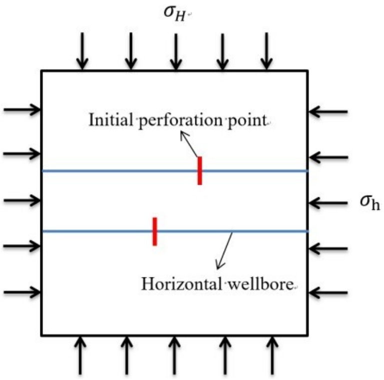


Figure 5. Synchronous fracturing

First, we simulated the fracture extension trajectory of two clusters of fractures in a single well. In order to observe the change of the stress field between clusters during multi-cluster fracturing, the fracturing simulation was conducted between the previous two fractures. Compare above two simulation results(Figure 6 and Figure 7) show that: when two symmetrical fractures are fracturing at the same time, due to the slippage of the fracture surface and cracking at the tip, compressive stress zones will be generated on both sides of the fracture, which will cause the two fractures to extend away from each other. After fracturing, perforating fracturing is performed in the middle of the two clusters of fractures. Under normal circumstances, the fracture propagate in the direction of the maximum horizontal principal stress (vertical direction), but the stress between the two clusters of fractures has reversed at this time, causing the fracture pressure of the post-fracturing to extend in the direction of the maximum horizontal principal stress. It can be seen that during the multi-cluster fracturing, as the fracture surface expands, the induced stress will reverse between the two fractures as propagation. This flipping helps to induce natural micro-fractures to communicate with hydraulic fractures to form a fracture network and improve oil and gas seepage.

In order to study the mutual interference of hydraulic fractures at an asymmetric position, numerical simulation of simultaneous fracturing was carried out under the same geological parameters. As is shown in figure 8. During propagation, hydraulic fracture tend to connect with each other instead of mutual repulsion. It can been seen that crack tip always tends to expand to the weak surface during fracture propagation, because the energy required for crack tip cracking in this propagation way is the lowest. Furthermore, in order to verify the conjecture, the horizontal well is set to have a certain angle with the minimum horizontal principal stress direction, so that in a single well multi-cluster fracturing, the stress field between fractures is asymmetric. As shown in figure 9, Similar to synchronous fracturing, when the stress of multiple fractures in the reservoir is not completely symmetrical, the fractures tend to be close to each other. It can be seen that although the fractures extend backwards in multiple clusters fracturing in simulation, in actual reservoirs, due to the difference in rock properties and inhomogeneity of the in-situ stress, hydraulic fractures will tend to be close to each other in most cases.

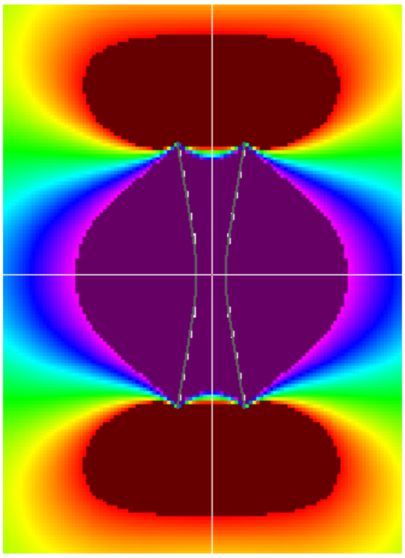


Figure 6. Multiple clusters fracturing(simulation result)

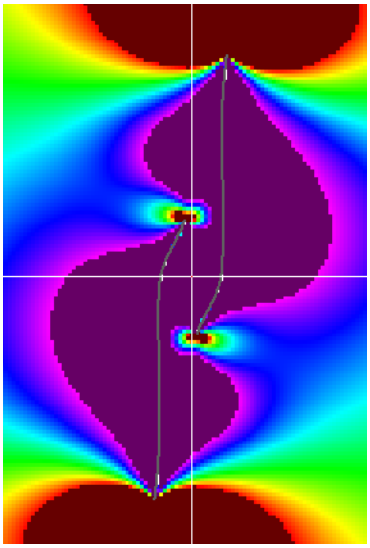


Figure 7. Synchronous fracturing(simulation result)

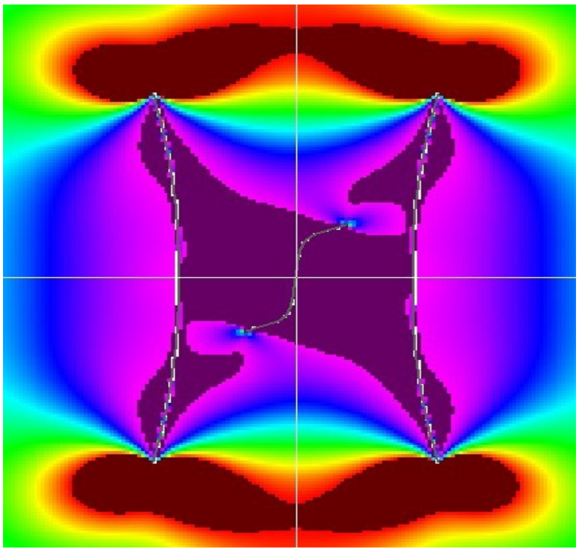


Figure 8. Direction reversal of stress

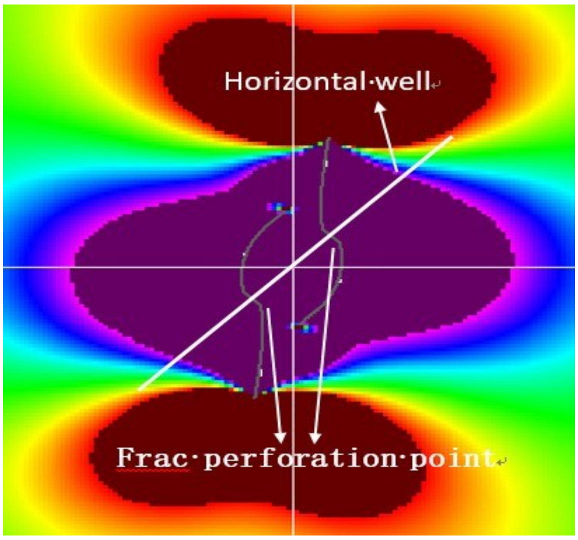


Figure 9. fracture propagate under asymmetric stress

4. **conclusion**
5. The following conclusions were drawn from the study of hydraulic fracturing and the propagation of multi-fractures and induced stress using a simulation model based on elastic mechanics and fracture mechanics: （1） In simultaneous fracturing, the length of the fractures is increased because the cracks draw near to each other. Two cracks eventually fuse into one in the case of aligned fracture distribution. Thus

   In order to create a more intricate fracture network during formation, it is better to choose an asymmetrical fracture distribution.

   2. While crack tips may exhibit the phenomena of exclusion in numerical simulations, in the

real reservoir scenario, cracks are more prone to connecting with each other as the reservoir expands.

Acknowledgments

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