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# Study on Fracture Turning and Extending Law of Refracturing in Horizontal Wells

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**Abstract**-The mechanism of refracturing fracture turning in horizontal wells was studied. The turning radius of fractures under different stress conditions was calculated by numerical simulation. The research results indicate that with the increase of time, the fracture turning radius increases gradually, and the change of the fracture turning radius is no longer obvious after the optimal fracturing time is reached. The variation law of reservoir stress field in the process of refracturing was studied, and the net pressure conditions in the fracture that produce complex fractures were given. Based on these studies, a mechanical calculation model for crack opening was established. The opening and extension laws of refracturing fractures under different conditions were calculated and analyzed by finite element method: with the increase of the difference of horizontal principal stress, the difficulty of opening natural cracks gradually increases; with the increase of induced stress perpendicular to the direction of hydraulic fractures, natural fractures are relatively easy to open.

## 1.Introduction

Horizontal well repeated fracturing is an effective technical means to achieve sustained and stable production and tap the potential of developed low-permeability reservoirs. The law of re-fracturing fracture extension is the focus and difficulty of re-fracturing research. Due to long-term production and the existence of the first artificial fracture, the in-situ stress field changes, resulting in the reorientation of the new fracture. Both laboratory tests and field practice have proved that the extension direction of the re-fractured fracture and the extension direction of the first artificial fracture have changed in varying degrees, and some have even undergone a 90-degree rotation, resulting in a new artificial fracture. In this paper, the mechanism of refracturing fracture diversion is studied, and the influence of the pressure conditions in the fracture and the natural fracture parameters on the fracture extension of staged fracturing are given, which is beneficial for guiding the on-site operation design of horizontal well refracturing.

## 2 Mechanism of fracture turning and determination method of turning radius in refracturing

After the formation of the initial hydraulic fracture, the local stress field around the wellbore and the initial fracture changes. At the beginning, the extension of the new fracture generated by the re-fracturing, it will be controlled by the changed local stress field and extend along a certain angle with the original geostress field. After extending for a certain distance, the new fracture will change direction. After the change, it will maintain the same extension direction as the initial hydraulic fracture, that is, it will extend towards the maximum principal stress. Therefore, the extension distance of the new hydraulic fracture before turning is the corresponding turning radius, which is determined by the local stress field. Therefore, the change of stress field is the core of the research on the turning of the re-fracturing fracture.

When the horizontal well is re-fractured, the hydraulic fractures between sections turn to connect mainly because the artificial fractures turn under the action of geostress and induced stress. The fracture turn caused by this stress reversal can promote the fractures in the fractured well section of the reservoir to communicate more with the undeveloped reservoir.

The crack turning radius under the condition of seepage induced stress and crack induced stress is calculated by using the Finite Element Method (COMSOL). Using the actual formation parameters and injection-production conditions, the formation turning radius is simulated and studied. The horizontal length is 700m, including 8 fractures, and the half length of the crack is 100m.

The turning range near the fracture tip of horizontal well is the largest, and the difference of induced stress under different time conditions is calculated by using COMSOL software.

When the formation induced stress difference is greater than 0, the formation stress turns, and the formation turning radius at different times is shown in Figure 5. It can be seen from the figure that the fracture turning radius gradually increases with the increase of

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time, and the turning range gradually remains stable after reaching 1000 days.

## 3 Study on fracture extension law of refracturing

### 3.1 Pressure conditions of natural fracture opening in reservoir

During the re-fracturing of horizontal wells, the diversion of hydraulic fractures between sections is mainly caused by the diversion of artificial fractures under the action of geostress and induced stress. The diversion of fractures caused by this stress reversal can promote the formation of complex fractures in the fractured well section of the reservoir. Figure 1 shows that the artificial fracture changes direction during the extension process, and communicates with the adjacent artificial fracture to generate complex fractures.

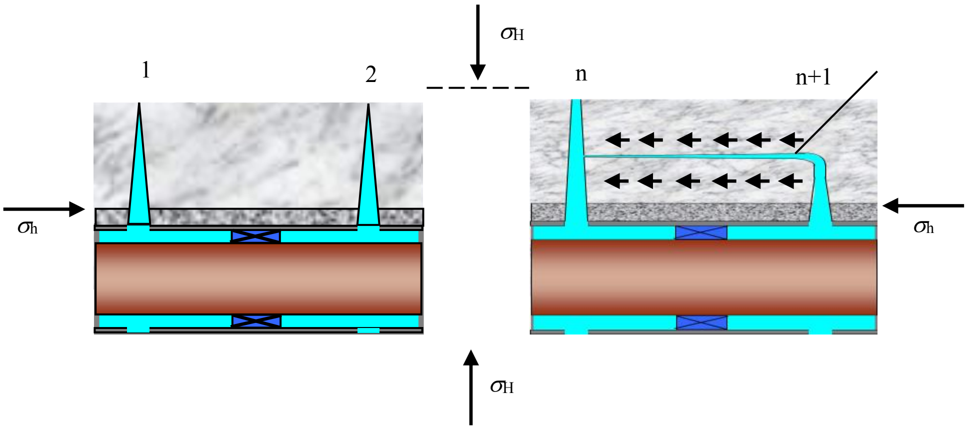


Fig.1 Diversion and connection of artificial fractures in horizontal wells

Laboratory experiments and field studies show that the main fracture of hydraulic fracturing always extends along the direction of maximum horizontal principal stress. After the formation of the first n cracks in the figure, the induced stress will be produced on the subsequent n+1 cracks, and the hydraulic fracture direction will be realized under the combined effect of stress superposition. Equation 1 describes the distribution and change of reservoir stress field in the process of repeated fracturing of horizontal wells.

$$\begin{cases} \sigma_H^{'} = \sigma_H + \sigma_{ax} = \sigma_H + \mu\left(\sum_{i=1}^{n}\sigma_{azi} + \sum_{i=1}^{n}\sigma_{ayi}\right) \\ \sigma_h^{'} = \sigma_h + \sigma_{az} = \sigma_h + \sum_{i=1}^{n}\sigma_{azi} \\ \sigma_v^{'} = \sigma_v + \sigma_{ay} = \sigma_v + \sum_{i=1}^{n}\sigma_{ayi} \end{cases} \quad (1)$$

$\sigma_H'$-the maximum horizontal principal stress direction geostress after the change of stress field, MPa,

$\sigma_h'$-Minimum horizontal principal stress direction geostress after stress field change, MPa,

$\sigma_v'$-Vertical geostress after stress field change, MPa.

For extended hydraulic fractures, when the induced stress difference in two directions reaches or exceeds the original maximum and minimum horizontal principal stress difference, the maximum and minimum horizontal principal stress of the reservoir will reverse, and the fracture extension will reverse, and its mechanical conditions can be expressed as:

$$\sigma_H^{'} \le \sigma_h^{'} \quad (2)$$

By substituting the induced stress calculation model into the above formula and sorting it out, the net pressure condition in the artificial fracture that the corresponding fracture turns to generate complex fractures can be obtained. There are two main conditions for fracture propagation of natural fracture reservoir: tensile fracture along natural fracture surface and shear fracture along natural fracture surface.

When tensile fracture occurs in natural fractures:

$$P > \sigma_n \quad (3)$$

When the shear stress used for natural fracture is large, the natural fracture is prone to shear slip.

$$|\tau| > \tau_0 + K_f\left(\sigma_n - P\right) \quad (4)$$

$\sigma_H$&$\sigma_h$-The maximum horizontal principal stress and the minimum horizontal principal stress respectively, MPa;

$\tau_0$-Cohesion of rocks in natural fractures, MPa;

$\tau$-Shear stress acting on natural crack surface, MPa;

$K_f$-Friction factor of natural crack surface, dimensionless;

$\sigma_n$-Normal stress acting on natural fracture surface, MPa;

$P$-Pore pressure near the wall of natural fracture, MPa。

According to the two-dimensional linear elastic theory, the shear stress and normal stress can be expressed as:

$$\tau = \frac{\sigma_H - \sigma_h}{2}\sin 2\left(\frac{\pi}{2} - \eta\right) = \frac{\sigma_H - \sigma_h}{2}\sin 2\eta \quad (5)$$

$$\sigma_n = \frac{\sigma_H + \sigma_h}{2} - \frac{\sigma_H - \sigma_h}{2}\cos 2\left(\frac{\pi}{2} - \eta\right) = \frac{\sigma_H + \sigma_h}{2} + \frac{\sigma_H - \sigma_h}{2}\cos 2\eta$$

(6)

$\eta$-Approach angle of hydraulic fracture relative to natural fracture（$0 \le \eta \le \pi/2$）,°.

Consider the effect of induced stress generated by the fractured fracture , the pore pressure near the wall of the natural fracture is:

$$P(x,t) = \sigma_h + \sigma_{az} + P_{net}(x,t) \quad (7)$$

$P_{net}$-Net pressure in crack, MPa; $\sigma_{az}$-Compressive crack induced stress, MPa。

The net pressure in hydraulic fracture required for tensile fracture of natural fracture is:

$$P_{net}(x,t) > \frac{\sigma_H - \sigma_h}{2}(1+\cos 2\eta) - \sigma_{az} \quad (8)$$

Similarly, the net pressure in the artificial fracture required for shear fracture is obtained as follows:

$$P_{net}(x,t) > \frac{1}{K_f}\left[\tau_0 + \frac{\sigma_H - \sigma_h}{2}\left(K_f - \sin 2\eta + K_f \cos 2\eta\right) - K_f \sigma_{az}\right] \quad (9)$$

*When* $\eta$=0, there is a maximum value on the right side of the inequality, and the maximum value is::

$$P_{max} = \frac{\tau_0}{K_f} + (\sigma_H - \sigma_h) - \sigma_{az} \quad (10)$$

If the cohesion of natural cracks is considered $\tau_0$=0,at this time, the maximum net pressure in the artificial fracture required for the shear fracture of the natural fracture or the weak surface of the formation is $\sigma_H$-$\sigma_h$-$\sigma_{az}$.

Based on the above two conditions, it can be seen that the mechanical condition of opening natural fractures to form branch fractures in natural fractured reservoirs is that the net pressure in the fractures exceeds $\sigma_H$-$\sigma_h$-$\sigma_{az}$ during fracturing construction.

### 3.2 Analysis of influence of natural fractures on fracture extension of multi-cluster staged fracturing

(1)Influence of horizontal principal stress difference on natural crack opening

During the calculation, the fracture pressure is taken as 2MPa, the crack approach angle is 30°, the induced stress in the vertical direction of the hydraulic fracture is 1MPa, the cohesion of the rock in the natural fracture is 0.5MPa, and the friction coefficient of the natural fracture surface is 0.3. The opening state of the natural fracture under the conditions of different horizontal principal stress difference is calculated as shown in Figure 2.

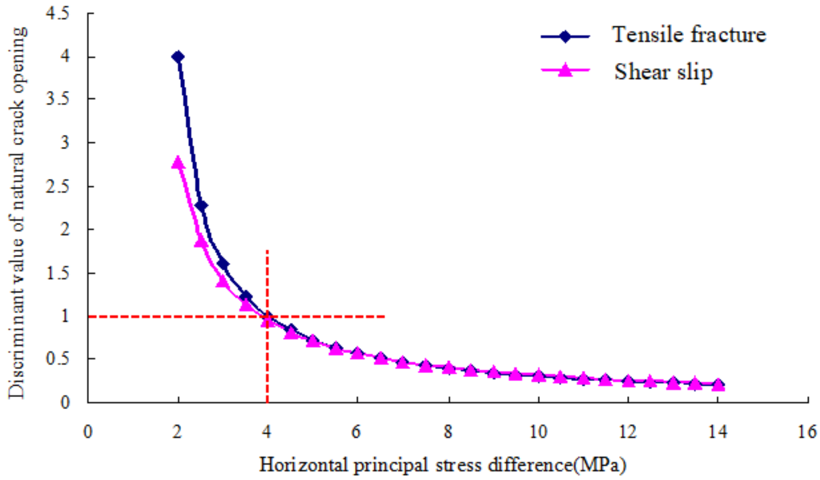


Fig.2 Natural crack opening of different horizontal principal stress difference

The calculation results show that when the fracture pressure, the approach angle of the fracture, the induced stress and the friction coefficient of the natural fracture wall are fixed, the difficulty of opening the natural fracture gradually increases with the increase of the difference of the horizontal principal stress of the formation; When the horizontal principal stress difference is 4MPa, it is the turning point of natural fracture opening. When it is greater than 4MPa, the natural fracture will not open, and the hydraulic fracture will extend through the natural fracture in the original direction.

(2) Influence of induced stress on natural crack opening

During the calculation, the net pressure in the hydraulic fracture is taken as 2MPa, the crack approach angle is 30°, the cohesion of the rock in the natural fracture is 0.5MPa, the friction coefficient of the natural fracture surface is 0.3, and the horizontal principal stress difference is 2.6MPa. The calculation of the natural fracture opening under different induced stress conditions is shown in Figure 3.

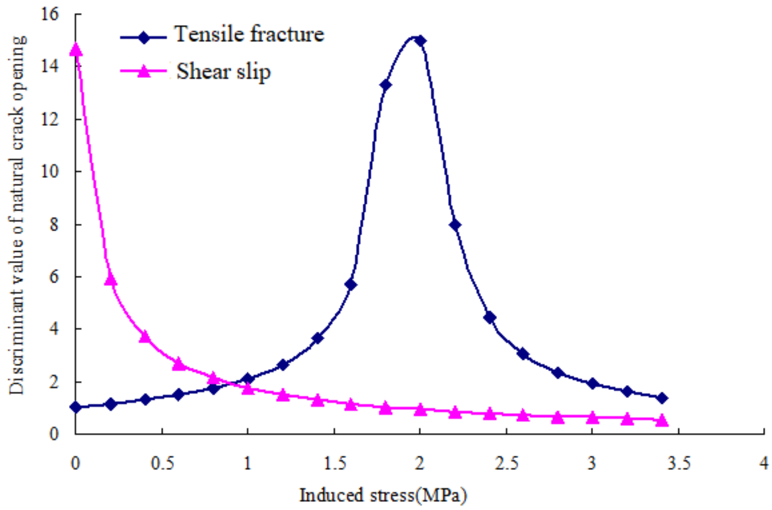


Fig.3 Natural crack opening of different induced stress conditions

when the net pressure in the hydraulic fracture, the crack approach angle and the friction coefficient of the natural fracture wall are fixed, with the increase of the induced stress perpendicular to the direction of the hydraulic fracture, the fracture is relatively easier to open. The induced stress is 1.8MPa, which is the turning point of the natural fracture opening. When the induced stress is less than 1.8MPa, the natural fracture can occur shear failure, so the induced stress is mainly shear failure in the range of 0.2~1.8MPa, When the pressure is greater than 1.8MPa, it is mainly opened by tension.

## 4 Conclusion

(1) Using COMSOL software, the fracture turning radius of re-fracturing under the condition of seepage induced stress and fracture induced stress is simulated and calculated. The fracture turning radius gradually increases with the increase of time, and there is a relatively optimal time for re-fracturing. After reaching this time, the change of fracture turning radius is no longer obvious.

(2) This paper analyzes the net pressure conditions in the fractures that produce complex fractures under different conditions, and concludes that the mechanical conditions for natural fractures to open and form branch fractures in natural fractured reservoirs are as follows: the net pressure in the fractures is greater than the maximum horizontal principal stress minus the minimum horizontal principal stress minus the induced stress of the fractured fractures

(3) The mechanical calculation model of fracture opening is established, the stress conditions of natural fractures under different combination conditions are calculated and analyzed, and the influence rules of natural fractures on hydraulic fracture extension are summarized: with the increase of the difference of horizontal principal stress , the difficulty of natural fracture opening gradually increases; With the increase of induced stress perpendicular to the direction of hydraulic fracture, the natural fracture is relatively easy to open.

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