Stress Shadow of fracture Law of Horizontal Well Seam Networks

Yiming Rui *, Chengbin Yang
PetroChina Southwest Oil & Gas field Company, Chengdu, China

*Corresponding author e-mail: 249575290@qq.com

Abstract. In order to improve the fracturing success rate and modification effect of multistage and multiple cluster volume fracturing in horizontal wells. This paper studies the theoretical model of crustal stress change caused by a single artificial fracture and also considers the superposition distribution model of the stress field. With the increasing net stress, the decrease of Poisson's ratio, the degree of interference between fractures will become more significant. When fractures reach a certain period, the interference degree remains unchanged. The emphasis of the study lies in the basis for the optimization method of forming active volumetric fractures and establishes a reservoir.

1. Introduction
The crustal stress field plays a decisive role in the formation of fracture network in the volume fracturing of low permeability reservoir. The formation of fractures affects the surrounding crustal stress field. For the staged fracturing of horizontal wells, through taking fracturing measures, the difference between the two horizontal principal stresses of the crust is reduced, thereby achieving the purpose of generating a complex fracture network [1].

Hydraulic fracturing produces artificial fractures, which influence the change of the stress field near the fractures [2]. This study aim to the theory of fracture interference and the influencing factors of fracture interference provides theoretical guidance for the establishment of the optimization method of space of fractures in the horizontal well.

2. A theoretical model of stress interference between crustal fractures

2.1. The conceptual model of crustal stress change caused by single artificial fracture
The crustal stress field plays a decisive role in the formation of fracture network structure [3]. Generally, values of horizontal minimum principal stress and horizontal maximum principal stress are different. Crustal stress exists in the reservoir objectively. The fractures in the reservoir will change the original crustal stress field around the fractures, and affect the shape and extension direction of the fractures either.

In 1946, Sneddon proposed a semi-infinite fracture model (plane-strain fracture model [4]. He set up a theoretical formula with this model though studying the formation stress field changes caused by fractures. Figure1 is a sketch map of the semi-infinite fracture model as follows.
Where $\sigma_{h_{\min}}$ is horizontal minimum principal stress, $\sigma_{h_{\max}}$ is horizontal maximum principal stress, respectively.

**Figure 1.** Sketch map of semi-infinite fracture

It indicates that the reservoir is homogeneous, isotropic, and linear elastic material. Using the method of theoretical analysis, we edited the calculation formula, which applies the stress at any point in the stratum near the fracture.

\[ \frac{1}{2}(\Delta \sigma_{x}+\Delta \sigma_{y})=-p_{o}\left(\frac{r}{q_{r_{x}}^{2}}\cos(0.5\theta_{L}-0.5\theta_{o})-1\right) \]  
\[ \frac{1}{2}(\Delta \sigma_{x}-\Delta \sigma_{y})=p_{o}\left(\frac{2r}{L}-\frac{E}{4q_{r_{y}}^{2}}\right)\sin(\frac{\theta_{L}}{2})(\theta_{L}+\theta_{o}) \]  
\[ \Delta \tau_{xy}=-p_{o}\left(\frac{2r}{L}\right)(\frac{E}{4q_{r_{z}}^{2}})\sin(\frac{\theta_{L}}{2})(\theta_{L}+\theta_{o}) \]  
\[ \Delta \sigma_{z}=\mu(\Delta \sigma_{x}+\Delta \sigma_{y}) \]

Where $L$ is Length between fractures, $p_{o}$ is Internal pressure of fracture, $\Delta \sigma_{x}$ is Fracture stress in $x$-direction, $\Delta \sigma_{y}$ is Fracture stress in $y$-direction, $\Delta \sigma_{z}$ is Fracture stress in $z$ direction, $\Delta \tau_{xy}$ is Shear stress in XY plane by Fracture.

2.2. The superposition distribution model of the stress field

Different stress fields form changes around the fractures after the first fracture is formatted in a horizontal well. The superposition of the stress field is formed by the second fracture and the first fracture together [5]. Thus several parallel transverse fractures build though application of superposition theory in Figure 2.

**Figure 2.** Sketch map of proving maximum stress variation on vertical direction of plane strain fracture model

The purpose of our study was to determine the stress variation characteristics of points between two fractures by considering superposition theory of elasticity. Due to the superposition of stress variation produced by each fracture, Stress change at any point in space. The expression of fracture stress factors can be presented as follows.

\[ \Delta \sigma_{x} = \sum_{i=1}^{n} \Delta \sigma_{x,i} \]  
\[ \Delta \sigma_{y} = \sum_{i=1}^{n} \Delta \sigma_{y,i} \]

Where $i$ is a number of fracture

Table 1 shows related calculation parameters when we consider two fractures as an example in Figure 3.

Figure 3 and Figure 4 show the stress field superposition of two fractures using calculation parameters analysis in the horizontal well. Figure 5 and Figure 6 shows the stress field superposition of
three fractures using calculation parameters analysis in the horizontal well. We found the result that the stress difference is beyond the original horizontal principal stress when the space of fracture reaches a specific value. When there are two fractures, the space of fractures is below 120 meters. When there are three fractures, the space of fractures is above 120 meters.

**Table 1. Basic parameters of fracture calculation**

| Calculation parameters      |                  |
|----------------------------|------------------|
| Fracture 1 Internal net pressure | 2MPa             |
| Fracture 2 Internal net pressure | 2MPa             |
| Distance between fractures  | 122m             |
| stress difference           | 2.8MPa           |
| Calculated step             | 30m              |

**Figure 3. Sketch map of two fractures in the stack**

**Figure 4. Stress difference with different space of fractures in two fractures**

**Figure 5. Sketch map of three fractures in the stack**
3. Main influencing factors of stress interference between crustal fractures

Some factors affect the interference between fractures. Through research and selection, this paper determines the main control factors of interference between fractures, including net stress of fractures, space of fractures, length of fractures, the influence of lithology, and other parameters [6].

3.1. Net stress of fractures

As shown in Figure 7, assuming that the distance between fractures is 20 meters, the length of fractures is 100 meters, and the original stress difference is 3 MPa, which is unchanging can be analyzed as follows. It shows a diagram of the relationship between net stress of fractures and stress difference when the net stress increase from 1MPa to 6MPa and scale is 0.5 MPa.

![Figure 7. Relationship between Net stress of fractures and stress difference](image)

In the analysis, it can be seen that the linear relationship between net stress and stress difference established. The stress difference decrease when net stress increase, which implies that net stress is becoming 2.5MPa, and the stress difference is zero.

3.2. space of fractures

As shown in Figure 8, assuming that the net stress is 2MPa, the length of fractures is 100 meters, and the original stress difference is 3 MPa, which is unchanging can be analyzed as follows. It shows a diagram of the relationship between space of fractures and stress difference.

![Figure 6. Variety of stress difference with different space of fracture in three fractures](image)
Figure 8. Relationship between fracture interval and stress difference

In the analysis, it shows that the stress difference decreases when the space of fractures increases; it also implies that the space of fractures is large enough, the stress difference curve changes from a single peak to a double peak.

3.3. Length of fractures

As shown in Figure 9, assuming that the net stress is 2MPa, the space of fractures is 30 meters, and the original stress difference is 3 MPa, which is unchanging can be analyzed as follows. It indicates a diagram of the relationship between length of fractures and stress difference.

Figure 9. Relationship between length of fracture and stress difference

In the analysis, it shows that in the early stage of opening, the fracture has a significant influence on the stress difference. However, when the length of fracture exceeds a certain period, the stress difference is unchanged.

3.4. Influence of lithology

Poisson's ratio change represents lithology change in the model of crustal stress differences caused by fractures [7]. As shown in Figure 10, assuming that the distance between fractures is 30 meters, the original stress difference is 3 MPa, the length of fractures is 150 meters, which is unchanging can express as follows. It indicates a diagram of the relationship between Poisson's ratio and stress difference.

Figure 10. Relationship between Poisson's ratio and stress difference
In the analysis, it indicates that the linear relationship between Poisson's ratio and stress difference establishes. The stress difference decreases when Poisson's ratio decreases, which implies that it enhances the influence of crustal stress change caused by fractures.

4. Conclusion
In this study, we demonstrated that a simulation method is established successfully through the stress superposition theory. This method can simulate the change of the extended stress field between fractures in horizontal wells. It also can analyze the stress field interference of multiple fracture extension under different physical properties.

The degree of main controlling factors on stress changes:
With the increasing net stress, if the difference between biaxial stress becomes smaller after interference, the degree of interference between fractures will become more significant. The interference of fractures will rise with the increase in the length of fractures. When fractures reach a certain period, the interference degree remains unchanged. With the decrease of Poisson's ratio, if the difference between biaxial stress becomes smaller after interference, the degree of interference of fractures will become higher. This research provides the basis for the optimization method of forming active volumetric fractures and establishes a reservoir.

References
[1] Yin Jian, Guo Jiansu, Zeng Fanhui, et al. Optimal interval between staged fracturing and perforating in horizontal wells Chemical method [J]. Petroleum drilling technology, 2012, 40 (5): 67-71
[2] Yang Lina, Chen Mian, et al. Mechanical analysis of mutual interference between multiple fractures in hydraulic fracturing [J]. Journal of Petroleum University (NATURAL SCIENCE EDITION), 2003, 27 (3): 43-45.
[3] Geomechanics Aspects of Multiple Fracturing of Horizontal and Vertical Wells M.Y. Soliman SPE86992 2008.09.
[4] Shrivastava, K., & Sharma, M. M. (2018, January 23). Mechanisms for the Formation of Complex Fracture Networks in Naturally Fractured Rocks. Society of Petroleum Engineers. Doi:10.2118/189864-MS.
[5] Mechanical analyses of casings in boreholes, under non-uniform remote crustal stress fields: Analytical & numerical methods, Yin F., Gao D.(2013) CMES - Computer Modeling in Engineering and Sciences, 89 (1) , pp. 25-37.
[6] Jammoul, M., Ganis, B., & Wheeler, M. F. (2018, August 21). Effect of Reservoir Properties on Interwell Stress Interference. American Rock Mechanics Association.
[7] Kumar, J. (1976, January 1). The Effect of Poisson's Ratio on Rock Properties. Society of Petroleum Engineers. Doi:10.2118/6094-MS.