

Influence of fracture extension on in-situ stress in tight reservoir

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Abstract. Currently, hydraulic fracturing is an important way to develop low permeability reservoirs. The fractures produced during the fracturing process are the main influencing factors of changing in-situ stress. In this paper, the influence of fracture extension on in-situ stress is studied by establishing a mathematical model to describe the relationship between fracture length and in-situ stress. The results show that the growth rate gradually decreases after the fracture reaches a certain length with the increase of fracturing time; the continuous extension of the fracture is the main factor to change the in-situ stress. In order to reduce the impact on the subsequent fracture extension due to the changing of in-situ stress, controlling fracturing time and fracture length without affecting the stimulated reservoir effect is an important way. The results presented in this study can effectively reduce the impact of changing of in-situ stress on subsequent fracturing construction.

Keyword: hydraulic fracturing; low permeability reservoir; in-situ stress; fracture extension; fracturing time

1. Introduction

In recent years, the variation of fracture geometry and in-situ stress field is the main influencing factor of fracturing construction. A large number of indoor experiments and field construction indicate that the fractures produced by hydraulic fracturing can change the magnitude and direction of the in-situ stress in the near-well area. Dowel [1,2] found that the supported fractures in the formation can change the stress distribution near the wellbore through the indoor experiments and field tests. The fracture induced stress field is the main research direction of hydraulic fracturing. Sneddon and Elliott [3] studied the variation of the stress field around the fracture in theory, and deduced the stress field calculation formula around the fracture in the infinite elastic body. The study thinks that the fracture length is large enough. For flat-type fractures, Sneddon [4] established a new equations to describe their effect on the surrounding in-situ stress field. I.D.Palmer [5] analyzed the induced stress produced by fracturing hydraulic fractures in coaled gas reservoirs. Based on this, the effects of fracture morphology and net pressure on reservoir permeability were studied. N.P.Roussel et al [6] studied the



effect of fracturing induced stress and induced stress produced by pore pressure on the fracture initiation and extension for the refracturing in horizontal wells. Wu Qi et al [7] established a induced stress model of single cluster fracture for the shale gas reservoir and studied that the stimulated reservoir effect is better at the cluster spacing of 20-30m than others. Liu Lifeng and Zhang Shicheng[8] demonstrated that changing the induced stress field produced by fracture near the wellbore to achieve the network. The application has achieved good results. On the basis of the fracturing network model and the fracturing reorientation model, a mathematical method was developed to analyze the effect of adding sand and forced closure on the horizontal principal stress [9]. The study of induced stress field caused by fractures is not considered to affect the subsequent crack extension, which needs to be further suggested. In this paper, the influence of fracture extension on the in-situ stress is analyzed. The relationship between the fracture length and the in-situ stress, and the influence of the fracture length on the minimum and maximum horizontal principal stress are given.

2. Mathematical physics model

2.1. Fracture extension model

- 2.1.1. Theoretical model basic assumptions.* (1) The formation is homogeneous and isotropic. (2) The deformation of rock is elastic strain and plane strain occurs in the vertical profile. There is no slip between the fracturing layer and the upper and lower layers, and the fracture profile is elliptical. (3) The fluid inside the fractures is one-dimensional flow along the x-direction. (4) The formation is non-permeable without considering the fluid leak-off. (5) The pressure drop in the x direction is entirely caused by the flow resistance of the fluid. (6) At the leading edge of the fracture extension, the fluid pressure is equal to the in-situ stress. (7) The fluid is pumped at constant injection rate. (8) The fracture height is a given constant and controlled by the upper and lower reservoirs.

2.1.2. Calculation formula of fracture half-length

$$L(t) = \frac{QW}{16\pi Hc^2} \left[e^{x^2} * \operatorname{erfc} \left(\frac{2c\sqrt{\pi}}{W} + \frac{2x}{\sqrt{\pi}} - 1 \right) \right] \quad (1)$$

$$W = \left[\left(\frac{128}{3\pi} \right) (n+1) \left(\frac{2n+1}{n} \right)^n \left(\frac{0.9775}{10^4} \right) \left(\frac{1}{60} \right)^n \right]^{\frac{1}{2}n+2} \times \left[\frac{Q^n K L h^{1-n}}{50E} \right]^{\frac{1}{2}n+1} \quad (2)$$

where: W is the maximum fracture width, mm;

Q is injection rate, m³/min;

n is fracturing fluid flow coefficient, dimensionless;

K is fracturing fluid consistency coefficient, Pa • sn;

L is fracture half-length, m;

h is fracture height, m;

E is rock elastic modulus, MPa.

When calculating the fracture half-length, assuming the value of fracture width and calculating the fracture half-length by formula (1). Then, putting the calculated fracture half-length into the formula (3), and obtain the fracture width. The fracture half-length and width can be determined by comparing the gap of calculated and assumed fracture width. If the gap is small, the fracture half-length and width can be chose; if the gap is large, the calculated fracture width should be put into the formula (1) again until the error meets the requirements.

2.2. In-situ stress calculation model

The two-dimensional induced stress field model affected by fractures is shown in Figure 1. In the xy plane, a certain point (x, y) around the fracture is defined, which the compressive stress is negative and the tensile stress is positive; The induced stress field model of the minimum and maximum horizontal principal stress are calculated as follows:

$$\sigma'_x = -p \frac{r \sin \theta \sin \left[\frac{3}{2}(\theta_1 + \theta_2) \right]}{h} \left(\frac{L^2}{r_1 r_2} \right)^{\frac{3}{2}} - p \left[\frac{r \cos(\theta - \frac{1}{2}\theta_1 - \frac{1}{2}\theta_2)}{(r_1 r_2)^{\frac{1}{2}}} - 1 \right] \quad (3)$$

$$\sigma'_y = p \frac{r \sin \theta \sin \left[\frac{3}{2}(\theta_1 + \theta_2) \right]}{h} \left(\frac{L^2}{r_1 r_2} \right)^{\frac{3}{2}} - p \left[\frac{r \cos(\theta - \frac{1}{2}\theta_1 - \frac{1}{2}\theta_2)}{(r_1 r_2)^{\frac{1}{2}}} - 1 \right] \quad (4)$$

In the formulas (3)-(4), p is the net pressure on the fracture surface; L is the fracture half-length;

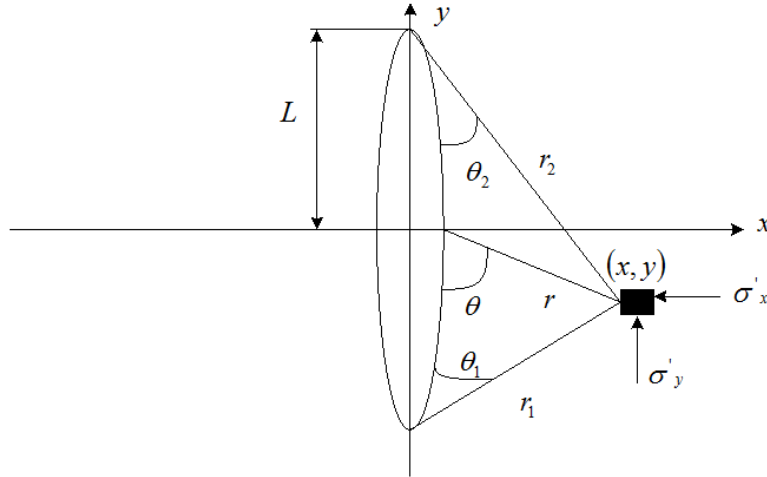


Figure 1. Schematic representation of a 2D fracture parameters

During the fracturing process, the stress field around the horizontal wellbore after fracturing is composed of the induced stress field generated by hydraulic fracture and in-situ stress field. Based on the superposition principle of stress, the composite stress field model around the wellbore after the initial fracture occurs can be expressed as

$$\sigma_x = \sigma_{xi} + \sigma'_x \quad (5)$$

$$\sigma_y = \sigma_{yi} + \sigma'_y \quad (6)$$

Where: σ_x, σ_y is the minimum and maximum horizontal stress in the direction of the composite stress, MPa;

σ_{xi}, σ_{yi} is minimum and maximum principal stress, MPa;

σ'_x, σ'_y is the induced stress of the initial fracture at the minimum and maximum horizontal principal stress directions, MPa;

The induced stress field produced by fracture around the wellbore after fracturing is the following:

$$\sigma'_x = \sum_{i=1}^{n-1} \sigma'_{x(ij)} \quad (7)$$

$$\sigma'_y = \sum_{i=1}^{n-1} \sigma'_{y(ij)} \quad (8)$$

Where $\sigma'_{x(ij)}, \sigma'_{y(ij)}$ is the i -th fracture produces an induced stress field component at the position j around the horizontal wellbore.

3. Model analysis

According to the above model, the induced stress field produced by the fracture extension is calculated. The calculated results are compared with the actual results. The average error is small, only about 7%. Therefore, the calculation result of the mathematical model proposed in this paper is more accurate, and the simplification and assumption are reasonable. The theoretical formula can provide the basis for analyzing the influence of the fracture extension on the in-situ stress.

In this section, the influence of the fracture extension on the maximum and minimum principal stress around the wellbore in the dense reservoir is analyzed. The main parameters are as follows: Poisson's ratio is 0.2; the permeability is 0.022mD; Young's modulus is 40GPa; the porosity is 0.12. Fracturing for 90 min, the relationship between fracturing time and fracture half-length are as follows:

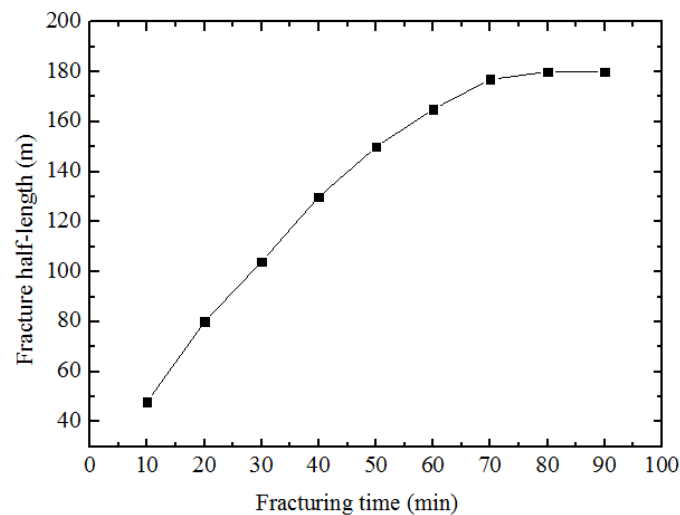


Figure 2. Relationship between fracturing time and fracture half-length

It can be seen from Fig. 2 that the fracture half-length improves with the increase of fracturing time. In the early stage of fracturing, the fracture growth rate is faster, but when fracturing time reaches 70 min, the fracture hardly grows. At this time, continuing to fracturing have little effect on stimulating reservoir, and brings unnecessary difficulties for the subsequent construction. In this paper, the fracture half-length reaches maximum value and closes to 180 m at the fracturing time of 70 min. In summary, the fracture does not always extend with the increase of fracturing time. Therefore, it is

effective to save the cost and improve the working efficiency by selecting the appropriate fracturing time without affecting the effect of reservoir reconstruction.

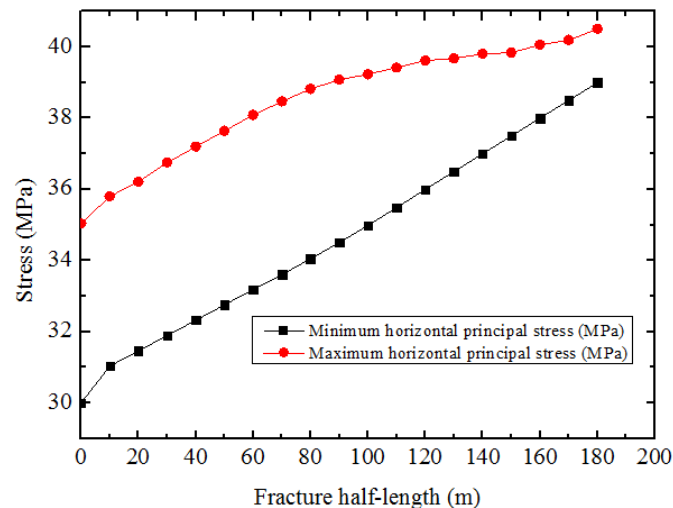


Figure 3. Relationship between fracture half-length and stress

It can be seen from Fig. 3 that the maximum and minimum horizontal principal stress of the reservoir near the wellbore increases with the increase of the fracture half-length, and the fracture extension has the greatest effect on the minimum horizontal principal stress. Moreover, the relationship between fracturing time and fracture half-length shows that the effect of fracturing on fracture extension is very small when the fracture half-length reaches 180 m. However, it can be seen in Fig. 3 that the in-situ stress value always improves with the increase of fracture half-length. It is the most direct and effective method to reduce the increasing value of in-situ stress by selecting the appropriate fracturing time to control the fracture half-length.

In summary, the selection of reasonable fracturing time is an effective way to control the fracture half-length. Controlling the fracturing time and the fracture half-length without affecting the effect of reservoir reconstruction can effectively reduce the influence of the induced stress on the subsequent fracture initiation and extension. At the same time, the growth of minimum horizontal principal stress is bigger than the maximum horizontal principal stress during the process of fracture extension.

4. Conclusion

As an important exploit means of low permeability oil and gas reservoirs, the fractures produced by hydraulic fracturing are the main factors that change the magnitude of in-situ stress. The subsequent fractures are difficult to initial and extent due to the increase of in-situ stress. Therefore, the effect of fracture extension on the in-situ stress must be taken into account in the design of fracturing optimization. The main conclusions are as follows:

1. The subsequent fractures are difficulty to initial and extend due to the increasing of in-situ stress. Selecting the appropriate fracturing time can effectively reduce the influence of fracture extension on the in-situ stress.
2. The effect of fracture extension on the minimum horizontal principal stress is greater than that on the maximum horizontal principal stress.
3. The stress contrast decreases with the fracture extension, the ratio of producing network will improve by subsequent fracture.
4. Controlling the fracture half-length reasonably is the main method to reduce the impact of induced stress on the subsequent fracture extension.

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