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Variation rules of fracture initiation pressure and fracture starting point of hydraulic fracture in radial well

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A B S T R A C T

Radial well technology in combination with hydraulic fracturing technology has gained encouraging achievements as a new method of increasing production in oil fields. Compared with conventional perforation fracturing, radial well fracturing has an obvious advantage in breaking through polluted borehole areas, and it is superior to horizontal well fracturing because of the shorter construction period, less consumption of fracturing fluid and lower damage to the reservoir. Currently, in China, the study on the position of fracture starting point and fracture propagation of radial well is still at the preliminary stage and the fracture initiation pressure and position of fracture starting point remain unclear. Consequently, it's difficult to design radial well completion parameters (length of radial well, diameter of radial well and fracturing truck units) precisely and implement the technology more efficiently. Based on fluid-solid coupling effect and the maximum tensile-stress criterion, this paper follows the concept of dynamic analysis and analyzes the influence rule of the length, diameter and azimuth of radial well, horizontal in-situ stress and natural fracture on fracture initiation pressure and fracture starting point under the stress of strike-slip fault by using ABAQUS to simulate and study local stress accumulation situation caused by drilling vertical well section, radial well section and fracturing section through finite element method. The result shows that initiation pressure and distance between well and fracture starting point increases as the length, diameter and azimuth of radial well section rise. Azimuth is most influenced, followed by length, and lastly diameter of radial well section. When the horizontal in-situ stress ratio (σ_H:σ_h) is decreased from 1.9 to 1.1, if the azimuth is 0°, the initiation pressure increases by 41.35%; if the azimuth is 90°, the initiation pressure declines 0.8%. However, the positions of these two fracture starting point remain unchanged. The permeability increases by four orders of magnitudes and the fracture initiation pressure goes up 34.5%, with no influence on the fracture starting point. When there existed natural fractures in the reservoir, the intersection between fracture section and radial well section firstly shows fracturing. Besides, the fracture initiation pressure and the hydrostatic fluid column pressure in vertical wellbore are equivalent. Reduced length and diameter of radial well section as well as reservoir permeability and properly increased azimuth of radial well are conducive to fracture at the toe end of the radial well section. On the contrary, fracture at shaft linings of vertical well section is easily occurred. The research result can be used to predict the direction of fracture propagation to some extent and is favorable for designing parameters of radial well completion and fracturing operation.

1. Introduction

Radial well is a horizontal well whose radius of curvature is much smaller than that of conventional well. The boreholes are usually produced by hydraulic jetting or drilling, showing the length of 30–100 m and the diameter of 25–50 mm (Wade et al.,1992; Wu, 1994; Li et al., 2000). The technique combined radial well and hydraulic fracturing as an emerging stimulation treatment has been used in Jiangsu, Shengli and Liaohe oil fields. This technique has the following advantages: (1) the borehole of radial well performs the function of guiding the direction of fractures and increasing the penetration of fractures; (2) through the branches of fracture, a larger producing area of reservoir can be connected. Compared with conventional fracturing, the fracturing effect is better and the effective period is longer; (3) the radial branches reduce the fracture initiation pressure as well as the operation pressure; (4) the height of fracture propagation is effectively controlled so as to prevent the water layers from

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connecting. The thin interbeds can be chosen for fracturing. The technique has a shortened operation time and causes less damage to oil layers from the foreign liquid.

Currently, research on the fracture initiation pressure in oriented perforation is large in amount, and the following three methods are commonly used: experimental method, numerical analysis method and numerical simulation method.

Ketterij, Huang and Lhomme used experimental method on the influence of perforation parameters of highly deviated well on fracture initiation pressure and fracture starting point. Stress calculations were performed to obtain the pattern of influence of perforation angle on fracture initiation pressure and fracture propagation (van de Ketterij and de Pater, 1997).

True triaxial apparatus was used to impose triaxial stress on the rock samples. By changing such parameters as depth and diameter of perforation and the included angle α between the axis of perforation and the maximum horizontal stress, the variation rules of fracture initiation pressure under different perforation parameters was analyzed (Huang and Li, 2007).

The rule of fracture initiation was studied by using horizontal fluid to impose pressure on open-hole section through experimental method. It showed that the fracture initiation had a direct connection with the seepage flow mechanism and the microscopic structure of the rock mass (Lhomme et al., 2002).

Luo and Zhu employed numerical analysis method to solve the problem of hydraulic fracture initiation in oriented perforation. Based on the stress state on the intersection between the borehole and perforation tunnel in the deviated well with casing perforation, Luo Tianyu proposed the method to calculate the tangential stress near the hole edge. Moreover, the calculations of stress field at the intersection between the two holes, fracture initiation pressure and fracture starting point in the presence of micro-circular plane were investigated. The method also was discussed for the calculation of fracture initiation pressure at the intersection of the two holes in annular space with tight cementation (Luo et al., 2007).

The analytical model of stress was derived around the cased wells by Zhu Haiyan. Combining with Hossain's model and the maximum tensile-stress criterion, the model of predicting the fracture initiation pressure and fracture initiation angle on the perforation tunnel during the oriented casing perforation was established. Later, the effective stress theory was utilized to establish the calculation model of fracture initiation pressure around the wellbore in shale gas reservoir. The influence of stratum dip direction and in-situ stress azimuth on the fracture initiation pressure also was analyzed (Zhu et al., 2013, 2014).

Numerical simulations based on computer have been carried out for hydraulic fracture initiation in oriented perforation. The influence of perforation on the fracture initiation pressure and fracture morphology in hydraulic fracturing was discussed. The fracture propagation models were established under different positions of perforation and different far-field principal stress. The impact of perforation parameters on fracture initiation pressure and fracture morphology was analyzed (Zhuang et al., 2008). The numerical model of fluid-solid coupling was constructed by using finite element method. The fracture initiation and propagation near the wellbore were discussed (Salehi and Nygaard, 2015). A 3D finite element method was applied in predicting the fracture initiation pressure under helix distribution perforation. The 3D numerical model of wellbore and the formation was built under cased hole completion (with the existence of cement mantle and casing) (Biao et al., 2011).

These scholars produced many research results of perforation parameters and fracture initiation pressure, but few of them paid attention to the research of such radial well completion parameters as length, diameter and fracture initiation pressure. As for the initiation position of radial well studies, no result has been found. In China, the study on fracture initiation and propagation in the fracturing of radial well is still at the preliminary stage. This technique is more frequently applied in the development of coalbed methane. The integration of operation of short-radius radial horizontal well and hydraulic fracturing was proposed for the increase of gas production in Hunchun Basin that has low-rank coal and good permeability and favorable gas-bearing conditions (Xian et al., 2010). Michael Patrick Megorden suggested the use of radial well in coalbed to improve and guide the geometry of fractures, and a certain effect was achieved (Megorden et al., 2013).

At present, the fracture initiation pressure and position are still unclear; as a result, such radial well completion parameters as length and diameter of radial well and fracturing truck unit cannot be effectively designed. Jiangsu Oil Field has taken the lead in carrying out radial well fracturing test in China and achieved satisfactory results, which proves the feasibility of radial well fracturing. Jiangsu Oil Field is located in Gaoyou sinking area in the south of Northern Jiangsu Basin where exist many strike-slip faults, such as Shigang, Chajian and Wubu faults. The radial well parameters and rock parameters applied in this study are all from X zone in Jiangsu Oil Field and the target system belongs to strike-slip faults.

In this paper, the author firstly introduces the theoretical basis and finite element discretization method of establishing fluid-structure interaction numerical model by ABAQUS, revealing the stress–percolation interaction mechanical mechanism of Pore Fluid-Stress module in ABAQUS software, which helps to better understand the applicable range and assumption conditions of the model. As the target system pertained to strike-slip fault area, strike-slip fault's stress mechanism was selected as the ground stress mechanism and 3D numerical modeling study was carried out concerning the radial well fracture initiation pressure and fracture starting point. Elasto-plastic model is adopted as the material property and given that the rock around the shaft lining is subject to the triaxial pressure and stress incurred by well sections removal. Drucker–Prager yield criterion is applied to judge the yield stress. In the process of hydraulic fracturing, the maximum tensile–stress criterion is adopted to judge whether fracture occurs to rock under tensile stress. The numerical simulation process is, in order, divided into the following three steps: simulation of the process of removing vertical well section, simulation of the process of removing radial section and simulation of fracturing process. Because the stress concentration phenomenon caused by removing rocks from drilling the vertical well section with initial stress and radial well section is taken into consideration (Hubbert and Willis, 1956; Valko et al., 1995; Aadnoy, 1988), the numerical model established is able to better simulate the stress changing situation around vertical well section and radial well section. Real reservoir rock parameters were taken as the criterion of the model, and the single factor influence on fracture initiation pressure and position was studied by using different parameters like the azimuth, diameter and length of radial well, horizontal in-situ stress ratio, permeability and natural fracture position through analysis on the numerical simulation result. Meanwhile, we also made in-depth analysis about “the region susceptible to fracture initiation” at the vertical well section and the toe ends of the radial well in case of different azimuth, diameters and lengths of radial well, horizontal in-situ stress ratios, permeability and natural fracture positions, and found how “the region susceptible to fracture initiation” regularly distributes. The research results are conducive to designing the radial well completion parameters and fracturing operation parameters by predicting the propagation direction of fractures to some extent.