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Original article

Affection mechanism research of initiation crack pressure of perforation parameters of horizontal well

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ABSTRACT

Horizontal wells show better affect and higher success rate in low water ratio cement, complex fracture zone, crevice and heavy oil blocks, it is the main measures to expand control area of a single well. Hydraulic fracturing technology is the most financial way to improve the penetration of the reservoir to increase the production. However, compare with the vertical wells, the fracture of Horizontal wells are more complex, and lead to the initiation crack pressure is much higher than vertical wells. In this paper, defined the crack judging basis, and established the finite element model which could compute the initial crack pressure, to research the affection mechanism of perforation azimuth angle, density, diameter and depth, to provide references of perforation project's design and optimize. The research of this paper has significances on further understanding the affection mechanism of perforation parameters.

1. Introduction

Drilling horizontal well is an important measure to reduce exploration and development cost, increase single well productivity and enhance the recovery rate. Especially, it boasts of good application effect and high success rate in terms of the exploration and tapping potentials of oil deposits characterized by low water, complex fault block, crack, heavy oil, etc [1,2]. The hydraulic fracturing technology is one of the most economic and effective ramping up production measures to innovate permeation reservoir and meet with industrial exploration need [3,4]. During the hydraulic fracturing, the increase of hydraulic force of fracturing will pose higher requirements on booster equipment and fracturing sling, and significantly raise the hydraulic fracturing cost.

In the early 1898, Ljunggren, C. and Amadei, B. researched the method to estimate virgin rock stressed from horizontal hydrofractures which started the rock cracked pressure prediction research [5]. And then, Hubbert, M. K. et al. studied the hydraulic fracturing mechanics, and developed the first realistic model relating the hydraulic fracturing test variables to the rock stress distribution [6]. Haimson, B. et al. researched rocks initial crack and crack extension during hydraulic fractures, their researches invoked the theory of poroelasticity to incorporate the fluid injection effect on the wellbore around rock stress distribution [7].

Hudson, J. A. et al. researched the rock tension strength theory and statistical the approach of rock failure that refer judgment of rock crack theory with rock mechanical properties [8,9]. Hoek, E., Bieniawski, Z. T. et al. concluded some strength criterion for rock massed with many rock crack tests and statistical [10,11]. El Rabaa, W. et al. studied the affection of initial cracked pressure during hydraulic fracture by wellbore geometry from horizontal wells with experimental methods [12]. Soliman, M. Y and Weijers, L. et al. interpreted the affection reason by the hole deviation of horizontal wells of the hydraulic fracture, and concluded some laws of the rock initial crack pressure [13,14]. Hossain, M. M. et al. researched the hydraulic fracture initiation and propagation of rock with the affection of trajectory, perforation and stress regimes [15]. Djurhuus, J. and Nelson, E. J. studied the way to inverse in situ stress state with fracturing data from oil wells and borehole image logs [16,17]. Wu, H., Jasarevic, H. et al. observed the hydraulic fracture initiation and propagation with simulation experiment [18,19]. Jiang, H. et al. researched the impact of

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oriented perforation on hydraulic fracture initiation and propagation [20]. Huang, J. et al. referred that the magnitude of the most tensile strength in the wellbore wall should always be compared with the tensile strength of the rock to predict hydraulic fracture initiation based on elastic theory, and some special cases have been found in which the most tensile principle stress reaches the tensile strength of the rock simultaneously at all point on the circumference of the wellbore [21]. Lecampion, B. et al. researched the hydraulic fracture initiation from an open-hole, the affection of wellbore size, pressurization rate and fluid-solid coupling of the fluid and wellbore [22].

Finite element method used widely with the fast speed developing of computing methods. Smart, K. J. et al. established the geomechanical model of hydraulic fracture initiation and propagation in a mechanically stratified geologic system [23]. Zhu, H. et al. in combination with the tensile failure criterion, a prediction model for the hydraulic fracture initiation pressure in the shale gas reservoirs is put forward, and the study provides a reference for the hydraulic fracturing design in shale gas wells [24]. Fan, T. et al. researched the impact of cleats on hydraulic fracture initiation and propagation in coal seams with experiments [25]. Stanchits, S. et al. onset of hydraulic fracture initiation monitored by acoustic emission and volumetric deformation, and three experiments were conducted on a low permeability sandstone block, loaded in a poly-axial test frame, to representative effective in situ stress conditions [26]. Lei, X. et al. researched the impact of perforation on hydraulic fracture initiation and extension in Tight Natural Gas reservoirs. Jeffrey, R. G. measured and analyzed the Full-Scale hydraulic fracture initiation and reorientation [27]. Dehghan, A. N. et al. using a triaxial hydraulic fracturing test system studied the mechanism of fracture initiation and propagation in naturally fractured reservoirs [28]. Fatahi, H. et al. using distinct element method studied the determination of hydraulic fracture initiation and breakdown pressure by numerical simulation [29]. Zhao, X. et al. researched the impact of hydraulic perforation on fracture initiation and propagation in shale rocks [30].

Also, perforation parameters are an important factor to influence the strata initiation fracture pressure. A good many scholars [31–33] have conducted empirical study on the calculation of initiation fracture pressure, and drawn some rules on the impact on initiation fracture pressure by the perforation parameters, and Zhu, X.et al. research the parameter control methods for the pumping tool string composed of perforating gun and fracturing plug in a horizontal well, and the results show that, with increasing well head pressure, the grease injection rate should be increased to improve sealing pressure, and the minimum weight of tool string should also increase, which show the difficulty of pressure increase [34]. However, the literature above doesn't illustrate in detail the mechanism of impact on the initiation fracture pressure of the strata by the perforation parameters. A basis for perforation hole fracture judgment is put forward herein. Besides, the impact on the initiation fracture pressure of the strata by the perforation azimuth angle, diameter, depth and density is studied through the establishment of the finite element model for calculating the initiation fracture pressure of the strata.

2. Mathematic model and perforation hole fracture judgment basis

2.1. Main stress of shaft

Acted by the crustal stress, the stress state in the perimeter of the shaft is one of the important factors affecting the initiation fracture pressure. The main stress σ_1, σ_2, σ_3 in three directions are separately [35]:

$$\begin{cases} \sigma_1 = \sigma_r \\ \sigma_2 = \dfrac{1}{2}[(\sigma_\theta + \sigma_{zz}) + \sqrt{(\sigma_\theta - \sigma_{zz} + 4\tau_{\theta z}^2}] \\ \sigma_3 = \dfrac{1}{2}[(\sigma_\theta + \sigma_{zz}) - \sqrt{(\sigma_\theta - \sigma_{zz} + 4\tau_{\theta z}^2}] \end{cases} \tag{1}$$

where: σ_r radial stress, σ_θ circumferential stress, positive stress in the axial direction of shaft, $\tau_{\theta z}$ tangential stress in the perimeter of well wall.

2.2. Perforation hole fracture judgment basis

Based on the state of load imposed in the perimeter of the perforation hole shown in Fig. 1, acted by the crustal stress, the rock surrounding the perforation hole is under the pressure state. During the hydraulic fracturing, the acting force of the fracture fluid in the perforation hole is also the pressure. Therefore, the rock surrounding the hole cannot present the tension stress state. However, there is indeed tension stress here. In order to resolve the aforementioned contradiction, the circumferential stress of the hole acted by the crustal stress is taken as the reference herein, and the variation of the circumferential stress of the hole acted by hydraulic fracturing (stress difference) is used as the basis for judging whether the hole is fractured, namely

$$\sigma = \sigma_e - \sigma_p \tag{2}$$

$$\sigma_e = \sqrt{\sigma_{e1}^2 + \sigma_{e2}^2 + \sigma_{e3}^2 + \tau_{e12}^2 + \tau_{e13}^2 + \tau_{e23}^2} \tag{3}$$

$$\sigma_p = \sqrt{\sigma_{p1}^2 + \sigma_{p2}^2 + \sigma_{p3}^2 + \tau_{p12}^2 + \tau_{p13}^2 + \tau_{p23}^2} \tag{4}$$

where: σ_e Mises stress value acted by the crustal stress, σ_{e1}, σ_{e2}, σ_{e3}, τ_{e12}, τ_{e13} and τ_{e23} respectively main stress or shear stress in each direction acted by the crustal stress, σ_p Mises stress value simultaneously acted by the crustal stress and fracturing fluid, σ_{p1}, σ_{p2}, σ_{p3}, τ_{p12}, τ_{p13} and τ_{p23} respectively main stress or shear stress in each direction simultaneously acted by the crustal stress and fracturing fluid.

When $\sigma > 0$, the rock is under pressure; when $\sigma < 0$, the rock is under tension. When the tension stress is more than the tensile strength of the rock, the strata fracture initiates. Therefore, the

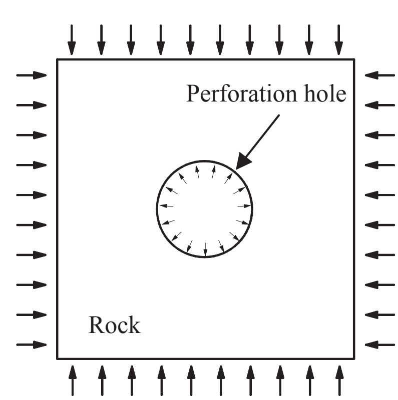

Fig. 1. The stress state of the perforation holes.