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Numerical Modeling of Hydraulic Fracture Propagation in Horizontal Wells based on Geological Parameters

Yu Fu, Fuwei Li

Petroleum Engineering School, Southwest Petroleum University, Chengdu, China

Abstract

Tight sandstone gas reservoirs are unconventional oil and gas resources with significant exploration and development potential. Hydraulic fracturing in horizontal wells is an effective method to enhance the productivity of these reservoirs. Multi-stage hydraulic fracturing in horizontal wells can create a stable network of primary fractures and fracture systems in low-permeability and homogeneous tight rock formations, successfully addressing issues such as low oil and gas production in tight reservoirs. However, in practical engineering, many of the perforations and fracture extensions in horizontal wells are ineffective, with some fractures deviating or even changing direction from their intended path. This study utilizes a finite element numerical simulation approach to investigate the fracture propagation behavior under different geological parameter conditions in this area. The results indicate that with a Poisson's ratio of 0.25 and an elastic modulus of 15 GPa, lower fracturing pressures and wider hydraulic fracture apertures are generated, which are beneficial for improving the effectiveness of hydraulic fracturing. The findings of this study will provide a scientific basis for the development of tight sandstone gas reservoirs in the Ordos Basin.

Keywords

Horizontal Wells; Fracture Propagation; Tight Sandstone; Geological Parameters.

1. Introduction

China's onshore tight gas reserves cover an advantageous exploration area of 32.46×104 km2 with estimated resources of 21.85×1012 m3, mainly distributed in the Ordos Basin, Bohai Bay, and Sichuan Basin. Among them, the tight sandstone gas resources in the Ordos Basin exceed 12×1012 m3, accounting for approximately 83% of the total natural gas resources in basin and mainly concentrated in the Sulige area [1]. Horizontal well fracturing is an effective method to increase the production of tight sandstone gas reservoirs[2]. However, the overall development of tight sandstone gas reservoirs in the Ordos Basin faces challenges due to the rapid lateral variations and vertical multilayer development of reservoirs. Deepening the understanding of fracture propagation in horizontal well hydraulic fracturing in the target blocks can help predict the post-fracturing fracture expansion patterns and provide theoretical guidance for optimizing construction parameters. This paper conducts numerical simulation experiments on multi-stage hydraulic fracture propagation in the northern and southeastern replacement areas of Block S, aiming to provide theoretical guidance for the design of multi-stage fracturing in field horizontal wells[3].

2. Fracture Propagation Model

During the hydraulic fracturing process, the propagation of fractures is one of the key issues in rock mechanics. To address this problem, the basic governing equations consist of the rock mass equation, the fluid flow equation (i.e., continuity equation) for the fracturing fluid, and the propagation criteria. In particular, rock deformation is primarily based on linear elastic fracture mechanics theory, while plastic deformation characteristics require the use of the B-matrix method to modify the elemental stresses based on plastic criteria[4-5]. To solve the fracture propagation, a hybrid method combining the finite element method (FEM) and the discrete element method (DEM) is employed. Specifically, the computational domain is divided into multiple solid elements, which are connected by virtual springs to transmit interaction forces, and the fracture of the springs represents the rock fracturing process. Additionally, there exists a fracture element between every two solid elements to compute the flow of the fracturing fluid and the distribution of fluid pressure. The fluid pressure acts as an external load on the fracture surfaces (i.e., contact surfaces between the solid elements). The deformation of the continuous solid elements is solved using the finite element method, while the fracture of the springs is calculated using the discrete element method. The conditions for fracture propagation are determined by the maximum tensile stress criterion and the Mohr-Coulomb criterion. These criteria need to be modified and optimized based on the specific circumstances to meet engineering requirements. In summary, the fracture propagation problem in hydraulic fracturing is a complex multi-physics coupling problem that requires the integration of knowledge from various fields such as rock mechanics, fluid mechanics, and mechanics. By employing a hybrid method that combines the finite element method and the discrete element method, the process of fracture propagation can be simulated more accurately, providing strong support and assurance for engineering practice. In the fracture propagation model for hydraulic fracturing, the following assumptions are made: (a) the reservoir matrix is homogeneous and isotropic; (b) the rock mass equation includes an inertial term to make the mechanical behavior dynamic, but an artificial damping term is introduced to make it a quasi-static process; (c) the influence of proppants on fracture propagation is not considered; (d) fractures only occur and extend along the interfaces between the elements, and it is assumed that the number of mesh elements is large enough to provide a stochastic path for fracture propagation[6-7].

3. Numerical Simulation Study on Factors Affecting Crack Propagation

This section analyzes the influence of Poisson's ratio and rock elastic modulus formation parameters on the fracture propagation pattern of staged fracturing in horizontal wells, providing theoretical guidance for fracturing construction in the replacement area of Block S.

3.1 Poisson's Ratio

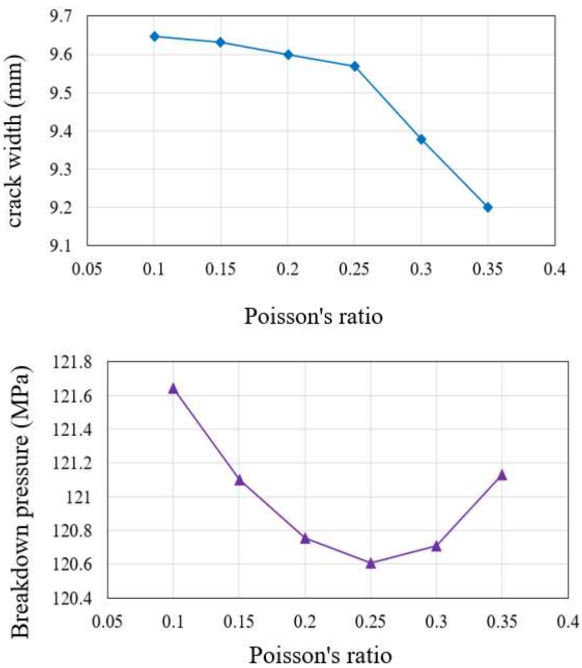

Figure 1. Variation of Crack Width and Fracture Pressure under Different Poisson's ratio

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Model parameters: fracturing 3 sections, horizontal stress difference 5MPa, Young's modulus 20GPa, fracture height 40m, section spacing 60m, construction displacement 10m3/min, Poisson's ratio set to 0.1, 0.15, 0.2, 0.25, 0.3, 0.35. The simulation results are shown in Figure 1.

The results show that the crack width decreases with the increase of Poisson's ratio. When μ≤ At 0.25, the crack width slightly decreases; and μ≥ At 0.25, the trend of crack width decreasing increases.

μ< At 0.25, with the increase of Poisson's ratio, the fracture pressure of reservoir sandstone decreases, and the decreasing trend gradually weakens to μ= At 0.25, the fracture pressure of sandstone is the smallest. When μ> At 0.25, the fracture pressure of sandstone increases with the increase of Poisson's ratio, and the increasing trend is strengthened. According to the comprehensive change of fracture width, when the Poisson's ratio is about 0.25, the fracture pressure is small and the hydraulic fracture width is large, which is conducive to improving the fracturing effect.

3.2 Elastic Modulus

Model parameters: fracturing 3 sections, horizontal stress difference of 5MPa, Poisson's ratio of 0.25, fracture height of 40m, interval of 60m, construction displacement of 10m3/min, elastic modulus of 10GPa, 15GPa, 20GPa, 25GPa, 30GPa. The simulation results are shown in Figure 2.

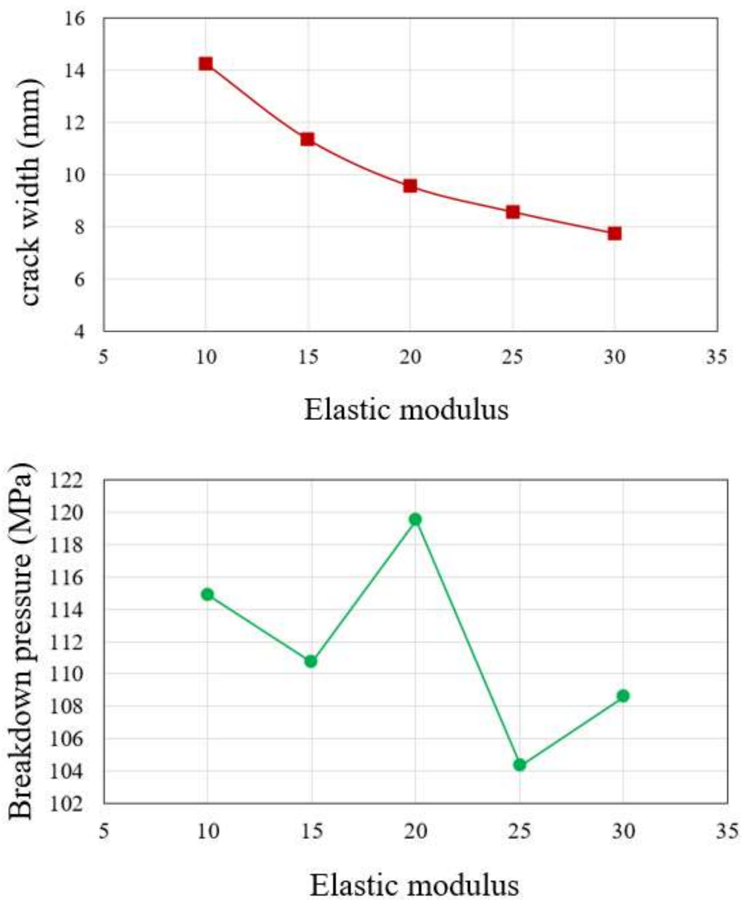

Figure 2. Changes in crack width and fracture pressure under different elastic moduli

As the elastic modulus increases, the length of hydraulic cracks tends to increase while the width of cracks gradually decreases. The elastic modulus of reservoir rocks is negatively correlated with the width of hydraulic fractures. The width of hydraulic fractures decreases with the increase of rock elastic modulus, and the decreasing trend gradually decreases. The higher the Young's modulus of rocks, the stronger their brittleness, and the less likely they are to undergo significant deformation.

Therefore, staged fracturing of horizontal wells in formations with stronger Young's modulus is more likely to form narrow and long fractures.

4. Conclusion

The numerical simulation experiment of multi-stage fracturing fracture propagation of horizontal wells was carried out in the northern and southeastern replacement areas of Block S, and a set of multi-stage and multi cluster fracturing fracture propagation model was established by comprehensively considering the stress interference, Fluid–structure interaction, and multi fracture flow distribution. By analyzing the influence of different formation parameters on the multi cluster fracture propagation, when the Poisson's ratio is about 0.25 and the elastic modulus is about 15GPa, The small fracturing pressure and the large hydraulic fracture width generated are beneficial for improving the fracturing effect.

References

[1] Zhang Rusheng, Wang Qiang, Zhang Guoguo, et al. Study on ABAQUS numerical simulation of three-dimensional expansion of Fracking fractures [J]. Petroleum Drilling and Production Technology, 2012,34 (06): 69-72.

[2] Li Y, Wei C, Qin G, et al. Numerical Simulation of Hydraulically Induced Fracture Network Propagation in Shale Formation [C] International Petroleum Technology Conference two thousand and thirteen.

[3] Hunsweck M J, Shen Y, Lew A J. A fine element approach to the simulation of hydraulic frames with lag [J] International Journal for Numerical and Analytical Methods in Geomechanics, 2013, 37 (9): 993-1015.

[4] Sun Feng, Pang Mingyu, Zhang Qihan, Xue Shifeng. Numerical simulation of simultaneous propagation of multiple fractures in horizontal well fracturing [J]. Journal of Central South University (Natural Science Edition), 2017,48 (07): 1803-1808.

[5] Zhang Jian, Zhang Guoxiang, Zou Yushi, et al. Numerical simulation of CO2 fracturing crack propagation law in tight reservoirs [J]. Petroleum Drilling and Production Technology, 2018,40 (03): 354-360+368.

[6] Liu Wenzheng, Yao Jun, Zeng Qingdong. Numerical simulation of Fracking fracture propagation in deep oil and gas reservoirs [J]. Chinese Science: Technical Science, 2019, 49 (02): 223-233.

[7] Wang Tianju, Chen Zan, Wang Rui, et al. A new method for optimizing the spacing of volume fracturing clusters in tight sandstone reservoirs [J]. Xinjiang Petroleum Geology, 2019,40 (03): 351-356.