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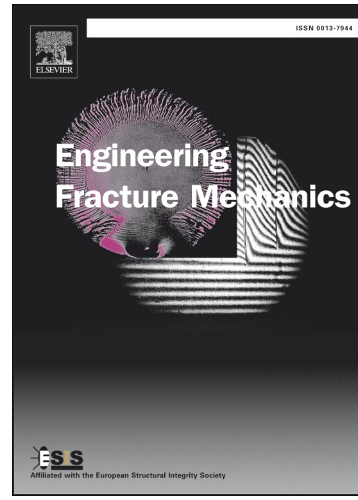

Numerical Investigation of Fracture Spacing and Sequencing Effects on Multiple Hydraulic Fracture Interference and Coalescence in Brittle and Ductile Reservoir Rocks

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Abstract

For unconventional resources exploration and development, hydraulic fracture pattern and associated dimensions are critical in determining well stimulation efficiency and ultimate recovery. When creating arrays of hydraulic fractures along horizontal wells, stress field changes induced by hydraulic fractures themselves can lead to fracture interference and coalescence. The resulting complex fracture geometry may compromise or improve the effectiveness of the stimulation job, depending on the nature of the context. Currently, the prevailing approach for hydraulic fracture modeling also relies on Linear Elastic Fracture Mechanics (LEFM), which uses stress intensity factor at the fracture tip as fracture propagation criteria. Even though LEFM can predict hard rock hydraulic fracturing processes reasonably, but often fails to give accurate predictions of fracture geometry and propagation pressure in quasi-brittle and ductile rocks, such as poorly consolidated sands and clay-rich shales. In this study, a fully coupled hydraulic fracture propagation model based on the Extended Finite Element Method (XFEM), Cohesive Zone Method (CZM) and Mohr–Coulomb theory of plasticity is presented, to investigate the interference and coalescence of fluid-driven hydraulic fractures that initiated from horizontal wells. The results indicate that fracture spacing and the relative timing of fracture initiation control whether the fractures compete against each other to form a divergent pattern or coalesce into a single, primary fracture. Fracture growth can be arrested after fracture tips pass by when simultaneously fracturing adjacent horizontal wells. Even though the in-elastic rock deformation due to shear failure can strongly impact fracture geometry and fracturing pressure, it has limited influence on hydraulic fracture interaction patterns.

Keywords: hydraulic fracture; fracture spacing; fracture sequencing; fracture interference; fracture coalescence; brittle; ductile; cohesive zone method (CZM); extended finite element method (XFEM)

1. Introduction

The combination of horizontal drilling and multistage hydraulic fracturing technology has made possible the current flourishing oil and gas production from shale reservoirs in the United States, as well as the global fast growing investment in unconventional resources exploration and development. Accurate prediction of multiple fracture propagations and a comprehensive understanding of hydraulic fracture interference from a single well and between neighboring wells are vital in optimizing well placement and hydraulic fracturing treatment design (such as determine fracture spacing, fracturing sequence, fracture half-length, etc.). The hydraulic fracturing process is primarily aimed at well stimulation, but it provides other benefits as well. These include sand production control, connection of layered and laminated formations by vertical penetration, and afford the ability to spread depletion deep into the reservoir, thus significantly increasing economically recoverable reserves (Economides and Nolte 2000).

When fracturing a horizontal wellbore, completions are distinguished by the methods of isolating fracturing section and diverting fracturing fluid to perforation tunnels. For open-hole completion, external casing packers are used as the isolation tool, and ports on sliding-sleeve are opened by dropped balls or coiled tubing. For cemented-casing completion, composite bridge plugs or internal casing packers are the isolation methods, and perforations or coiled tubing activated ports divert fracturing fluid. In these completions, starting from the toe of the horizontal well and working back to the vertical part of the well, a horizontal well is generally fractured multiple times, through a series of stages, to create multiple fractures to increase the reservoir contact area, as shown in **Fig.1**. In each stage, the well is perforated in multiple perforation clusters with the aim of creating a separate fracture within each cluster. The number of clusters and the number of perforations within each cluster are selected based on the designed injection rate during fracturing. The process of dividing a horizontal well into different stages and propagating multiple fractures simultaneously from each cluster in a certain stage is often called “multistage fracturing”.

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