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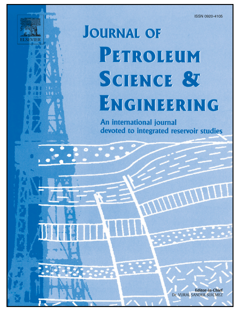

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Managed Saffman-Taylor Instability During Overflush in Hydraulic Fracturing

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Abstract

Overflushing is a common practice in multistage completions of horizontal wells in unconventional formations. It consists in displacing the suspension by a thin fluid, away from the wellbore and into the fracture. It can, however, overly displace proppant and leave a significant portion of the fracture unsupported near the wellbore, or trigger gravity slumping, again leaving unpropped area near the wellbore. That unpropped area can then close during production, damaging the performance of the fracture. A novel modeling approach was investigated to gain insight into the overflush process and determine secure bounds for maintaining the fracture performance.

From a fluid mechanics viewpoint, overflushing is the displacement of a Hershel-Bulkley fluid by a power law fluid in a Hele-Shaw cell, leading to Saffman-Taylor instability at the fluids interface. Whereas most hydraulic fracturing simulators use power-law rheology model, we used a novel numerical approach accounting for the yield-stress behavior of the slurry. Using the lubrication approximation, we derived a model, which includes transport equations for fluid volume fractions and a nonlinear elliptic equation for pressure with mixed-type boundary conditions. Validation was previously performed against three sets of experiments in Hele-Shaw cells, comprising gravitational slumping and displacement of fluids with fingering.

Based on fracture mechanics, we analyzed how large a portion of the fracture may be left unsupported before it is severely pinched during drawdown. A parametric study was performed on the displacement of the yield-stress slurry by the overflushing fluid. Qualitatively, when fingers of the overflushing fluid can be created at the overflush/slurry interface, large slurry pillars are preserved in the near-wellbore area, which may keep the fracture open. Three main scenarios of fluids distribution are identified and classified in terms of the oveflush fluid-to-slurry viscosity ratio ξ: (i) the slumping-dominated regime, where light clean overflush fluid goes on top of sedimenting heavy proppant-laden suspension ($\xi \gtrsim 0.1$), (ii) an intermediate scenario of slumping combined with fingering ($\xi \sim 0.01$), and, finally, (iii) a pure fingering-dominated scenario, when the slurry viscosity is high ($\xi < 10^{-3}$). The third scenario minimizes the geomechanical risks of overflushing by providing tiny fingers that are unlikely to be pinched out during fracture closure.

Keywords: Hele-Shaw cell, hydraulic fracturing, Saffman-Taylor instability, yield stress, Bingham fluid

1. Introduction

Hydraulic fracturing of underground formations is one of the most efficient oilfield technologies associated with production of hydrocarbons [9]. The process involves the initiation and propagation of a primary hydraulic fracture via injection of a typically highly-viscous clean fluid through the perforations in the well casing, which stage is then followed by proppant placement by injection of a particle-laden suspension into an open hydraulic fracture, with the aim of creating a high-conductivity channel after fracture closure and during subsequent production. In horizontal wells drilled through low-permeability (tight) formations, the common practice is to create sequentially several (up to one hundred) hydraulic fractures in order to maximize the area of hydrocarbon recovery. Each fracturing sequence (also called a stage) usually ends with what is called an overflush, where pure fluid is injected to clean the well from the particle-laden suspension in order to minimize the risk of failure during the subsequent fracturing stages. During the overflush, some of the clean fluid enters the hydraulic fracture through the perforations, displaces the particle-laden suspension and leaves a particle-free zone near the perforations.

The practice of overflushing, i.e., displacing the fracturing treatment away from the wellbore and into the fracture with a thin light fluid (Fig. 1), is common in multistage completions of horizontal wells. It ensures that proppant is cleared for subsequent operations or stages, and may prevent proppant flowback during well start-up. Overflushing, however, may damage the overall fracture performance due to a combination of factors: first, proppant may be displaced far away enough from the well that the fracture is unsupported near the well and closes there during drawdown. Furthermore, fracture closure takes long enough in very low permeability reservoirs, so that gravity slumping can take place. Due to slumping, the overflushing

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