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ORIGINAL PAPER

Borehole Failure Mechanisms in Naturally Fractured Formations

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Abstract

The possibility that pressure-loaded natural fractures in naturally fractured formations may contribute to wellbore instability merits further investigation. The present study analyzes in detail the state of stress around a wellbore with pressurized natural fractures nearby. Synthetic examples are given of unanticipated well instability when pressure-loaded natural fractures occur in the vicinity of the wellbore at the time of first penetration of the naturally fractured formation. The locations of shear failure are controlled by the stress field distortion due to the fluid pressure in the natural fractures. Various shear failure criteria are used to quantify where and when the critical stress for shear is reached. Rather than shear failure, tension failure may also occur at the wellbore. For example, wellbore stability is jeopardized by unintended circulation loss when the mud load causes unexpected hydraulic fracturing during drilling operations. The method of solution is a recently developed linear superposition method (LSM) of elastic displacements. The LSM models show static solutions of the stress state, and a dynamic version of the method (TLSM) uses time-stepped superposition to model fracture propagation processes. Time-stepped solutions show how fluid pressure-loaded natural fractures near a newly drilled well may alter the fracture propagation paths. The study also includes examples of stress concentrations near boreholes prepared with slotted perforations commonly used during fracture treatment operations in both conventional and unconventional fields.

Keywords Stress interference · Wellbore stability · Natural fractures · Hydraulic fractures · Fracture propagation · Linear superposition method (LSM) · Time-stepped linear superposition method (TLSM)

1 Introduction

Wellbores in naturally fractured reservoirs are prone to loss of drilling mud due to unintended hydraulic fracturing, which then absorbs the drilling fluid (Ehlig-Economides et al. 2000; Majidi et al. 2008; Razavi et al. 2017; Salimi et al. 2010). Drilling engineers aim to keep the wellbore stable at all times, which includes limiting the risk of mud loss. The loss of drilling mud into the crevasses created by propagating fractures removes mud lubrication, which may lead to stuck pipe and drill-string failures. The unintended hydraulic fracturing may also lead to severe formation damage that will be detrimental to future production (Bubshait and Jha 2020).

Traditionally, the method used to control the well is based on careful computation of the required mud density to apply the appropriate pressure on the unshielded section of the wellbore beyond the casing depth. The mud weight and casing changes must be designed to keep the wellbore stable. Wellbore stability models commonly assume certain simplified conditions in the formations traversed by the well trajectory (Aadnoy and Looyeh 2012; Fjaer et al. 2008; Jaeger et al. 2007). The critical data used are formation strength (tensile strength, shear strength, friction angle, cohesion), pore pressure data of the formations along the drill trajectory, and the native stress state in the reservoir (Wang and Weijermars 2019a). For anisotropic rock

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