A fully coupled finite element model for simulating hydro-dynamical plugging of unwanted hydraulic fractures in wellbore strenghtening

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For a successful drilling operation, a proper mud weight must be maintained between two limits. The pore pressure gradient being the lower and the fracture pressure gradient of the formation being the higher one. These limits are often called the "*mud weight window*". It is possible that this range may become too narrow under certain conditions like drilling in deep or ultra-deep-water, construction of highly deviated wells, passing through depleted zones and penetrating naturally fractured zones. In such cases an unwanted hydraulic fracture may be induced thereby causing the loss of drilling fluids in the surrounding formations with an estimated annual loss to the global drilling industry of about 2-4 billion [1-5].

Wellbore strengthening, often shortened to WBS, usually incorporates the addition of lost-circulation materials (LCMs) of various sizes, types, and mechanical properties to the drilling fluid. These particles are intended to plug the induced or natural fractures that cause damage to the wellbore. This way, the maximum pressure a wellbore can tolerate is increased artificially so that mud losses are diminished. Hence WBS intends to enhance the effective fracture pressure and widen the mud weight window rather than actually increasing the strength of the formation. In particular, these techniques aim to alter the stress distribution near the wellbore and the fluid pressure inside the fracture to increase the maximum sustainable pressure of a wellbore without propping unwanted hydraulic fractures. The efficiency in arresting the unwanted induced hydraulic fractures works by bridging, plugging, or sealing the unwanted hydraulic fracture [1-3]. The physical mechanisms through which LCM operate are not fully understood. Current hypotheses regarding these mechanisms are: the stress cage [6,7], fracture closure stress [8,9], and fracture propagation resistance [10,11].

An open question that exists is the efficiency of the plug and its implications on the stress change during plugging. In the impermeable formation, a plug may be perfect if it completely isolates the fluid from reaching the tip or it may allow some fluids to reach the tip. If the fracture is plugged in a permeable poroelastic formation, the plug cannot be perfect as the pressure behind the tip balances the pressure of the formation and that of the invasive fluids. Thus, the influence of bridging on the closure stresses provides useful information about the effectiveness of plugging.

In this work, we investigate with the finite element method the fully coupled stress change in impermeable and permeable strong formations, by creating and allowing an unwanted hydraulic fracture to propagate up to 5m (in the toughness dominated regime) and then plugging it, to obtain numerically the in-situ stress change at the location of the tip and the plug. The toughness dominated regime implies that most of the energy in the process is expended in fracturing the rock rather in the viscous fluid flow which is more suitable for short fractures. Furthermore, the toughness dominated regime finds applications in ultra-deep formations where the fracture propagates in a highly compressive stress state and most of the energy is expended in splitting the rock. After plugging the fracture, the in-situ stresses are recovered and a critical evaluation of the stress change is performed to assess the effects of the efficiency of the plug on the closure stresses [14,15].

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