Modeling the growth of planar 3D hydraulic fractures in the presence of in-situ stress contrast

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Hydraulic fractures are tensile (mode I) fractures propagating under in-situ compressive stresses due to the injection of a fluid at a given rate. Although the primary industrial application is related to the enhancement of the permeability of petroleum and geothermal reservoirs, the technique is also used in block caving mining. In most sedimentary basin, the in-situ stress tensor at depth is sufficiently deviatoric and the maximum stress is vertical. The created fracture thus propagates in a vertical plane perpendicular to the minimum in-situ stress direction. However, the value of the minimum horizontal stress typically exhibits vertical variations between sedimentary layers.

In this contribution, we present an efficient numerical scheme for the propagation of a planar 3D hydraulic fracture based on the implicit level set algorithm first proposed by Peirce and Detournay (2008) [1]. This scheme recognizes the highly non-linear and multiscale nature of the elasto-hydrodynamic problem near the fracture tip e.g.[2, 3]. It couples the solution of a semi-infinite hydraulic fracture in the tip region with a classical discretization of the fracture away from the front. It allows the accurate solution of both viscous and toughness dominated propagation regimes on a relatively coarse grid. The elasticity and lubrication equations are solved in a fully coupled manner using respectively boundary element and finite volume. The planar fracture is discretized by a Cartersian grid, and the fracture front is represented as a level set. Due to the restrictive CFL condition of the elasto-hydrodynamics system of equations, the evolution of the fracture front is solved implicitly over a time-step. The current fracture velocity at any given point along the fracture front is thus solved for iteratively.

After benchmarking the scheme with known solutions for the viscous and toughness (storage and leak-off) dominated propagation of a radial hydraulic fracture, we perform comparisons with laboratory experiments where stress contrasts were carefully machined [4]. We then investigate numerically several configurations with a fine-scale vertical variation of the value of the minimum horizontal stress and discuss its influence on the development of the fracture geometry for different propagation regimes.

References

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