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When, and for how long, two tough layers can contain the propagation of a fracture driven by the injection of a viscous fluid

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Hydraulic fracturing (HF) is a technology that consists of growing a tensile (mode I) fracture via the injection of a viscous fluid from a wellbore. It is mainly used to enhance the production of geological reservoirs of fluids but also to measure the in-situ stress field. The vertical growth of HF outside the formation of interest is a critical criterion determining the feasibility of the technique [1]. In sedimentary basins, HFs are typically observed to be contained at depth and to propagate horizontally in a “finger-like” geometry [1]. Such containment is usually explained by the increase of the horizontal confining stress in the layers above and below the stimulated formation. The variation of material properties, such as elastic modulus, permeability and fracture toughness can also contribute to containment [2-3].

In this work we quantify the effect of fracture toughness variation by considering a 3D-planar HF in an infinite linear-elastic and impermeable medium with 3 layers of different toughness. The propagation begins in the central layer and the fracture grows radially as it approaches the bounding layers. These are characterized by a higher toughness compared to the central one. It is known that in the case of propagation in a homogeneous medium (radial), the main energy dissipation mechanism evolves from viscous fluid flow at early time, to the energy spent in the creation of the new fracture faces at late time [4]. The opposite is true for a very elongated fracture propagating between two parallel layers [5], this suggests that the effect of containment provided by the bounding layers will vanish at late time. These two transitions are taking place respectively before and after the fracture touches the interfaces of the bounding layers. We found that only two dimensionless numbers control the problem, giving rise to a family of solutions. These numbers are the ratio of fracture toughness between layers and a dimensionless toughness characterising the propagation regime at the time where the HF touches the bounding layers. Combining this scaling analysis with fully coupled 3D numerical simulations, we establish when and for how long, the propagating fracture remains contained before breaking through the top and/or the bottom layer.

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