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Gravity driven hydraulic fracture with finite breadth

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ABSTRACT

This study outlines a new method for disposing of hazardous (e.g., nuclear) waste. The technique is called Abyssal Sequestration, and it involves placing the waste at extreme depths in Earth's crust where it could achieve the geologically long period of isolation. Abyssal Sequestration involves storing the waste in hydraulic fractures driven by gravity, a process we term as gravity fracturing. In short, we suggest creating a dense fluid (slurry) containing waste, introducing the fluid into a fracture, and extending the fracture downward until it becomes long enough to propagate independently. The fracture will continue to propagate downward to great depth, permanently isolating the waste. Storing solid wastes by mixing them with fluids and injecting them into hydraulic fractures is a well-known technology. The essence of our idea differs from conventional hydraulic fracturing techniques only slightly in that it uses fracturing fluid heavier than the surrounding rock. This difference is fundamental, however, because it allows hydraulic fractures to propagate downward and carry wastes by gravity instead of or in addition to being injected by pumping. An example of similar gravity-driven fractures with positive buoyancy is given by magmatic dikes that may serve as an analog of Abyssal Sequestration occurring in nature. Mechanics of fracture propagation in conditions of positive (diking) and negative (heavy waste slurry) buoyancy is similar and considered in this work for both cases. Analog experiments in gelatin show that fracture breadth (horizontal dimension) remains nearly stationary when fracturing process in the fracture "head" (where breadth is "created") is dominated by solid toughness, as opposed to the viscous fluid dissipation dominant in the fracture tail. We model propagation of the resulting "buoyant" or "sinking" finger-like fracture of stationary breadth with slowly varying opening along the crack length. The elastic response of the crack to fluid loading in a horizontal cross-section is local and can be treated similar to the classical Perkins–Kern–Nordgren (PKN) model of hydraulic fracturing. The propagation condition for a finger-like crack is based on balancing the global energy release rate due to unit crack extension and the rock fracture toughness. It allows to relate the net fluid pressure at the tip to the fracture breadth and rock toughness. Unlike the PKN fracture, which breadth is known a priori, the final breadth of a finger-like fracture is a result of the fracturing process in the fracture head. To resolve the breadth, we relax the local elasticity assumption in the fracture head by neglecting viscous pressure drop there. We then combine the finger crack solution for the viscous tail with the 3D pulse solution for the fracture head.