Evolution of fracture permeability during effective pressure cycles

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For the example of a carbonate rock (Treuchtlinger Marmor) containing one single, artificial fracture with an 80 µm shear offset the transient response of fracture permeability to cyclic changes in effective pressure was experimentally investigated. Permeability measurements were conducted step-wise during a first pressure cycle and continuous during the second one. Several modes of deformational response to pressure changes were distinguished and quantified. It showed that fracture stability and thus permeability evolution were primarily dependent on the inherent mechanical properties of the rock matrix within the pressure limits applied. During first pressurization, the fracture asperities are interpreted to undergo irreversible brittle deformation only until the true contact area counterbalances the maximum effective pressure applied and the unconfined compressive strength of the material. The pressure response of fracture permeability then is quasi-elastic and reversible, at least at the short term. However, at elevated effective pressures a slow decrease in fracture permeability was observed induced by time dependent creep-like fracture closure. This not only has implications for the time scales of fluid transport within natural fracture systems but also for geotechnical applications that involve hydraulic fracturing in carbonate lithologies. Additionally, a numerical FEM-model was set up to constrain the applicability of the steady state method for continuous monitoring of permeability changes under dynamic loading conditions. More precisely, the model was aimed to investigate the time span for a steady state pressure distribution to develop in a single-fractured sample of low matrix permeability displaying a wide range of fracture apertures. The results of this simulation suggest that the permeability of fractured samples subject to dynamic changes in fracture aperture, as observed for the experiment, can be measured continuously for fracture apertures larger than 10 µm as steady state conditions were found to redevelop almost instantaneously within the fracture. Therefore, neither a step-wise permeability determination nor the application of other methods (e.g., pore pressure pulse or oscillating flow) is required for these conditions.

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