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Fracture instability caused by cold water injection

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This study has been motivated by microseismic activity observed during enhanced geothermal well stimulations. Induced seismicity due to fluid injection is of great concern in enhanced geothermal stimulation but it is also of interest in other fields of research, such as hydrocarbon reservoirs and CO_2 sequestration.

In general terms, induced seismicity occurs when the isotropically effective stress reduction, due to the fluid pressure increase caused by fluid injection, is high enough to produce failure conditions.

The objective is to test the conjecture that cold water injection produces mechanical instability not only due to hydraulic effects, but also due to coupled thermal effects.

To test this conjecture, two sets of model runs have been performed on very simplified geometries of a horizontal and a vertical fracture. For each geometry, both hydro mechanical (HM) and hydro thermo mechanical (THM) numerical simulations have been performed to analyze the processes involved in geothermal reservoir stimulation. Isothermal water injection in a fracture produces an overpressure that reduces the effective stresses and tends to open the fracture. Nevertheless, fractures are confined by the surrounding rock mass, which opposes to its opening and shearing. The overall effect is sensitive to boundary conditions, stiffness and permeability of fracture and matrix.

Cold water injection produces a higher overpressure because the water viscosity increase is more pronounced than the water density increase for decreasing temperature. This results in a larger fracture opening tendency. However, cold water also contracts the rock. The effect of the contraction is twofold. On the one hand, contraction of the fracture filling tends to compensate hydraulic expansion. As a result, inside the fracture, stability is comparable to that of the isothermal case. On the other hand, cooling of the matrix adjacent to the fracture also causes it to contract, but now in the direction of opening the fracture. These opposing trends lead to very unstable conditions at the fracture edges because the normal effective stress is highly reduced. Therefore, induced seismicity is likely to be triggered when injecting cold water.

The results confirm that indeed THM effective stresses are consistently more unstable (closer to a hypothetical yield surface) than HM effective stresses.

The overall phenomenon is complex because all processes are highly coupled in non trivial ways. Thermal and hydraulic characteristic times are different from each other and also between fracture and matrix. Therefore, it is not clear a priori which process dominates. Furthermore, the mechanical effect of pressure and temperature changes is very sensitive to problem settings. Identifying the parameters controlling seismic potential requires further work.