Contribution ID: **821**

Type: **Oral 20 Minutes**

CFD-DEM Modeling of Fracture Initiation Induced by Fluid Injection

Wednesday, 16 May 2018 09:50 (15 minutes)

The fluid injection involved in CO2 sequestration will result in a change in formation pressure and stress state, which may induce fracture initiation and pose a danger to the long-term secure carbon storage. This work attempts to study fracture initiation based on grain-scale fluid-rock interactions.

CFD-DEM model involves the discrete element modeling (DEM) of solid granular medium and the computational fluid dynamics (CFD) modeling of fluid flow. CFD-DEM model is coupled with bonded-particle model (BPM) to mimic the cement that bonds the framework grains. The numerical model is implemented by coupling the open source discrete element code LIGGGHTS and the CFD toolbox OpenFOAM. The resolved CFD-DEM approach that models the solid phase using the fictitious domain method can capture the particle-particle/fluid interactions even at high particle concentrations. Two benchmark problems with analytical solutions are used to verify the resolved CFD-DEM approach: (1) a falling spherical particle in a fluid and (2) pressure drop through a random packing.

We generate a three-dimension random granular packing that is subjected to constant boundary stresses and vertical drag forces from miscible fluid flow injection. Fracture initiation manifests through either a cluster of bond breakage caused by the drag force exceeding the local skeletal force or opening-mode particle displacement depending on the cementation degree. The fluid flow localization caused by positive feedback at weak points related to local heterogeneity promotes fracture initiation. A regular packing with no weak point under a similar initialization inhibits fracture initiation. Fracture initiates from the artificial defect placed in the center and propagates perpendicularly to the minimum stress under the anisotropic principal stresses. The fracture evolution in the unconsolidated particle packing is similar to experiments in uncemented sediments. Sensitivity analyses are performed for physical properties and operational parameters including fluid viscosity, grain and cement micromechanical properties, principal stresses and injection velocity. This work, for the first time, uses the resolved CFD-DEM approach to study how particle-scale processes contribute to the injection-related fracture initiation.

References

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Session Classification: Parallel 6-C

Track Classification: MS 4.23: Fluid flow-fracture phenomena in porous media