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Multiscale modeling of multiphase compressible non-isothermal fluid flow in deformable porous media

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Understanding the coupling between multiphase fluid flow in pores with distinct sizes and solid deformation induced by flow or external stresses is crucial for the development of many important geotechnics. Most well-established models for describing coupled fluid-solid mechanics are not capable of characterizing hybrid-scale systems containing both solid-free regions and porous media. The recent so-called Darcy-Brinkman-Biot (DBB) framework, which is based on the well-known Darcy-Brinkman equation and utilizes a unique set of volume-averaged partial differential equations, can capture capillary, viscous, inertial, interfacial, and gravitational forces at both the pore and Darcy scales. The solver tends asymptotically to the solution of the two-phase Navier-Stokes equations when used as a pore scale model and to the solution of the two-phase Darcy equations when used as a continuum scale model. Previous extensive tests have demonstrated the versatility of this solver to model multiscale multiphase flow in deformable porous systems, such as fluid-induced material deformation and failure.
In this work, we build upon these previous studies to extend the DBB framework to compressible non-isothermal fluid flow. Through careful addition of new energy conservation equations and pressure equations, we show that this new solver can predict heat transfer in compressible fluids and deformable solids. The model' s numerical implementation, hybridBiotThermalInterFoam, is achieved in the Computational Fluid Dynamics (CFD) software OpenFOAM. This model is then rigorously validated via an example application in the engineered barrier system (EBS) in a nuclear waste repository. Results show that the new solver is capable of predicting fracture propagation and healing in bentonite buffers exposed to strong thermal fluxes and complex aqueous chemistry conditions. The disjoining pressure and complex rheology of the clay matrix are explicitly represented as a function of porosity and salinity. This setting enables the application of thermo-poro-plastic relations to predict the potential for EBS fracturing. Finally, the predictions generated by this model are cross-validated against other existing THMC simulators and experimental measurements. The development in this work creates the first model representing multiphase compressible non-isothermal fluid flow in multiscale deformable porous media.

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