Numerical simulation of coupled thermal-hydrological-mechanical-chemical processes during in situ conversion and production of shale oil

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Production of oil and gas from oil shale using in situ techniques involves heating of oil shale in the formation using an external energy input. Thermal stresses and pore pressure build-up resulting from heating and pyrolysis, along with the associated rock failure, can lead to large enhancements in permeability; ultimately resulting in a connected flow pathway for the generated hydrocarbons to migrate into the producers. To accurately mimic such processes, the complex interplay between strongly coupled thermal, hydrological, mechanical and chemical (THMC) processes needs to be modeled. To the best of authors' knowledge there are no existing simulators that provide highly coupled modeling capabilities. Hence, Los Alamos National Laboratory (LANL), in collaboration with ExxonMobil, is modifying LANL's multi-phase, fluid-flow simulator FEHM to add the capabilities needed to simulate coupled THMC processes, specifically relevant to oil shale production. These capabilities include elasto-plastic deformation of oil shale, conversion of kerogen into oil and gas, multi-phase flow of oil and gas, and porosity and permeability modifications resulting from stress changes. The simulator employs a fully implicit formulation for solving mass, flow, energy and mechanical deformation equations and is expected to be robust and numerically stable. An overview of the theoretical approach used to develop the numerical simulation capabilities will be provided. A simple test problem, involving pyrolysis of oil shale, changes in pore-pressure and thermal stresses, subsequent changes in porosity and permeability due to induced stresses, and multi-phase flow of generated hydrocarbons will be used to demonstrate some of the newly added capabilities of the simulator. Although there are no other numerical simulators that can be used for benchmarking all these capabilities, predictions of some of the newly added features are compared with predictions of STARS and ABAQUS.