SUBSURFACE WELLBORES

Subsurface: An Exascale Subsurface Simulator of Coupled Flow, Transport, Reactions, and Mechanics

An urgent challenge in the field of subsurface wellbores involves understanding and predicting the behavior of hundreds of thousands of deep wells drilled to locate and extract natural resources. The performance of a wellbore hinges on the behavior of very thin interface features controlling the leakage of fluids along the well casing–cement boundary. Similarly, leakage of buoyant fluids (e.g., CO_2) through caprocks may be controlled by micron-scale asperities in fracture networks that are themselves subject to geomechanical and geochemical modification. At the reservoir or field scale (~1–10 km domain size), multiphase flow and reactions in fractured porous media are typically modeled using continuum models that use averaged quantities and bulk parameters that do not fully take into account thermal, hydrological, chemical, and mechanical-related heterogeneity at different spatial and temporal scales. A more rigorous treatment is to resolve the pore-scale (0.1–10 micron) physical and geochemical heterogeneities in wellbores and fractures so as to improve their ability to predict the evolution of these features when subjected to geomechanical and geochemical stressors. The Subsurface project is using exascale to integrate the complex multiphysics processes occurring at multiple scales, from the micro to the kilometer scale, in a high-resolution reservoir simulator.

A wide range of processes take place in the subsurface that involve the evolution of fractures, including both opening and closing due to some combination of mechanical and chemical stresses. This project focuses on the science challenge of overcoming the failure of a wellbore for CO_2 sequestration in saline reservoirs, with consideration of a wellbore segment of up to 100 m and times up to 1 year. Wells are considered to be high-risk pathways for fluid leakage from geologic CO_2 storage reservoirs because breaches in this engineered system have the potential to connect the reservoir to groundwater resources and the atmosphere. The geologic carbon storage community has raised further concerns about wellbore stability because of acidic fluids in the CO_2 storage reservoir, alkaline cement meant to isolate the reservoir fluids from the overlying strata, and steel casings in wells that are inherently reactive systems. This is of particular concern for the storage of CO_2 in depleted oil and gas reservoirs with numerous legacy wells engineered to variable standards.

In contrast to the conventional treatment of wellbore failure currently modeled at large scales on the order of 100 m to 1 km and 10 years, accurate prediction of fracture evolution depends on microscale resolution of fracture asperities (i.e., pillars) controlling permeability and chemical reactivity. Microscale resolution is also needed to accurately predict fracture permeability because very rough fractures are typically held open by pillars of this scale. Chemical corrosion (i.e., dissolution) or mechanical corrosion (i.e., pressure solution) of these asperities occurs at the same micron scale. The localized subdomain needed to resolve reactive transport processes at microscale resolution during fracture propagation is a domain size up to 10 cm (in the length of the wellbore) × 1 cm (along an azimuth in the cement annulus) × 1mm (in the radial direction) with 1 micron grid resolution. This domain size is assumed to be the minimum domain needed to capture coupled reactive transport and mechanics effects in a fracture (e.g., pillar collapse).

The Subsurface project addresses this exascale computing challenge by coupling two mature code bases: (1) Chombo-Crunch, developed at LBNL, which currently handles Navier-Stokes and Darcy flow coupled to multicomponent geochemical reaction networks, and (2) the GEOSX code, developed at LLNL, which handles geomechanical deformation and fracture+Darcy flow at a variety of scales.

A science challenge problem has been developed that focuses on the evolution of a single fracture in wellbore cement, beginning at Stage 1 with diffusion-controlled reaction and a weakening of the cement that leads to fracturing. The propagation of the fracture as a result of further chemical reaction and fluid pressure–driven deformation is simulated with 1 micron resolution within the fracture and is coupled to a coarser resolution (10 micron) representation of the porous cement adjacent to the evolving fracture. The resulting challenge problem is estimated to require 1 trillion grid cells with 16 trillion degrees of freedom once the hydraulic, mechanical, and chemical variables are included. Based on prior experiments and modeling, the challenge problem is estimated to extend for 10 days of simulation to capture the evolving fracture and associated reaction fronts.

PI: Carl Steefel, Lawrence Berkeley National Laboratory

Collaborators: Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, National Energy Technology Laboratory

Progress to date

- Hybrid Raja (OpenMP) + MPI implementation of Geos completed.
- Coupling of Geos and Chombo-crunch via HDF5 API done.
- Design specification, baseline implementation, and Kernel implementation on GPU done for DSL Proto.

The Subsurface project will use exascale computing to develop coupled applications for resolving fracture problems in subsurface models ranging from 1 micron fracture scales up to 100 m reservoir scales.