Evaluation of Stress Dependent Permeability Through Digital Rocks to Support Geomechanics Modeling

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Abstract

Characterization of the reservoir rock elastic and plastic behavior is essential to build reliable geomechanics models of subsurface formations. These formations may be subjected to the loading process during injection and the unloading process during recovery. As a result, effective stresses in the poroelastic media change their magnitude, affecting permeability and continuous fluid flow. The value of permeability typically decreases with rising effective stress. The study investigates stress-dependent permeability in late Carboniferous sandstones by employing a series of geomechanical experiments and micro computed tomography (microCT).

Reservoir porosity, permeability and pore collapse are defined via 3D X-ray microCT following concurrent loading and unloading of Thick Wall Cylinder test using raising axial and confining pressure applied to sandstone rock samples. Three-dimensional models with 20 microns and 2 microns voxel sizes were created for each of the ten geomechanical testing stages to measure variations in pore and grain volumes. Pore and pore throat connectivity/damage were visualized and characterized from high-resolution micro-CT scan images. The characterization of pore geometry provided valuable data for the understanding and modeling of fluid transport and mechanical processes occurring in a real porous media system. Pore size distribution by digital porosimetry was adopted here, considering the connectivity to the intrusion-sided and closed pores. Fluid flow was numerically simulated at the micron-scale using direct voxel-based flow modeling within the pore space, with the Navier-Stokes-Brinkman model utilized to evaluate changes in permeability.

The numerical simulation results showing variations in porosity, permeability, pore and pore throat sizes were dependent on initial petrophysical properties, rock types, pore structures and geometries, cementation, and rock mechanical properties. Compressive failure is considered the main form of formation damage, resulting in pore size collapse and pore throat damage. Absolute permeability reduction was generally highest in permeable sandstones with large pores. Conversely, ‘tight’ sandstone samples have the most significant relative loss of permeability as they contain long narrow pores and throats, where even minor reductions in porosity (relative 3%) can cause pore throat disconnections and significant decreases in absolute permeability by as much as relative 25%. Therefore, pore geometry is the fundamental control of stress-dependent permeability in sandstone reservoirs.

The dynamic characterization of pore geometry provides a framework of petrophysical properties evaluation to ensure efficient recovery within an elastic limit to avoid significant permeability damage.