Porosity and Permeability Computation with Multiscale X-ray Micro Computed Tomography Imaging in Late Carboniferous Sandstones

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Abstract

Digital rock physics (DRP) is utilized to build models of rocks and estimate their physical properties by X-ray micro computed tomography (MicroCT) combined with scanning electron microscopy (SEM). MicroCT records the attenuation of X-rays passing through a rock sample. A three-dimensional model can be created, where each resolvable cubic sub-domain is a voxel. DRP assigns each voxel to a mineral or pore space based on its CT number. Dense voxels will be assigned as grains, and light voxels as pores. If resolution is not high enough to identify small features such as grain contacts, information from pore and grain is “mixed" as a single value and the partial volume effect occurs. The segmentation is a key to the success of the flow properties numerical simulations. Permeability can be predicted by numerically simulating fluid flow through the segmented pore space. In this study, multiscale imaging was used to refine the segmentation algorithm and model permeability of clastic successions in the late Carboniferous Juwayl Formation. The original set of ten sandstone full plugs was initially scanned with twenty microns resolution that is not sufficient to characterize micron-size pores and evaluate the full permeability spectrum. Two microns resolution interior tomographies were acquired to improve the characterization of pore system interconnectivity. Segmentation of the higher resolution images demonstrate an increase of 5-7% porosity. Absolute permeability was modeled via the Stokes-Brinkman numerical solver with both high-and low-resolution images showing greater values in high-resolution tomograms. These provided connected pore systems for all ten interior tomograms, however, full-plug images do not represent connected porosity in five plugs out of ten. The Random Forest machine-learning engine utilizing Gabor and Sobel tools was deployed to extrapolate the three-dimensional high-resolution porosity map into the low-resolution grayscale volumes of the full plugs. The results demonstrate significant enhancement of porosity and permeability that takes into account sub-resolution porosity, not visible in low-resolution images alone, but defined through the machine learning algorithm. The results of this modeling improve estimations of porosity, permeability, pore size distribution, effective elastic moduli, electrical conductivity and other properties derived from digital images. These estimations are in agreement with the results of physical laboratory experiments.