Geophysical Research Abstracts
Vol. 16, EGU2014-15165, 2014
EGU General Assembly 2014

Development and Comparison of Techniques for Generating Permeability Maps using Independent Experimental Approaches

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We have developed and evaluated methods for creating voxel-based 3D permeability maps of a heterogeneous sandstone sample using independent experimental data from single phase flow (Magnetic Resonance Imaging, MRI) and two-phase flow (X-ray Computed Tomography, CT) measurements. Fluid velocities computed from the generated permeability maps using computational fluid dynamics simulations fit measured velocities very well and significantly outperform empirical porosity-permeability relations, such as the Kozeny-Carman equation.

Acquiring images on the meso-scale from porous rocks using MRI has till recently been a great challenge, due to short spin relaxation times and large field gradients within the sample. The combination of the 13-interval Alternating-Pulsed-Gradient Stimulated-Echo (APGSTE) scheme with three-dimensional Single Point Ramped Imaging with T1 Enhancement (SPRITE) – a technique recently developed at the UNB MRI Center – can overcome these challenges and enables obtaining quantitative 3 dimensional maps of porosities and fluid velocities.

Using porosity and (single-phase) velocity maps from MRI and (multi-phase) saturation maps from CT measurements, we employed three different techniques to obtain permeability maps. In the first approach, we applied the Kozeny-Carman relationship to porosities measured using MRI. In the second approach, we computed permeabilities using a J-Leverett scaling method, which is based on saturation maps obtained from N2-H_2O multi-phase experiments. The third set of permeabilities was generated using a new inverse iterative-updating technique, which is based on porosities and measured velocities obtained in single-phase flow experiments. The resulting three permeability maps provided then input for computational fluid dynamics simulations – employing the Stanford CFD code AD-GPRS – to generate velocity maps, which were compared to velocity maps measured by MRI.

The J-Leveret scaling method and the iterative-updating method lead to quantitatively very similar permeability maps and both reproduce the heterogeneous flow patterns in the measured fluid velocity maps very well. Simulations based on Kozeny-Carman permeabilities fail to reproduce main features of the measured velocity maps. This suggests that empirical, solely porosity-based relationships can only to a very limited extend be used to describe rock heterogeneities at the meso-scale.