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Predicting Physical Properties of Porous Media at Sub-Pore scales from Natural to Complex Heterogeneous Systems: Application in tight reservoirs

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Introduction

The numerical simulation of flow at sub-pore scales in a real natural porous media pattern is of great challenge for engineering and scientific study. However, the pore-scale description is essential in improving our understanding of the flow and transport in porous media.

Given a correct representation of pore space we can perform pore-scale numerical calculations that predict all the single phase flow properties in natural porous media patterns which include absolute permeability, thermal conductivity, electrical resistivity, formation factor and NMR spectra. We subsequently perform numerical calculations of immiscible two-phase flow, which is essential in the understanding of the mechanisms involved in hydrocarbon recovery.

Theory and/or Method

One important aspect of this problem is to obtain an adequate 3-D numerical model of flow in the pore space. The first step is an accurate geometrical description of the pore-space. Currently, we use one of two approaches: (1) Generate porous media patterns for a given particle size distribution to mimic unconsolidated sand packing using physics-based modeling of the geometry. (2) Use x-ray tomographic or other pore space images and reconstruct the 3-D porous media. Either way we generate a 3-D grid in this pore-space and solve for the corresponding governing equations. For example, for the absolute permeability, we obtain the flow velocity from the Navier-Stokes equations, for the electrical resistivity, we obtain the current density from Ohm's law, for the thermal conductivity, we include a heat flux, and for NMR study we solve the equations of molecular diffusion. This approach can be described as a version of Digital Core Analysis (DCA) or Digital Core Physics (DCP).

DCA/DCP avoids simplification of geometry with respect to the pore and throat shapes. This is in contrast to network models that the shapes of the pore and throat are approximated to regular shapes so that there will be an inherent estimation in the simulation of different phenomena in porous media. The results of the DCA/DCP are used to check the accuracy of the network models. Higher resolution images are needed for a more accurate description of the porous media, in particular when dealing with highly heterogeneous media. For DCA/DCP this can become a computationally formidable task, and in this case, the validated network models can be used as an alternative to calculate the physical properties of the corresponding porous media patterns as they are computationally less expensive due to their simplifications.

Examples

In this study we use a sample Nordegg image as in Figure 1 and solve the physical properties of this media and in turn use the results in order to validate the corresponding network model. In Figure 2 we use DCA/DCP to obtain the velocity distribution by injecting a pressure of 100 Pa at the inlet (x-direction) and 0 Pa at the outlet. The other sides are treated as impervious wall boundary conditions

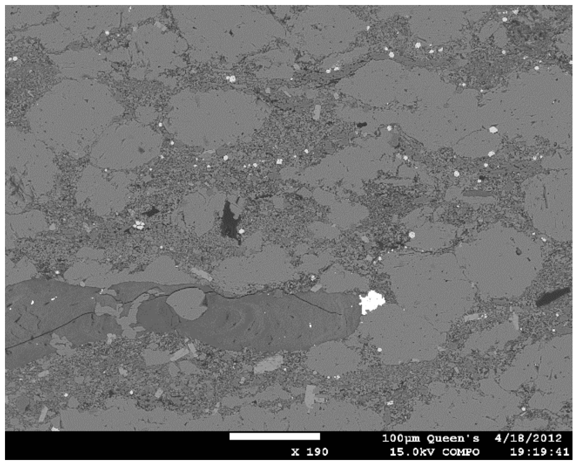
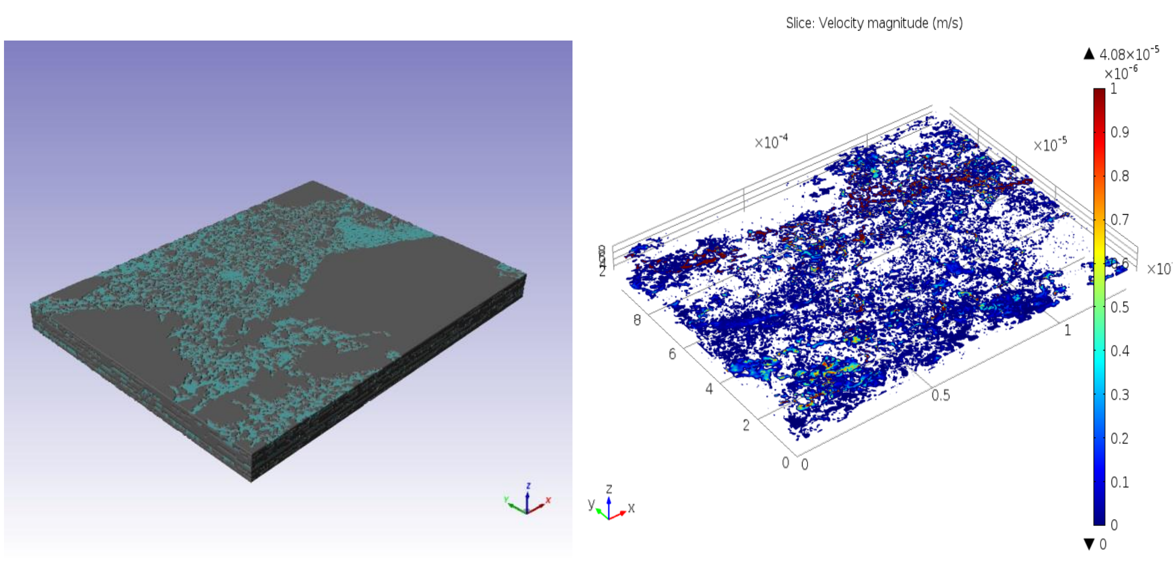


Figure 1: Cross-section of the porous medium



(a) (b)

Figure 2: (a) Reconstructed 3-D image (b) Velocity distribution with the pore space

Conclusions

We obtain the physical properties of real natural porous media patterns at the sub-pore level. We attempt to extend this approach to highly heterogeneous systems with applications to tight reservoirs. Accurate predictions require high resolution images which for the purpose of numerical simulation can become computationally expensive. We use the high resolution image from Nordegg and solve the single phase flow properties, then use the results to validate the corresponding network model .

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