Quantitative use of dynamic 3D tomography for reservoir, CCS and environmental applications

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Abstract. We have developed a software (4D-coreINV ©) to simulate and invert core flood experiments conducted under 3D industrial X-ray tomography on core samples having a length of up 30 cm. The tomographic acquisitions are processed to obtain 3D fluid saturation maps and are typically acquired with resolutions of 50 microns with a time spacing of 3 minutes. In addition to fluid saturations, the pressure difference across the sample is measured every 5 seconds. One experiment typically lasts 10 hours. All this produces a huge amount of data (million numbers) that are history-matched to obtain 11 parameters that define the following properties and relationships:

1) Porosity-permeability relationship,
2) Permeability-Irreducible water saturation relationship,
3) Initial water saturation – residual hydrocarbon saturation relationship,
4) Capillary pressure curve,
5) Relative permeability curves.

From the computational point of view, the process is quite different from a history match carried out in reservoir studies or in 1D core flood simulations, because the data to be matched are several orders of magnitude more numerous. The advantage of operating in 3D is that accurate results can be obtained also in case of heterogeneous rocks and/or displacements affected by viscous fingering.

The data processing consists of a Global Sensitivity Analysis (GSA, which is performed by using an algorithm based on Morris Indices theory) and the minimization of an objective function that quantifies the difference between simulation results and experimental data (this is performed by using an algorithm based on Differential Evolution). All forward simulations are performed with the reservoir simulator Echelon, which has been adapted to work at the lab scale, mimicking the boundary conditions of a laboratory core flood experiment. The high computing performance provided by Echelon (GPU-based calculation) and the possibility to parallelize the forward simulations are fundamental to maintain acceptable execution times, even on high-resolution simulation grids.

GSA enables us to diagnose the behavior of the 11 unknown parameters and to identify the most-influential ones. This allows streamlining the forthcoming computational efforts linked to the minimization of the objective function. Since non-uniqueness is strongly enhanced by the tremendous amount of data that we deal with, we consider a stochastic inverse modeling framework. This provides the probability distributions of the influential parameters and not only their most probable values, giving the uncertainty ranges for forthcoming risk analysis work.