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A Bayesian deep-learning approach to characterize CO2-brine saturation functions from experimental data

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An efficient management of a CO2 storage site requires an uncertainty assessment for storage capacity and injectivity. For the case of a saline aquifer onshore Denmark, an unsteady-state core-flooding experiment was conducted in order to assess a potential risk of CO2 injectivity impairment. The experimental results indicate that the rock mineralogy, samples permeability, and samples dimensions were essentially unaffected by CO2 flooding, but precipitated salt and some fines were detected after the end of experiment.

The experimentally obtained differential pressure readings and the brine effluent volume are history-matched to estimate the uncertainty range of the saturation functions for the two-phase water-scCO2 system. The Brooks-Corey (1964) parametrization is used for the relative permeability functions, and the Skjaeveland et al. (1998) parametrization –for the capillary pressure function. The fluid system is modelled with the Peng-Robinson equation of state for the aqueous phase with CO2 dissolution, geochemical reactions, and with salt precipitation. An implementation of this model with a commercial simulator GEM (CMG, 2022) appears to be computationally expensive for multiple forward solutions; a faster simplified two-phase immiscible model, built using MRST (Lie, 2019), is used as a proxy to the full model.

A global search method with multiple starting guesses is used to obtain a number of non-unique solutions to the inverse problem using the MRST model. However, the used forward solver is prohibitively slow for a Bayesian uncertainty quantification of the problem at hand.

A feedforward neural network is set up to approximate the mapping between the tuples of Brooks-Corey-Skjaeveland parameters and the values of the residual between the experimental results and the MRST predictions. The neural network, trained on the convergence history of the global search method, reaches good accuracy overall with Pearson's correlation coefficient up to 0.99 and several orders of magnitude speedup as compared to the forward solver run time.

The history-matched values of the optimization parameters are interpreted as samples of a Gaussian prior distribution. It is shown that the parameters of the capillary function are subject to larger uncertainty, as compared to the parameters of the relative permeabilities. The posterior distribution is obtained by evaluating the joint distribution for small values of the residual. Using the neural network as a forward problem solver allows to sample the posterior distribution and to obtain the maximum a posteriori estimation of the sought optimization parameters.

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