Multi-Phase Flow in Fractured Rocks: From Pore-Scale Processes to Field-Scale Responses

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Abstract. This work introduces a workflow to quantify how pore-scale processes impact the field-scale responses through multi-scale uncertainty quantification and sensitivity analysis. There are three components within our workflow: 1) performing high-resolution Navier-Stokes (NS) simulation at pore-scale to obtain hydraulic aperture of discrete single fractures, 2) performing two-phase flow simulations at pore-scale to construct relative permeability curves, and 3) embedding pore-scale parameters into core-scale for predicting field-scale objective, such as recovery factor. At pore-scale, we start with three parameters that characterize the fractures: roughness, tortuosity, and mechanical aperture. We then construct hydraulic aperture, relative permeability, and fracture's volume surrogates using polynomial chaos expansion (PCE). At core-scale, we perform Monte Carlo simulation and deploy Kernel Density Estimator (KDE) to re-construct hydraulic aperture, relative permeability, and fracture's volume distributions. We also use Gaussian copula to accommodate the correlation among them. The objective function is recovery factor at field-scale. The final results are time-varying probability density function (PDF) of recovery factor and its sensitivity analysis. Using Sobol indices, we can obtain multi-scale sensitivity analysis to quantitatively demonstrate the effect of pore-scale parameters to the recovery factor at field-scale. From this study, fracture roughness significantly influences the hydraulic aperture estimation and further impacts the core-scale hydraulic properties estimation, and finally significant effect on recovery factor calculation. Therefore, in the future, pore-wall roughness should be included into the NFR characterization workflow.