Gradient-based inversion for subsurface porosity using the adjoint two-phase flow equations: A pseudo-transient approach

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Porous flow is of major importance for reservoir-scale processes such as waste fluid sequestration or oil and gas exploration. The motion of a low-viscous fluid through a high-viscous matrix (rock) can be described by the coupled nonlinear hydro-mechanical equations. This two-phase flow may result in the initiation of porosity waves, triggering high-porosity vertical pipes or chimneys. Such fluid escape features may lead to localized and fast vertical flow pathways that may be problematic in the case of e.g. CO\textsubscript{2} sequestration. Determining the porosity in such environments is a major challenge. Seismic imaging methods can localize the high-porosity chimneys very well in the inverted wave speed field but the conversion to porosity is not straightforward.

Here, we develop an inversion framework that allows us to invert for the porosity using fluid velocities as observables and investigate its behavior for simple examples. We introduce the adjoint framework for the two-phase flow equations, which allows for efficient calculation of the pointwise gradients of the flow solution with respect to the porosity. These gradients are then used in a gradient descent method to invert for the pointwise porosity. Technically, the forward and adjoint equations are solved using a parallel iterative finite-difference pseudo-transient approach, which executes optimally on latest manycore hardware accelerators such as GPUs. Numerical results show that an inversion for porosity is feasible and that the porosity is very locally sensitive to the fluid velocity.