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Comparison of iterative methods and preconditioners for the solution of miscible two-phase flow in heterogeneous porous media

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The geological sequestration of CO_2 is considered as one option to mitigate anthropogenic effects on climate change. To describe the behavior of CO_2 underground we consider mass balance equations for the two phases, CO_2 and brine, which include the dissolution of CO_2 into the brine phase and of H_2O into the gas phase (c.f. [1]).

After discretization in time with the implicit Euler method and in space with the Box method (c.f. [2]), we end up with a nonlinear system of equations. Newton's method is used to solve these systems, where the required Jacobians are obtained by automatic differentiation (AD) (c.f. [3]). In contrast to approximate Jacobians via finite differences, AD gives exact Jacobians through a source code transformation. These exact Jacobians have the advantage that no additional errors are introduced by the derivative computation. In consequence, fewer Newton iterations are needed and a performance increase during derivative computation can be observed (c.f. [4]).

During the initial stage of a CO_2 sequestration scenario the movement of the CO_2 plume is driven by advective and buoyancy forces. After injection is finished solubility and density driven flow become dominant. We examine the performance of different iterative solvers and preconditioners for these two stages. To this end, we consider standard ILU preconditioning with BiCGStab as iterative solver, as well as GMRES, and algebraic and geometric multigrid methods.

Our test example considers, on the one hand, a homogeneous permeability distribution and, on the other hand, a heterogeneous one. In the latter case we sample a heterogeneous porosity field from a Gaussian distribution and, subsequently, derive the corresponding permeabilities after [5]. Finally, we examine to which extent the amount of dissolved CO_2 depends on the heterogeneities in the reservoir.

References

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