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XFEM/GFEM Multiphase Flow Simulations in Porous Media for Carbon Sequestration

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Carbon sequestration (CS) is the process whereby carbon dioxide (CO_2) emissions are captured at point sources (e.g. coal-fired power plants) and injected into deep brine-filled aquifers. It is essential to ensure that injected CO_2 will remain in place. In areas of historic oil and gas exploration abandoned wells become an important source of leakage. Large uncertainties in leakage pathways exist, and thus stochastic methods are required. To use stochastic methods in a practical way, underlying simulations must be numerically efficient.

The large scale difference between the cross-sectional areas of the wells (cm^2) and the aquifers (km^2) makes traditional techniques, such as the Finite Element Method (FEM), prohibitively expensive for this problem. The eXtended / Generalized Finite Element Method (XFEM/GFEM) allows accurate leakage estimations at significantly reduced computational costs due to the efficient treatment of the pressure singularities at the abandoned wells.

We present an XFEM method to approximate the pressure in the system based on vertically averaged multiphase flow equations that describe the interaction of CO_2 and brine in a porous medium [1]. This method is an extension of an XFEM method for a single fluid in a porous medium described in [2,3]. The pressure singularities at the wells are handled via logarithmic enrichment functions. The average saturation of CO_2 is modelled using a Streamline Upwind Petrov-Galerkin (SUPG) FEM to discretize space and an implicit Finite Difference Method (FDM) to discretize time. The significant computational advantages of using XFEM to approximate pressure will be demonstrated. It will be shown that XFEM offers accurate leakage approximations at a fraction of the computational cost of FEM.

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