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Carbon-dioxide storage in the subsurface: towards an understanding of crack development in the cap-rock including phase transition processes

K. Häberle and W. Ehlers
Institute of Applied Mechanics, Faculty of Civil- and Environmental Engineering, University of Stuttgart, Germany
(kai.haeberle@mechbau.uni-stuttgart.de, wolfgang.ehlers@mechbau.uni-stuttgart.de)

Supercritical CO_2 can be injected into deep saline aquifers to reduce the amount of CO_2 in the atmosphere and thus, lessen the impact on the global warming. Qualified reservoirs should be in a sufficient depth to guarantee the thermodynamical environment for the supercritical state of CO_2. Furthermore, an impermeable cap-rock layer must confine the reservoir layer, in order to collect the CO_2 in the desired region. In CO_2 storage it is crucial to guarantee the safety of the storage site and to eliminate possibilities of leakage. Therefore, deformation processes of the rock matrix and the cap-rock layer, which might be induced by the high pressure injection of CO_2, must be investigated. The increase in stress may also cause crack development in the cap-rock layer. These could either be new developing fractures or the break-up of already existing but cemented cracks or faults. If such cracks occur, CO_2 could migrate to shallower regions where the temperature and pressure cannot support the supercritical condition of the CO_2 anymore. Thus, it is important to describe the phase transition process between supercritical, liquid and gaseous CO_2. This requires a proper understanding of the thermodynamical behaviour of CO_2 within the reservoir.

The Theory of Porous Media (TPM) provides a useful continuum-mechanical basis to describe real natural systems in a thermodynamically consistent way. Hence, the TPM is applied to model multiphasic flow of CO_2 and water and include elasto-plastic solid deformations of the porous matrix. The Peng-Robinson equation is implemented as a cubic equation of state to describe the phase behaviour of CO_2 in the liquid, gaseous and supercritical region. However, in the two-phase region the isotherms show a horizontal section and kinks at the boiling and vapour curve. This cannot be represented by a continuously differentiable function such as the Peng-Robinson equation. To circumvent this problem, the Antoine equation provides additional information by defining the saturation pressure for a given temperature.

The injection of CO_2 will increase the reservoir pressure which then will cause solid deformations. The extended Finite Element Method (XFEM) will be used to account for the discontinuities arising from crack development due to these solid deformations. The XFEM bears the advantage that the finite element mesh must not be adapted to the crack. Instead, to describe the discontinuity of the crack, the field quantities are locally enriched by defining additional degrees of freedom at the intersected finite elements. Herein, special attention has to be paid to the matrix-fracture interaction of the fluid phases.

Numerical examples are performed to investigate the injection of CO_2 into a saline aquifer. These are computed with the FEM program PANDAS, which allows solutions of strongly coupled multiphasic problems in deformable porous media.