Description of the master’s thesis

Carbon Capture and Storage (CCS) technologies offer a big potential for the reduction of CO₂ emissions as they can be applied to large stationary sources. The CO₂ captured in the scope of a CCS project can be stored in different geological formations, such as unminable coal beds, depleted oil or gas reservoirs or deep saline aquifers. The latter features the largest storage capacity and is therefore of particular interest.

In the realization of CO₂ storage projects, numerical simulations play an important role as they serve as a tool for the screening of potential storage sites, for capacity estimations and risk assessments. However, the requirements for such simulations are very high due to the many physical processes and the large spatial and temporal scales involved. For an accurate description of the fluid flow and transport processes, it is necessary to describe geomechanical processes as well, because one has to account for the feedback of the mechanical deformation on hydraulic parameters such as the porosity and permeability. This further increases the computational demand. However, the dominance of the different physical processes varies in space, making it possible to reduce the overall computational cost by applying spatial model coupling concepts (Darcis, 2013).

![Figure 1: Sketch of the spatial model coupling applied in this thesis.](image)

For an accurate description of the rock mechanics, the domain has to be chosen larger than for a purely hydraulic model, as the mechanical boundary conditions strongly influence the solution on a relatively large scale. In this thesis, a spatially coupled model which applies a hydro-geomechanical model (El2p-model) to the regions in the vicinity of the injection well and a purely mechanical model (El-model) in greater distances has been developed and tested.

The results for different coupling radii and domain dimensions were analyzed with respect to many different quantities, while the focus was on the pressure, the surface uplift above the injection well.
and on the hydraulic parameter distribution within the aquifer. It was observed that the solution with respect to the hydraulic quantities was not significantly affected by the larger mechanical domain. The mentioned boundary effects were clearly observable in the horizontal displacements for which Dirichlet boundary conditions were applied at the outer radial boundary. However, the vertical displacements, less influenced by the chosen Neumann boundary at the outer radius, resulted to be of one order of magnitude higher. This, in turn, led to a reduced impact of the boundary effects on the flow field, which explains the above mentioned observations.

![Figure 2: permeability distribution in the aquifer at $t = 5$ years after injection start for an uncoupled El2p-model with a radial extent of 2 km (el2p2000) and with the mechanical subdomain enlarged up to a radius of 8 km (R2).](image)

![Figure 2: pressure distribution in the aquifer for $t = 5$ years for an uncoupled model with a radial extent of 8 km (R8) and with an enlarged mechanical subdomain up to a radius of 20 km (elDispR20).](image)

One outcome of the above mentioned facts is that the correct modelling of the pressure, as the driving force of the system, is the main factor determining the quality of the results. For later simulation times, the boundary condition for the pressure at the outer radial boundary becomes a decisive factor for the pressure distribution inside the domain, which leads to increasing errors over time.

In order for the pressure to evolve more correctly, the outflow of fluid out of the domain has to be modeled, which was the aim in the next part of the thesis. A pragmatic approach of approximating the current pressure gradient at the outer boundary and using it to model the flux out of the domain is presented and tested.

Since the spatial extent of the flow processes increases with time, it was furthermore tried to achieve a speed-up by enlarging the more complex El2p-subdomain in time, so that the calculation of the two-phase flow processes is restricted to domain areas where they are actually important. A speed-up of 20% could be achieved by the method while fully reproducing the results of a reference scenario of full complexity.
Figure 3: CPU time vs. model time of the reference scenario (R8) and the scenario with the moving outer radial boundary of the El2p-subdomain.

References