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THE LONG-TERM FATE OF CO_2 INJECTED INTO AN AQUIFER

Erik Lindeberg, Per Bergmo, Arild Moen, SINTEF Petroleum Research, Trondheim

CO_2 from the Sleipner offshore gas processing plant has been injected into the Utsira formation since 1996 and this may continue during the whole lifetime of the gas production project if no alternative use of the CO_2 will arise. During this period an estimated 22 million tonne CO_2 will be injected. In the multi-institutional SACS project, repeated 3D seismic surveys have been performed to monitor the injected CO_2. Data from pre-injection seismics and well logs have been used to build a local reservoir model of the formation near the injection well. At this site the Utsira formation consists of a more than 200 m thick high-permeable sand body intersected by thin discontinuous shale layers. The seismic images of the CO_2 bubbles seen in the repeated 3D seismic were used to calibrate the reservoir model.

In the present work information from the local model has been used to build a consistent 3D reservoir model covering an area of 128 km^2 to predict the fate of CO_2 during thousands of years by simulation. This model must include the major features of the local model that control transport of CO_2 on the relevant time scale. The fluid model of CO_2 and brine must feature correct volumetric data (densities), phase behaviour (solubility) and transport properties (viscosities and diffusion coefficient). Capillary pressure and relative permeability describing the interaction between the porous media and the fluids have been measured in laboratory experiments on Utsira cores. Computational constraints limit the number of grid blocks in the model to less than one million if acceptable computation times shall be achieved. This represents a substantial coarsening of the grid compared to the local model. Preserving the physical consistency of the major transport phenomena in the new grid is a major challenge. In the model the cap rock shales is assumed to provide a capillary seal for the CO_2 phase preventing upward migration, but allowing molecular diffusion of CO_2 through the overlaying strata.

The results of the simulations show that most of the CO_2 accumulates in one bubble under the cap seal of the formation a few years after the injection is turned off. The CO_2 bubble spreads laterally on top of the brine column and the migration is controlled by the topography of the cap seal only. Molecular diffusion is driven by concentration gradients and can usually be neglected in reservoir simulations because it is slow compared to other transport processes. It is attenuated due to diminishing concentration gradients, which is a result of the diffusion process itself. In this case, however, diffusion of CO_2 from the gas cap into the underlying brine column will have a most pronounced effect. The brine on top of the column, which becomes enriched in CO_2, is denser then the brine below due to the special volumetric properties of the CO_2-brine system. This creates an instability that sets up convectional currents maintaining a large concentration gradient near the CO_2/brine interface enhancing the dissolution of CO_2. After 300 years the CO_2 bubble reaches its maximum area covering 23% of the model. After this dissolution is the dominating effect on bubble extension and the bubble gradually shrinks and finally disappears after 4000 years. A simulation test of an alternative injection scenario was also performed. In this case CO_2 was injected continuously with a rate of 0.86 million tonne per year corresponding to the present rate. The CO_2 bubble covered in this case 65% of the area of the model after 300 years. At this time the model was too small to reliably predicting fate of the CO_2 due artefacts from boundary effects. To predict CO_2 distribution for longer time or to estimate the total storage capacity of the Utsira formation a larger model would be required. The storage effect due to chemical reaction between CO_2 and rock minerals was not taken into account in the present simulations, but can be included when experimental data is available.

Upward molecular diffusion of CO_2 through the water saturated overlaying shales can potentially represent an escape path for CO_2 into the atmosphere. Along this pathway injected CO_2 will not reach the sea floor until several hundred thousand years after the end of injection. This escape mechanism can in practice be neglected.