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Coupled Flow and Geomechanical Testing of Low Permeable Material - Application for CO2 Storage

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SUMMARY

The work presented is part of a national research project focusing on methodologies for testing cap-rock material and measure flow and mechanical properties that are important for the process of qualifying future storage locations. A flow through cell is used to flood a shale core where both axial and radial strains of the core are measured together with the acoustic velocities in the axial direction. The experimental results indicate that re-activation of micro cracks in shale plays an important role for the percolation and flow of CO2 in shale for the stress conditions given in the experiment. Current experimental experience raises several questions related to sample preparation, test conditions and flow mechanisms inside the sample during invasion and penetration of CO2.

The ability for cap-rock to seal and prevent CO_2 from leaking out of a geological containment is essential for the concept of storing anthropogenic CO_2 into the subsurface. Methods to test the ability in the laboratory are being developed with focus on characterizing the flow and mechanical properties of cap-rock under realistic conditions (e.g. temperature, fluid and pressure). The mechanical properties of cap-rock are important input data for e.g. estimating the storage capacity and the ability to sustain the pressure build up in the reservoir due to massive injection of CO_2. Properties like stiffness, strength and failure envelope can be measured in the laboratory and are input parameters in geomechanical simulations to evaluate potential cap-rock failure during the injection phase. In addition, mechanical data coupled to flow properties are needed when performing modeling studies of the entire storage system and assessing the potential for CO_2 to penetrate into the cap-rock and overburden.

Typical cap-rock ranges from soft mudstone with low strength and sound velocity close to water to hard and cemented shale with high strength and sound velocity above 4000 m/s (Fjær et al. 2008). The permeability depending on rock composition (clay content) and burial depth vary across several orders of magnitude from 0.1 – 1000 nD (Yang and Aplin 2007). Because of the low permeability experimental measurements of flow and mechanical properties require extra efforts compared to more permeable reservoir rock.

In our study a flow through cell is used to flood a shale core (40 mm long and 38 mm diameter) with supercritical CO_2 at temperature above of 35° C and at pressures above 7.5 MPa. A pressure gradient is applied across the sample to obtain a breakthrough of CO_2 in the core. During flooding both axial and radial strain of the core are measured together with the acoustic velocities in the axial direction. The measurements are performed both for the brine saturated core and at various stages during flooding with CO_2.

This test on the Draupne formation sample allowed us to set up a method to evaluate the sealing efficiency of a cap-rock. The experiment was based on a breakthrough test of supercritical CO_2 into a brine saturated shale sample. The test was monitored with several measurements, which all agreed on the timing of the breakthrough: the increase of flow out correlated with a radial dilation of the sample and a reduction in the P-wave velocity (Figure 1). The results are strongly indicating flow of CO_2 along a few high permeable pathways due to re-opening of existing fractures. This evidence is supported by the strain measurements indicating radial dilation and fluid sampling showing that the exit fluid consisted of more than 96% pure CO_2 while the sample after the test contained a high amount of water.

Our interpretation suggest that the pore pressure increase at the bottom of the sample, simulating an accumulation of CO_2 in the reservoir caused a re-opening of the fractures in the lower part of the sample and started a flow along them. This flow through the cracks allowed a capillary percolation through the upper part of the sample where cracks are kept closed by the higher effective pressure. The experimental results indicate that re-activation of micro cracks in shale plays an important role for the percolation and flow of CO_2 in shale for the stress conditions given in the experiment.

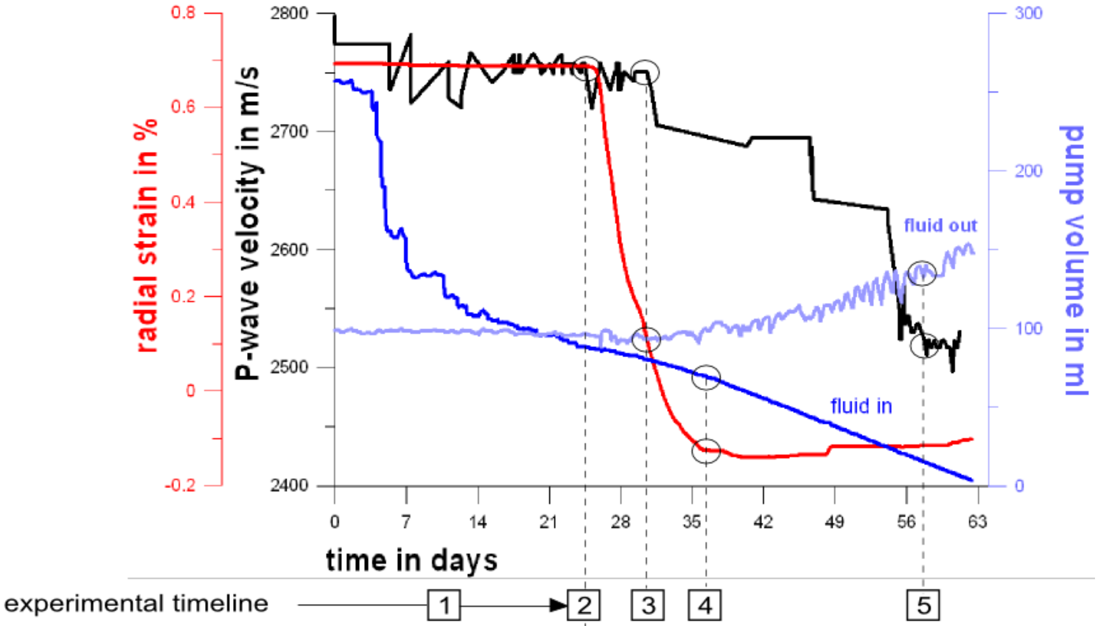

Figure 1 Analysis of correlation between data monitored during the invasion of CO_2 in a shale plug from the Draupne Formation in the North Sea. First indications of CO_2 invasion in the plug is observed at a pressure difference of 3.5 MPa across the shale plug, whereas steady state flow is achieved at a pressure difference of 4 MPa.

The aim of the work which is part of a national research project (SSC RAMORE, http://www.geo.uio.no/ssc-ramore) is to develop a methodology to test cap-rock material and measure flow and mechanical properties that are important for the process of qualifying future storage locations. Current experimental experience raises several questions that need to be addressed. 1) How can we optimize the equipment to measure flow properties on extremely low permeable rock? Testing on low permeable shale is very time consuming (3-6 months) and must be done with caution to control excess pore pressure. In addition, wrong sample preparation and handling could introduce artificial effects altering the mechanical properties or cause changes in pore structure by e.g. drying. 2) How can we be best monitor invasion of CO_2 into the sample and how would rock physic properties be influenced by the presence of CO_2 in the pore space? We measure the acoustic properties of the sample during the experiments and combined with other data we can justify the flow mechanisms inside the sample during invasion and penetration of CO_2. Further, 3) what would be the most realistic mechanical testing procedure? Current equipment is designed to measure flow and deformation at isotropic stresses, however, reservoir compaction is often simulated by uniaxial compression. Also, 4) upscaling of the data measured in the laboratory for application in reservoir models needs to be considered. Is it possible to back-calculate the laboratory measurements using reservoir modeling tools? And finally, 4) are we measuring the right properties and testing on representative material? So far we have focused on intact shale material where penetration of CO_2 is found to be less likely without forcing it through the sample. Fractures and faults are often considered as the most likely cause for leakage apart from wells and boreholes. Hence, future studies should also include fractured material that could provide valuable data to the modeling community.

References

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