Underground storage of CO2 is taking off

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Carbon Capture and Storage (CCS) is an important part of the solution to the climate problem of our planet. It is an area where the competence from a century of petroleum activity is a key enabler and geomechanics plays a major role to store large amounts of CO_2 in the underground safely.

A milestone was achieved at the end of last year when the Norwegian Parliament approved the Longship project, a full-scale CCS project involving CO_2 capture at a cement factory, transport and underground storage near the Troll field in the North Sea. The storage will take place in the Johansen Formation, a virgin saline aquifer at around 2400 m depth below seabed with near hydrostatic pore pressure. The other main option for underground storage is depleted oil and gas fields. The Dutch Porthos project is an example of this type. The plan is to capture CO_2 from industry in Rotterdam and store in depleted offshore gas fields in the range 3100-3400 m below seabed. For NGI's part these projects mean transition from CCS related research to also direct project work. Core material from reservoir and overburden from the Longship Eos well is currently tested in the rock mechanics laboratory, hand in hand with integrity analyses of the storage site. The work related to the Porthos project has been independent review of storage safety.

For CCS to have significant impact on CO_2 concentration in the atmosphere, huge storage volumes are required. These volumes exist but they must be safely managed. In 20 years, CO_2 injection has been going on at the Sleipner Field in the North Sea. Due to the moderate injection flow compared to the size and high permeability of the Utsira aquifer, the reservoir pressure has not changed significantly. Thereby, stress change and deformations have been small and thus no geomechanical issues in terms of fault activation and fracturing. However, the evolving large-scale projects will meet another reality because of the need to maximize the storage capacity. For injection of CO_2 into aquifers, the reservoir pressure will have to increase above the initial pressure and an important geomechanical task is to advice a safe limit for the excess pressure. This limit will be pivotal for the storage capacity. Classical failure mechanisms are accounted for when determining such limit; typically fault activation by exceeding the shear strength and fracturing of the caprock. The typical large storage depth means that CO_2 with ambient temperature from surface cools down the injection zone and surroundings due to the temperature gradient. Large depth also means high stiffness of the formation, making the thermal stress change significant. Hence, poro-elasto-plastic-thermal analysis is required, comprising all the constituents of the system: formation framework (grain skeleton), grains and fluids. Fracturing out of the reservoir may take place if the reservoir pressure exceeds the total minimum horizontal stress at the base of the caprock. When evaluating such failure, it has been observed that cooling affects the minimum horizontal stress of the caprock as well as the pore pressure in the caprock. This comes in addition to the permeability dependent poro-elastic effect in the caprock. Figure 1 illustrates that the margin between the increasing reservoir pressure and the reducing minimum horizontal stress of the caprock becomes narrower after some years of injection and cooling.

Figure 1 Comparison of initial stress condition (straight lines) and stress after 50 years of injection with cold CO_2. Blue: pore pressure. Red: minimum horizontal stress. Black: Vertical stress. The reservoir is green

Injection into a depleted gas field will also ultimately meet a limit of the reservoir pressure but another phenomenon is more pronounced, at least at the transition from gas production to CO_2 injection. If there is no active aquifer, the post production reservoir pressure is very low. Because of the complex PVT behavior, the temperature of the CO2 then becomes very low. It is evidence that such cold CO_2 flowing through the injection wells cools down and shrinks the steel, cement and formation, creating a micro annulus outside the well. This is issue may limit the acceptable reservoir pressure and remedial measures are sought. In some circumstances shear induced creep of the surrounding formation may close such annulus.

Safe injection and storage mean risk management and NGI has developed probabilistic methods for such use. A typical finding is that the minimum horizontal stress of the caprock and the horizontal stiffness of the caprock have major influence on the safety and should be given high priority when developing CCS sites. Ongoing research on the risk related to CO_2 storage in faulted reservoirs is addressed in the FRISK project (https://www.ngi.no/eng/Projects/FRISK) and will contribute to qualification of faulted reservoirs as safe CO_2 storage sites.

Risk evaluations also indicate that optimal storage will benefit from compensation measures such as monitoring. An example of an ongoing research project where NGI takes part is given in Figure 2. The project is called SENSE (https://sense-act.eu/) and investigates how surface deformation may provide information about the behavior of underground CO_2 injection. As in unconventional oil and gas, microseismic is also a relevant monitoring method for CCS.

Figure 2 Principal sketch for the SENSE project - Assuring integrity of CO_2 storage sites through ground surface monitoring

NGI is an active partner in the Norwegian CCS research center (sintef.no/projectweb/nccs/). NCCS aims to fast-track CCS by working closely with the industry on research that addresses major barriers in making CCS happen in Norway, Europe and the world.

https://www.ngi.no/eng/Projects/ACT4storage

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