Development of digital twins for underground CO2 storage reservoir integrity

Introduction

Largest risk for bankability and insurability of underground CO2 storage projects is the total amount of CO2 which can be stored safely within the planned time of CO2 injection. To avoid any leakage of CO2 from the storage complex to surface, geological trap with impermeable cap rock layers on top of the storage complex is critical for reservoir integrity. To ensure geological trap any injection induced fracture activation especially near or in cap rock layers needs to be minimized. Another risk to large scale CO2 injection is induced seismicity, which is frequently seen in basement rocks below the storage layers at large scale onshore wastewater injections in North America [Zoback 2025]. Both phenomena are related to the increase of reservoir pore pressure due to injections and in theory are controlled by not overstepping pore pressure limits during operation. But in the reality of CCS projects the assumptions to forecast critical pore pressure levels in the reservoir are affected by large uncertainties about in situ conditions of pore pressure and stress and strength anisotropies in and around the storage complex. As a result, unexpected fracture activation or induced seismicity can occur, with the potential to stop or significantly scale down the injection rates and with that the storage volumes.
To quantify that risk and be prepared to manage and minimize microseismicity or induced seismicity during operation as best as possible a digital twin of underground CO2 storage reservoir integrity would be very helpful.

Method and/or Theory

Digital twins are one of the megatrends in industry to quantify risks and allow predictive forecasts to optimize operation. One part of information for the digital twins will come from measurements and observation data another part from numerical modelling. That will include all measurements and observations which are anyway mandatory part of Monitoring, Measurement and Verification (MMV) of CCS projects, but will need in addition truly 3D Thermo-Hydro-Mechanical (THM) simulation models which represent all relevant mechanisms of induced fracturing and seismicity connected with the pore pressure evolution during injection, including all relevant anisotropies in strength, stress, permeabilities, etc. Geodynardo has started 2023 a research program to evaluate leading edge simulation capabilities of 3D THM simulation software regarding the forecast quality due to fracture and seismicity related phenomena to be used in digital twins for reservoir integrity. The simulator was developed by an industrial consortium of Dynardo, Ansys and Shell and successfully used for 3D fracture propagation simulations in unconventional oil and gas applications [Bai 2016]. Here forecast quality was proven for fracture initialization and propagation as well as the effects of different operational conditions to the fracturing and the resulting oil and gas production. By applying the simulator to large scale CCS projects forecast quality will be discussed.

Examples

Using publicly available data of large CCS projects (Snovhit, Sleipner, In-Salah, Quest) a THM simulator based on ANSYS software is evaluated to be able to reproduce pressure evolution and induced fracture/seismicity phenomena during CO2 injection.

Using available injection data, geological data, data about in-situ conditions, pressure history and measures of CO2 containment of the Snovhit CCS project first effective storativity and viscosity of the replacement process of the brine by CO2 in the pore spaces of the saline aquifer are identified.

Using available injection data, geological data, data about in-situ conditions and micro seismic measures of the In Salah CCS project fracturing at high injection rates and the risk of reaching the gas production layer was reproduced [Vasco 2019].

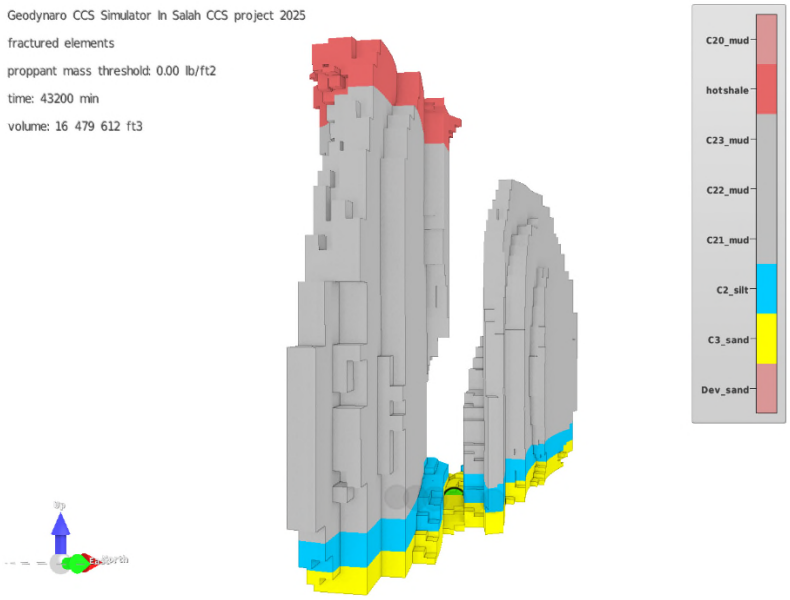

Figure 1 *Showing the fracture evolution at In Salah CO2 project after 30 days of high injection rates*

Using available injection data, geological data and data about in-situ conditions of the Sleipner CCS project the risk of penetration of the intra-reservoir barriers within the storage complex is investigated.

Using available injection data, geological data, data about in-situ conditions, pressure history and micro seismic measures of the Quest CCS project the start of microseismicity and the containment of microseismicity below the storage complex was reproduced [Harvey 2021].

Conclusions

In all reservoirs it was demonstrated that the relevant phenomena's of dynamic pressure evolution as a result of CO2 injections as well as the related microseismicity (In Salah, Quest) could be reproduced. That demonstrates the readiness of the THM simulator to be used within a digital twin of reservoir integrity to forecast, quantify and manage risks related to injection induced fracture activation and seismicity.

References

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