KEM Research review, evaluation and interpretation (max. 4 pages + annex)
TITLE *Geomechanical and geochecmial factors determining fault criticality during pressure (non) cycling of underground CO_2, H_2, N_2 storage.*

KEM Quality review

Description of the scientific quality of the results (team, research method, research results, quality of the products, …), if needed external review result (project evaluation text website)

The main goal of the project was to re-assess the causes of seismicity, specific risk factors including chemical processes in the reservoir, and safe operational bandwidths for reservoir storage conditions during pressure (non) cycling of underground storage of CO_2, H_2, and N_2 in depleted gas fields. The study is a follow-up of the KEM-01 study, which studied storage of natural gas.

The research was conducted by M3E, with Politecnico di Torino and La Sapienza, University of Rome, as subcontractors. The project started in September 2022 and finished in January 2023. The expertise of the research team covered the topics relating to the plan of action in a very good manner, exhibiting state-of-the art scientific understanding of factors causing induced seismicity and how these can be investigated by use of numerical modelling tools.

The deliverables were presented in six final reports, corresponding to the six work packages of the project. The final reports present a detailed investigation of the defined research questions based on literature review and numerical modelling. The numerical modelling is based on a one-way coupling, where the pore pressure is computed by the ECLIPSE software and then the pore pressure change is used as an external force in the geomechanical ATLAS software to estimate the point of activation with respect to temporal loading, maximum slip tendency, and maximum slip distance on the faults. These results were used in quantitative ranking of the analysed scenarios from the most to the least prone to induce fault activation.

Overall, the project has delivered very well. The literature review is sufficiently comprehensive, and the modelling is performed in a sound manner, with reasonable model assumptions and simplifications, given the scope of the project. Furthermore, limitations of the study and interpretation of results with respect to the available data are satisfactorily pointed out and discussed.

KEM Evaluation of the results

Evaluation whether the research questions are addressed adequately (questions answered, precision and uncertainties on outcomes, potential consequences on current practice addressed, ..) (project evaluation text website)

The research questions were addressed by studies reported in the six work package reports.

The report on WP1 is a literature review of the factors causing unforeseen seismicity from CO_2, H_2 and N_2 storage operations. Mechano-chemical effects of CO_2 on faulted rocks is presented along with a review of relevant case studies. For CO_2 injection the chemical effects on mechanical properties of faults are considered negligible based on the reviewed literature. Some indications are also given for H_2 and N_2 injection, but, as the report points out, there is a lack of documentation on the influence of H_2 and N_2 on fault frictional properties and cohesion, which limits the related findings.

The report on WP2 presents analysis of laboratory tests on mechanical weakening and damage of the reservoir rock and caprock induced by CO_2, H_2 and N_2 injection. For the caprock and reservoir both weakening and hardening effects have been observed as a consequence of CO_2 exposure. For sandstones, both up to 30% increase and 30% decrease in deformation modulus due to CO_2 exposure is observed. For H_2, there is a lack of quantitative data, but qualitative rock degradation is reported. As N_2 is used as a control gas, geochemical effects can be neglected.

In the WP3 report, storage scenarios are defined, and results of simulations of pore-pressure changes are presented based on compositional simulations conducted with the Eclipse software. The geological and geophysical scenarios are the same as in the KEM-01 study, and representative of lithology found in the Netherlands. The geometry of the cases considered is based on a setup with five faults with various configurations equivalent to those from the KEM-01 study. The wellbore positions and configurations are also the same as in the KEM-01 study. All the storage simulations are done after a primary 10-year production of CH_4. Results are presented for two storage scenarios of CO_2 and N_2. The first scenario includes a very high injection rate for each injection well in order to achieve a high increase in pressure over a period of two years and reproduce the results of the KEM-01 study. This scenario represents an extreme limiting case, which imposes a high stress on the system in terms of pressure changes. The other scenario represents realistic maximum injection rates over a period of thirteen years for the case of CO_2 storage and six years for the case of N_2 storage. For H_2 storage, after a refilling injection of H_2 in the reservoir, ten years of cyclic storage is investigated, where each cycle has a production period of six months and an equally long injection period. Two storage scenarios are considered: one is set with very high injection and production rates to achieve a large pressure variation within each cycle, whereas the other imposes more realistic rates.

The report on WP4 presents the numerical approach and simulation model for the geomechanical analysis of the different storage scenarios. The geometric configurations were the same as those used in KEM-01. Compared to KEM-01, the numerical approach for the modelling of fault deformation is updated based on improvements in methodology. Furthermore, geochemical effects on reservoir mechanical parameters were introduced, corresponding to the specific fluid being injected.

In the WP5 report, analysis based on investigation of a range of simulation test cases is presented. The analysis is based on altering fault geometries and mechanical parameters of the faults and reservoir compared to a reference case, following the scenarios presented in the KEM-01 study. In addition, for CO_2 storage, both a weakening scenario and a hardening scenario are considered as a proxy for potential geochemical effects and compared to the reference case. For the weakening scenario, the deformation modulus of the reservoir was reduced by 30% during the injection phase. For the hardening scenario, the deformation modulus of the reservoir was increased by 30% during the injection phase. For H2-storage, a weakening scenario was additionally considered, where the deformation modulus was reduced by 30% during the injection and cyclic storage phase.

The report on WP6 presents a comparison of the scenarios from WP5. The main measure for fault criticality considered is the area of the fault with slip tendency larger than 0.8 divided by the horizontal length of the fault. Considering the period of storage operations after the primary production period, all scenarios are then ranked based on the measure for fault criticality, maximum value of fault sliding, and point of fault activation. The results show that the scenarios leading to activation during the primary production period also have a higher slip tendency during the storage period. In this case, reactivation occurs during (non) cyclic storage if the pressure in the reservoir at the end of injection or during storage cycles is close to the initial reservoir pressure before primary production. For the considered scenarios, the altering of reservoir deformation modulus mimicking geochemical effects had a negligible impact on fault criticality. The report concludes that the findings made in KEM-01 for underground storage of CH_4 are valid also for CO_2, H_2, and N_2 storage, and, hence that the guidelines for safe operational bandwidth as defined in KEM-01 are valid also for CO_2, H_2, and N_2 storage.

With the deliverables provided, the KEM panel concludes that all research questions have been well addressed.

KEM interpretation of the outcome

The interpretation of the results (consequences on methods/data to be used in practice, con risk instrument modules, on inspection procedures and operator procedures, ..) (project evaluation text website)

The KEM Scientific panel recommends adopting the guidelines for safe operational bandwidth as defined in KEM-01 also for CO_2, N_2 and H_2 storage. A re-assessment of the project's findings on geochemical effects causing mechanical weakening should be made at the point where more data from laboratory experiments and case studies becomes available.

Closure text for the website

A summary in simple terms of the goal, the outcome and impact on mining policies or toolboxes of the research project (project evaluation text website)

Depleted gas reservoirs can be used for storage of natural gas, but also for storage of CO_2, N_2, and H_2. The injection and production of different fluids change the hydraulic and mechanical state of the reservoir at depth, and lead to small deformations of the subsurface and possibly also induced earthquakes, which correspond to movement along fault planes. In the earlier KEM-01 study, storage of natural gas was assessed with respect to hydromechanical causes of seismicity, risk factors, and safe operational bandwidths for reservoir pressure. In the current project, the goal was to make a re-assessment of these matters, considering underground storage of CO_2, H_2, and N_2, including an assessment of whether geochemical dissolution effects should be considered a risk factor.

Based on simulation of a range of scenarios, the project concludes that the findings in KEM-01 for underground gas storage are also valid for storage of CO_2, N_2, and H_2. A main risk factor is whether faults have slipped during the primary production of the reservoir. In this case, reservoir pressures during storage operations must be safely bounded. Based on the modelled scenarios, geochemical effects are negligible for CO_2 storage. For N_2 and H_2 geochemical effects were not possible to quantify, due to lack of available data from laboratory experiments and case studies.