

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)

Commingle production involves the simultaneous exploitation of multiple hydraulically isolated reservoirs through a single tubing string. Although this concept has been extensively studied in hydrocarbon production, the results cannot be directly transferred to geothermal systems due to significant differences, including higher injection and production flow rates and larger temperature contrasts between reservoir and reinjected fluids. The project "Potential hazards related to the use of multiple reservoirs in geothermal operations" studied commingle production from geothermal reservoirs based on thermo-hydro-mechanical (THM) modelling. The objective of the project was to determine the effects of reservoir and fluid properties on fluid circulation and pressure behaviour in geothermal operations involving production from multiple reservoirs, as well as the associated implications, hazards, and potential mitigation measures.

The research was conducted by VITO, with Sproule ERCE as a subcontractor, combining strong expertise in geothermal reservoir engineering, geomechanics, and modelling of THM reservoir processes.

The project focused on the analysis of a representative dual-zone production scenario for a geothermal doublet in a Dutch geothermal setting, corresponding to siliciclastic sedimentary aquifers. Considering this setting, the consortium employed a clear and well-structured methodology to address the defined research questions. Starting from a literature review, followed by the construction and evaluation of generic reservoir models and the further study of a site-specific geological model, the project proceeded to the evaluation of the impact of unbalanced flow and the assessment of mitigation and prevention measures for minimizing hazards.

The modelling framework focused on numerical modelling of fluid flow and heat transport, with mechanical effects assessed through analytical and semi-analytical methods rather than through fully coupled geomechanical simulations. This is an appropriate strategy, considering the original problem formulation and research questions stated by SoDM, the complexity of the problem, and the scope of the project. The modelling assumptions and setup, as well as model limitations, are generally well documented.

The modelling explored a relevant parameter space, including reservoir permeability and thickness contrasts, thermal gradient, fluid composition (density, viscosity), well completion design, and skin effects. The discussion of the results is supported by figures showing relevant quantitative metrics (e.g., flow imbalance duration, pressure changes, and subsidence estimates).

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 three research questions defined as the basis for the project were addressed in a thorough and technically credible manner.

Effect of reservoir, well, and fluid properties on flow and pressure (RQ1)

The report demonstrates that differences in reservoir permeability, thickness, and well-related parameters provide the dominant controls on flow distribution and pressure evolution during commingled geothermal production. The Base Case comprised two highly-permeable and laterally continuous sandstone reservoirs, each 50 m thick, separated by a 200 m impermeable seal, representative of Dutch low-enthalpy geothermal systems at depths of roughly 1,500–2,500 m. A single producer–injector doublet, spaced 1,500 m apart, is completed vertically in both reservoirs, with no hydraulic communication apart from the wells. End-member cases, such as laterally discontinuous reservoirs or wells having large negative skin with a relatively low permeability, are shown to generate long-lasting flow imbalances and the strongest pressure deviations relative to the Base Case.

Effects of unbalanced flow and associated hazards (RQ2)

The study identifies unbalanced flow as an inherent but mostly transient feature of commingled production. Potentially associated hazards are discussed, and subsidence and fault reactivation are explicitly evaluated. The modelling results show how geothermal operations induce pressure and temperature changes within the producing reservoirs. As explained in the project report, the analytical and semi-analytical assessments of mechanical effects are based on different assumptions, and consequently yield differing results. The analytical approach is more conservative and predicts reactivation even in the Base Case (near the injection well). The semi-analytical assessment of mechanical effects, which is based on the nucleus-of-strain approach that smooths spatial stress variations and may underestimate differential stresses, does not predict shear failure for the Base Case and discontinuous-reservoir cases that are simulated. Overall, the report shows that even within typical Dutch operational constraints, certain geological configurations that promote unbalanced flow may result in elevated hazards. These are related to (i) reactivation of nearby faults due to over-injection into one of the reservoirs combined with cooling effects from the injected fluid, and (ii) subsidence due to accelerated reservoir depletion in one of the reservoirs. The study does not assess the occurrence of depletion-related fault reactivation.

Mitigation measures (RQ3)

The report provides a set of mitigation and prevention measures for effects of unbalanced fluid circulation. These include well design options (e.g., zonal isolation, swellable packers), adaptive operational strategies, continuous monitoring (pressure, temperature, flow, subsidence), and the use of bow-tie analyses. Under unbalanced fluid circulation conditions, the report indicates that the upper pressure bound for geothermal operations should be limited to values close to the hydrostatic gradient.

Uncertainties are acknowledged where appropriate, particularly regarding geological heterogeneity, fault properties, and thermo-mechanical parameter values. In addition, model limitations are appropriately discussed. Overall, considering the limitations of the models, the research questions are answered in line with the expectations of the project.

KEM interpretation of the outcome

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

Focusing on a representative Dutch setting, considering dual-zone production from a clastic reservoir, the report provides a comprehensive investigation of commingled geothermal reservoir exploitation, including the investigation of reservoir pressure and temperature across a range of relevant scenarios. Special attention is given to conditions that may lead to unbalanced fluid circulation. Effects of unbalanced fluid circulation are evaluated, with a focus on fault reactivation and subsidence. The report suggests relevant mitigation measures for the effects of unbalanced fluid circulation.

The study reinforces the importance of:

- location-specific reservoir characterization, including the assessment of reservoir continuity and connectivity,
- cautious treatment of reservoirs that are thin, laterally discontinuous, or poorly connected,
- monitoring strategies for early detection of unbalanced flow and pressure and temperature deviations,
- adaptive control of operations.

Based on the results of the report and the acknowledged limitations of the models used, further study employing more advanced, fully coupled THM models would be a next step to provide more precise answers to the research questions. Such models would more comprehensively capture the interactions between pressure, temperature, and rock stresses, and allow a more refined assessment of fault reactivation for selected, relevant scenarios.

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)

Commingled production refers to the simultaneous exploitation of multiple hydraulically isolated reservoirs through a single wellbore. Focusing on the Dutch setting, this study provides an assessment of commingled geothermal production and the conditions that can lead to unbalanced fluid circulation between reservoirs. It highlights how pressure and temperature changes may influence subsurface behaviour, including fault reactivation and subsidence. The findings emphasize the importance of well-defined operational limits, thorough reservoir characterization, and continuous monitoring to support operational decisions.