KEM Innovation/Research Question (max. 4 pages + annex)

TITLE *Seismic Risk due to Cooling Effects in Geothermal Systems*

Objective

This research question aims at improving the understanding geothermal water injection under various conditions with different volume and rate regimes and the risk assessment method of geothermal injection wells. This should help SodM in their inspection task as well as the sector to optimise production plans, estimating the life time of the doublets and assessing the time needed to establish thermal and hydrostatic equilibrium again.

It is considered to be important to develop better guidelines and tools to as initial conditions and being able to define safe operating procedures of geothermal injection (and Production) wells.

State of the art, background

Within the Netherlands and various efforts developing in what is called the "energy-transition", where fossil-fuel based energy resources are replaced by renewables. One branch of this transition where relatively big steps can be made is district heating, where conventional central heating boilers are largely replaced by geothermal heat. Within the Netherlands geothermal energy is commonly extracted from brine within sub-surface hot sedimentary aquifers, HSA (Willems et al., 2017), and in some cases faults are actively used too (e.g., Reith et al., 2019). In the latter category some small scale seismicity has been measured (to date up to M_L 1.7, Buijze et al., 2019). Geothermal heat extraction is commonly executed using a doublet system (comprised of an injector and producer) and a heat exchange facility at the surface. At the injector well, the cooled down brine is re-injected. This causes a portion of the reservoir to cool down, the extent of this is noted as the cold front (e.g., Daniilidis et al., 2020). As a result of the temperature reduction, stress in the reservoir rock can drop due to a thermal contraction effect (e.g., Jeanne et al., 2017; Pandey et al., 2018). The effect is generally thought of as similar to the simple effective stress law, in the sense of lowering normal stresses in Mohr-Coulomb analysis (e.g., De Simone et al., 2013; Buijze et al., 2019;).
The nature of the Dutch subsurface is such that normal faults are regularly encountered (e.g., Duin et al., 2006), and as such some existing and planned geothermal systems may influence the stress state on nearby faults due to operational parameters (e.g., Segall & Fitzgerald, 1998; Gan & Elsworth, 2014; Blöcher et al., 2018;). Faults can be bounding faults, as well as minor faults within the targeted reservoir. In some cases faults are identified with confidence, for example through evaluation of seismic data prior to drilling activities. In other cases they are interpreted due to baffles found by interference tests between wells. Yet in other cases, faults are not identified, for example due to the offset being less than seismic resolution.
If one therefore considers that faults are ubiquitous in the Dutch subsurface, there are multiple scenario's imaginable where a cold front from a geothermal injection well reaches a fault, thereby cooling sections of that fault which result in reduction of stresses (e.g., Jacquey et al., 2015). In addition, sections of the fault can be locked while still at high temperature, while other parts that have been cooled may be in an unstable stress state. The size of the fault-patch that is unstable will likely be a large influence on the maximum area that would slip in an earthquake event (e.g., Yoon et al., 2014; Wassing et al., 2014), and thereby directly influences the magnitude of a seismic event that may be expected.
To identify what data, in combination with operational parameter space (or operational limits) are needed to be able to adequately assess safe use of the Dutch subsurface for geothermal heat extraction, the Dutch State Supervision on Mines (Staatstoezicht op de Mijnen, hereafter SodM) is looking to expand their knowledgebase, as well as that of the scientific and operator community. Anticipating larger scale geothermal operations and to help the sector to sound knowledge, clear guidelines and risk assessment tools need to be available and continuously be improved taking into account the latest insights. To this end SodM has identified key research questions and deliverables.

Research Question

- ***R1. In which generic geometries (or scenarios) of reservoir + fault(s) and a doublet in a given far-field stress state are there elevated risks of fault instability?***
- ***R2. Under what parameters are faults within reach of the thermal front radiating from the injection well, within the lifetime of a typical geothermal system (i.e., before thermal breakthrough at the producer well)?***
- ***R3. What is the influence of fault permeability in relation with the reservoir permeability on the size of the fault plane that is cooled down due to the injection of cold water?***
- ***R4. How does the stress tensor change on various spots of a fault plane trough time with the development of a cooled patch?***
- ***R5. What is the magnitude of seismic events that can be expected due to combined thermal cooling effects?***

Deliverables expected

- D1. A review study (literature study) that discusses how combinations of mechanical (e.g., stress field, geometry, fault roughness) and operational (e.g., flow rate, injection pressure, return temperature) factors may lead to unforeseen seismicity. (M6)
- D2. A numerical model study that verifies the main findings from D1. (M12)
- D3. A numerical model study where scenario's that are representative of the Dutch Subsurface are used to evaluate the significance of various mechanical and operational parameters. (M12)
- D4. Based on D1, D2 and D3; a ranking of operational parameters (and magnitudes) that may lead to seismicity, conventional geothermal systems (i.e., HSA with faults in normal faulting regime) in the Netherlands. (M18)

D5. Similar to D4, but set in an Ultra Deep Geothermal / Enhanced Geothermal System- scenario, targeting depths below 4 km and temperatures above 120 °C (i.e., larger pressure/temperature differences). (M18)
D6. A combined recommendation of required data prior to operation that required for safe operation of both type of geothermal systems. (M18)

Timeline

Generally following the chronology of the deliverables listed above, although some of the work can be done in parallel. Deadlines will be defined at a kick-off meeting. As a general guideline the deliverable due date is listed as number of months since start. The s work should be finished within a period of 1.5 years (18 months).

Expected use

Deliverables will function as an internal SodM guideline, allowing SodM to adequately identify potential hazards caused by operational parameters. A focus of which will be on thermal effects on faults. Deliverables may be combined to form contributions to international scientific journals that are well read by the community and open access, such that the work is available to the general public.

Expertise and tools preferred for the team

The applicant should have knowledge of the following skills: Geothermal reservoir engineering / modelling, seismological model, fault slip analysis. Furthermore, there should be a track record of numerical modelling through equivalent studies, access to numerical codes and potentially field data, possibly from international sources.

Quality assurance, Organisational and communication requirements

SodM will organize a kick-off meeting (The Hague) where due dates for deliverables are set. For quality assurance SodM suggests holding progress meetings, to be scheduled around milestones (M6, M12) so deliverables can be discussed. Communication of final results (following deliverable D6) will be communicated through the SodM website, along with a management summary (in Dutch) by SodM.

Remarks and Suggestions

The project does not cover field and/or laboratory testing without third party funding, and in agreement with SodM. The applicant should have access to required benchmarked software packages. In case in-house developed code is used, this should be adequately benchmarked prior to the start of the project. Knowledge utilization by means of conference and/or journal contributions will have to be approved by SodM prior to submitting the work.

References

Blöcher, G., Cacace, M., Jacquey, A. B., Zang, A., Heidbach, O., Hofmann, H., ... & Zimmermann, G. (2018). Evaluating micro-seismic events triggered by reservoir operations at the geothermal site of Groß Schönebeck (Germany). Rock Mechanics and Rock Engineering, 51(10), 3265-3279.

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Duin, E. J. T., Doornenbal, J. C., Rijkers, R. H. B., Verbeek, J. W., & Wong, T. E. (2006). Subsurface structure of the Netherlands-results of recent onshore and offshore mapping. Netherlands Journal of Geosciences, 85(4), 245.

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Yoon, J. S., Zang, A., & Stephansson, O. (2014). Numerical investigation on optimized stimulation of intact and naturally fractured deep geothermal reservoirs using hydro-mechanical coupled discrete particles joints model. Geothermics, 52, 165-184.

Selection ranking criteria (only for KEM expert panel only). *Scale: 1(no) - 5(yes) and short comment*

	Considerations		PE 1	PE 2	PE3	PE4	PE5
Scientific	State of the art OK?						
	Valid I/R question?						
	Realistic expectation?						
	Categorisation OK?						
	Scientific publishable?						
	RA Tool improvement?						
	….						
Feasibility	Deliverables?						
	Deadlines?						
	Budget allocated?						
	Openness?						
	…						
	….						
Building trust	Concerns addressed?						
	Risk reduction focus?						
	Quality assured?						
	Communication OK?						
	Reputation team OK?						
	Open products?						
	….						
Total (weighted) score							

Suggestions of experts and/or research entities

PE	Organisation name		Names of experts
PE 1	GFZ Potsdam Geo-energy group		Guido Blöcher, Mauro Cacace, Antoine Jacquey
PE 2	TU Delft		David Bruhn, Alex Daniilidis, Denis Voskov, Sanaz Saeid
PE 3	TNO-AGS		Jan.-Diederik van Wees (and group)?
PE 4	Lawrence Berkley National Laboratory		Pierre Jeanne?
PE 5	??		??