

KEM Research Question (max. 4 pages + annex)

TITLE Effect of fluid injection on seismic risk in depleted reservoirs

Objective

Maximum 200 characters (short description of the objective of the research question, which knowledge gap is resolved)

Worldwide, the production of natural gas from subsurface porous reservoirs has led to surface subsidence and induced seismicity, caused by the compaction of the depleting reservoir. Fluid injection during or after production is a potential measure to influence the reservoir pressure and, hence limit, reservoir compaction. As such, injection may result in a lower risk of induced seismicity compared to scenarios without fluid injection. However, fluid injection in itself might also (locally) trigger seismicity. Next to pressure effects, fault failure may result from temperature effects as the injected fluid has typically a lower temperature than the receiving reservoir. The overall objective of this study is to assess the net effect of fluid injection on seismic risk in depleted reservoirs.

State of the art, background

Maximum 400 characters (description of state of the art knowledge, practices and flaws, including link to references documents, data, models).

Previous research

In previous years, research was conducted by TNO and NAM on the feasibility of pressure maintenance by large-scale fluid injection (2014-2016, see references). It was concluded that injection can maintain reservoir pressure in depleting reservoirs, such as the Groningen gas field, and that fluid injection is technically feasible. However, the overall net effect of large-scale fluid injection on seismic risk was not quantified and the seismic risk associated with different fluid injection scenarios was only studied in a qualitative way. Therefore, it is currently unclear whether fluid injection can be used to minimise the risk of induced seismicity in depleting or depleted gas fields.

A feasibility study for the Groningen field (NAM, 2016) indicated that establishing a large-scale fluid injection operation in the short term was hardly feasible, due to the major investments required for the production of large volumes of injection fluid, as well as the lengthy time required to construct the injection well infrastructure. It was therefore decided by NAM not to pursue this option any further. However, various experts in the field advocate to continue investigating this option, especially for the Groningen field.

In 2022, the KEM-24 study was published, which investigated the effect of fluid injection on seismicity, using the Groningen reservoir as an example. Building upon previous studies and available data on the Groningen reservoir, a model was developed to investigate the effect of fluid injection on seismicity. The results of this study were, however, inconclusive. The model was incapable to simultaneously mimic historic changes in the reservoir pressure and observed seismicity. As such, the forecasting potential of the model could not be validated. One reliable finding of this study was that injection of N₂ is more efficient in affecting reservoir pressures compared to CO₂. Therefore, in this follow-up only N₂ injection is considered.

Studies into geothermic systems have shown that the injection of relatively cool fluids into relatively warm reservoir may trigger seismicity. Injection of a cold fluid causes a portion of the reservoir to cool down. This temperature reduction is accompanied by thermal contraction of the reservoir rock, leading to a stress drop and potentially activating nearby faults (e.g. De Simone et al., 2013; Jeanne et al., 2017; Pandey et al., 2018). So, it is important to consider this temperature effect, in addition to pressure effects, when evaluating the potential for fluid injection into depleted reservoirs.

Despite all efforts, there is no definite answer on the net effect of fluid injection in depleted reservoirs on seismic risk. Therefore, the KEM-panel has recommended to conduct a follow-up research. The State Secretary of Economic Affairs and Climate Policy decided to follow this recommendation and therefore KEM-24b is initiated.

Using Groningen reservoir data and models as an example

The Groningen reservoir has been extensively studied within various research programmes (e.g. KEM, DEEP-NL) and an adequate earthquake monitoring system has been in place since 2015, yielding an unparalleled amount of data and insight into the behaviour of the reservoir. In addition, for the Groningen reservoir, a validated seismic hazard and risk analysis (SHRA) model is available. This model was originally developed by NAM and since 2018 adopted and further developed by TNO. As such, the Groningen reservoir is a good candidate to investigate fluid injection and its effect on seismicity. This would require adjustment of the SHRA, as the current version does not have the functionality to investigate the pressure and temperature effects of fluid injection.

Historic influences on the current situation of the Groningen field

In addition to data and models, the current situation of the Groningen field should also be considered. Because of the occurrence of a vast amount of seismicity, the Dutch government has decided to terminate gas production from the Groningen field as soon as possible (in 2023 of 2024). Because of historic gas production, there is a pressure difference between the northern and southern part of the field (with northern pressures being higher). After gas production is terminated, it will take several decades for the pressure to fully equilibrate, meaning that there is still a potential source for seismicity for some time, especially in the northern part of the gas field. Injection scenarios should therefore focus on the phase after the production stop.

Research Question

Maximum 400 characters (what to be addressed and what not AND [Link to KEM Research Agenda](#))

1. Are there examples of fluid injection in reservoirs similar to the Groningen reservoir?

Worldwide fluid injection has been applied in several fields. Are any of those similar to Groningen in size and/or reservoir and overburden characteristics? What can be learned from these cases in terms of important criteria, factors, and relevant research questions?

2. What are possible injection scenarios for mitigating seismicity once production has stopped?

What scenarios could be applied to mitigate seismicity after production? Would those scenario's focus on minimising the pressure difference across the field, overall increase of pressure everywhere in the field, or are there other options? How much fluid, taking N₂ as an example, should be injected to have an effect on reservoir pressures and the seismicity? Is that feasible in terms of time constraints and/or infrastructure?

3. How can the SHRA model be adapted to include fluid injection?

The current version of the SHRA model is not capable to include pressure and temperature effects of fluid injection. In what way should the different parts of the model be adapted to be able to study the pressure and temperature effect of fluid injection?

4. What is the effect of fluid injection on the overall seismic risk?

What is the effect of the injection scenarios defined in research question 2 on the seismic hazard and risk profile of the Groningen field compared to a scenario without injection. How do the results compare?

Deliverables expected

Maximum 400 characters (list of deliverables expected, way of publication and intended usage by client)

1. Seismological model adaptation for N₂ injection.
2. Assessment report on the effect of fluid injection on seismicity for the Groningen field, including answers to the research questions 1-4 and the results of the SHRA for various injection scenarios defined in research question 2. The report should also include a Dutch summary that is readable for the general public.

Timeline

Maximum 200 characters (phases, milestones, end of project dates)

The project should not last longer than six months.

Expected use

Maximum 200 characters (general knowledge, contribution to risk instrument, contribution to risk assessment, benefit)

Lessons learned from this study can be adopted for other fields where fluid injection may be considered in relation to energy storage (e.g. natural gas, hydrogen or compressed air) or waste storage (e.g. CO₂ or waste water).

Expertise and tools preferred for the team

Maximum 200 characters (lists of expertise and tool skills expected, required)

The team should have access to and be experienced with the SDRA model for the Groningen reservoir. Additionally, the team should have knowledge of reservoir engineering and geomechanics. Experience in working with data from the Groningen field and awareness of the historic gas production and current situation is also a requirement.

Quality assurance, Organisational and communication requirements

Maximum 200 characters qc process, (review level, location, collaboration and meeting schedule wishes)

A representative of the KEM panel will be involved in monthly progress meetings from the onset of the project, ensuring continuity and reporting to the KEM panel. The progress in the project and any issues should be presented at the bi-annual KEM panel meetings. The results of the project should be reviewed by independent researchers, organized by the project team.

Remarks and Suggestions

Maximum 200 characters (extra information concerning the Innovation/Research question)

None

References

No limit (reference list of papers, tools and reports)

- De Simone, S., Vilarrasa, V., Carrera, J., Alcolea, A., & Meier, P. (2013). Thermal coupling may control mechanical stability of geothermal reservoirs during cold water injection. *Physics and Chemistry of the Earth, Parts A/B/C*, 64, 117-126.
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- Jeanne, P., Rutqvist, J., & Dobson, P. F. (2017). Influence of injection-induced cooling on deviatoric stress and shear reactivation of preexisting fractures in Enhanced Geothermal Systems. *Geothermics*, 70, 367-375.
- NAM (2016). Groningen Pressure Maintenance Study.
- NAM (2016). Expert panel report: Induced seismicity resulting from injection (workshop Amsterdam 9-10 June 2016).
- Pandey, S. N., Vishal, V., & Chaudhuri, A. (2018). Geothermal reservoir modeling in a coupled thermo-hydro-mechanical-chemical approach: A review. *Earth-Science Reviews*, 185, 1157-1169.
- TNO (2014). Literature review on Injection-Related Induced Seismicity and its relevance to Nitrogen Injection (TNO 2014 R11761).
- TNO (2015). Injection-Related Induced Seismicity and its relevance to Nitrogen Injection: Description of Dutch field cases (TNO 2015 R10906).
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- TNO (2015). Description and analysis of field cases of injection in The Netherlands (TNO 2015 R10906).