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Investigating the Effect of Fracture Properties on Peclet Number of Enhanced Geothermal Systems

Khashayar Khezri, Emad Jahangir, Dominique Bruel, and Murad Abuaisha

Mines Paris-PSL Research University
(khashayar.khezri@minesparis.psl.eu)

2 Minutes Presentation

PhD Project Overview

Concept & Model Development

Results

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European Doctoral Network on Geo-energy

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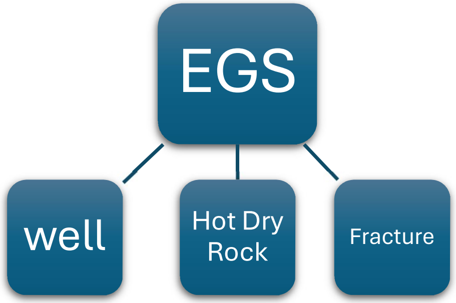
Funded by the European Union

PhD Project Overview

One of the unresolved issues in studying induced seismicity in Enhanced Geothermal Systems (EGS) is the occurrence of <u>delayed induced seismicity</u> and the underlying processes driving this phenomenon.

Understanding delayed induced seismicity in EGS is crucial due to its severity post-injection, often surpassing seismic events during injection This study aims to advance understanding by modeling Thermo-Hydro-Mechanical (THM) coupling processes, examining how lags in pressure and temperature perturbation zone jointly influence stress field within fractured rock and trigger delayed induced seismicity.



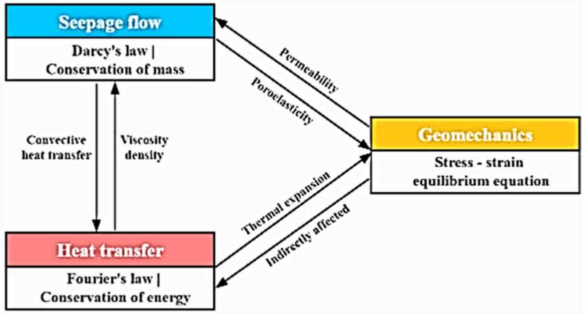
EGS

well

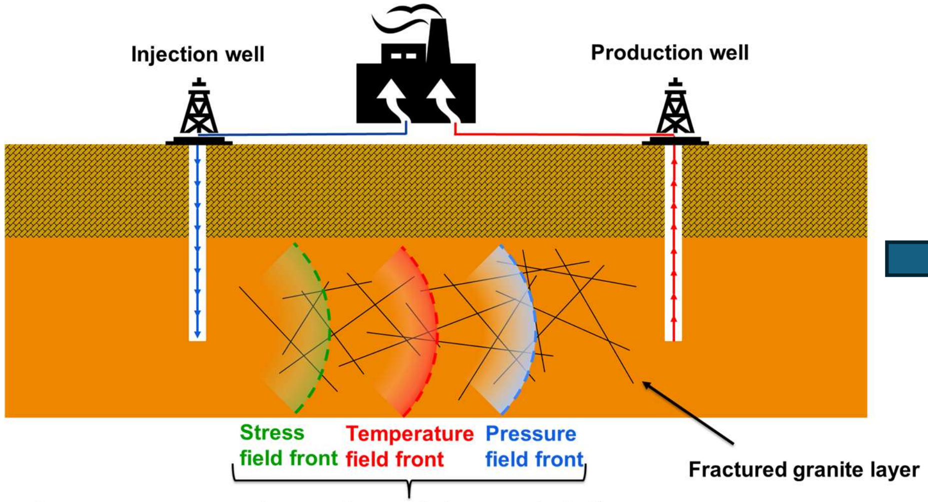
Hot Dry Rock

Fracture

THM Coupled model

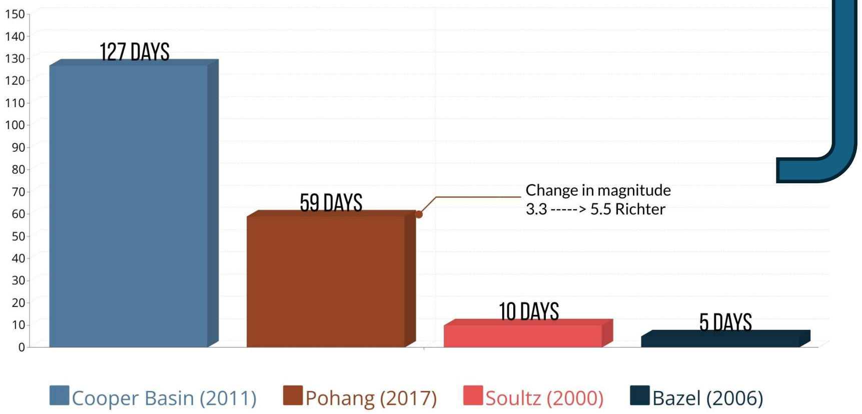


Zheng, Jun, et al. (2022)



Lag among pressure, temperature and stress perturbation zones

Severe Delayed Induced Seismic Events



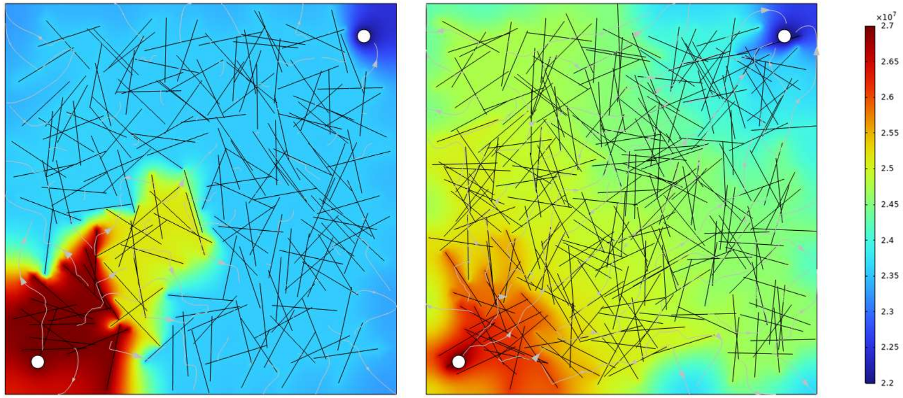
2 Minutes Presentation

Results

- Percolation Number ⟺ Fracture Network Connectivity

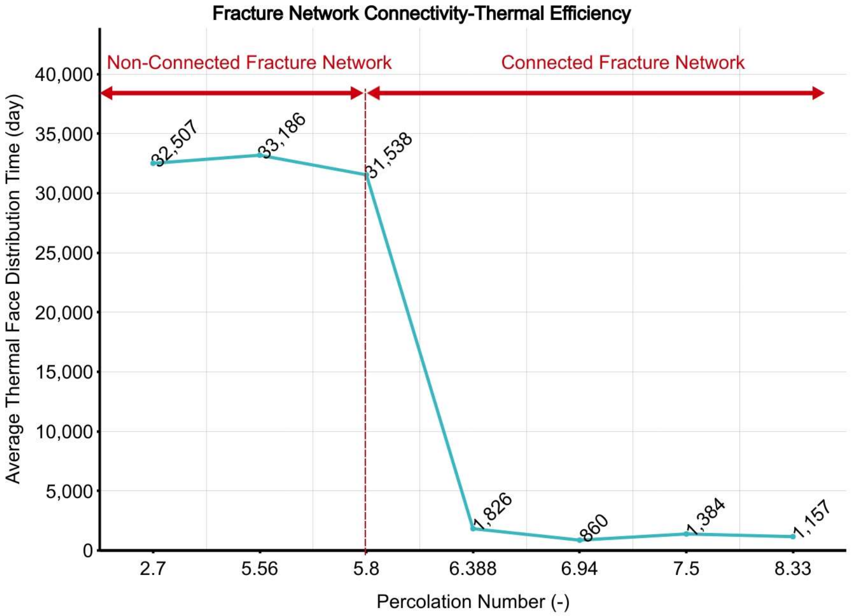
P critical=5.8

Pressure distribution in two different fracture networks with different connectivities



Non-connected fracture network with 200 fractures
P= 5.55<5.8

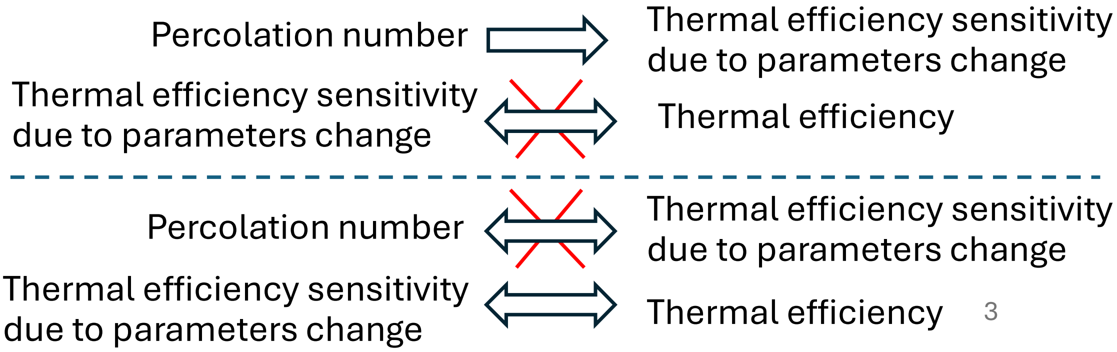
Connected fracture network with 300 fractures
P= 8.33>5.8.



- Sensitivity Analysis

Convection
- Permeability, Porosity (not effective)

Conduction
- Thermal Conductivity, Heat Capacity, Density, Porosity



Percolation number ⟹ Thermal efficiency sensitivity due to parameters change

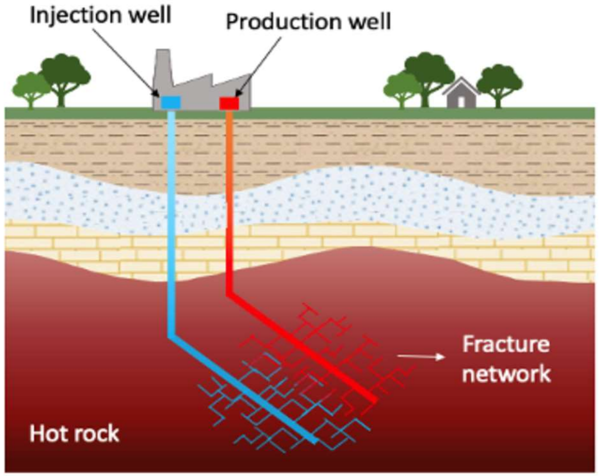
Thermal efficiency sensitivity due to parameters change ⟺̸ Thermal efficiency

Percolation number ⟺̸ Thermal efficiency sensitivity due to parameters change

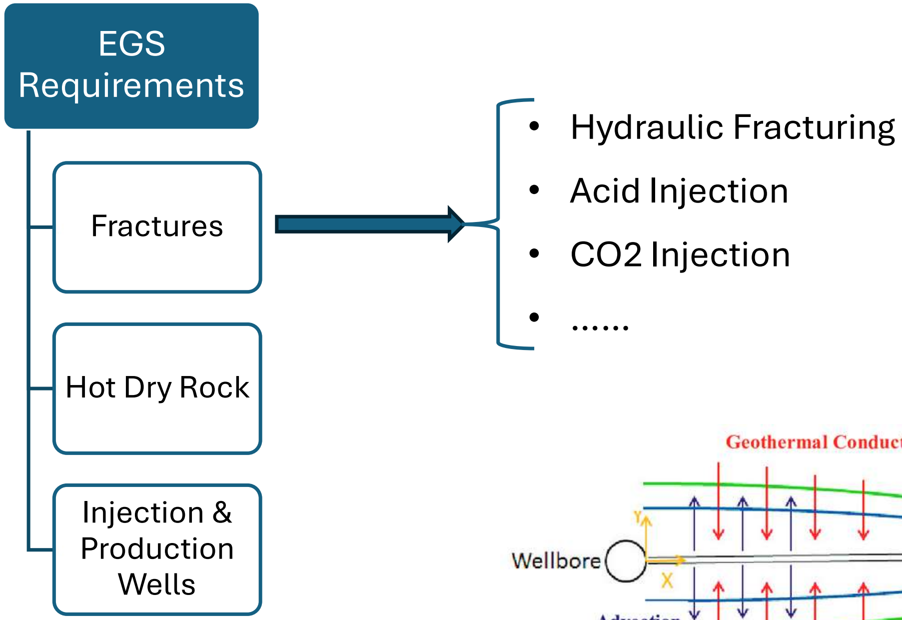
Thermal efficiency sensitivity due to parameters change ⟺ Thermal efficiency

Enhanced Geothermal Systems

Enhanced Geothermal Systems (EGS) accesses heat sources deeper in the Earth's crust, making geothermal energy viable in regions lacking active tectonic activity and broaden geothermal energy production to diverse geographical areas



Rangel Jurado, et al (2022).

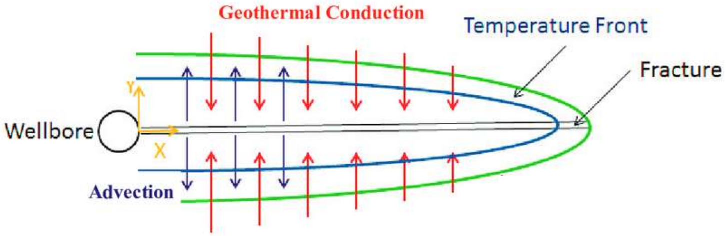


EGS Requirements

- Fractures
- Hot Dry Rock
- Injection & Production Wells

Fractures →

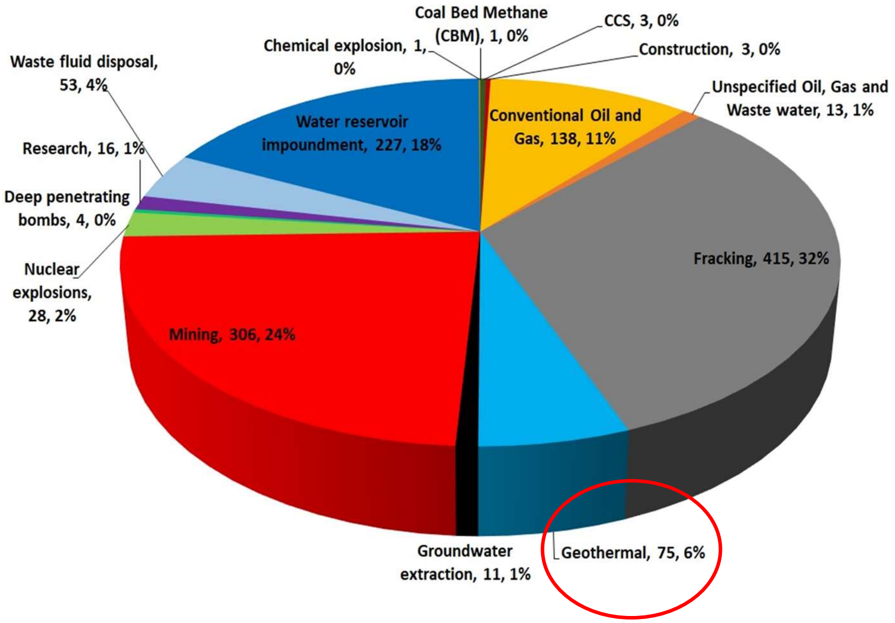
- Hydraulic Fracturing
- Acid Injection
- CO2 Injection
- ……

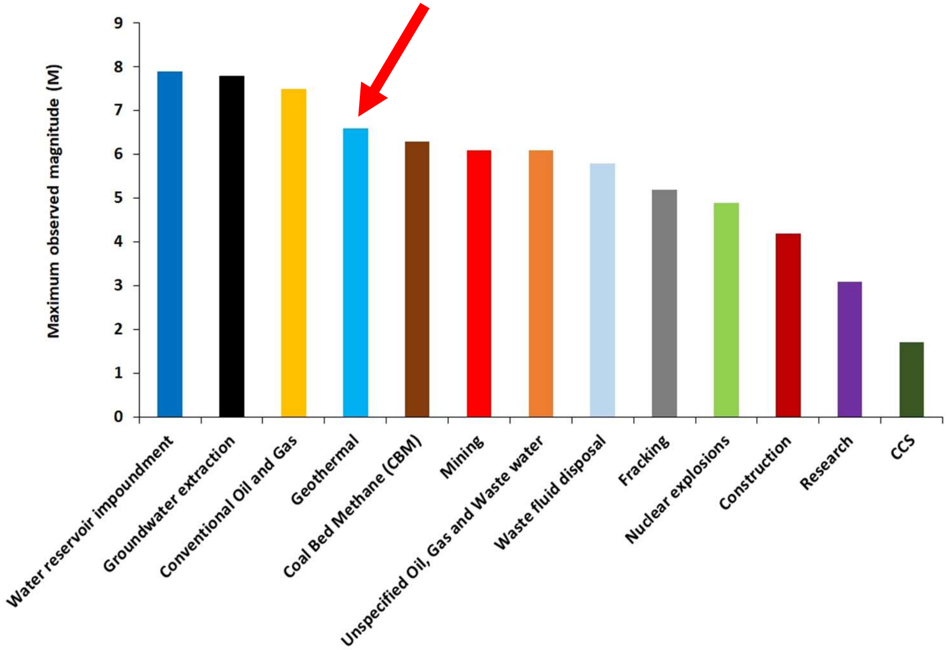


Taylor, Jacob, and Steven Bryant (2014)

Induced Seismicity

Induced seismicity emerges as an adverse outcome of EGS, arising from the necessity to establish interconnected fractures for fluid circulations. By studying previous seismic events, it can be observed geothermal exploitation caused low number of seismic events with high magnitude which can be a sign of less control of induced seismicity in this field



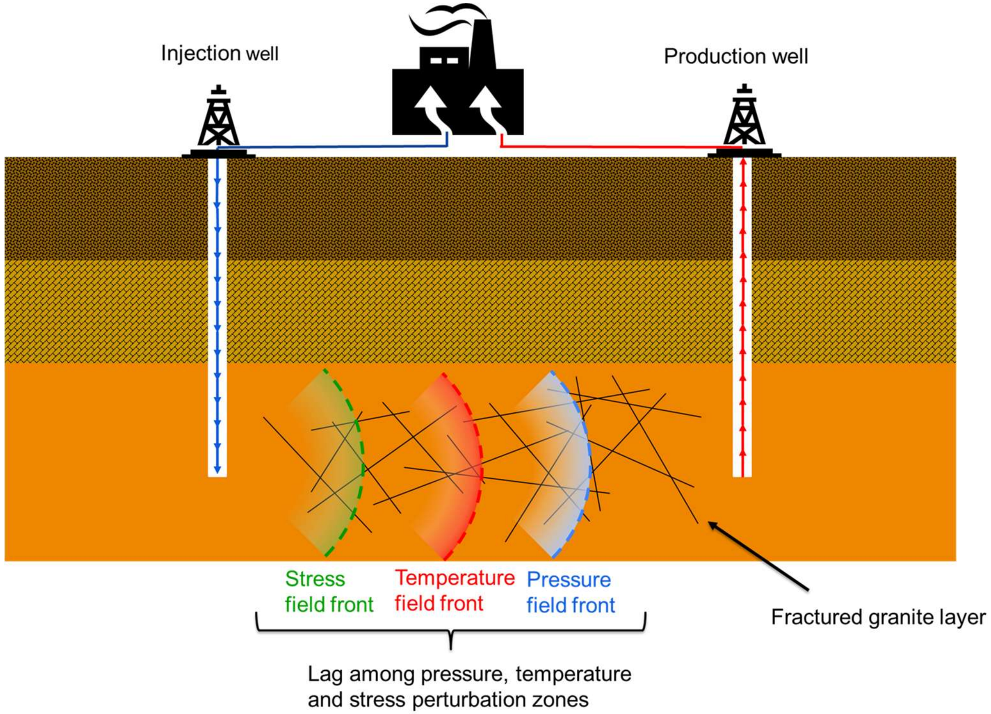


Source: www.inducedearthquakes.org

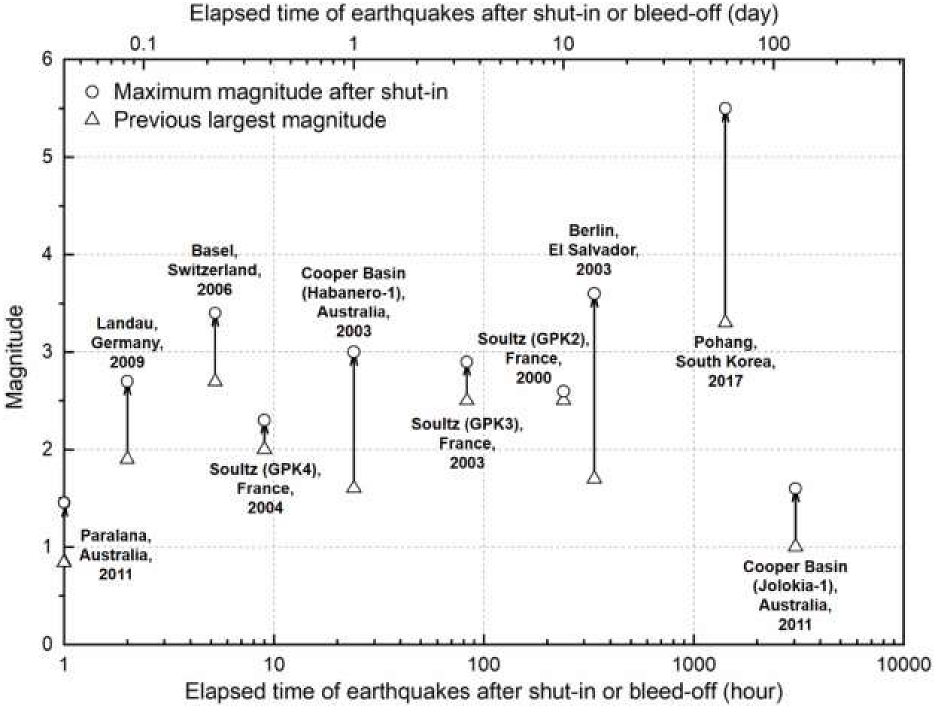
Delayed or Post-Injection Induced Seismicity

In the case of studying induced seismicity in geothermal energy, one of the open questions is post-injection or delayed induced seismicity and the effective processes behind this phenomenon. Finding an answer to this question becomes critical when post-injection seismic events, in many cases, are observed to be more severe the ones recorded during injection.

Expected reason: delayed in pressure, temperature front



earthquake magnitude jumps and its delay of occurrence after shut in or bleed of in different geothermal projects



Kim, Kwang-Il, et al. (2022):.

PhD Project Overview

Project Description

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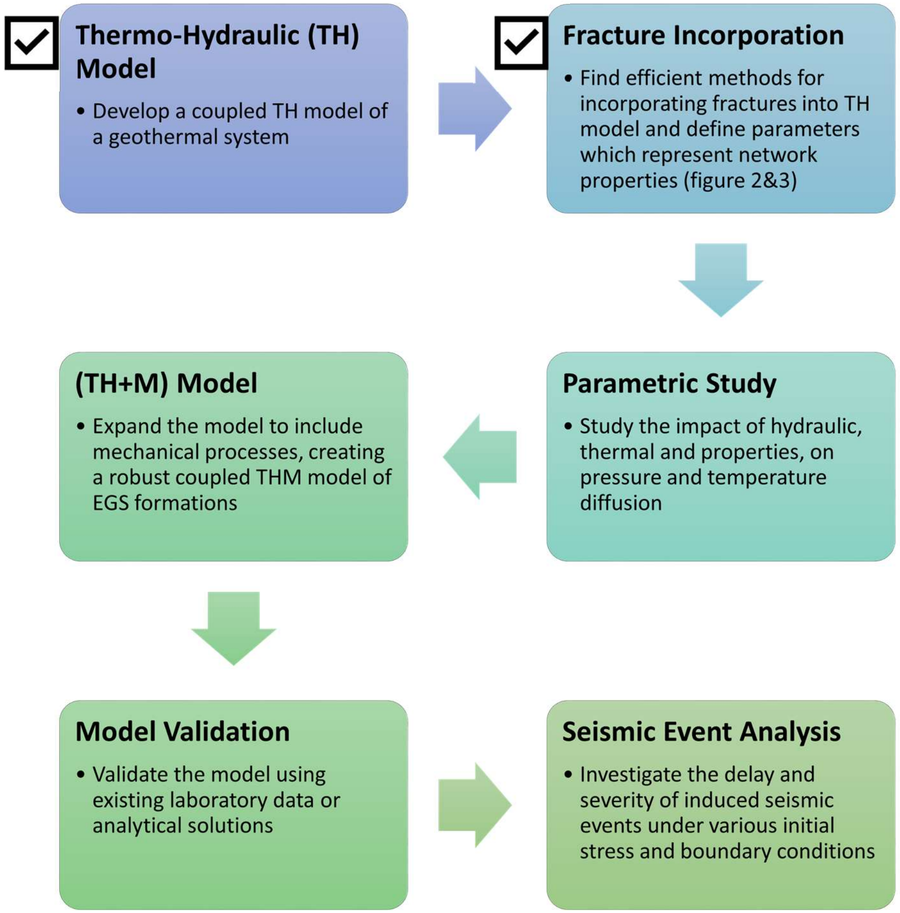
European Doctoral Network on Geo-energy

DC7-PhD: Dynamic fracturing in a THM framework: Upscaling applications to geo-energy production and induced seismicity

This research project aims to improve the control over induced seismicity events during deep geothermal energy exploitation by enhancing our understanding of pressure and temperature diffusivity, and their interactions with existing stress fields in fractured rock. To achieve this, robust fully coupled thermo-hydro-mechanical models will be developed that include dynamic fracturing processes. By applying the model to various project configurations and using statistical analysis, we can identify the combinations of processes that result in severe induced seismicity

Approach



☑ **Thermo-Hydraulic (TH) Model**
- Develop a coupled TH model of a geothermal system

☑ **Fracture Incorporation**
- Find efficient methods for incorporating fractures into TH model and define parameters which represent network properties (figure 2&3)

Parametric Study
- Study the impact of hydraulic, thermal and properties, on pressure and temperature diffusion

(TH+M) Model
- Expand the model to include mechanical processes, creating a robust coupled THM model of EGS formations

Model Validation
- Validate the model using existing laboratory data or analytical solutions

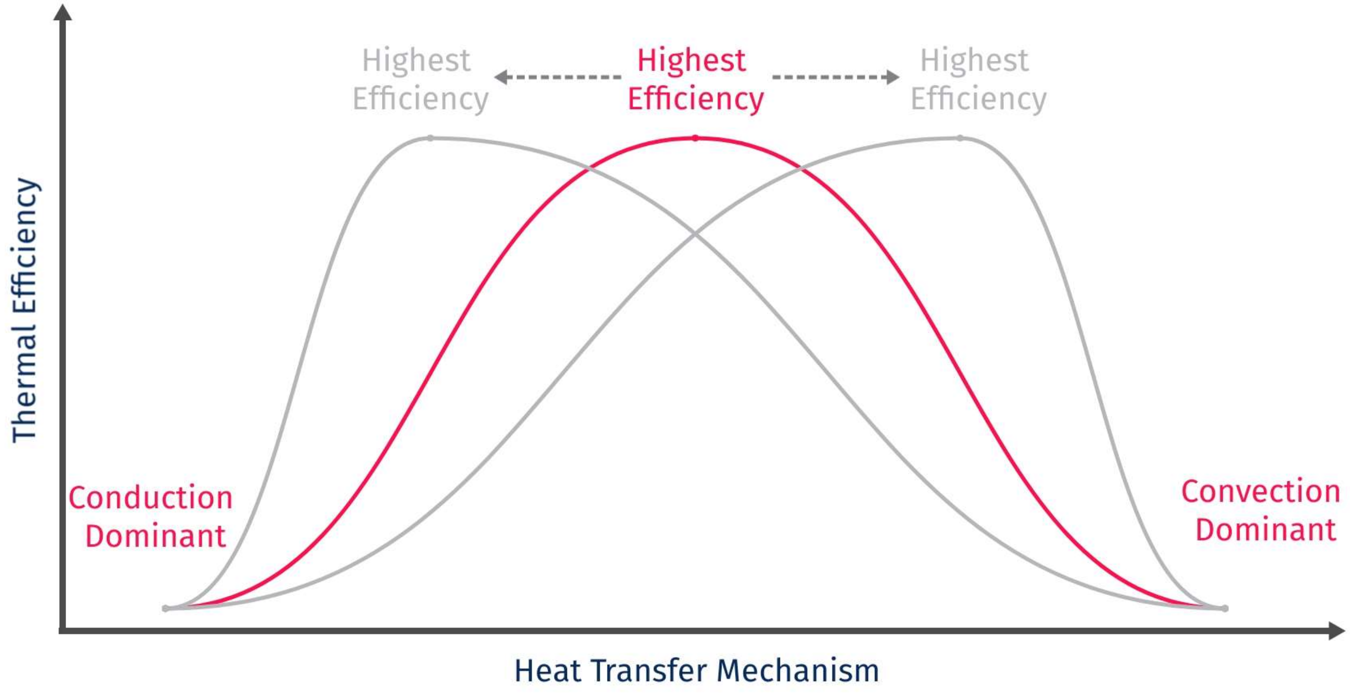
Seismic Event Analysis
- Investigate the delay and severity of induced seismic events under various initial stress and boundary conditions

Concept and Model Development

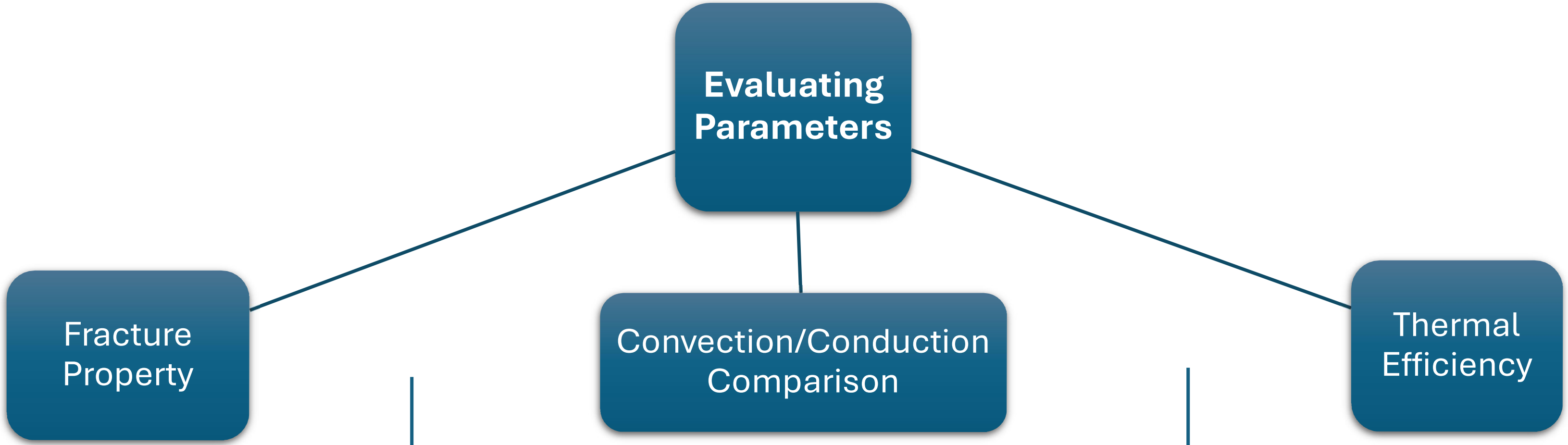
Convection vs Conduction

Heat transfer in porous media involves two main mechanisms: convection and conduction. While conduction dominates in low-porosity rocks, fractures enhance fluid movement, making convection more significant. Balancing these mechanisms and determining the optimal Peclet number is crucial for the geothermal energy industry to extract adequate volume of water at the desired temperature, which is essential for smooth operation of geothermal systems

Maximum efficiency is depended on fracture network properties



Studying Parameters



Percolation Number

Assumption:
- Random fracture orientations
- Random fracture location

$$p = \int_{l_{\min}}^{l\max} \frac{n(l)l^2}{L^2} dl$$

$$p_c = 5.6 - 5.8$$

$$disconnected < p_c < connected$$

Macroscopic Peclet Number

$$Pe_M = \frac{t_{thermal}}{t_{hydraulic}} = \frac{A / D_T}{L_f / u_f}$$

$$D_T = \frac{\lambda_{eff}}{\rho C_{P_{eff}}}$$

Dimensionless temperature in production well

$$T^* = \frac{T_{production} - T_0}{T_{injection} - T_0}$$

$T^* = 0.5$ Average thermal face

Concept and Model Development

Sensitivity Analysis

Percolation Number

- Generating four fracture networks with different percolation number

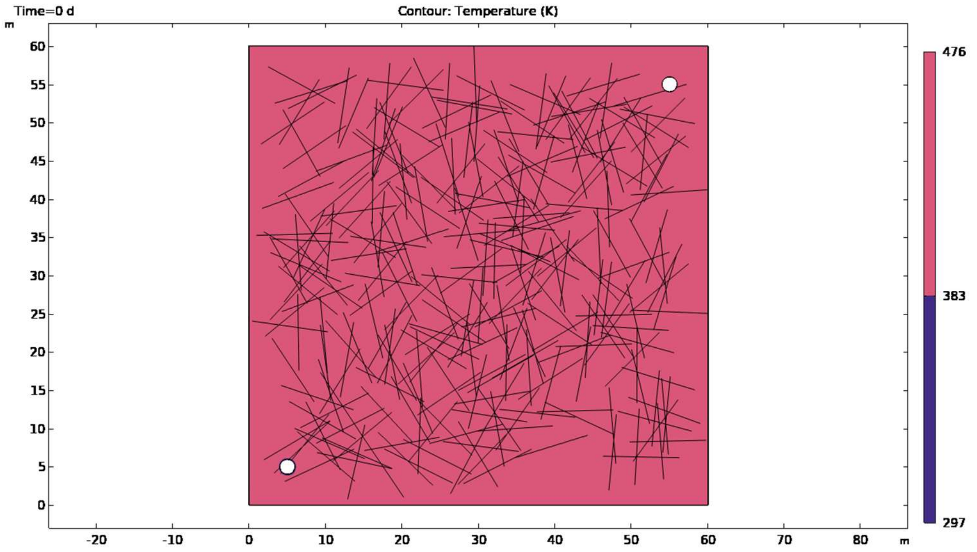
Once-at-a-time (OAT) sensitivity analysis

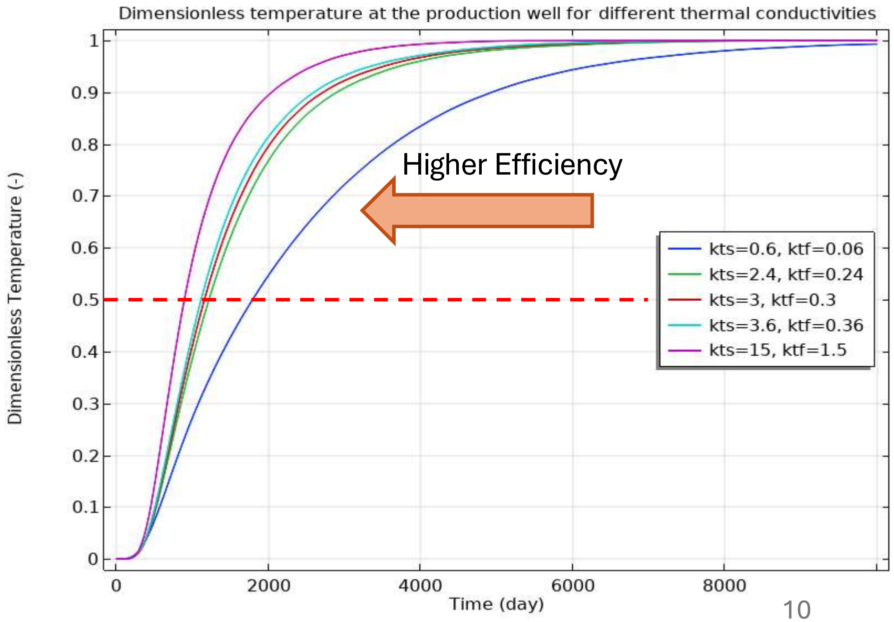
- Permeability
- Porosity
- Thermal conductivity
- Heat capacity +density

Study the sensitivity results

- Peclet number sensitivity
- Thermal Efficiency
- Thermal Efficiency sensitivity

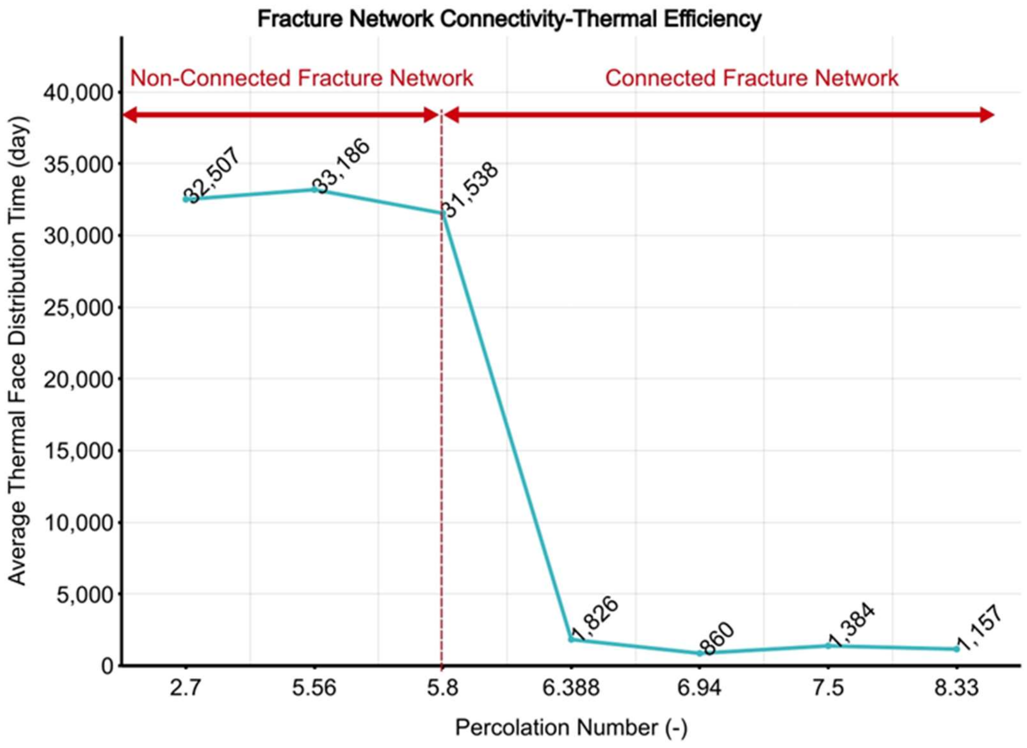
Thermal Efficiency Definition



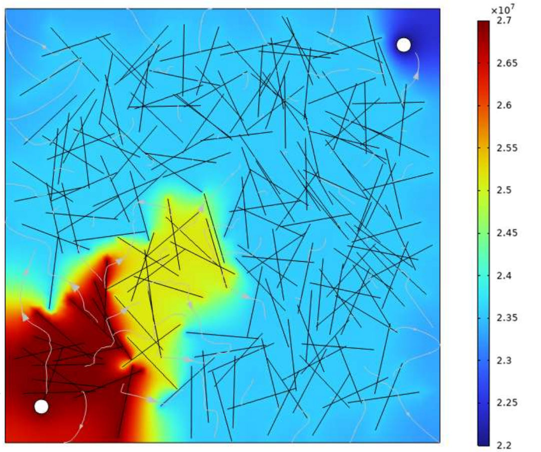


Percolation Number- Fracture Connectivity

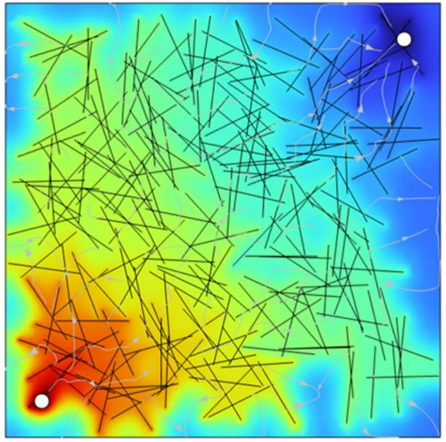
In order to assess the accuracy of the percolation number in distinguishing connected from disconnected fractures, we generate various fracture networks with differing percolation numbers. Subsequently, we compare the pressure distribution and average thermal face velocity among these fracture networks.



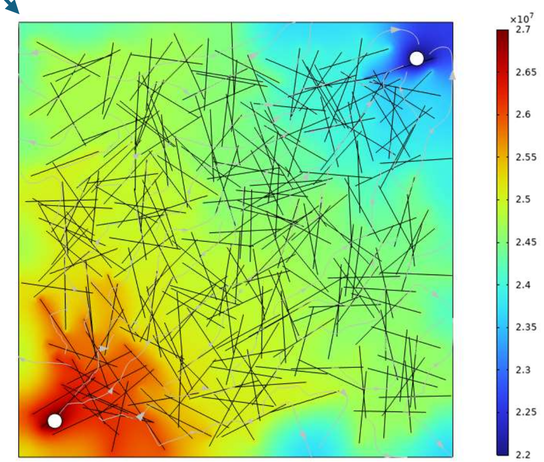
Pressure Distribution in Domain



Disconnected fracture network
200 fractures P= 5.55<5.8



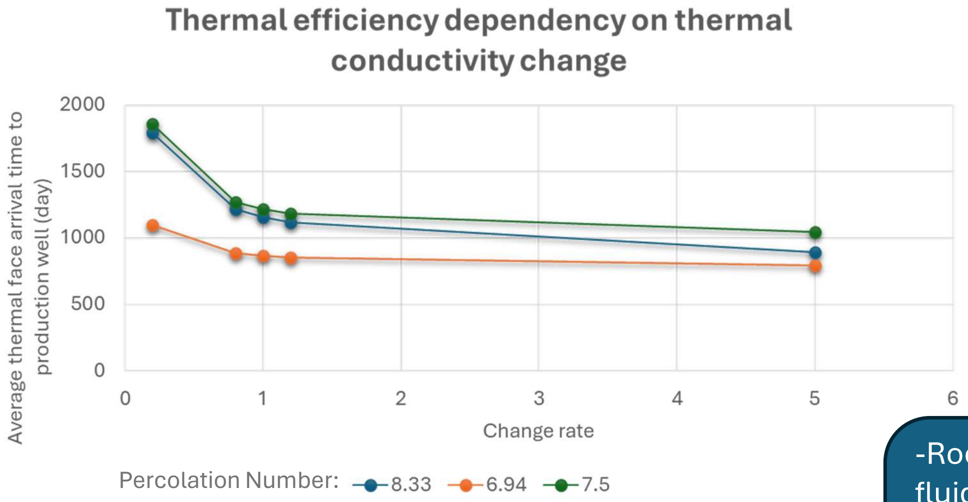
Connected fracture network
250 fractures P= 6.94>5.8

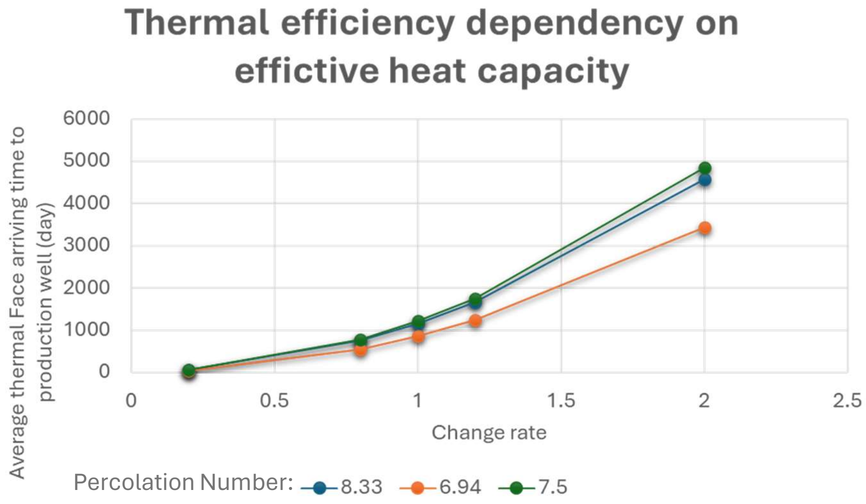


Connected fracture network
300 fractures P= 8.33>5.8.

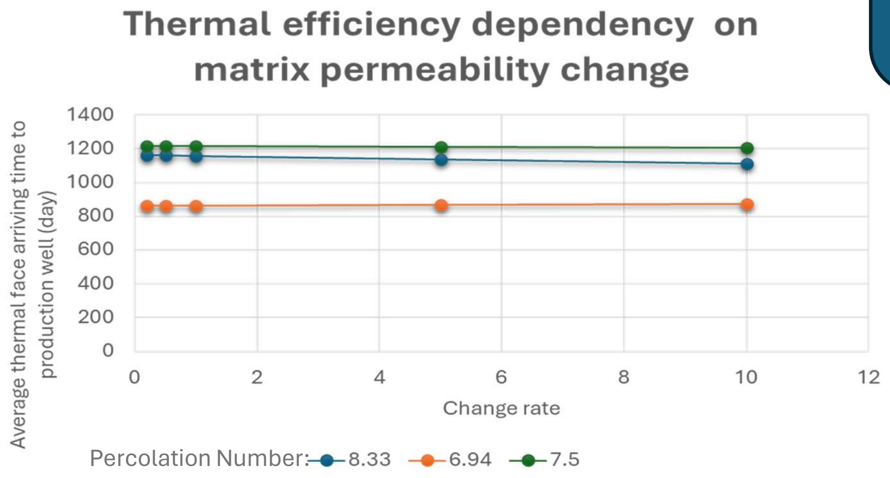
Results

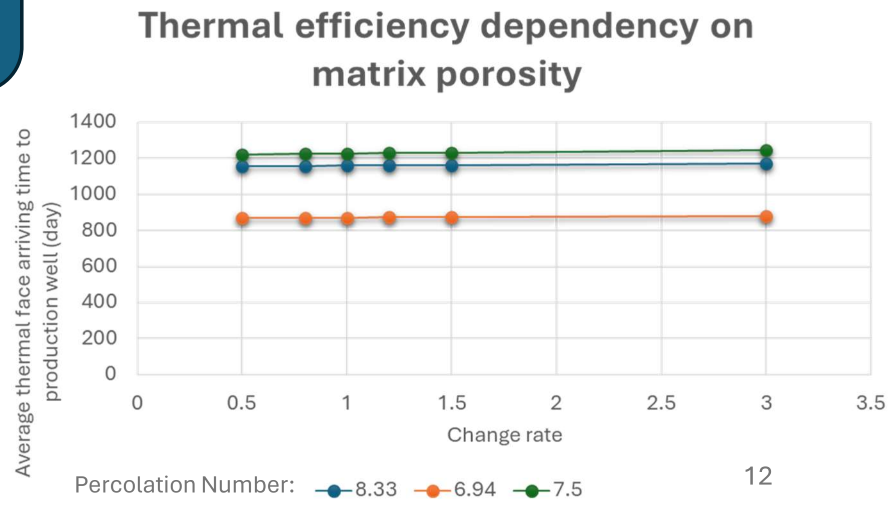
Thermal Efficiency Dependency





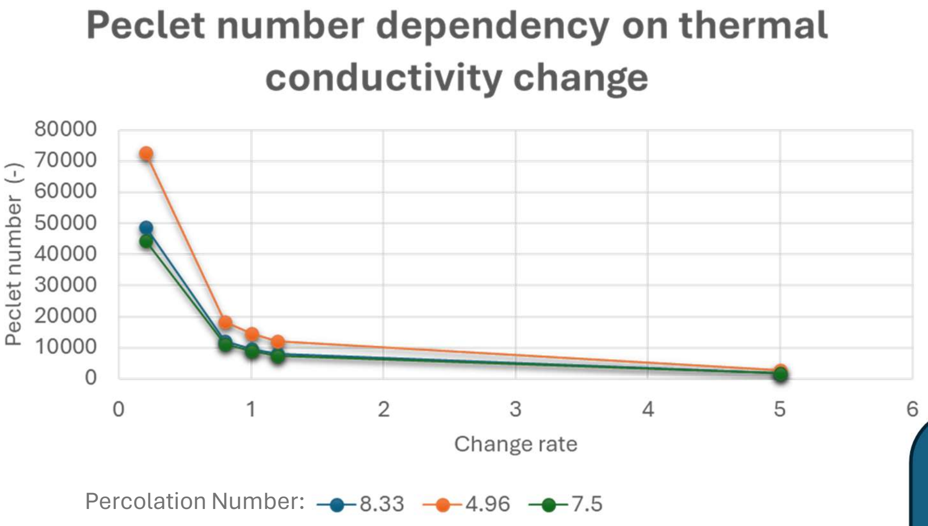
- -Rock thermal & fluid properties
- -Percolation number weak effect on thermal efficiency

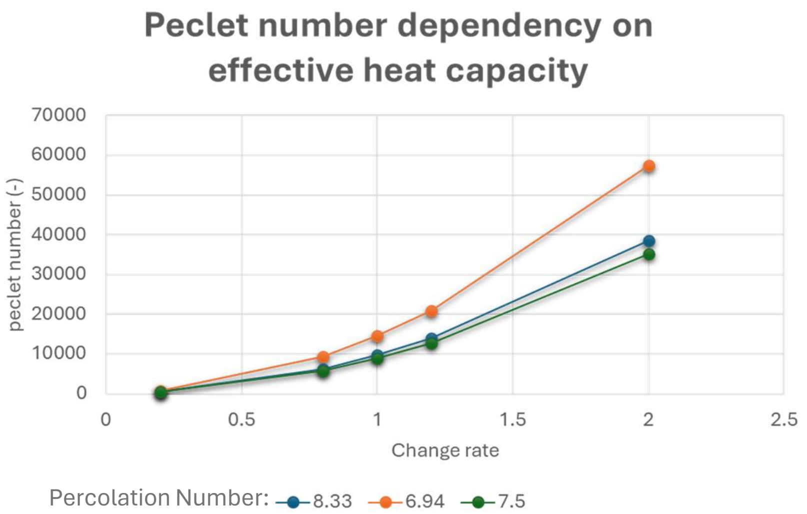




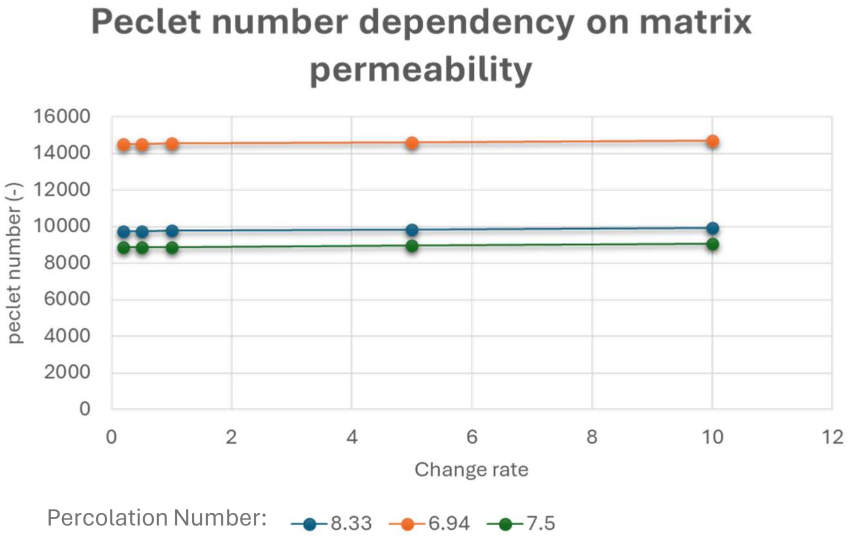
Results

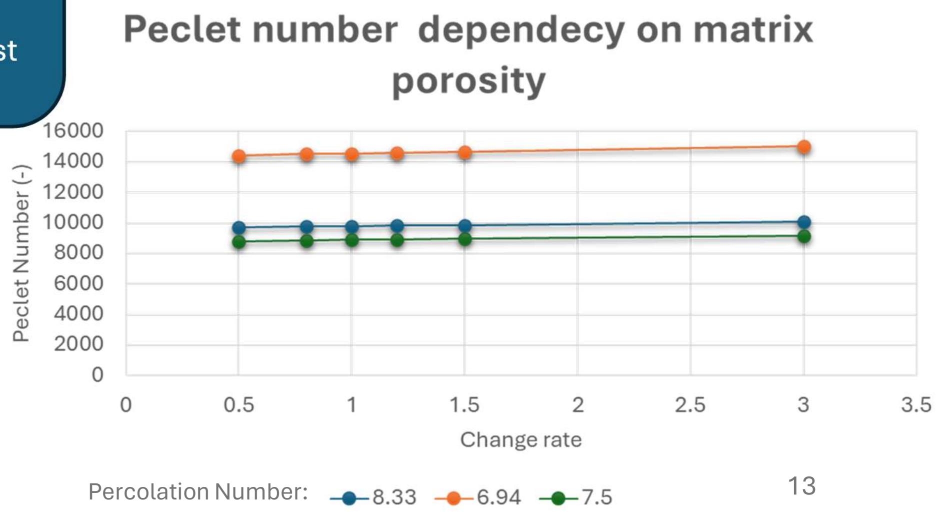
Peclet Number Dependency


Peclet number dependency on thermal conductivity change


Peclet number dependency on effective heat capacity

-Same trend with thermal efficiency results
-Most efficient fracture network=highest peclet number

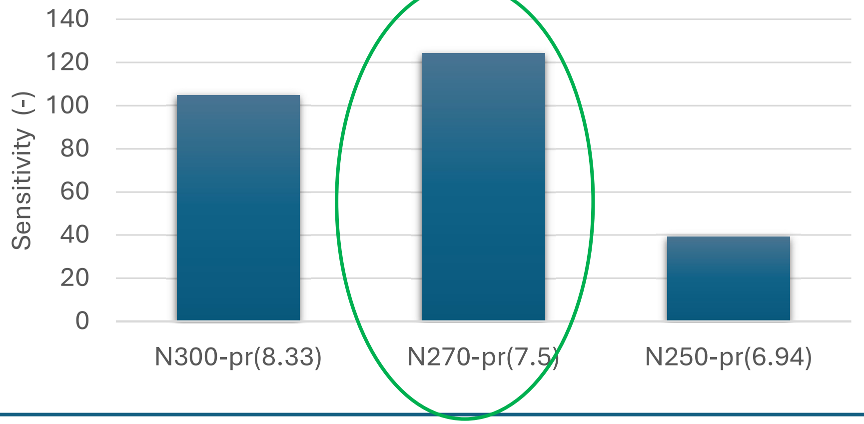

Peclet number dependency on matrix permeability


Peclet number dependecy on matrix porosity

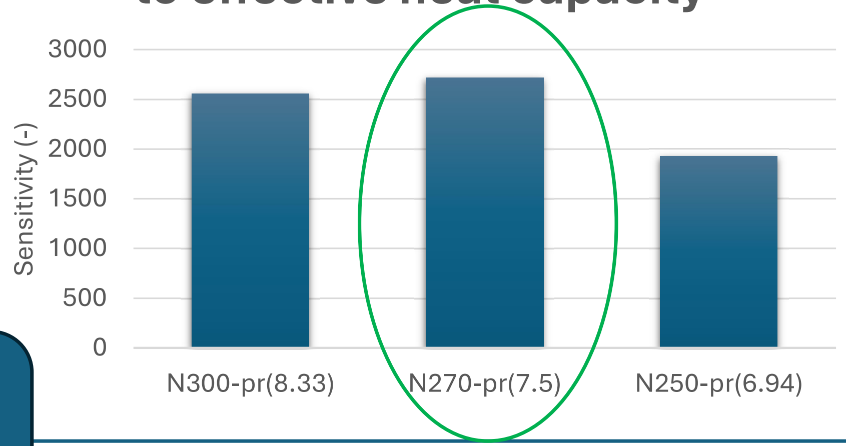
Results

Thermal Efficiency Sensitivity

Thermal efficiency sensitivity to thermal conductivity change

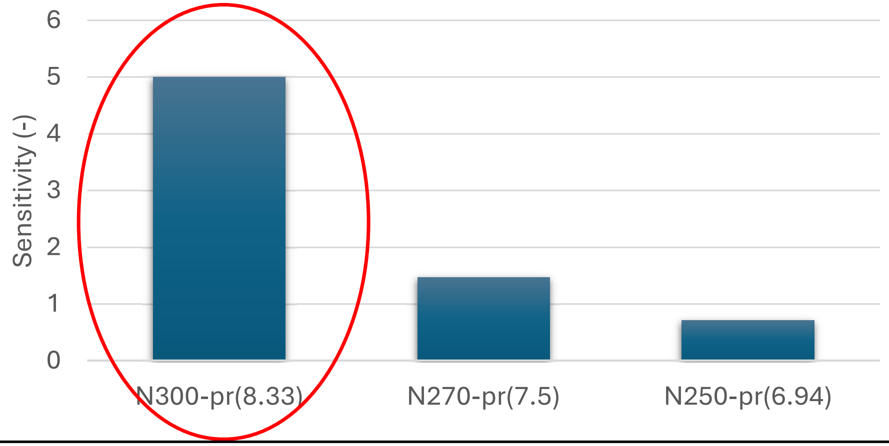


Thermal efficiency sensitivity to effective heat capacity

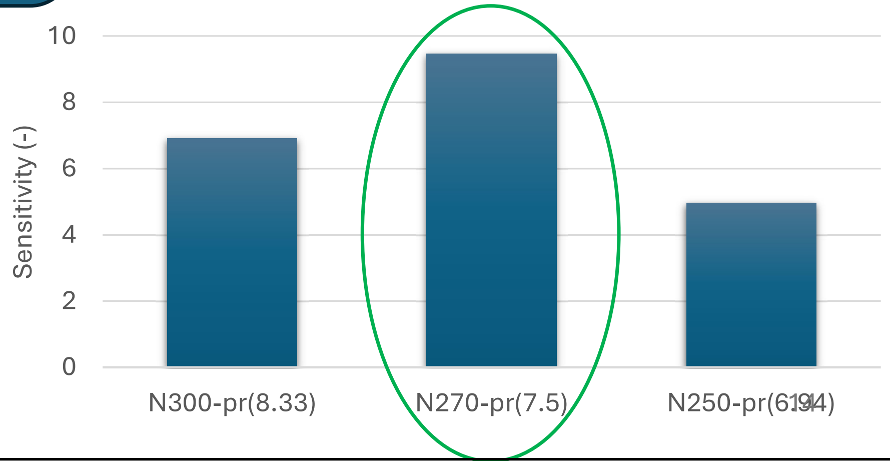


Different effect of permeability on thermal efficiency compare to other parameters

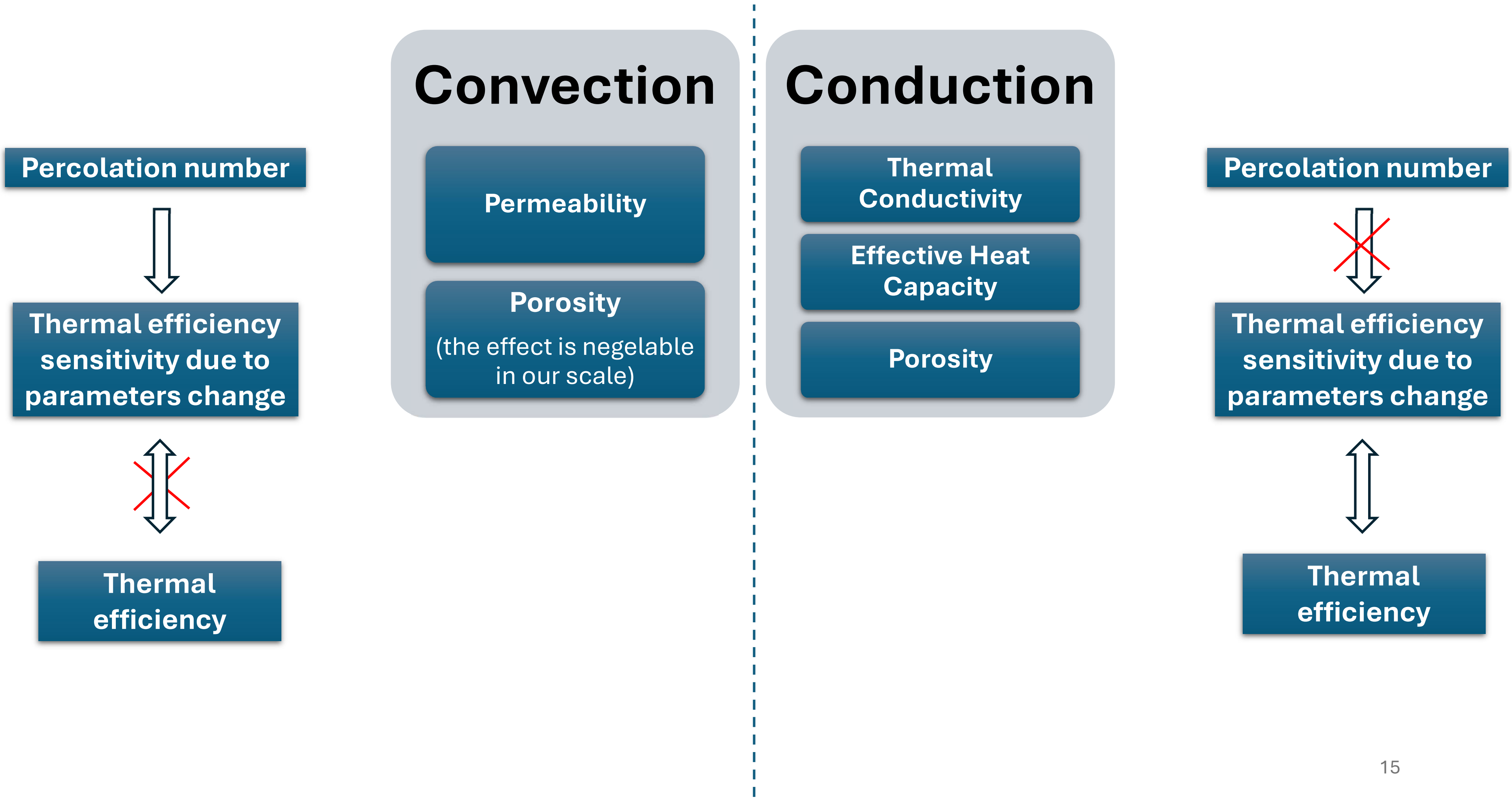
Thermal efficiency sensitivity to matrix permeability



Thermal efficiency sensitivity to matrix porosity



Discussion



Percolation number

Thermal efficiency sensitivity due to parameters change

Thermal efficiency

Convection

Permeability

Porosity

(the effect is negelable in our scale)

Conduction

Thermal Conductivity

Effective Heat Capacity

Porosity

Percolation number

Thermal efficiency sensitivity due to parameters change

Thermal efficiency

Conclusion

The percolation number effectively discerns the connectivity or disconnection of the fracture network in our numerical model.

While the percolation number is valuable, it alone cannot comprehensively characterize the behavior of a connected fracture network; additional parameters, such as fracture network density, are necessary to assess other fracture properties beyond connectivity.

In cases where effective parameters in convection change within the model, the percolation number governs the sensitivity of thermal efficiency. However, the fracture network with the highest percolation number (or highest thermal efficiency sensitivity) may not necessarily be the most thermally efficient.

When effective parameters in conduction change, it appears that the percolation number has no effect on thermal efficiency and sensitivity. However, the fracture network that provides the highest efficiency exhibits the least sensitivity to related parameters (parameters affecting conduction).

Many of these parameters are interconnected, particularly as they change with porosity alterations, and the overall behavior of the model cannot be fully understood through simple sensitivity analysis methods. The objective of this study was to gain an initial understanding of the model's behavior at a field scale. Future studies will concentrate on developing alternative theories to describe fracture behavior in connected networks and employing more complex sensitivity analysis to achieve more precise results.

References & Acknowledgement

References

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Acknowledgement

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