THM modelling of seismic velocities changes at DeepStor heat storage demonstrator

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Motivation

High-temperature aquifer thermal energy storage (HT-ATES) systems are attracting interest for securing a heat demand in a sustainable manner. In these systems, hot water is injected into a reservoir over the summer months while exchanged cold water is injected over the winter season[1].

The reservoir geomechanical and thermo-hydraulic properties change due to temperature and pressure variations. Monitoring these properties changes is key to run a heat storage system safely and efficiently. We try to determine if active seismic imaging could be a suitable method to characterize the time-space evolution of a reservoir.

With view on designing future geophysical assessment and monitoring systems, we perform thermo-hydro-mechanical (THM) modelling, based on the DeepStor demonstrator characteristics, to determine the changes in the poroelastic properties of the underground

The changes in the parameters from the THM model are linked to seismic sensitive variables, such as velocities and impedances, using empirical equations. Hence, we can quantify the effects of injection on such variables and determine if it would be possible to detect them with active seismic surveys.

1 - DeepStor Demonstrator

- Some of the renewable technologies (solar, wind) depend largely on weather or daylight conditions.
- Aquifer thermal energy storage (ATES) allows to store energy in near surface aquifers regardless of the weather conditions.
- High-temperature (HT) ATES, which are located deep in the subsurface, can reach temperatures higher than 50°C.[1,3]
- DeepStor serves as a demonstrator, to validate the technical feasibility of HT-ATES[2]
- It is located in a former oil reservoir, in the area with the highest measured thermal anomaly in Germany: 170 °C at 3km depth[2]
- The reservoir has an estimated thickness of 10m and temperatures of about 70-80°C, at a depth of 1200m.
- To correctly design a geophysical monitoring layout, the expected values for the different parameters (V_s, V_P, density) must be determined.

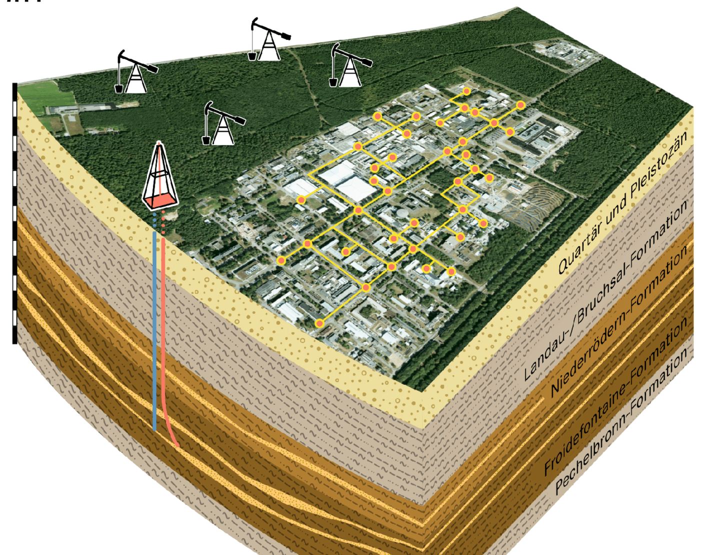

Figure 1. Conceptual model for DeepStor. The target is around 1200m depth, at the Meletta bed sands.

Sharing is encouraged

2 - Thermo-Hydro-Mechanical Model

Conceptual model

- Based on the structural model of the DeepStor site subsurface.
- Only one potential reservoir layer.
- The inclination of the layers is not considered, resulting in a horizontal geometry with parallel layering.
- The model assumes a single well that serves as injector during the summer months and as producer the rest of the year.
- Material properties (porosity, permeability, bulk modulus…) are based on the available literature of the site.
- Operating parameters (flow rate, injection temperature) are taken from the planned operational framework.

Parameter	Value			
	Upper layer	Reservoir	Lower layer	Fluid
Dynamic viscosity [Pa.s]	-	-	-	4.18×10^{-4}
Volumetric heat capacity [$MJ.m^{-3}K^{-1}$]	-	-	-	4.2
Specific heat capacity [$MJ.m^{-3}K^{-1}$]	1.25	11.9	1.25	-
Thermal conductivity [$W.m^{-1}K^{-1}$]	1.4	2.5	1.4	0.6
Permeability [m^2]	1×10^{-18}	6.6×10^{-14}	1×10^{-18}	-
Initial Porosity [%]	15 (5, 20)	15 (5, 20)	15 (5, 20)	-
Density [$kg.m^{-3}$]	2360	2410	2420	1000
Shear modulus [GPa]	11.3	14.6	15.4	0
Bulk modulus [GPa]	27.9	36.0	37.9	2.0
Biot Coefficient	1 (0.46)			
Injection temperature [°C]	140			
Injection/production flow rate [$L.s^{-1}$]	2 (10)			

Table 1. Material and operation parameters. The changed values are shown in brackets

Numerical model

- THM equations are solved by the open source code TIGER (THMC sImulator for Geoscientific Research[4]) which is implemented within the object-oriented framework MOOSE[5].
- The numerical model extends for 5 x 5 x 0.15 km and consists of a reservoir layer of 10m thickness.
- The well is located at the center of the model.
- The mesh consists of tetrahedral elements with a size that ranges from 0.5m around the well location to 250m at the boundaries.
- The simulation of injection and production cycles lasts 10 years.
- The porosity changes due to variations on the thermal (th), mechanical (mec) and hydraulic (hyd) components (comp) of the strain tensor[6]:

$$\phi = \beta + (\phi_0 - \beta) exp\left(c\left(1 - \exp\left(^{-comp}/_{c}\right)\right)\right)$$

- $comp = th + mec + hyd$, with $th = \alpha \Delta T$, $mec = -\frac{\Delta V}{V}$, $hyd = \frac{1-\beta}{K_{rock}} \Delta P$
- $c = \ln\left(\frac{\beta}{\beta - \phi_0}\right)$
- $\beta = Biot\ coefficient$

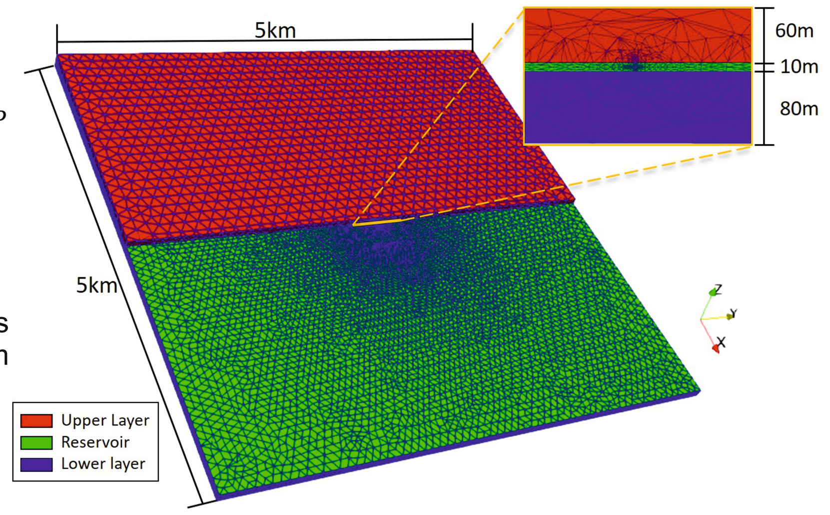

Figure 2. Numerical model layout. Its lateral extend prevents from boundary effects.

3 - Porosity and Velocity Changes

Methodology

- Simulation of injection/production cycles for 10 years
- Change of 3 parameters:
  - Biot Coefficient: 0.46 and 1
  - Initial porosity: 5, 15 and 20%
  - Flow rate: 2 and 10kg/s
- Use of Wyllie's equation[7] to obtain V_P: $\frac{1}{V_P} = \frac{\phi}{V_{P\,fluid}} + \frac{1-\phi}{V_{P\,rock}}$

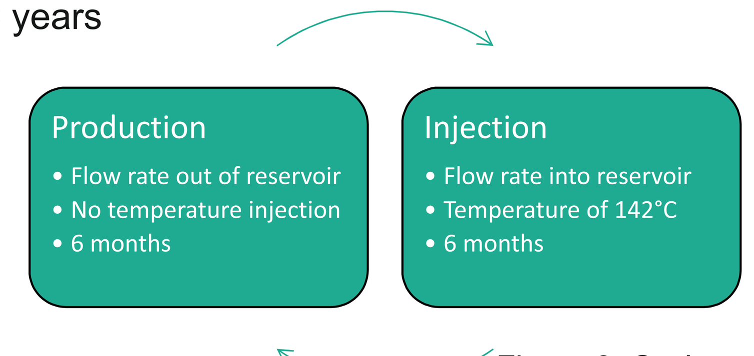

Figure 3. Cycle stages

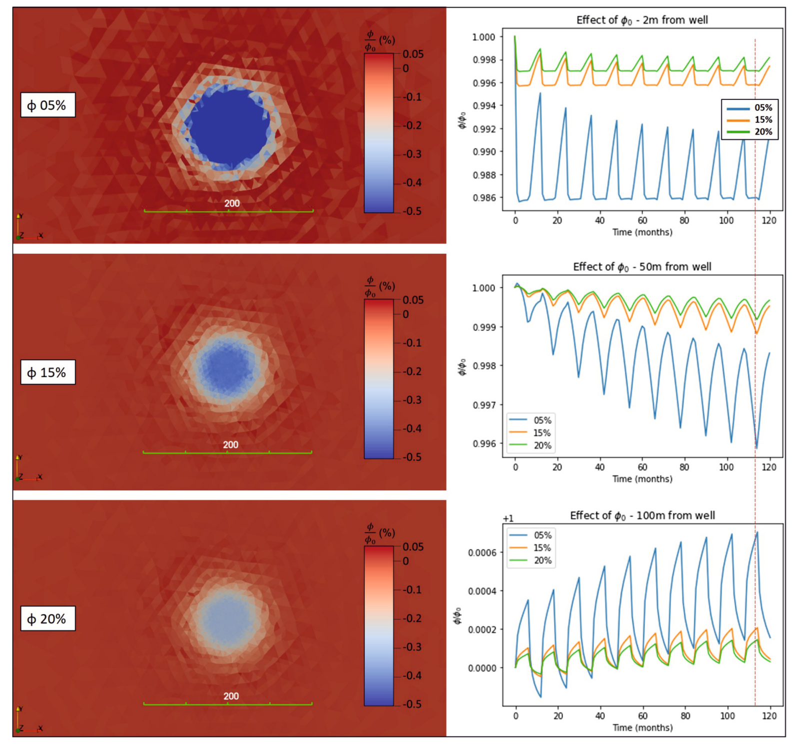

Figure 4. Porosity changes. Left: Effect of initial porosity on the final porosity after 114 months. Right: Change in porosity as a function of the distance to the well

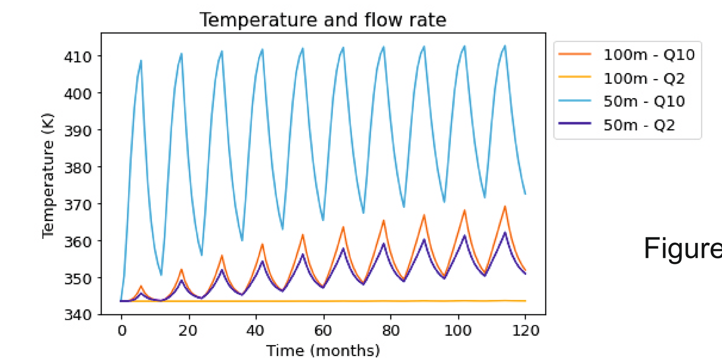

Figure 5. Effect of the flow rate on the temperature transport.

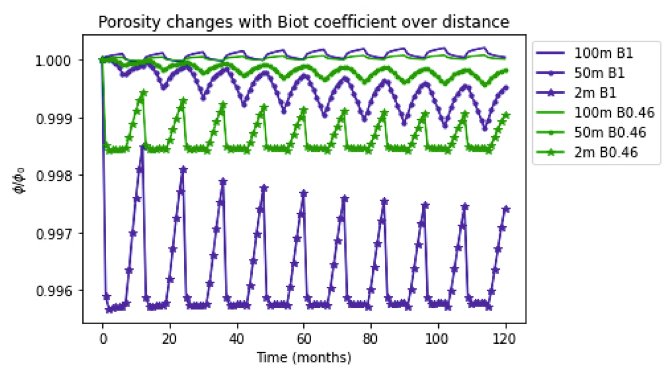

Figure 6. Effect of the Biot coefficient on the porosity.

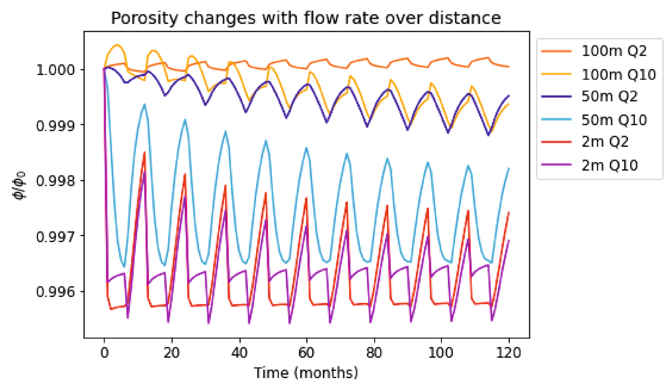

Figure 7. Effect of the flow rate on the porosity.

Results

- Biot Coefficient:
  - A value different from 1 permits the fluid component term to have an effect in the porosity equation.
  - A value of 0.46 reduces the porosity changes almost by half in every case.
- Initial porosity:
  - The lower the initial porosity is, the higher is its relative change
- Increase in flow rate:
  - Induces a larger change in porosity.
  - The effect of the temperature reaches further, hence, the porosity changes on a larger scale and further away from the source.
- The rock is permanently deformed. The porosity changes continuously, it doesn't return to its original value.
- Changes in porosity are very small. The maximum value is around 1.2% change.

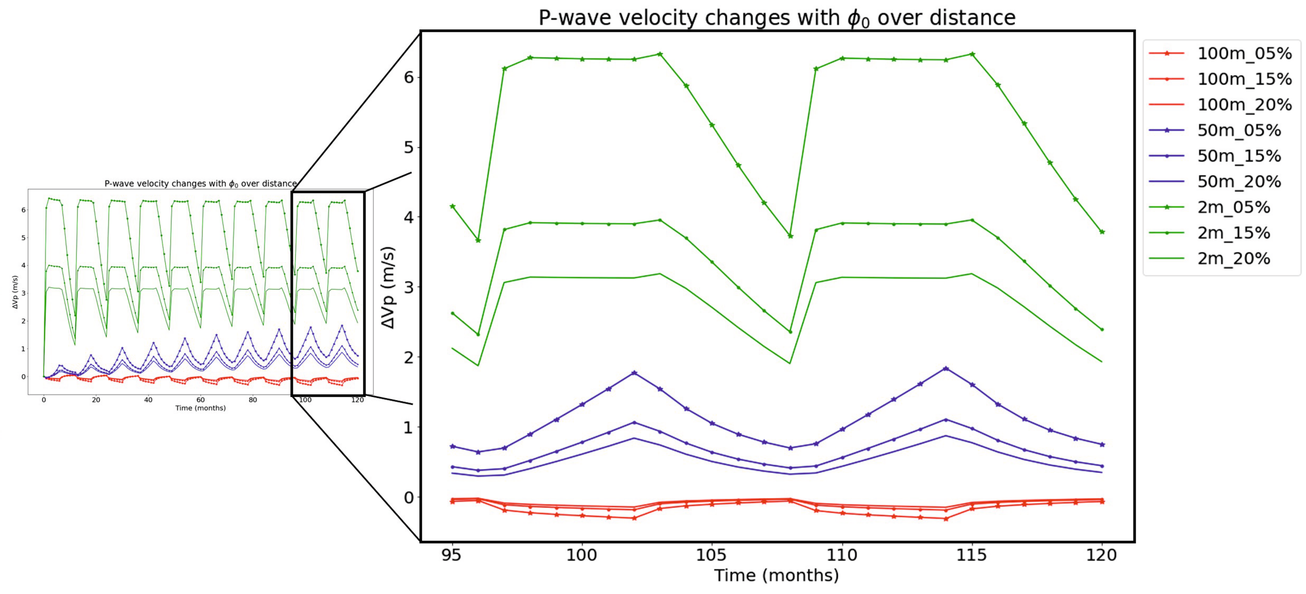

Figure 8. P-wave velocity for 2kg/s injection cycles. At 100m away (red) the changes are the smallest. For each distance (2m, 50m 100m), an initial porosity of 5% (stars) shows the highest change in velocity.

4 - Conclusions and Outlook

- Simulations assume pure water, with no added chemicals and no chemical reactions.
- Computing the seismic velocities is challenging as they are sensitive to several rock properties.
- The change in porosity associated to pressure and temperature variations is very small, reaching up to 1% after 10 years in the best-case scenario.
- Detecting seismic velocities changes at DeepStor with the current expected material and production parameters will require a very high-sensitive monitoring network.
- Other porosity-velocity models must be evaluated.

Acknowledgements

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References

1. Stricker K, Grimmer JC, Egert R, et al. The Potential of Depleted Oil Reservoirs for High-Temperature Storage Systems. Energies. 2020;13(24):6510. doi:10.3390/en13246510
2. Bremer J, Nitschke F, Bauer F, et al. VESTA - Very-High-Temperature Heat Aquifer Storage. Eur Geotherm Congr 2022 Proc. Published online October 17, 2022. https://europeangeothermalcongress.eu
3. Wesselink M, Liu W, Koornneef J, van den Broek M. Conceptual market potential framework of high temperature aquifer thermal energy storage - A case study in the Netherlands. Energy. 2018;147:477-489. doi:10.1016/j.energy.2018.01.072
4. Gholami Korzani M, Held S, Kohl T. Numerical based filtering concept for feasibility evaluation and reservoir performance enhancement of hydrothermal doublet systems. J Pet Sci Eng. 2020;190:106803. doi:10.1016/j.petrol.2019.106803
5. Permann CJ, Gaston DR, Andrš D, et al. MOOSE: Enabling massively parallel multiphysics simulation. SoftwareX. 2020;11:100430. doi:10.1016/j.softx.2020.100430
6. Chen Y, Zhou C, Jing L. Modeling coupled THM processes of geological porous media with multiphase flow: Theory and validation against laboratory and field scale experiments. Comput Geotech. 2009;36(8):1308-1329. doi:10.1016/j.compgeo.2009.06.001
7. Wyllie MRJ, Gregory AR, Gardner LW. ELASTIC WAVE VELOCITIES IN HETEROGENEOUS AND POROUS MEDIA. GEOPHYSICS. 1956;21(1):41-70. doi:10.1190/1.1438217