Modeling of Short-Term Stimulation and Long-Term Operation of EGS Reservoirs

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In short:

A central problem of "Enhanced Geothermal Systems", EGS, represents the understanding of processes associated to the forced injection of cold fluid in a fractured medium. The dynamic response of a geothermal reservoir is determined from time constants specific to individual processes. As such, the hydraulic pressure is most important for short-term reservoir variations and temperature for long-term variations.

The quantification of these processes is in the reservoir volume generally only accessible through numerical modeling. Pressure, temperature and stress can only be measured locally in a borehole, but the full 3D distribution of these fields is hidden. Typical modeling approaches are:

- Deterministic reservoir models with good control of all physical processes but problematic complex meshing and often simplified geometries
- Stochastic reservoir models having a refined representation of fractures/fault zones but neglecting often matrix interaction. They often include hybrid approach using interpolation schemes to map individual properties on another process

Herein, elaborated examples of these modeling are presented on stochastic (short-term hydraulic-mechanic behavior, H-M) and deterministic (long-term hydro-thermal-mechanic behavior, H-T-M).

These examples are calculated with the FRACTure and HEX-S simulators that are using an identical finite element kernel.

Coupling Schemes for EGS Reservoir models

Hydraulic — PRESSURE FIELD
- transient
- Darcy
- non-linear (fracture aperture, non-Darcian)
- ρ(T, P) buoyancy
- μ(T, P)

Thermal — TEMPERATURE FIELD
- transient
- diffusion
- advection
- λ(T, P), ρ(T, P)

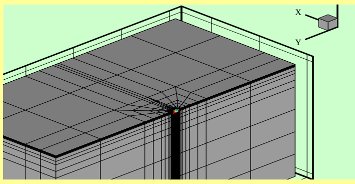
Matrix Elasticity — STRESS FIELD
- Steady state
- linear
- Poro-Elasticity
- Thermo-Elasticity

Fracture Mechanics — FRACTURE APERTURE
- Shearing
- Compliance

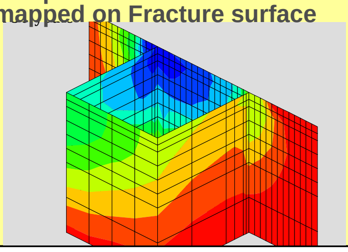
Interaction of H-T-M processes on pressure field

Deterministic Reservoir Model: FRACTure

Numerical Discretisation



Temperature field mapped on Fracture surface



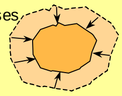
Elastic Matrix Mechanisms

Injection of cold fluid in a hot rock matrix

Thermo-elastic matrix stresses

$$S_{ii}^{T} = 3 \cdot K \cdot \beta_T \cdot \Delta T$$

with K Bulk modulus, β_T coeff. linear expansion

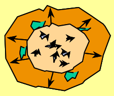


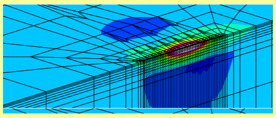
Injection of pressurised fluid in ambient matrix

Poro-elastic matrix stresses

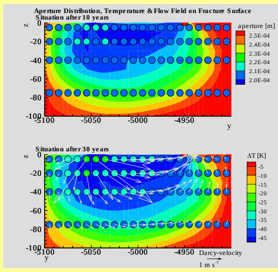
$$S_{ii}^{P} = \alpha_B \cdot \Delta P$$

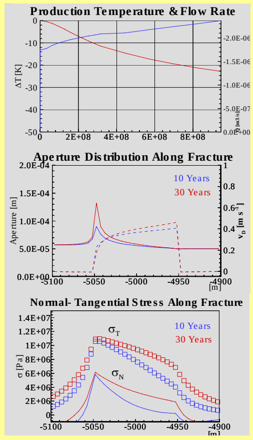
with α_B Biot coeff.





Dynamic Reservoir Behavior

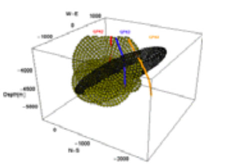




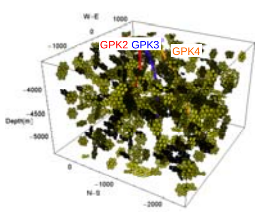
Mixed Deterministic-Stochastic Reservoir Model: HEX-S

Fracture model

Deterministic slip patches



Stochastic realization



Fracture Mechanisms

Penny-shaped cracks with individual slip patches

Coulomb Shear Criteria

$$\Delta\tau = \tau - \sigma_{n,eff} \cdot \tan(\Phi_{basic} + \Phi_{dil})$$

$$U = \Delta\tau / K_s ; \quad a_S = U \cdot \tan(\Phi_{dil})$$

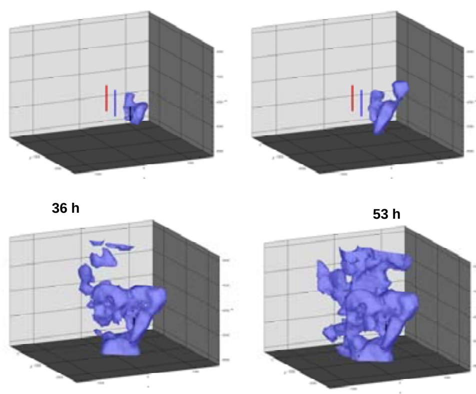
Compliance

$$a = \frac{a_0}{1 + 9 \cdot \sigma_{n,eff} / \sigma_{n,ref}}$$

Jacking Aperture: $\sigma_{n,eff} < 0$

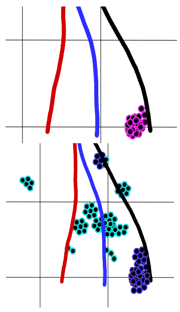
Dynamic Reservoir Behavior

2.7 h — 5 h — 36 h — 53 h



Iso-Surface = 0.0001 m

Shearing 10h and 1 day



CONCLUSION

The dynamic behavior of EGS systems is evident from numerous measurement. The role of numerical modeling is extends from quantifying subsurface processes to forecasting the varying impact

- Different modeling approaches have been used to determine the impact of physical processes
- An EGS reservoir behaves dynamic throughout its lifetime

Outlook

Complex inversion concepts can be used jointly with experiments to investigate subsurface

Modeling will be used to improve EGS strategies

Reference

- Kohl, T., Evans, K.F., Hopkirk, R.J., & Rybach, L., 1995, Coupled hydraulic thermal and mechanical considerations for the simulation of Hot Dry Rock reservoirs, Geothermics, 24(3), pp 333-343
- Kohl T., Mégel T., 2007, Predictive modeling of reservoir response to hydraulic stimulations at the European EGS site Soultz-Sous-Forêts, Int. J. of Rock Mechanics, In press