Using a THMC Simulator to Examine the Effects of Porosity Reduction in Geothermal Reservoirs

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EFRACK 3D

- EFRACK 3D is a fully coupled Thermo-Hydro-Mechanical and Chemical (Non-reactive flow), multi-GPU simulator.

- Yield function and the fluid pressure are shown with a resolution of 64x64x64.

- Conceptual model:
  - It is a rock cube under triaxial compression of 10 MPa and with an initial temperature of 120°C.
  - Maximum fluid injection pressure of 9.55 MPa and a temperature of 60°C.

- Results:
  - At the vicinity of the injection point localized events are popping and the evolution of the fracture network is shown in 3D.
  - We can visualize the massive failure of the domain mainly at the edges.
EFRACT3D
Motivation
Why Quartz?
The reactive flow model:
  - Approach
  - Conceptual model
  - Mathematical model
Outlooks
**EFRACK3D: THERMO-HYDRO-MECHANICAL-CHEMICAL (NON-REACTIVE FLOW) MULTI-GPU SIMULATOR**

| M → H | * Permeability increment when fracturing  
|       | * Mechanical over-pressurization  
|       | * Porosity dependent on volumetric strain |
| M → T  | * Shear heating |
| H → M  | * Effective stresses  
|        | * Gassmann equations |
| H → T  | * Darcy velocity |
| H → C  | * Darcy velocity |
| T → M  | * Thermal stresses |
| T → H  | * Thermal pressurization |
| C → T  | * Heat capacity dependent on P,T,C |
| C → H  | * Fluid density dependent on P,T,C  
|        | * Fluid compressibility dependent on P,T,C  
|        | * Fluid expansion coefficient dependent on P,T,C  
|        | * Fluid viscosity dependent on P,T,C |
Porosity changes due to quartz precipitation and dissolution affects the general response of the host rock.

Scaling affects the machinery and hinders the productivity of the geothermal energy project.

Permeability decrease due to quartz/calcite precipitation has been proposed to affect the temporal decay of aftershocks following large earthquakes.

Sustainable reservoir development requires a combined analysis of the thermo-hydro-mechanical and chemical processes.
WHY QUARTZ?

- Energy production requires deep geothermal reservoir exploration.
- Geology of deep geothermal reservoirs in Switzerland is mostly Granite.
- Aftershock theory occurs at larger depths.

(Stober & Bucher 2013)
The reactive flow model assumes a coupling between heat and fluid mass transport.

\[ H_4SiO_4(aq) = SiO_2(s) + 2H_2O(l) \]
The combination of chemical and mechanical porosity changes is not a trivial problem.

Proposed solution

- The term that describes the change in porosity and permeability due to chemical processes should be “integrable” with EFRACK 3D.

- To describe the change in porosity due to chemical reactions, we look at the change in diameter of the grain due to quartz precipitation and dissolution.

- Combine the change in porosity due to mechanics with the change in diameter due to chemical processes.
MATHEMATICAL MODEL

Required Input
- Initial Conditions
- Boundary conditions
- Rock and fluid properties

Reactive flow model
- System of equations

Desired Output
- Solute transport of the mineral
- New Porosity
- New Permeability
- New contact surface area $A$

$t = t + dt$
The Center for Hydrogeology and Geothermics (CHYN)

MATHEMATICAL MODEL

\[
\frac{\partial C'}{\partial t} = D_m \nabla^2 C' + \nabla \cdot \mathbf{v} C' - \frac{K}{\phi} C'
\]

\[
C' = c - c_{eq}
\]

Diffusion coefficient within the reservoir matrix

\[
log c_{eq} = -\left(\frac{1107}{T}\right) - 0.025
\]

\[
K = \frac{A}{M} k_-
\]

\[
log k_- = -0.707 - \frac{2589}{T}
\]
Mass conservation of silica is given by the Partial Differential Equation:

\[
\frac{\partial (\phi C')}{\partial t} = -\nabla (uC') - \phi K(C')
\]

Kozeny-Carman Equation for permeability:

\[
k = cd^2 = \left(\frac{\phi^3}{180(1 - \phi)^2}\right) d^2
\]
- Estimate **porosity** and **permeability** evolution in the reservoir rock due to THMC processes.
- Visualize possible **localized cracking** due to pore pressure development and better understand fluid driven aftershocks.
- Add some variety by introducing a **multi-GPU technology**.

**Reactive Flow Model**

EFRACK3D

Fully coupled THMC 3D model
Thank you for your attention.

Questions?

Visit poster WP 1.2-1
THANK YOU FOR YOUR ATTENTION

References: