Full Coupling of Flow, Thermal and Mechanical Effects in COMSOL Multiphysics® for Simulation of Enhanced Geothermal Reservoirs

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Abstract

Introduction
The effective modeling of enhanced geothermal systems (EGS) requires the coupling of geomechanics, fluid flow and thermal processes. An understanding of the complete system with these coupled processes is vital, not just for reservoir stimulation targeted at enhancing reservoir performance, but also for the understanding, prediction and prevention of induced seismicity. The injection of cold water leads to alterations in in-situ stresses and strains in the reservoir, which can result in fracture initiation, opening, and activation of faults and joints leading to induced seismicity. Indeed, many commercial EGS sites (like Soultz and Geysers) have shown significant seismicity upon injection and production. However, thermal effects tend to be neglected in models for reservoir stimulation, although there is strong evidence that they can play an important role [1].

Use of COMSOL Multiphysics®
We developed a model for EGS in COMSOL Multiphysics® with a full coupling of flow, heat transfer and mechanics (Figure 1), using three built-in Interfaces: Darcy's Law, Solid Mechanics and Heat Transfer in Porous Media. Poroelasticity describes the influence of pore pressure on stress and strain. In turn, the changes in stress and strain change permeability and porosity, which influences fluid flow. Heat-convecting fluid flow (cold water injected in hot rock) influences the temperature distribution, which in turn influences the fluid viscosity (and density), altering again the flow itself. The temperature change will also create thermal stresses, effecting the geomechanics. In the geomechanical model we used Mohr-Coulomb failure and associated shear dilation for fault reactivation. The model has been verified and benchmarked against existing models and is currently being related to actual EGS field operations in France (Soultz) and in Iceland.

We have especially investigated the role of temperature changes on the stimulation and production stage of geothermal operations. The first step was to estimate temperature profiles around the injection well and the thermal stress effects (Figure 2). In the next step we compared a model that was fully coupled to a model where thermal effects were neglected, and its consequences for the prediction of possible induced seismicity. Our setup allowed us to easily evaluate different injection scenarios and different assumptions for underlying physical

processes. Preliminary results show that neglecting thermal effects is not justified, since they do change the physics of the system. Permeability behaves differently (before enhancement it decreases, Figure 3), and shear strain changes the sign indicating role of cooling processes (Figure 4).

The induced seismicity is directly proportional to the seismic moment which depends on failing area, shear displacement and shear modulus, and can be calculated using COMSOL Multiphysics®. This way, geomechanical coupled modeling can be related to seismic hazard assessment which leads to understanding, predicting and preventing undesired seismicity.

Reference

Gunnarsson, G., Mastering reinjection in the Hellisheidi Field, SW-Iceland: A story of successes and failures. PROCEEDINGS, 36-th Workshop on Geothermal Reservoir Engineering Stanford Univ, Stanford, California, January 31-february 2, 2011. SGP-TR-191

Figures used in the abstract

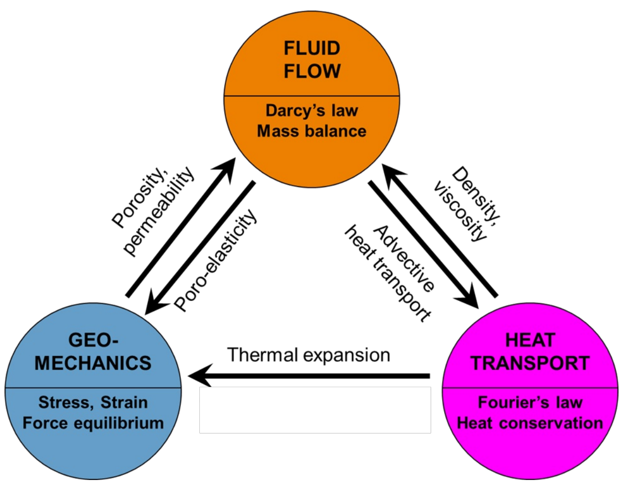

Figure 1: Coupling of Geomechanics, fluid flow and heat transport in EGS.

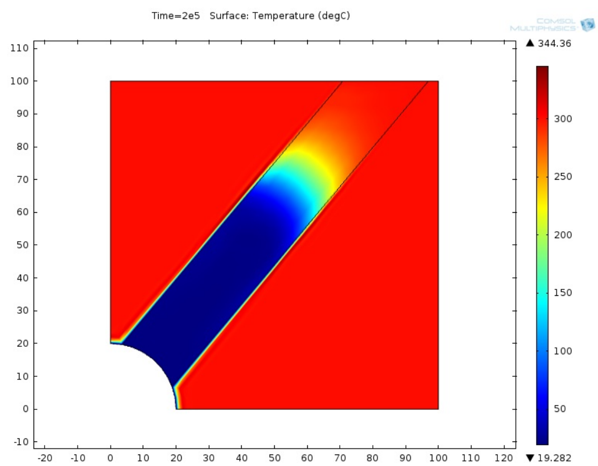

Figure 2: 2D Temperature distribution after 55 hours of injection. Matrix Temperature is 300 C and Temperature of injected fluid is 20 C

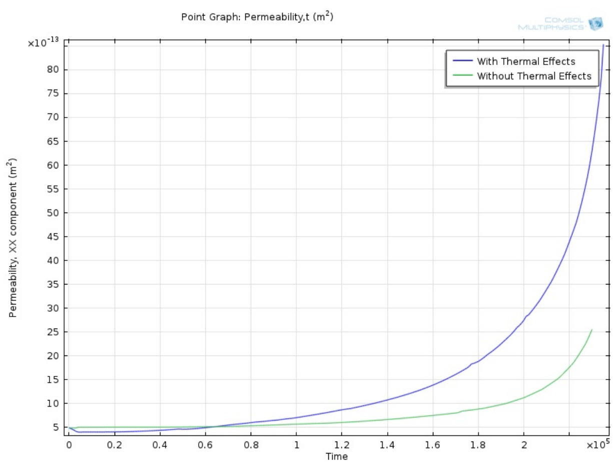

Figure 3: Evolution of permeability in fracture zone for fully coupled system and system where temperature effects are neglected. Initial fracture permeability is 500 mD.

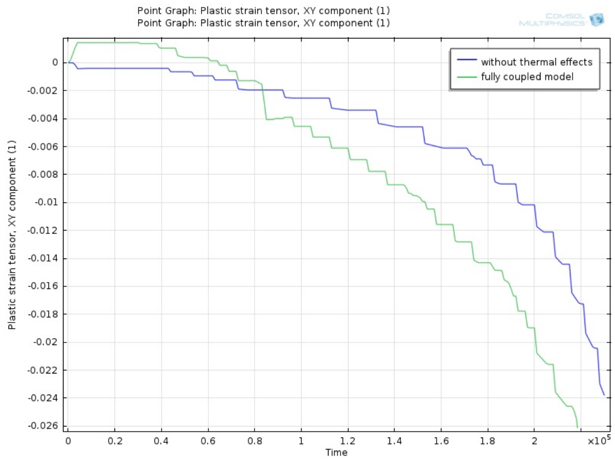

Figure 4: Comparison of shear strain for fully coupled system to system where thermal effects are neglected.