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THM modelling of hydrothermal circulation in deep geothermal reservoirs

Vincent Magnenet (1), Christophe Fond (1), Jean Schmittbuhl (2), and Albert Genter (3)

(1) ICUBE, UMR CNRS 7357, 72, Route du Rhin CS 315, F-67411 ILLKIRCH Cedex, (2) EOST, CNRS/UdS, 5 rue René Descartes, F-67084 STRASBOURG Cedex, (3) GEIE EMC, Route de Soultz, BP 40038, F-67250 KUTZENHAUSEN

Numerous models have been developped for describing deep geothermal reservoirs. Using the opensource finite element software ASTER developped by EDF R&D, we carried out 2D simulations of the hydrothermal circulation in the deep geothermal reservoir of Soultz-sous-Forêts. The model is based on the effective description of Thermo-Hydro-Mechanical (THM) coupling at large scale. Such a model has a fourfold interest: a) the physical integration of laboratory measurements (rock physics), well logging, well head parameters, geological description, and geophysics field measurements; b) the construction of a direct model mechanically based for geophysical inversion: fluid flow, fluid pressure, temperature profile, seismicity monitoring, deformation of the ground surface (INSAR/GPS) related to reservoir modification, gravity or electromagnetic geophysical measurements; c) the sensitivity analysis of the parameters involved in the hydrothermal circulation and identification of the dominant ones; d) the development of a decision tool for drilling planning, stimulation and exploitation.

In our model, we introduced extended Thermo-Hydro-Mechanical coupling including not only poro-elastic behavior but also the sensitivity of the fluid density, viscosity, and heat capacity to temperature and pressure. The behavior of solid rock grains is assumed to be thermo-elastic and linear. Hydraulic and thermal phenomena are governed by Darcy and Fourier laws respectively, and most rock properties (like the specific heat at constant stress c_s^σ(T), or the thermal conductivity λ(T,ϕ)) are assumed to depend on the temperature T and/or porosity ϕ. The radioactivity of the rocks is taken into account through a heat source term appearing in the balance equation of enthalpy. To characterize as precisely as possible the convective movement of water and the associated heat flow, water properties (specific mass ρ_w(T,p_w), specific enthalpy h_m^w(T,p_w) dynamic viscosity μ_w(T), thermal dilation α_w(T), and specific heat c_w^p(T)) are assumed to depend on pressure and/or temperature. The entire set of material properties is extracted from references dealing with investigations at Soultz-sous-Forêts when existing.

The reservoir is described at large scale (about 10 km in width and 5 km in height) and it is assumed that the medium is homogenous, porous, and saturated with a single-phase fluid (considering homogenized effective porous and/or fractured layers, neglecting the details of the fracture networks). We performed a feasability study and show that a large scale convection regime is possible using realistic parameters. The size of the convection cell (2.8km) are shown to be compatible with field observations.