Flexible parallel implicit modelling of coupled thermal–hydraulic–mechanical processes in fractured rocks

Antoine B. Jacquey[a], Mauro Cacace[a], Guido Blöcher[a], Ernst Huenges[a], Magdalena Scheck-Wenderoth[a,b]

a. GFZ Potsdam, German Research Centre for Geosciences, Potsdam, Germany.

b. RWTH Aachen University, Aachen, Germany.

antoine.jacquey@gfz-potsdam.de

Keywords: THM coupled processes, FEM modelling, fractured reservoirs

ABSTRACT

In this study, we present an overview of recent and ongoing efforts to develop a robust, yet efficient multi-physics and multi-component porous media modelling framework applicable to reservoir applications. We rely on numerical approaches to characterize interactions among thermal, hydraulic, mechanical, and ultimately chemical processes across relevant time and length scales of interest to applications including extraction of geothermal heat and fossil energy as well as storage of water, carbon dioxide, nuclear waste and thermal energy.

Based on the MOOSE (Multiphysics Object Oriented Simulation Environment, Gaston et al., 2009), we have developed a numerical simulator called GOLEM (Cacace and Jacquey, 2017, Jacquey and Cacace, 2017) to solve, in a tightly implicit manner the governing equations for groundwater flow, heat and non-reactive mass transport by including poro- and thermo-elastic as well as inelastic (viscous and plastic) deformation processes and their non-linear feedbacks. Equations of State (EOS) for relevant fluid properties (density and viscosity) as based on the latest IAPWS (International Association for the Properties of Water and Steam, 2008) release as well as structure-property (poro-perm) relations are also considered to close the systems of equations. The simulator is interfaced to an in-house developed geometric/meshing software (MeshIt, Cacace and Blöcher, 2015) which enables the integration of details of the three-dimensional geological architecture of real case reservoirs into a consistent Finite Element/Volume representation. Interface FEM elements are used to represent all components, that is, 3D reservoirs units, 2D faults and fractures, 1D boreholes and 0D localized sources. The resulting equations are homogenized relying on the concept of effective (hydro- mechanical) aperture for the lower dimensional elements (i.e. fractures and wells) which therefore ensure local mass and energy conservations as well as continuity of the problem variables (pore pressure, temperature and matrix displacements) across all element interfaces (Jacquey et al., 2017).

The flexibility of the software for the (up)scale of reservoirs is discussed by presenting results obtained for the Groß Schönebeck geothermal facility, Germany (see Figure 1). In a first study case, THM simulations of the reservoir behaviour during injection and production are discussed. The aim of this study is to quantify how existing fault zones and induced fractures affect the overall productivity and long-term sustainability of the system. The second study case investigates the impacts of a hydraulic stimulation treatment and production of geothermal fluid on the stability of the fault systems present at depth within the reservoir. Finally, we will present the impacts of a stimulation treatment onto the far field hydraulic of the reservoir by means of poroelastic coupling.

The second part opens a discussion on ongoing studies, in which we aim at improving the understanding of the processes responsible for micro-cracking and strain localisation. The model formulation will be briefly presented. It considers a damage rheology to account for the organization of micro defects and appropriate elasto-viscoplastic constitutive equations to simulate the hardening and softening of the elastic stiffness of the porous rock. Localization of the deformation is modelled by introducing a viscoplastic component, non-linearly dependent on the rate and amount of damage accumulated throughout the loading history of the rock. Hydro-mechanical coupling is also integrated via appropriate porosity and permeability dependencies as constrained by laboratory triaxial tests under controlled p-T conditions combined with microstructural analysis of the post-mortem samples. We will end the contribution by addressing planned activities to extent the current model formulation to non-isothermal loading conditions.

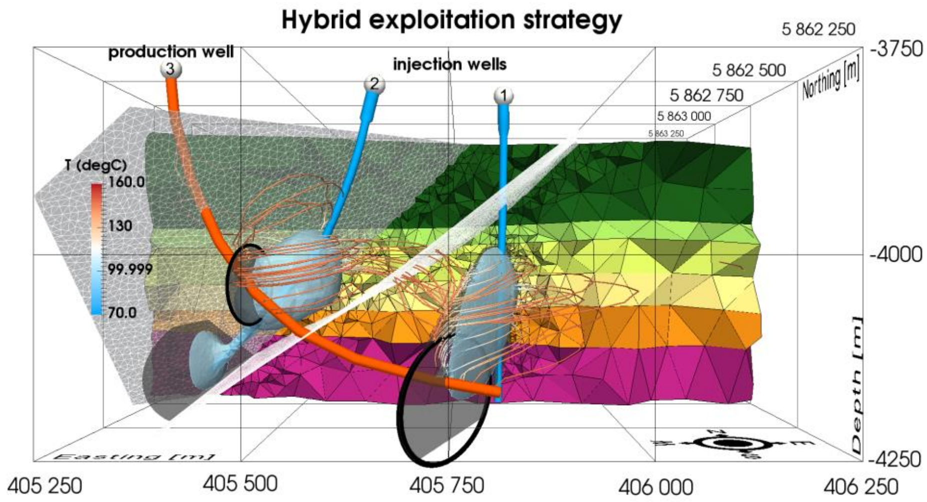

Figure 1: Example of results obtained from a simulation of the Groß Schönebeck geothermal reservoirs illustrating the evolution of the breakthrough temperature together with flowlines after approximately 30 years.

REFERENCES

Gaston, D., Newman, C., Hansen, G. and Lebrun-Grandié, D., 2009. MOOSE: A parallel computational framework for coupled systems of nonlinear equations. Nuclear Engineering and Design, 239(10):1768-1778. https://doi.org/10.1016/j.nucengdes.2009.05.021.

Cacace, M. and Jacquey, A. B., 2017. Flexible parallel implicit modelling of coupled thermal–hydraulic–mechanical processes in fractured rocks. Solid Earth, 8:921-941, https://doi.org/10.5194/se-8-921-2017.

Jacquey, A. B. and Cacace, M., 2017. GOLEM, a MOOSE-based application v1.0. Zenodo. http://doi.org/10.5281/zenodo.999401.

IAPWS: Release on the IAPWS Formulation 2008 for the Thermo- dynamic Properties of Seawater, Tech. rep., IAPWS, available at: http://www.iapws.org.

Cacace, M. and Blöcher, G., 2015. MeshIt – a software for three dimensional volumetric meshing of complex faulted reservoirs. Environ. Earth Sci., 74:5191–5209, https://doi.org/10.1007/s12665- 015-4537-x.

Jacquey, A. B., Cacace, M. and Blöcher, G., 2017. Modelling coupled fluid flow and heat transfer in fractured reservoirs: description of a 3D benchmark numerical case. Energy Procedia, 125: 612-621. https://doi.org/10.1016/j.egypro.2017.08.227.