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Numerical Simulation of Fractured Matrix Systems for Geothermal Applications

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In solid rock aquifers low matrix permeability is often accompanied with fractures and faults of different scales. Therefore, numerical modelling of such coupled systems is very complex. Density and temperature dependent flow of groundwater and mass transport processes are coupled in fractured systems. These processes have to be modelled along discrete surfaces joined to the common matrix representation. This leads to high demands on the quality of finite element mesh generation. This paper presents a strategy to calculate three dimensional finite element meshes, which allows the modeling of density and temperature dependent groundwater flow in a coupled matrix fracture aquifer system for geothermal applications. The local effects on the distribution of pore pressure and water contents cannot be represented by a homogenization of the fractures to an additional porous continuum (double porosity). For example, it is not possible to approximate the tailing effects and the sharp temperature front using by double porosity models. Often three-dimensional fracture matrix systems are reduced to a two-dimensional model by using vertical cross-sections. This two-dimensional description of flow processes in fractured layers neglects the flow paths which arise from connections between intersected fractures in space. Therefore, the model it will always underestimate the true conductivity of these layers. For that reason, a generator for stochastic three-dimensional fractures and a mesh generator that links these fractures to the rock matrix (SPRING, 2010) which is able to calculate the coupled system in three dimensions were developed.

For modeling the high coupled Heat Transport- and Groundwaterflowprozesses the finite element method based software package SPRING was applied. The non-linearities due to the density- and temperature dependent flow, the coupled modeling of the saturated-unsaturated flow and the nonlinear leakage are taken into account.

Examples for such an application can be found in the Munich Malm and a regional model comprises a total area of around 4,000 km², with the Finite Element mesh consists of around 3 Mio. Elements. By changing scenarios (for different values of exfiltration rate), different situations are obtained. In geothermal applications, high extraction rates can lead to an exhaustion of the source within a short period of operation. Therefore low rates of extraction and reinjection are recommended for a sustainable and promising utilization of the thermal reservoir at this specific location.

In solid rock porous rock mass is combined with fractures and faults. The interaction between fluid flow and the deformation in poroelastic fractured media is described in a numerical model. Deformations of rock caused by loadings or changes of the hydraulic boundary conditions influence the pore water pressure, which superimposes the stress in the grain structure. The coupled processes are of strong influence on the transient flow. The saturation of pore water is another important aspect, which is considered in the mathematical model.

The system of coupled, highly non linear, non symmetrical, partial differential equations is discretized with finite elements in space and with finite differences in time. The macro-fractures, which strongly influence the flow, are generated stochastically and modeled with discrete joint elements.