Heat Transfer in Borehole Heat Exchangers From Laminar to Turbulent Conditions

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Abstract

Borehole heat exchangers (BHE) in connection with heat pumps and floor heating in many countries are becoming an alternative to conventional heating or cooling systems using fossil resources. They are one building block of the suite of alternative low-carbon, sustainable and renewable energy sources. Modeling is a convenient tool in order to understand and optimize the heat transfer between the technical system, consisting of borehole, pipes and grout, and the surrounding ground, which is crucial for the performance of the BHE. We describe how a 1D model component for flow and heat transport in the technical part can be coupled with a 2D or 3D component for the ground.

The concept for the implementation of the model follows the procedures described by Al-Kouri (2011). For verification of the chosen approach a first test model was set up for a benchmark specified in a FEFLOW white paper (FEFLOW 2014). As in a thermal response test heated water enters a co-axial BHE. In the test the steady state is examined within the grout under a constant temperature boundary condition at the borehole walls. Figure 1 depicts the temperature profiles in the up- and downflowing legs of the BHE as well as at the interface to the grout. The check of the heat flux balance along the borehole, depicted in Figure 2, shows the excellent performance of the implementation.

Using the before described approach a second model is presented that simulates the change of temperature during operation of a geothermal plant, which is planned at a site in Northern Germany. The geology is dominated by a sub-surface salt formation with favourable conditions for geothermal production. Figures 3 and 4 show the temperature distribution in the vicinity of the borehole after 5 and 30 a of constant operation.

Using a COMSOL Multiphysics® model, concept is developed that enables the simulation of coupled hydraulic and thermal processes, which are relevant for systems of geothermal energy utilization. The concept can be applied for 1D, 2D and 3D models in cartesian or axisymmetric coordinates, for steady-state as well as for transient problems. Convective processes resulting from groundwater or seepage flow can be included (not shown here).

Geological layers, complex geometries, inhomogeneities, anisotropies of the porous medium can be accounted for. It is possible to use the same concept for heat exchangers of different designs (U-turn, double U-turn). For smooth pipe walls thermal conductances are derived for

laminar, transitory and turbulent flow conditions. For rough pipes these should be altered accordingly. Of course the transient response of the system due to varying pumping regimes can be simulated. It is possible to take different conditions at the boundaries into account. For shallow boreholes changing conditions, i.e. of temperatures and/or fluxes, at the ground surface are important. Such influences can be examined using the presented model approach.

Reference

Al-Khouri R., Computational Modeling of Shallow Geothermal Systems (Multiphysics Modeling), CRC Press, 2011

FEFLOW, DHI-WASY Software, Finite Element Subsurface Flow & Transport Simulation System, White Papers, Vol 5, http://www.feflow.com/uploads/media, 2014/white_papers_vol5_01.pdf2014

Figures used in the abstract

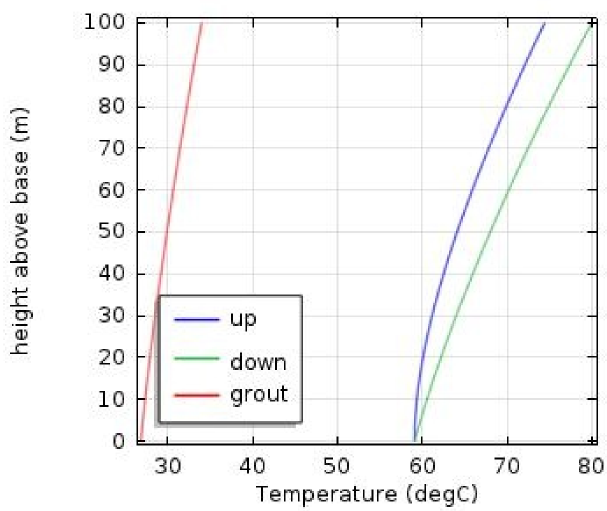

Figure 1: Temperature profiles in pipes and grout interface for test model

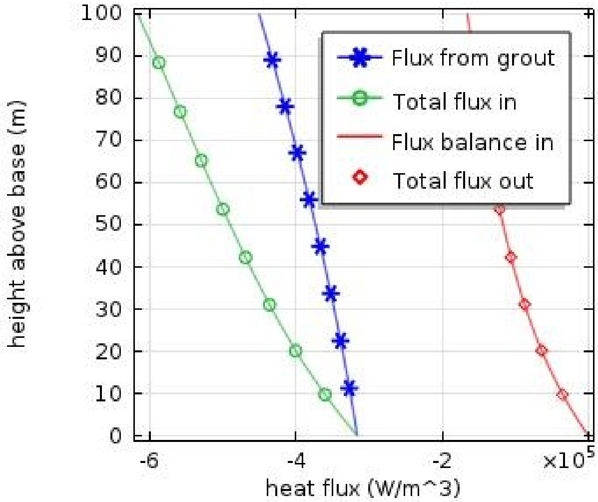

Figure 2: Heat flux check for test model

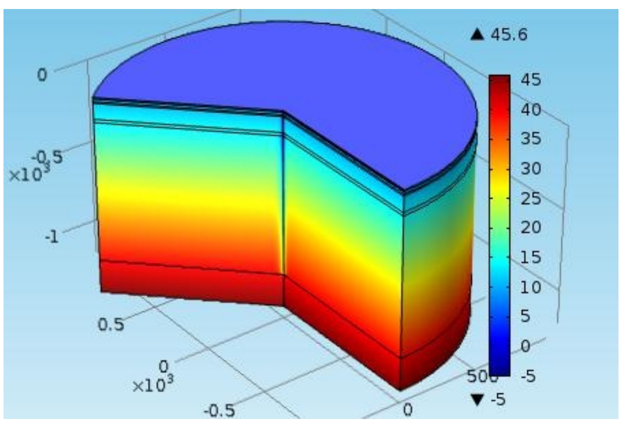

Figure 3: Temperature distribution after 5 a of operation

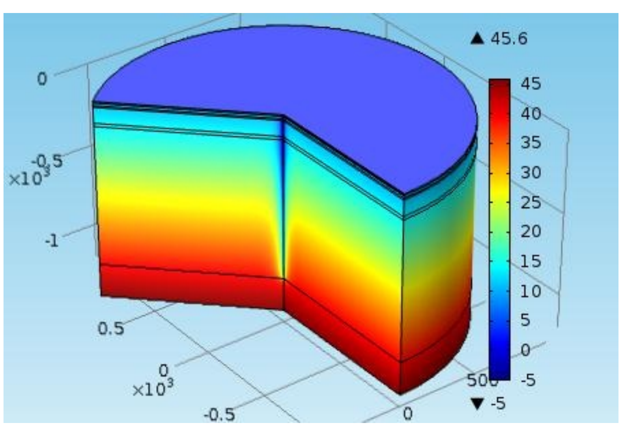

Figure 4: Temperature distribution after 30 a of operation