Heat Transfer in Borehole Heat Exchangers from Laminar to Turbulent Conditions

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

Ekkehard Holzbecher, Hannes Räuschel

Georg-August Univ. Göttingen, Goldschmidtstr. 3, 37077 Göttingen, Germany.

Introduction: 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.
Here the coaxial type is used, for which a cross-sectional view through the borehole is depicted in Figure 1.

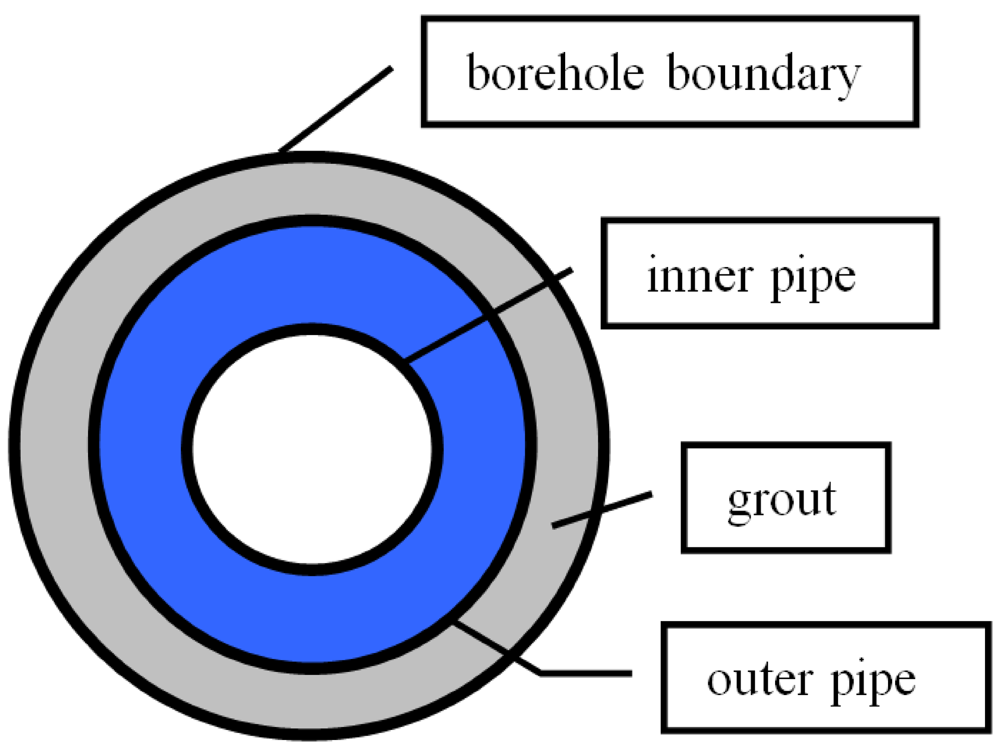

Figure 1. Sketch of cross-section through a co-axial heat exchanger

Components and Couplings: The BHE itself is modelled by 1D models directed along the borehole, one for downflow and one for upflow. The coupled 1D models are can be embedded in a 2D vertical cross-section or 3D model of the surrounding porous medium. A fluid flows through the inner pipe and the annular cross-section.
In all components we utilize heat transfer modes. For downflow and upflow we use heat transfer in fluids, for the ground heat transfer in porous media. The components are coupled in various ways by extrusions, which are sketched in Figure 2. Temperature differences are used to calculate source/sink-terms j and boundary fluxes j_s. For conductances we adopted the formulae from FEFLOW (2014), which are well established for smooth pipe boundaries.

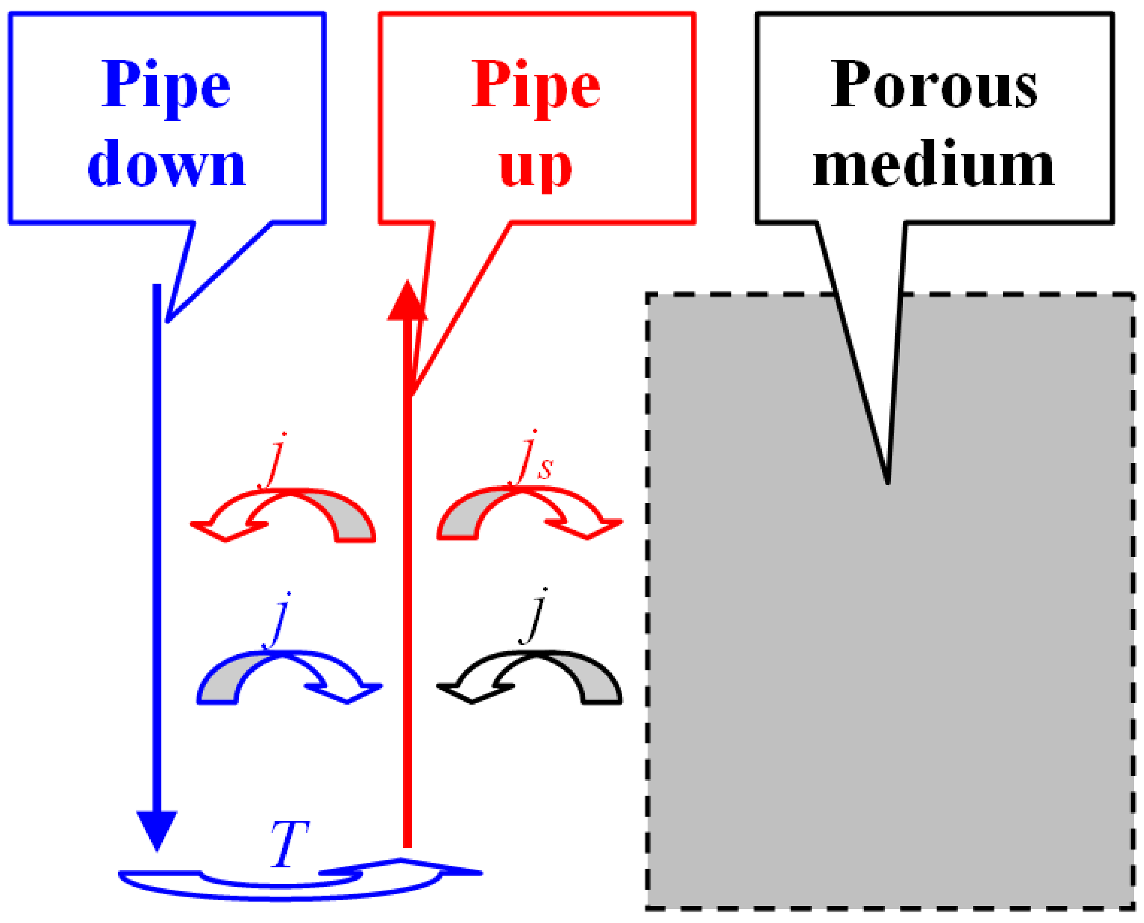

Figure 2. Sketch of components and extrusions

Application: For the location Hambühren salt dominates the geological profile: the overlying cap-layer has a thickness of 130 m.
Figure 3 shows the cooling radius caused by the BHE after 30 a, while Figure 4 shows the temperature profiles of downflow and upflow pipes.

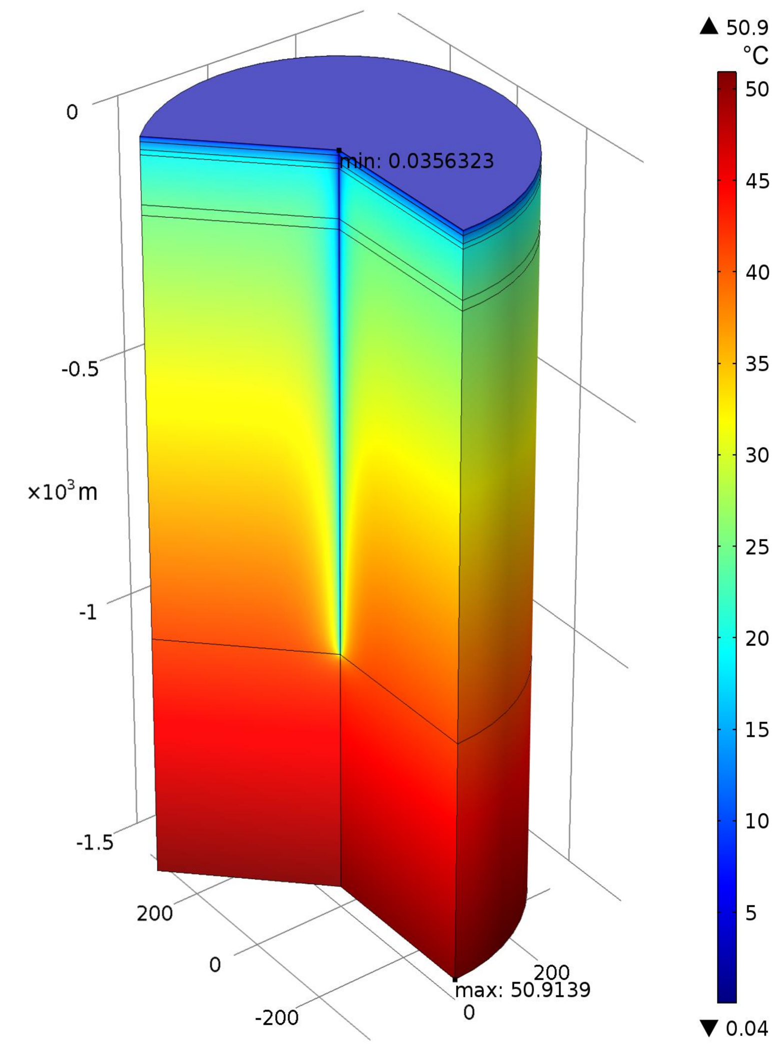

Figure 3. Temperature [°C] field at planned installation in Hambühren, after 30 a

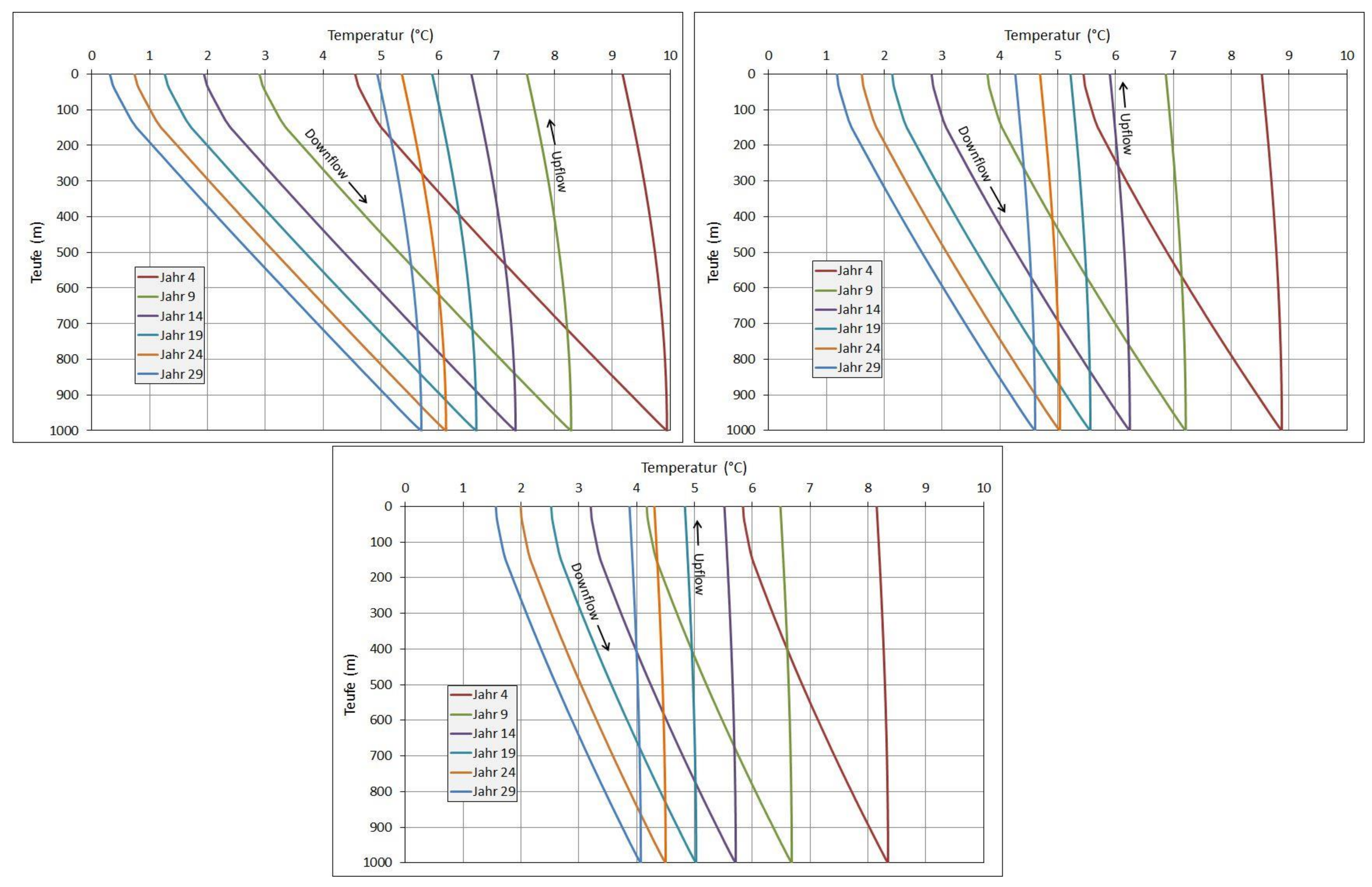

Figure 4. Temperature [°C] profiles in downflow and upflow pipes; in dependence of operation time (Jahr=year); three subfigures for different flow rates (4, 6, 8 l/s); for planned geothermal facility at Hambühren (Germany)

Conclusions: Using COMSOL Multiphysics® a model concept is developed that enables the simulation of coupled heat transfer in pipes and surrounding porous medium. Concerning the conductances we distinguish between laminar, turbulent and transitory regimes, valid for pipes with smooth walls.

Reference:

DHI-WASY Software, Finite Element Subsurface Flow & Transport Simulation System, White Papers, Volume 5, 108p (2014)

Acknowledgements:
The authors appreciate the support of 'Niedersächsisches Ministerium für Wissenschaft und Kultur' and 'Baker Hughes' within the GeBo G3 and G7 projects. Thanks for cooperative support concerning the application to GeoDienste GmbH (Hannover, Germany).

Excerpt from the Proceedings of the 2014 COMSOL Conference in Cambridge