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LIAG Leibniz Institute for Applied Geophysics

Thermo-hydraulic modelling and simulation of BHEs for an optimized shallow geothermal energy utilization in urban areas in Germany

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Introduction

Ground coupled heat pumps are widely recognized as exceedingly energy efficient heating and cooling arrangements for a broad range of building applications. Properly capturing and implementing the geological settings as well as the thermal and hydraulic conditions at the local- and regional-scale of the first 400 m depth below the Earth surface remains a challenging task for geoscientists. We illustrate in this work the current modelling setup and numerical efforts taken to simulate a variety of multiple borehole heat exchangers (closed loops) and shallow geothermal wells (open loops) in different geological settings typical of the first 400 m depth below the Earth surface in Germany.

Shallow geothermal utilization concepts

The performance and thermal productivity of borehole heat exchangers (BHEs) for shallow geothermal utilization is not only a function of the material properties but also of their topological form and construction. Nowadays, most typically implemented configuration consists of two parallel arranged U-shaped pipes which are embedded in a high-conductive thermally-enhanced grout filling out the borehole. An alternative design is a pipe inside of another pipe, with heat carrier fluid flowing downwards inside the inner pipe and upwards in the space between the pipes or the other way around (coaxial design).

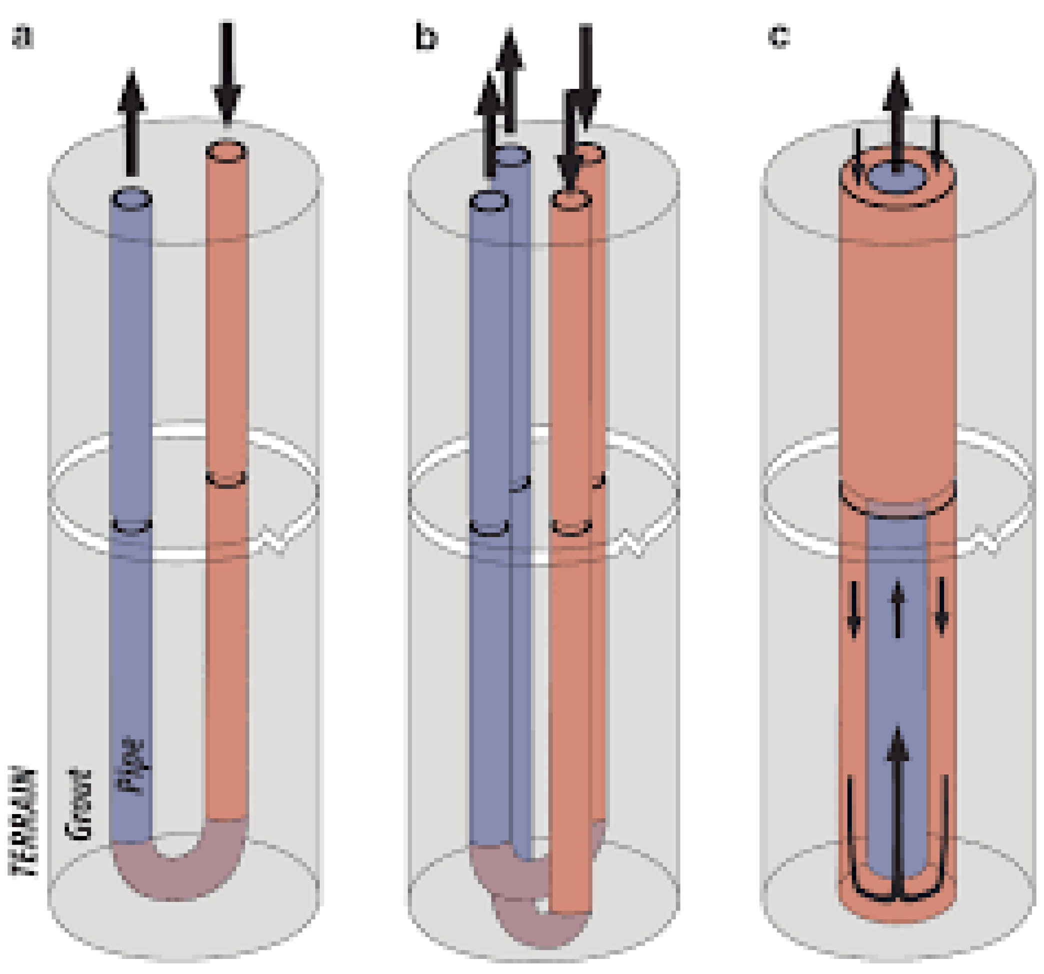

Fig. 1: Shallow geothermal installations as closed loops in which a heat carrier fluid is recirculated (after García Gil et al. 2022). (a) Single U-tube, (b) double U-tube, and (c) annular coaxial exchangers.

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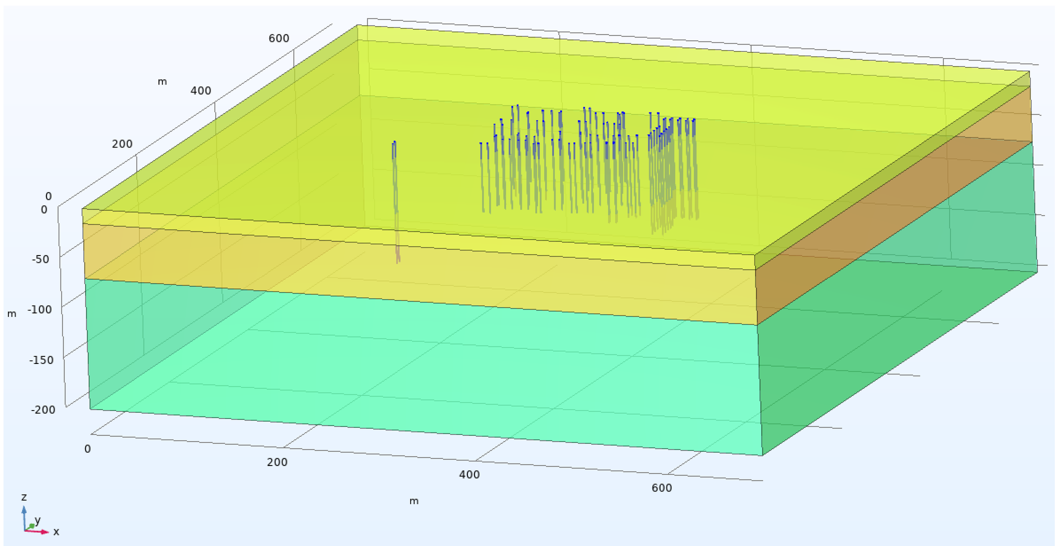

Fig. 2: Model setup consisting of three layers, containing a large field of 88 BHEs of small thermal power <30 kW and different depths for heating single family houses. Each BHE is composed of a double U-tube arrangement. They are surrounded by thermally-enhanced cement-bentonite. They are embedded in porous media.

Model setup and governing equations

A real case of installed BHEs has been implemented, considering real positions and dimensions of the BHEs as well as the local geology and related material parameters. COMSOL Multiphysics has been used to setup the model. Typical operational schemes have also been examined. The initial temperature distribution in the soil and subsoil is expressed as a harmonic vibration:

$$T(z,t) = T_0 + G \cdot z + A \cdot e^{-z \cdot \sqrt{\frac{\pi}{a \cdot t_p}}} \cdot$$
$$\cdot \cos\left(z \cdot \sqrt{\frac{\pi}{a \cdot t_p}} - 2\pi \frac{t}{p_p}\right).$$

The heat transfer in the BHEs is expresed as follows:

$$A\rho c_p \frac{\partial T}{\partial t} + A\rho c_p \mathbf{u} \cdot \nabla T = \nabla \cdot A\lambda_f \nabla T +$$
$$+ f_D \frac{\rho A}{4 r_i} |\mathbf{u}|^3 + Q.$$

The heat exchange between the working fluid and the grout material reads as:

$$\mathbf{n} \cdot (\lambda \nabla T) = \lambda_{res} \frac{T_{int} - T_{ext}}{d_W}$$

The heat transfer in porous media is given by;

$$\left(\lambda c_p\right)_{eq} \frac{\partial T}{\partial t} + \left(\lambda c_p\right)_f \mathbf{u} \cdot \nabla T =$$
$$= \nabla \cdot (\lambda_{eq} \nabla T) + Q.$$

The velocity field $\mathbf{u}$ in the advective term is solved numerically by the combination of Darcy's law and the continuity (mass conservation) equation for an incompressible fluid:

$$\mathbf{u} = -\frac{\kappa}{\mu} \nabla p; \qquad \nabla \cdot \mathbf{u} = 0.$$

3-D Meshing

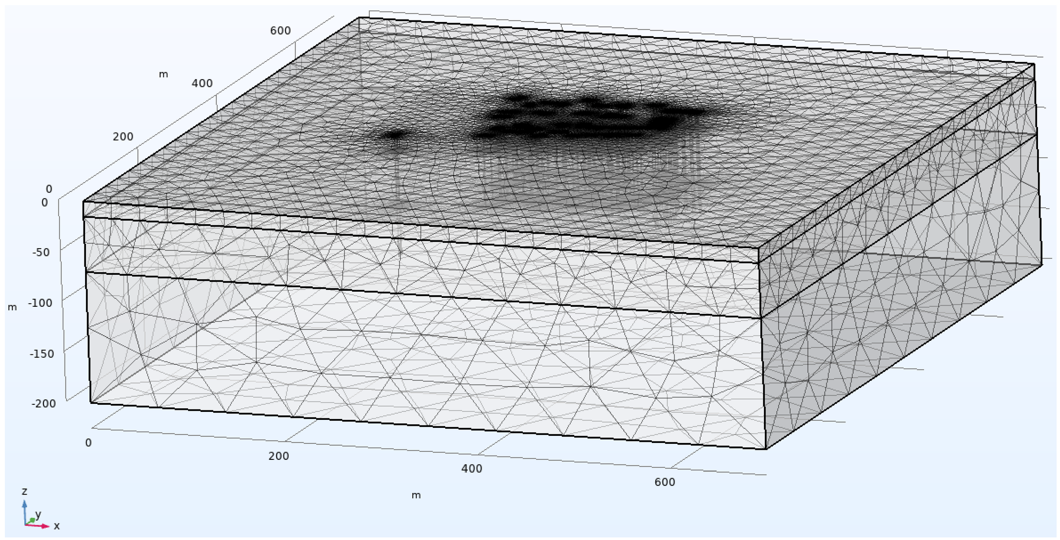

Fig. 3: Different mesh operations have been applied to capture the relatively large aspect ratio between the smallest and biggest element. Optimal 3-D meshing remains an ongoin effort in this work since the mesh created is too big and requires reduction.

Results and conclusions

Preliminary numerical studies habe been conducted. Model reduction and submodeling techniques to analyze local effects in large models are required to successfully simulate system evolution with reasonable computational load.

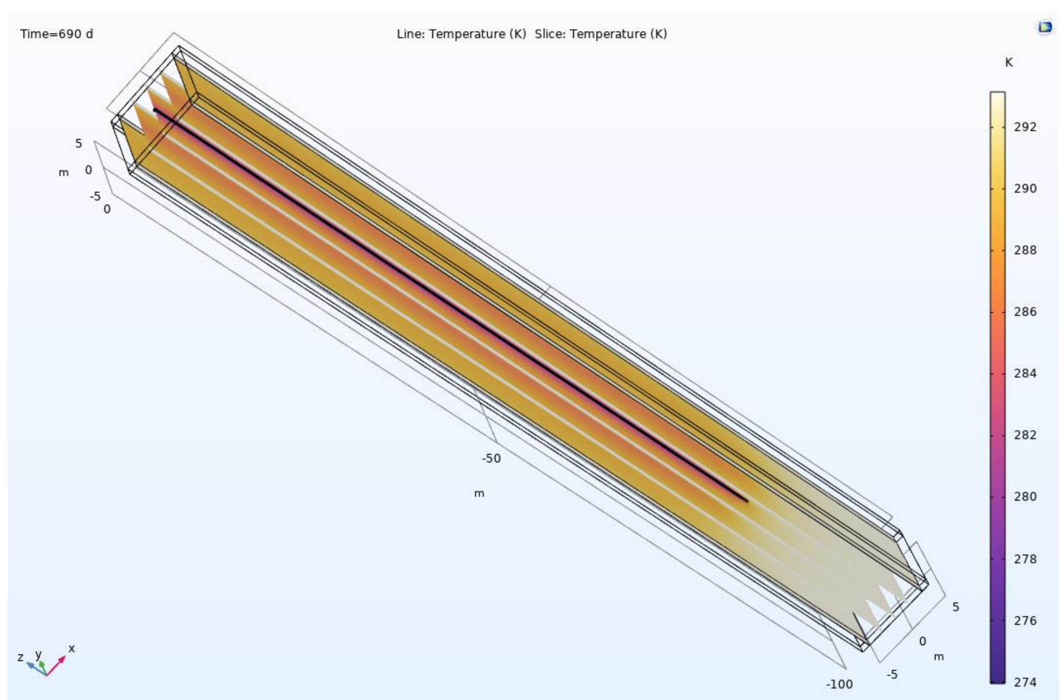

Fig. 4: Temperature distribution around one BHE. The thermo-hydraulic interaction between multiple BHEs and the optimal design of a BHE field are main focuses in this work.

Acknowledgement

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References

García Gil, A., Garrido Schneider, E., A., Mejías Moreno, M., and Santamarta Cerezal, J., C., 2022. Shallow geothermal Energy. Theory and Application. Series edi. Juan Carlos Santamarta Cerezal. Springer Hydrogeology.