# Coupled Heat Transfer in Borehole Heat Exchangers and Long Time Predictions of Solar Rechargeable Geothermal Systems

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**Abstract:** An increased share of renewable energies is regarded as an integral part of a strategy towards a sustainable future. With regard to the heat supply sector this may be achieved using solar thermal collectors or heat pump systems with borehole heat exchangers. During the last years solar thermal and geothermal systems have generally been installed separately. Now, several proposals are discussed in which the two technologies are combined as both can benefit from each other. The EFRE project Geo-Solar-WP (high-efficient heat pump systems with geothermal and solar thermal energy sources) handles the different aspects of such coupled thermal systems. Part of the project focuses on transport processes of heat and groundwater in the subsurface. Here we intend to present the respective modeling approach using COMSOL Multiphysics 4.2a and 4.3.

**Keywords:** geothermal energy, borehole heat exchangers, heat transfer in porous media

## 1. Introduction

Within the project we want to have a detailed look at the development of a system of three borehole heat exchangers (BHEs) in a triangular arrangement. They are operated by a system of two heat pumps and three high precision modules. The modules allow emulating solar collector circuits, domestic hot water and space heating circuits [1].

Since the whole system consists of several complex components, their numerical simulation is primarily done using system simulation programs like TRNSYS. Nevertheless, a focused view on the thermal development of the subsurface under consideration of the hydro-geologic issues needs more detailed finite element simulation. We set up models, which are able to simulate test runs of the geothermal system regarding hydro-geological measurement results. The main objective is to predict the long time behavior of thermal recharged systems under different circumstances. One essential question is which conditions are convenient for thermal recharging and which situations let those approaches be less useful.

## 2. Test Site

The project test side is located on the area of the ISFH in Emmerthal. It consists of three BHEs (SN, SO, SW) arranged in a triangle and two groundwater observation wells of comparable depths. One well (BM) is located in the middle of the triangle and the other one (BS) southwards of it. Figure 1 shows the test side from above.

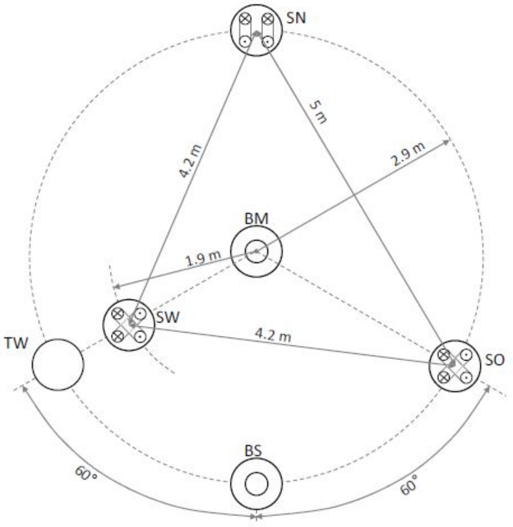

**Figure 1.** Top view on the test site at the ISFH

One aim of our project work is to get detailed information about the hydro-geological parameters at the test site. This was done by pump tests in the groundwater wells BM and BS and by evaluating the data with the novel hydraulic tomography technique [2]. This gives us clues concerning the distribution of important parameters (hydraulic conductivity, specific storage) between the wells. The results can be extrapolated to the surrounding of the boreholes and can be used as input data for further investigations, i.e. the advective heat transport between the BHEs and the behavior of the subsurface flow under different conditions.

## 3. Numerical Model

### 3.1 Heat Transfer in Pipes

For accurate long-time predictions of thermal rechargeable subsurface heat pipes, a numerical model must consider different physical aspects, constraints and processes. The heat transport inside the pipes, as well as the heat exchange between the pipes and the subsurface are calculated using heat transfer in solids, in fluids and in porous media. The latter can be strongly influenced by subsurface flow fields.

The heat balance in porous media can be described by the following equation:

$$(\rho C_p)_{eq}\frac{\partial T}{\partial t}+\rho C_p\vec{u}\cdot\nabla T=\nabla\cdot(k_{eq}\nabla T)+Q$$

with the vector field $\vec{u}$ as the Darcy velocity and $Q$ as the heat source (or sink). Here, the velocity field may be given as a result of a subsurface flow calculation.

The most challenging part of the simulations is the heat transport within the pipes and between the pipes and the surrounding. The high ratio of the radius of the pipes to their length ($r/l\approx 10^{-4}$) makes it rather impossible to solve the equations of motion for the fluid. Nevertheless there is no need to know the exact flow field since there are several approaches which provide good approximations of the effective transversal heat transport of fluid flow in pipes. One possibility is to give the velocity within the pipes as the mean velocity $\vec{u}_{pipe}$ of a certain flow rate and to calculate the heat transport using the heat equation. Since the heat exchange between the pipes and the subsurface is highly governed by the flow conditions in the pipe, it is necessary to calculate an effective thermal conductivity of the pipe walls. The latter must consider the thermal resistance of the pipe wall and of the heat transfer from the pipe into the fluid:

$$k_{eff}^{-1}=k_{pipe}^{-1}+k_{transition}^{-1}=\frac{1}{k_{pipe}}+\frac{1}{h\cdot r_i\cdot\log\left(\frac{r_o}{r_i}\right)}$$

The right term depends on the Nusselt number of the flow regime by way of the convection coefficient

$$h=\frac{Nu\cdot k_w}{r_i}.$$

We already showed that the Churchill-Bernstein correlation for the Nusselt number as a function of the Reynolds number provides a suitable approximation for the heat transport between the pipes and the borehole filling [3].

## 4. Results

### 4.1 Simulation of System Test Runs

The accuracy of the simulation approach is verified by comparing the simulation and experimental results of a test run. Here, only one BHE of the system is used. The inlet temperature and the flow rate of the experiment are taken as transient input values of the model. Figure 1 shows the results of two different test runs. The upper one is a 2 hour short run, the lower one took about one day. The difference of the results at the beginning of the longer run are due to different initial conditions of the experimental field and the model, since these are not exactly known and may be affected by previous experiments. Altogether, the simulation approach promises to work accurate.

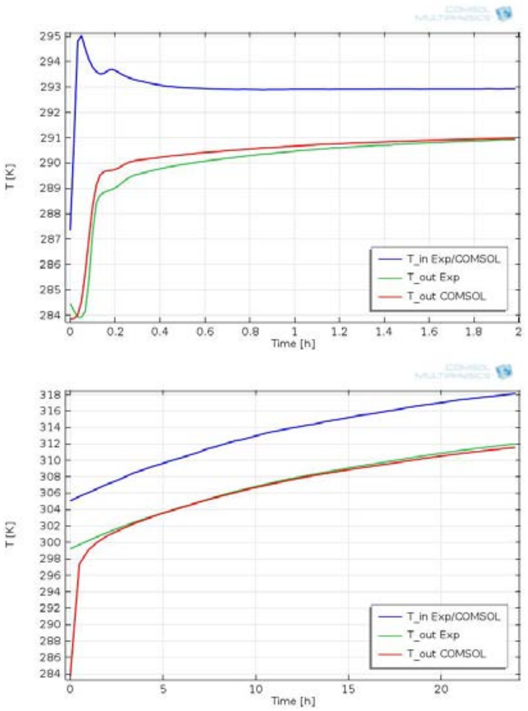

**Figure 3a+b.** Results of two experimental test runs from the ISFH and dedicated simulation output data.

## 4.2 Thermal Recharging

One subject of the project is the investigation of synergy effects of a coupled BHE and solar collector system. One possible way for the reasonable usage of abundant heat available from solar heat collectors is to inject it into the subsurface by a BHE. This process would effect a thermal recharge of the claimed subsurface or serve as a thermal storage respectively. Apparently, groundwater flow might cause subsurface heat transport that departs the injected heat. Nevertheless, groundwater flow itself has a recharge effect on the area around a BHE. We use our model to demonstrate some different scenarios and to see the effect of recharge approaches on the long time behavior of the thermal conditions in the subsurface.

Figure 4 shows a one year simulation of a system without subsurface flow. The two lines show the outlet temperatures. In one case, the subsurface was thermally charged for a half year before starting heat extraction for another half year. Figure 4a shows the results of simulations without groundwater flow (u=0[m/s]). The benefit of the charging holds for the rest of the year, since the outlet temperature stays significantly higher. Figure 4b shows the analogue calculation with a small subsurface flow velocity of 0.1[m/s]. Here, the outlet temperature of the thermal charged system converges faster against the one of the uncharged system, so the benefit of the thermal charge gets partially lost.

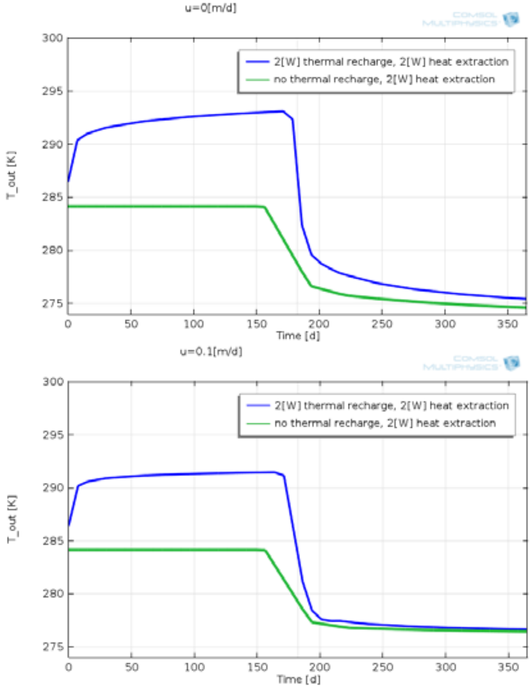

**Figure 4a+b.** Comparison of outlet temperatures for a one year simulation with and without previous thermal charging. **a:** u=0[m/d], **b:** u=0.1[m/d]

Figure 5 shows a vertical temperature slice through the BHE model after a half year of thermal injection. While the injected heat stays locally stored above the groundwater table (at a depth of about 30[m]) it is transported downstream by advection underneath. The biggest part of it gets lost in this manner.

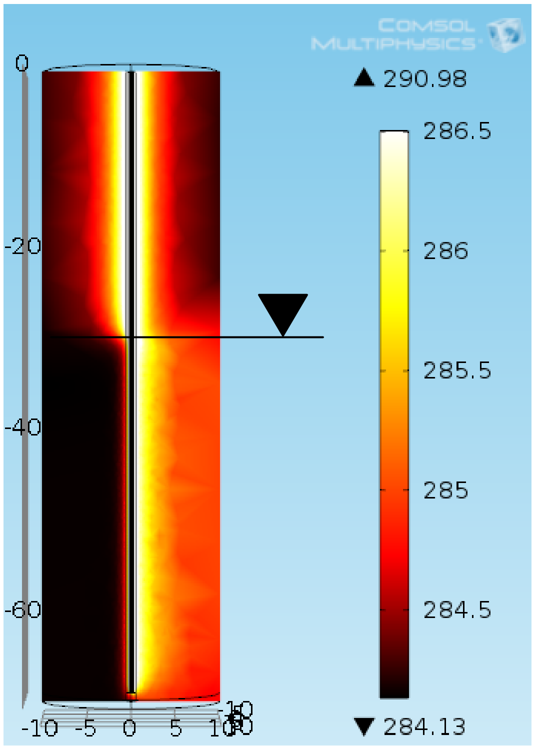

**Figure 5.** Slice of the temperature (in [K]) distribution in the nearby subsurface after one half year of thermal charging. Groundwater flow direction is directed from left to right.

## 5. Outlook

Since the simulation results of the BHE models are promising we intend to work further with this approach. The next step will be to implement the other two BHEs of the array. This approach has a high amount of degrees of freedom. So we also intend to investigate if the new COMSOL *Pipe Flow Module* is a more efficient tool for the realization of this intention. This module treats the heat transfer of pipes as a 1D problem, which can be embedded into a higher dimensional environment. In that we the mesh-size and corresponding degrees of freedom can be limited. The calculation of the heat transfer coefficients works similar to our full 3D approach, the module also bears the typical approximations for the Darcy friction factor (Churchill-Bernstein, Haaland, etc.).

## 6. References

[1] P. Pärisch, M. Kirchner, W. Wetzel, S. Voß, R. Tepe: Test System for the Investigation of the Synergy Potential of Solar Collectors and Borehole Heat Exchangers in heat Pump Systems, Proceedings of the ISES Solar World Congress 2011, 28.08.-02.09.2011, Kassel, Germany

[2] Hu, R. et al. (2011): Hydraulic tomography analog outcrop study: Combining travel time and steady shape inversion. Journal of Hydrology, Volume 409, Issues 1-2, 28 October 2011, Pages 350-362. doi:10.1016/j.jhydrol.2011.08.031

[3] Oberdorfer P., Maier F., and Holzbecher E. (2011): Comparison of Borehole Heat Exchangers (BHEs): State of the Art vs. Novel Design Approaches. In: Proceedings of COMSOL Conference 2011 (Stuttgart), CD-ROM-Publication

## 7. Acknowledgements

The project “Hocheffiziente Wärmepumpensysteme mit Geo- und Solarthermie- Nutzung” (High-efficient heat pump systems with geothermal and solar thermal energy sources, short name: Geo-Solar-WP) is funded by the European Union (European Regional Development Fund) and the Federal State of Lower Saxony.