Seasonal cold storage with borehole heat exchangers: an application study using numerical simulations

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The objective of this work is the numerical study of a geothermal probe field, considered as a network of borehole heat exchangers (BHEs). The probe field is located in Bochum, Germany. The BHE network is used for the purpose of heat rejection from laboratory facilities to the ground during warm seasons, i.e., it is a novel and renewable seasonal cold storage technology.

Model reduction strategy for BHE network

The intended application consists of a parallel flow network of 35 double U-shaped BHEs in a 5 x 7 rectangular array. This array has been previously determined to be the best one among a set with other possible configurations [1]. The BHEs dive 100m deep into the ground, and the distance between neighbors in the array is 6m (equidistant neighbors). The network operates on a rationale of maximizing the working fluid (brine) residence time. In this way, the BHE effectively operates on a laminar flow regime. Notwithstanding the laminar flow regime, the dimensions of the network are such that an aspect ratio of 1:10000 is obtained, where 1 is the order of magnitude of the inner pipe diameter through which the brine is transported, and 10000 is the order of magnitude associated to the length or depth of the BHE. Therefore, some form of modeling is required in order to guarantee sufficiently resolved numerical simulations at an affordable computational cost. This is a common issue related to numerical simulations of BHEs, e.g., [2]. In this case, the followed model reduction strategy is straightforward: considering the fixed configuration, we perform a time scale analysis associated to the range of expected underground heat transfer required to satisfy a given cooling requirement (design). The time scale analysis is done with the help of a simulation, such that we verify, for a time scale of one year, that the effect of neighboring probes on radial heat rejection is negligible. This allows us to work with an isolated BHE. All numerical evaluations utilized the open source library OpenFOAM [3]. Figure 1 shows the temperature field obtained for an array of consecutive BHEs. It is seen that the temperature of the ground is not modified under the assumed operating conditions.

Numerical simulation of an isolated BHE

In order to verify the accuracy of the model, numerical simulations are carried out to evaluate the outlet temperature of the isolated BHE considering time-dependent inlet conditions, which are associated to the measured, weather-related, ground surface temperature data. The results of this numerical test for a time span of 70h are shown on Figure 2. The bulk outlet temperature is shown, demonstrating that the modeled BHE is dominated by underground heat conduction, given the very close agreement between simulation results and data measured on-site for a geothermal response test (TRT) [4].

Conclusions and outlook

A numerical study on a modeled BHE network has been carried out. The presented heat transfer model is dominated by underground heat conduction. The modeling strategy was required due to the very high aspect ratios present in the application. Turbulent flow would add yet another level of complexity to this problem, in which case a further multiscale approach would be required. For the study case presented here, the model upon consideration, despite its simplicity, delivers relevant design information, and could be used in the future for similar and relevant study cases.

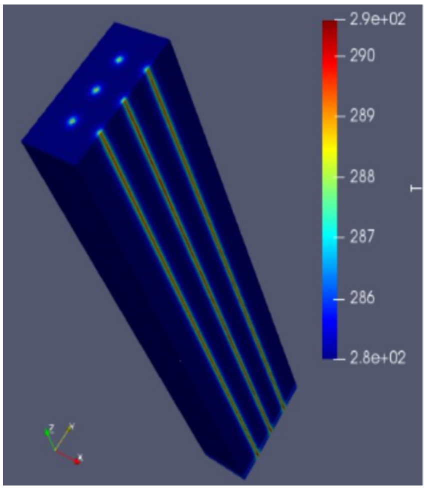

Figure 1: Cross-sectional view of the underground temperature field obtained for an array of BHEs.

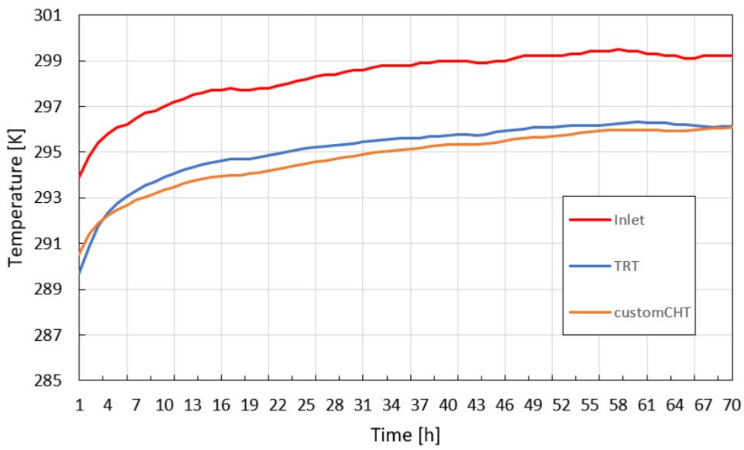

Figure 2: Bulk inlet and outlet temperatures of the isolated BHE. The bulk outlet temperature is labeled customCHT, as a reference to the OpenFOAM solver used for the numerical simulation, chtMultiRegionFOAM. Reference TRT data is also shown for reference [4].

References

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