Thermal Performance of a Deviated Deep Borehole Heat Exchanger: Insights From a Synthetic Heat and Flow Model

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Abstract

Earth heat exchangers are drawing increasing attention and popularity due to their efficiency, sustainability and universality. In addition, DBHE can offer higher temperatures and more return on investment than conventional system. DBHE is also an alternative to geothermal power generation or to direct use applications in an extreme engineered (or enhanced) geothermal systems (EGS). However, the functioning of deep borehole heat exchangers (DBHE), in contrast to those of shallow, remains poorly known. This is mainly due to the depths involved; information from wells is sparse which may lead to uncertainty on subsurface site characterization.

Therefore, this work tends to delineate the effects of uncertainty related to variation of subsurface physical parameters (i.e., groundwater flux, thermal conductivity and volumetric heat capacity of solids, porosity, thermal dispersivity) on DBHE performance. The modeled system consists of a closed-circuit, made of two highly deviated BHE that converges below 5,000 m deep, settled in a homogeneous porous reservoir (fig. 1).

Therefore, there is no fluid exchange between the wellbore and its surroundings. Only heat is conducted from subsurface formations into the circulating (or working) fluid, through the well casing. Thus, the injected fluid gains heat as it flows along the tubing length.

The transient numerical model was built with the help of COMSOL Multiphysics, accounting for flow and heat transport. The Pipe Flow Module (Non-Isothermal Pipe Flow interface) is coupled to the Subsurface Flow Module (Heat Transfer in Porous Media and Darcy's Law interfaces). Linking this physics interfaces together allows the computation of the heat transfer between the pipe network, represented by 1D edges, to the 3D solid-fluid system as well as its consequence on flow, pressure and temperature conditions in both DBHE and porous media (figs. 2 and 3). Furthermore, the Non-Isothermal Pipe Flow interface is capable of handling multi-layer pipe wall (i.e., casing, liner, cement) as well as pressure losses along the pipe length. Consequently, COMSOL Multiphysics can address fully-coupled geothermal processes related to the operation of a DBHE with complex well architecture.

In application to geothermal exploration problems, Monte Carlo approach is conducted to

estimate the impact of thermo-hydrogeological physical quantities and enables the prediction of failure due to insufficient thermal power production. In this study, the Monte Carlo ensemble is provided according to each parameter theoretical statistical distribution. Fluid outlet temperature, specific heat extraction rate as well as thermal plume development are analyzed over 6-month and 25-year operation period, according to numerous stochastic realizations. The probability of success or failure of the project is estimated in respect of the reservoir uncertainty for a feasible and sustainable use of DBHE over a continuous-operating period of 25 years.
First results show a relative hierarchy of parameter significance on hydro-thermal performance of the closed-loop scheme. Moreover, this paper discusses the implications of natural heterogeneity associated with deep geological formations on technical feasibility of such system.

This research is carried out in the FONGEOSEC - AMI project handled by a consortium headed by Fonroche Géothermie and including BRGM, Enertime, Enesol Géothermie, Flodim, Foragelec, UPPA-LaTEP, Opérantis, ARMINES, ENSEGID.

Figures used in the abstract

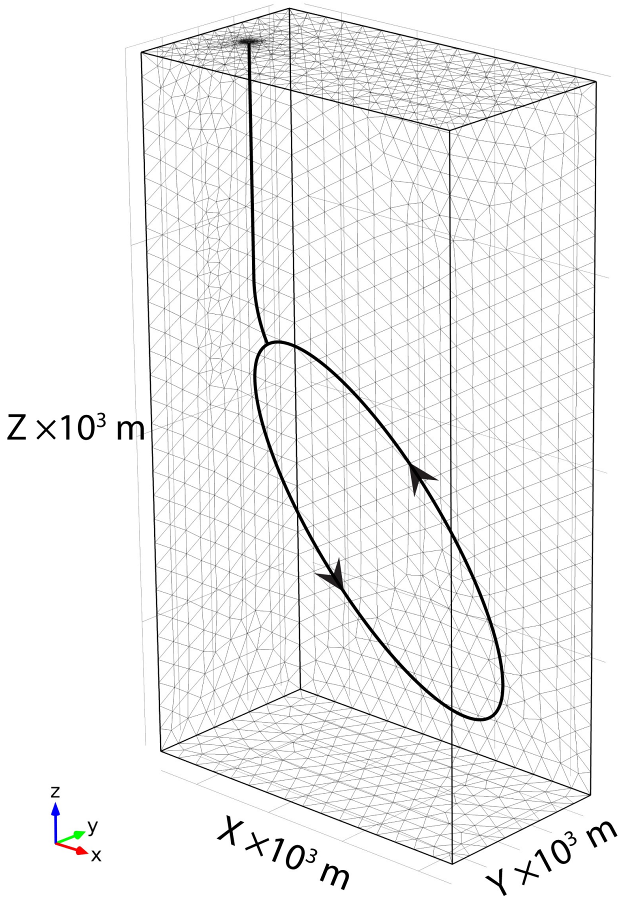

Figure 1: Schematic representation of the 3D model and its mesh. Note that due to confidentiality reasons, DBHE trajectory is represented with restrictions.

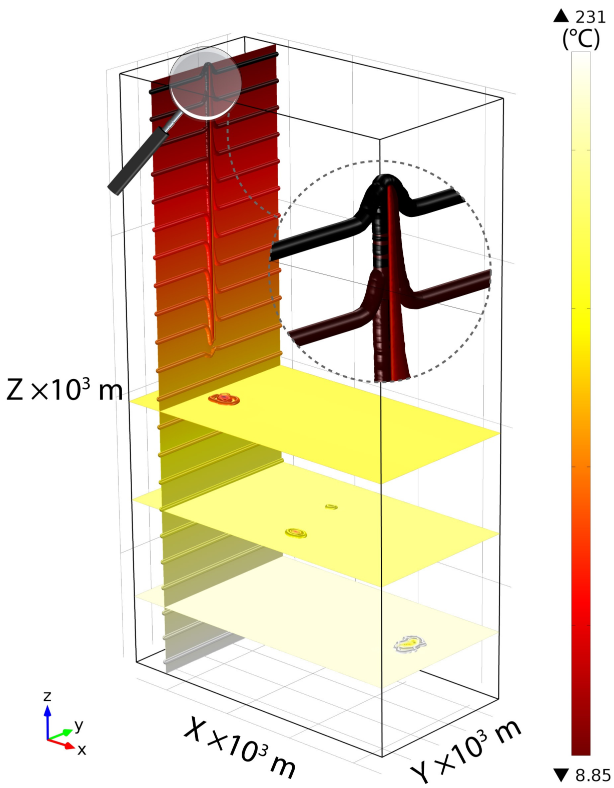

Figure 2: Temperature map of the solid media (°C) obtained at the vicinity of the DBHE for the base scenario after 50 years of operation.

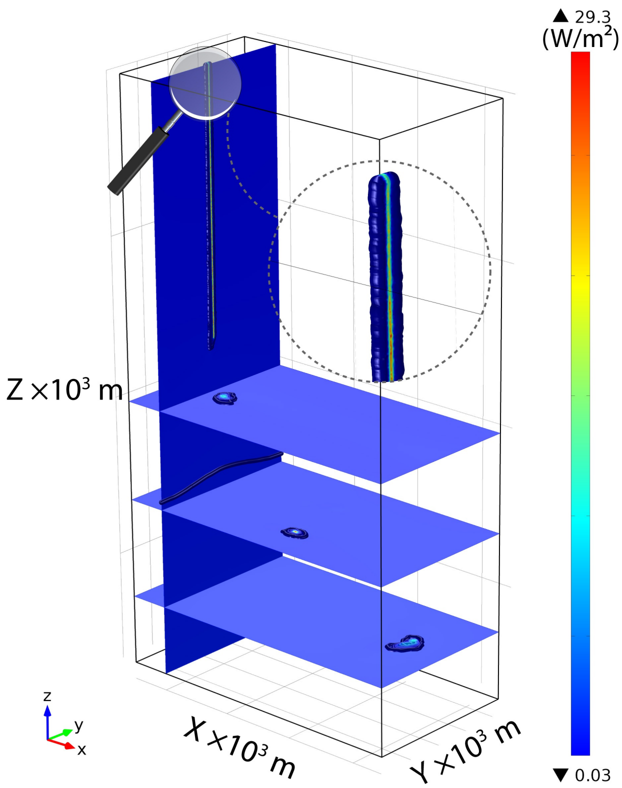

Figure 3: Gradient temperature map of the solid media (W/m²) obtained at the vicinity of the DBHE for the base scenario after 50 years of operation.