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BASIMO – borehole heat exchanger array simulation and optimization tool

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Abstract

Innovative applications and novel modifications of borehole heat exchangers (BHE) require new simulation tools. Currently, features like inclined or partly insulated boreholes necessitate fully discretized models. However, those models come at high computational cost. We present a tool, which uses an analytical solution for the BHE coupled with a numerical solution for the subsurface heat transport. A tetrahedron mesh bypasses the limitations of structured grids for borehole path geometries, while BHE properties changing with depth are considered. The tool benefits from the fast analytical solution of the BHEs while still allowing for a detailed consideration of the BHE properties.

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1. Introduction

Globally, space heating and domestic hot water production constitute about a quarter of the final energy consumption [1]. In countries, which are affected by winter seasons, this fraction can be substantially higher (cf. [2]). Renewable energy sources like solar collectors are increasingly used to cover the heat demand [3, 4]. They have the

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potential to reduce the consumption of fossil fuels and to mitigate the CO_2 emissions. However, like the demand, the renewable heat supply is subject to seasonality in higher latitudes. Excess heat is available in summer, while the heat demand is highest in winter. Consequently, renewable heat sources rely on seasonal storage systems [3-8]. Shallow arrays of borehole heat exchangers are already in use for seasonal heat storage at comparably low temperature levels [9-12]. In many countries legal regulations restrict alterations of the groundwater that may have a negative impact on the drinking water quality [13]. Excessive heating of the shallow subsurface can induce microbial growth and, therefore, has to be prevented in these aquifers [14].

Instead, medium deep borehole thermal energy storage systems (BTES) can store the heat in greater depth at high temperature levels evading the topmost aquifers. For that purpose, medium deep BTES have to be fitted with an insulation in the upper section of the borehole. This can be achieved by larger borehole diameters and the use of insulating grouting material in the regarding borehole section. [15-17]

Compared to shallow installations, drilling is an even more critical cost factor for the construction of a medium deep BTES. Thus, simulations of the storage operation are imperative prior to the investment. Furthermore, the design of the BHE array has to be optimized to avoid badly sized systems. Consequently, a simulator for the BHE array should allow for mathematical optimization [17]. Also, a partly insulated borehole corresponds to depth-dependent BHE properties and implies additional special requirements to numerical models. These requirements rule out most of the available simulation tools like EED [18], FEFLOW [19] or line source-based approaches (e.g. [20, 21]). Up to now, only fully discretized models could fulfill these requirements. However, fully discretized models come at high computational cost and are not a viable option for the simulation of entire arrays of BHEs.

In this paper, we present BASIMO: a **B**orehole heat exchanger **A**rray **SIM**ulation and **O**ptimization tool. It comprises a simulator that employs the finite element method (FEM) to calculate the transient conductive heat transport in the subsurface. The thermal response of the BHEs is calculated using an adapted analytical solution based on thermal resistance and capacity models (TRCM), which allows for the consideration of partly insulated boreholes, but still grants fast computation compared to fully discretized models [22]. As the simulator is MATLAB-based, it can be readily used with the MATLAB Global Optimization Toolbox [23] for the mathematical optimization of the storage performance with respect to variable system parameters. For elaborate optimization problems, the computational time can be reduced using a previously trained proxy model [17]. Furthermore, it is possible to link BASIMO to building models for coupled BTES-building simulations.

2. BASIMO

BASIMO was initially developed for the design optimization of BTES [17]. On the one hand, this determines the required features for the simulator, namely the consideration of borehole insulation and the possibility to couple the simulator to mathematical optimization algorithms. On the other hand, it allows for certain simplifications: BTES systems typically target low permeable rocks for heat storage, as groundwater flow decreases the storage efficiency [15]. Therefore, BASIMO neglects the convective heat transport in the subsurface, which decreases the computational cost significantly. Nevertheless, BASIMO can also be used for the simulation of regular BHE arrays in mere heat extraction scenarios as long as groundwater flow is non-existent. BASIMO applies a dual continuum approach where the numerical calculation of the subsurface heat transport is separated from the simulation of the thermal interactions within the BHEs. The latter can be solved analytically, which significantly saves computation time otherwise required for the full discretization of the borehole. The program structure of the simulator is illustrated in Fig. 1.