3D Numerical Modeling of Vertical Geothermal Probes

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Abstract

The research project is assessing the possibility of using vertical geothermal probes drilled into a rock mass (bedrock) for storing the thermal energy produced by solar panels and later releasing it. The project relies on the installation of an experimental system and the use of original heat transfer model developed in 3D with COMSOL Multiphysics. The underground device, set up entirely in Paleozoic schist in the Eastern Pyrenees (France), consists of three subvertical boreholes, 180 m deep, equipped with double-U geothermal probes. The probes are instrumented with an optical fibre that enables temperature monitoring inside boreholes via a distributed temperature sensing (DTS) system from Sensornet.

The temperature rise in the borehole (arrival of the thermal pulse) is too complex for an analytical interpretation, because of its highly transitory character and the dynamic thermal interactions between the down leg and up leg of the U-shaped probe. The resulting numerical model compares very satisfactorily with the experimental data down to one metre resolution for both the rise in temperature and the period of relaxation (cooling). The heat exchanges in the shallow part of the bedrock in contact with the atmosphere could only be imperfectly modeled. The numerical 3D modeling was therefore carried out with COMSOL Multiphysics, taking into account heat flows between the different materials involved (i.e. the bedrock, sealing grout, polyethylene probe tube, heat transfer fluid, surface insulator). The modeling is constrained by the experimental data of the applied thermal shock.

The result of the thermal shock simulated by the developed three-dimensional numerical model, when compared against the obtained experimental measurements, would appear to be very satisfactory. Figure 1 shows the numerical model simulation of the thermal shock's temperature changes against the experimental data for two simulated measurement positions along the probe. The simulated spatiotemporal evolutions, for different depths are comparable with experimental measurements, on both the injection tube (descending part) and return tube (rising part). The fluid's outlet temperature is also close to the experimental measurements. The developed model, using both the Dittus-Boetler correlation and the shell and solid coupling in modeling, shows its effectiveness for this type of device.

The balance between the amount of energy injected during the injection period and the amount of energy stored (transferred) in the different materials of the system was established as a check on the model. The energy balance appears consistent (Figure 2).

We now have a calibrated numerical model enabling us to simulate a variety of experimental patterns for the injection and withdrawal of heat in a rock mass (Figure 3).

Reference

1. Fujii et al. (2009) – An improved thermal response test for U-tube ground heat exchanger based on optical fiber thermometers. Geothermics 38 (2009), 399-406.

2. Acuna J., Mogensen P., Palm B. (2009) – Distributed thermal response test on a U-pipe borehole heat exchanger. 11th Conf. on Energy Storage, Effstock2009, Stockholm, Sweden

Figures used in the abstract

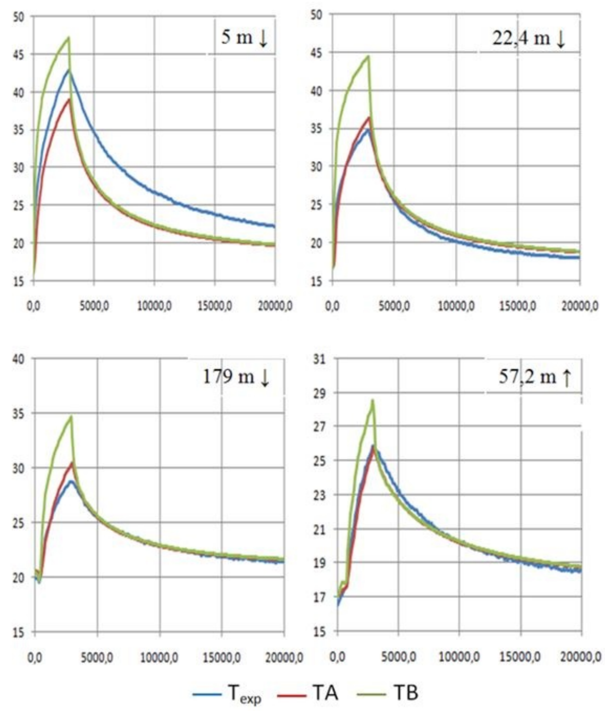

Figure 1: Figure 1: Thermal evolution with depth

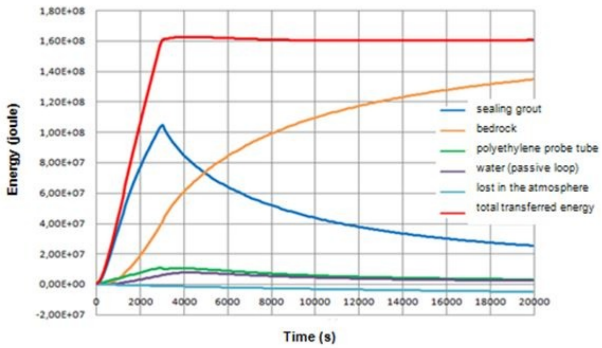

Figure 2: Figure 2: Evolution of the stored energy with time

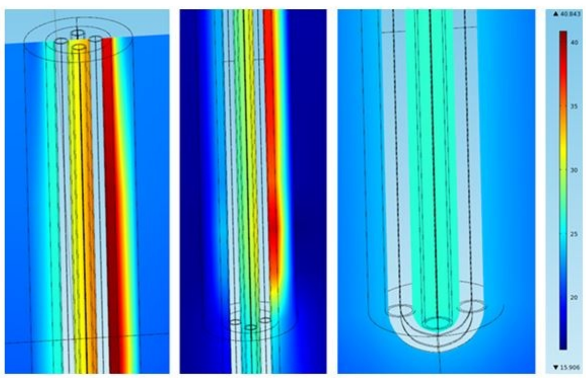

Figure 3: Figure 3: Spatial distribution of the temperatures at t = 6000 s