ESTIMATION OF SOIL AND GROUT THERMAL PROPERTIES THROUGH GEOTHERMAL RESPONSE TEST

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Introduction

On account of environmental and energetic emergency, the usage of high efficiency energy systems, like ground coupled heat pumps (GCHP), has been advanced. The proper design of the GCHP, particularly of the ground heat exchanger (GHE), requires the knowledge of the soil thermal properties. For this aim and for evaluating the performance of existing GHE, the Thermal Response Test (TRT) method is often adopted, especially in vertically oriented loops: it consists in providing constant heat power to a carrier fluid (usually water), which is circulated through the GHE; the comparison between TRT data and the Line Source Model solution [1] allows to set out two important properties for the GHE design, i.e. the soil thermal conductivity and the borehole thermal resistance.

More complex models have been suggested, like the Cylinder Source Model [2], which takes into account the finite dimension of the heat source. Line Source and Cylinder Source approaches are the main used ones due to their simplicity. They allow restoring only the value of the soil thermal conductivity and the borehole thermal resistance, for this reason, the value of the soil thermal capacity per unit volume is usually assumed known in the GHE design. Moreover, these approaches require quasi steady-state data for good results and, consequently, they need, at leat, 80 hours to be carried out, [3].

More accurate approaches to improve the TRT predictive capabilities can be found within parameter estimation procedures supported by numerical tools, i.e [4]; recently, parameter estimation procedures have been coupled to numerical transient tri-dimensional GHE models, which allow a better description of the heat transfer phenomenon.
Although these techniques are more complex than the standard TRT method, they allow getting results already in a transient thermal regime, reducing the time requested by the test; moreover, they allow simultaneously restoring both the soil and the grout thermal diffusivity.

Parameter estimation Methodology

In the present paper, a flexible parameter estimation technique based on a tri-dimensional numerical model of the geothermal system is applied to simulated TRT data, in order to validate a procedure aimed to restore the proper value of both the soil and the grout thermal properties.

A general procedure, suitable to estimate unknown parameters through the comparison between experimental results and the corresponding theoretical model, is based on least squares minimization; in particular, the methodology here presented is based on the Gauss Linearization Method [5]. The parameter estimation model is supported by a transient, tri-dimensional numerical finite element model of a vertical GHE implemented within the Comsol Multiphysics® environment [6].

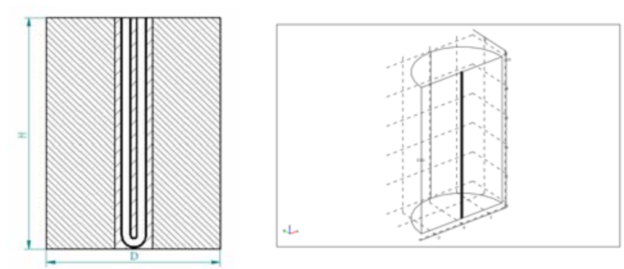

Figure 1 – Geothermal Energy Storage System's Geometry.

It consists of a 3D model (Figure 1) that couples the tri-dimensional transient conduction heat transfer problem within the soil, the grout and the HDPE tubes, with the one-dimensional convective problem within the carrier fluid in the U-tube borehole, by means of the "weak boundary condition"; moreover, the condition of constant heat rate to the fluid, generally considered in the application of the TRT, is here approximated by means of a "periodic temperature boundary condition".

In order to estimate the proper value of both soil and grout thermal conductivity and heat capacity per unit volume, a preventive sensitivity analysis of the unknown parameters on the outlet fluid temperature distribution has been carried out for 22 hours (Figure 2).

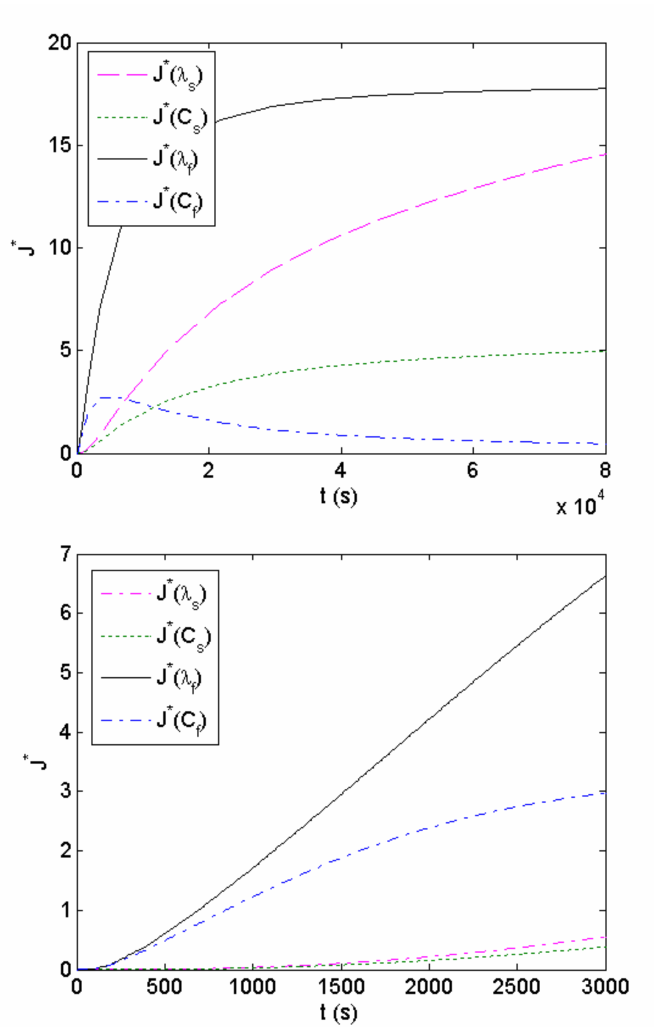

Figure 2 - Sensitivity analysis versus time for 22 hours and for 3000 seconds.

This sensitivity analysis suggests to split the estimation procedure into two subsequent steps: in particular, in the first 3000 seconds, that is in the time interval in which the sensitivities of both the grout thermal properties are significant, the parameter estimation procedure enables to restore the grout thermal conductivity and heat capacity per unit volume; these values are then considered the input values in the second step, in which the parameter estimation procedure is applied to the remaining 21 hours data of the simulated test to restore the soil thermal conductivity and heat capacity per unit volume.

To improve the accuracy of the procedure, further reiterations of these two steps are considered: the estimated soil thermal properties represent the input values in a subsequent grout parameter estimation procedure, in which the initial guess values are the estimated grout thermal properties of the previous step.

Results

The signal, representative of the experimental outlet fluid temperature distribution, has been simulated by adding a random Gaussian noise N(0; 0.5^2) to the exact solution of the direct problem describing the TRT, in which the thermal properties of both the grout and the soil have been assumed known. The noisy signal, reported in Figure 3, has been adopted as input data of the minimization procedure based on the Gauss Linearization Method.

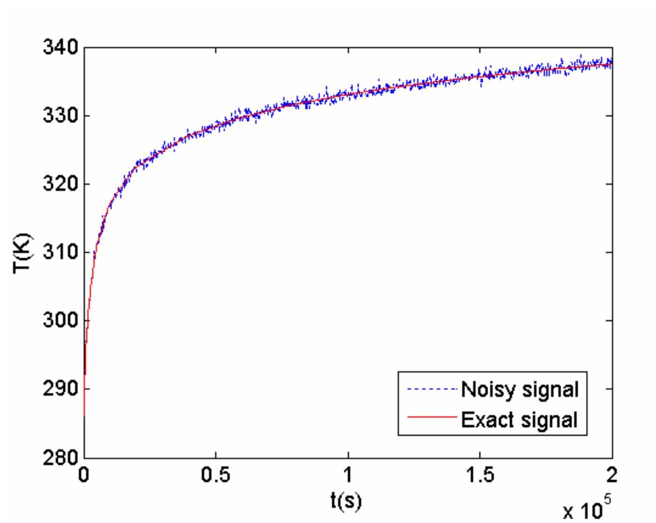

Figure 3 –Noisy and numerical temperature distributions.

The two-steps procedure is repeated until the grout thermal properties relative variations are less than 0.1%.

Figure 4 shows the values that the grout and the soil thermal properties assume during the consecutive application of the iterative two-steps estimation procedure, where R indicates the number of these consecutive applications.

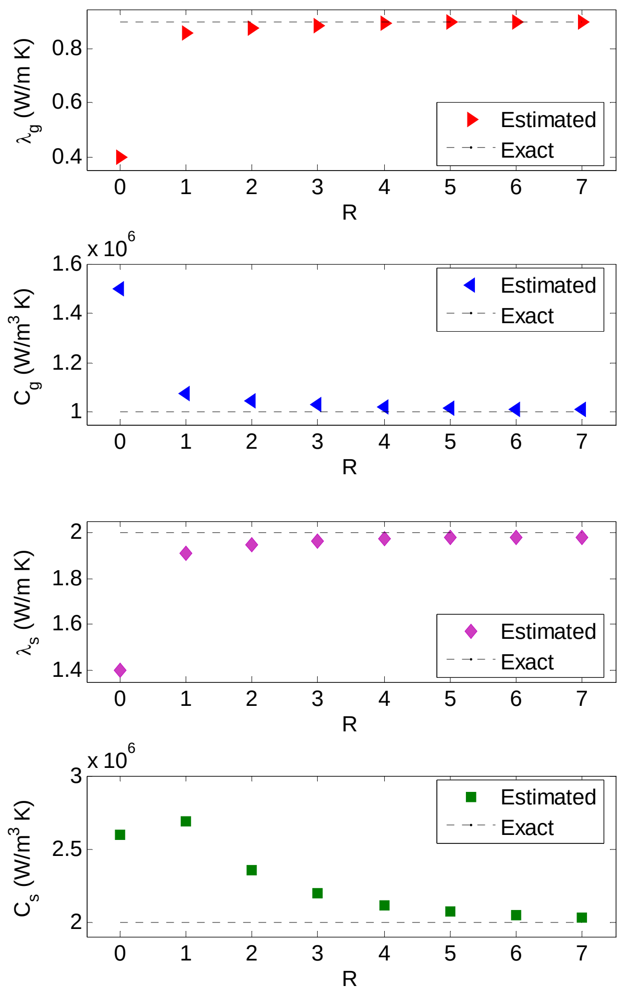

Figure 4 – Convergence of the grout and the soil thermal properties values versus the number of the consecutive application of the two-steps iterative estimation procedure.

These results allow validating the procedure applied to restore the proper value of both the soil and the grout thermal properties; while it estimates the grout and the soil thermal conductivity with an accuracy of less than 1%, the grout and the soil heat capacity per unit volume are restored with an accuracy of less than 1.5%.

It can be concluded that this methodology is suitable for the estimation of the four parameters of interest in the GHE design by considering a global time interval of only 22 hours.

References

[1] P. Morgensen, Fluid to Duct Wall Heat Transfer in Duct System Heat Storage, *Proc. International Conference on Surface Heat Transfer in Theory and Practice*, pp.652-657, Stockholm, 1983.

[2] S. Kavanaugh, K. Rafferty, Ground-Source Heat Pumps: Design of Geothermal Systems for Commercial and Industrial Buildings, pp.22-31, *American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1997.*

[3] W.A. Austin, C. Yavuzturk, J.D. Spitler, Development of an in-situ system for measuring ground thermal properties, *ASHRAE Transactions*, vol. 106(1) pp.365-379, 1999.

[4] J.A. Shonder, J.V. Beck, Determining effective soil formation thermal properties from field data using a parameter estimation technique, *ASHRAE Transactions*, vol. 105(1) pp.458-466, 1999.

[5] J.V.Beck, K.J.Arnold, Parameter estimation in Engineering and Science, *John Wiley & Sons*, New York, 1977.

[6] L. Schiavi, 3D simulation of the Thermal Response Test in a U-tube Borehole heat Exchanger, *Comsol Conference Proceeedings*, Milan Italy, 2009.