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Numerical Simulation of the Thermal Resposne Test Within the *Comsol Multiphysics®* Environment

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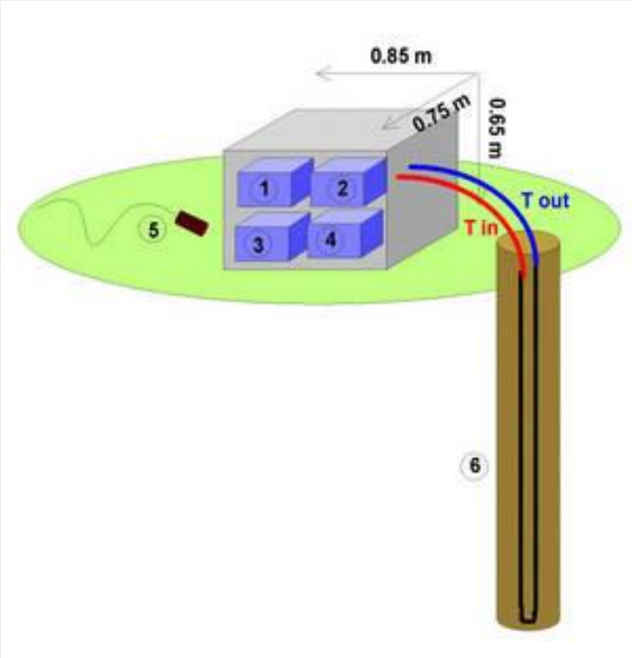
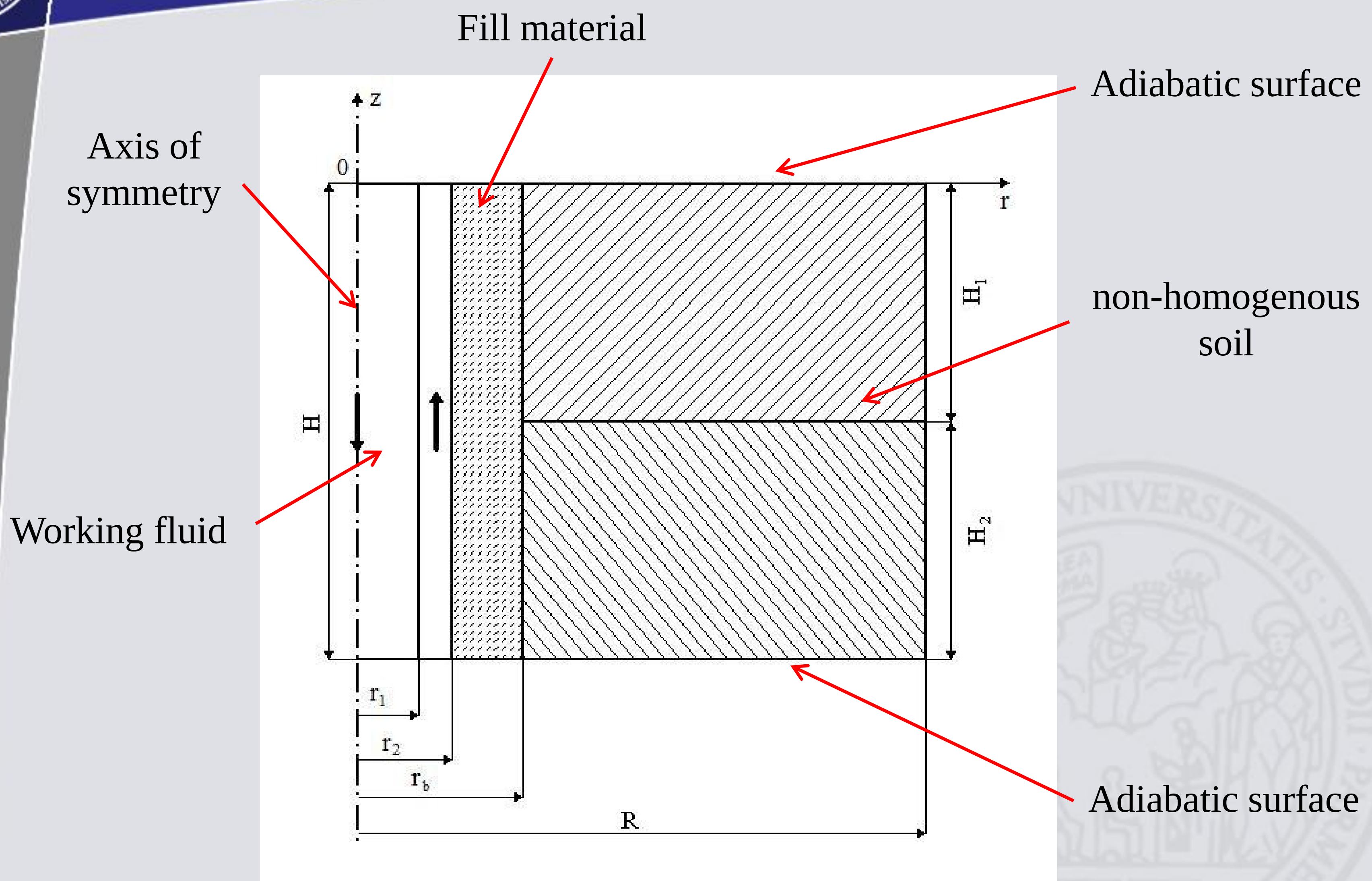
Introduction

The Thermal Response test allows in-situ-determination of the equivalent or effective ground thermal conductivity and borehole thermal resistance.

In the present work the finite element method, implemented within the *Comsol Multiphysics®* environment, has been adopted to solve the partial differential equation governing the heat transfer problem in a tube-in-tube borehole energy storage system.



Model



Geometry of the geothermal borehole system

Line Source Model

Model is approximated by the Line Source Model Analitical solution

$$T(r,t) = T_0 + Q/(4\,\pi\,\lambda\,H)\;E_1[r^2/(4\,\alpha\,t)]$$

- the thermal properties of the heat exchanger and soil are the same
- the pipe in which the working fluid flows is placed on the symmetry axis of the system and it has a negligible diameter
- the fluid temperature doesn't change along the axial direction

$$T_f(t) \cong m + k \ln(t)$$

$$m = T_0 + Q/(4\,\pi\,\lambda\,H)\,(\ln(4\,\alpha\,/r_b^{\,2}) - \gamma) + R_b\,Q/H$$

$$k = Q/(4\,\pi\,\lambda\,H)$$

The estimation procedure is based on the comparison between the temperature of working fluid, experimentally acquired and evaluated as the arithmetic mean between the inlet and outlet fluid temperature, and equation.

Governing equations

Transient heat transfer conduction is governed by the Fourier equation

$$\rho c_p \frac{\partial T}{\partial t} = \lambda \operatorname{div}\left(\overrightarrow{\text{grad } T}\right)$$

Initial condition $T(r,0) = T_0$

Thermal boundary condition at r = r_2

$$-\lambda \left.\frac{\partial T_F}{\partial r}\right|_{r=r_2} = h_o\left[T_o(z,t) - T_F(r_2,t)\right]$$

By assuming that the convection problem both in the tube and in the annular section of the heat exchanger is one-dimensional, and by modelling the thermal coupling between the two counter-current stream through the thermal conductance per unit length U, the energy equation for the tube side fluid flow:

$$A_i \rho_f c_{pf}\left(\frac{\partial T_i}{\partial t} + u_i \frac{\partial T_i}{\partial z}\right) = U\left[T_o(z,t) - T_i(z,t)\right]$$

Initial condition $T_i(z,0) = T_{i,0}$

The corresponding equation for the annular section is:

$$A_o \rho_f c_{pf}\left(\frac{\partial T_o}{\partial t} + u_o \frac{\partial T_o}{\partial z}\right) = U\left[T_i(z,t) - T_o(z,t)\right] + h_o p\left[T_F(r,t) - T_o(z,t)\right]$$

Initial condition $T_o(z,0) = T_{o,0}$

Governing equations

The condition of constant power supplied to the working fluid is implemented by the condition:

$$T_i(0,t) = T_o(0,t) + \Delta T$$

ΔT constant over the whole temporal domain

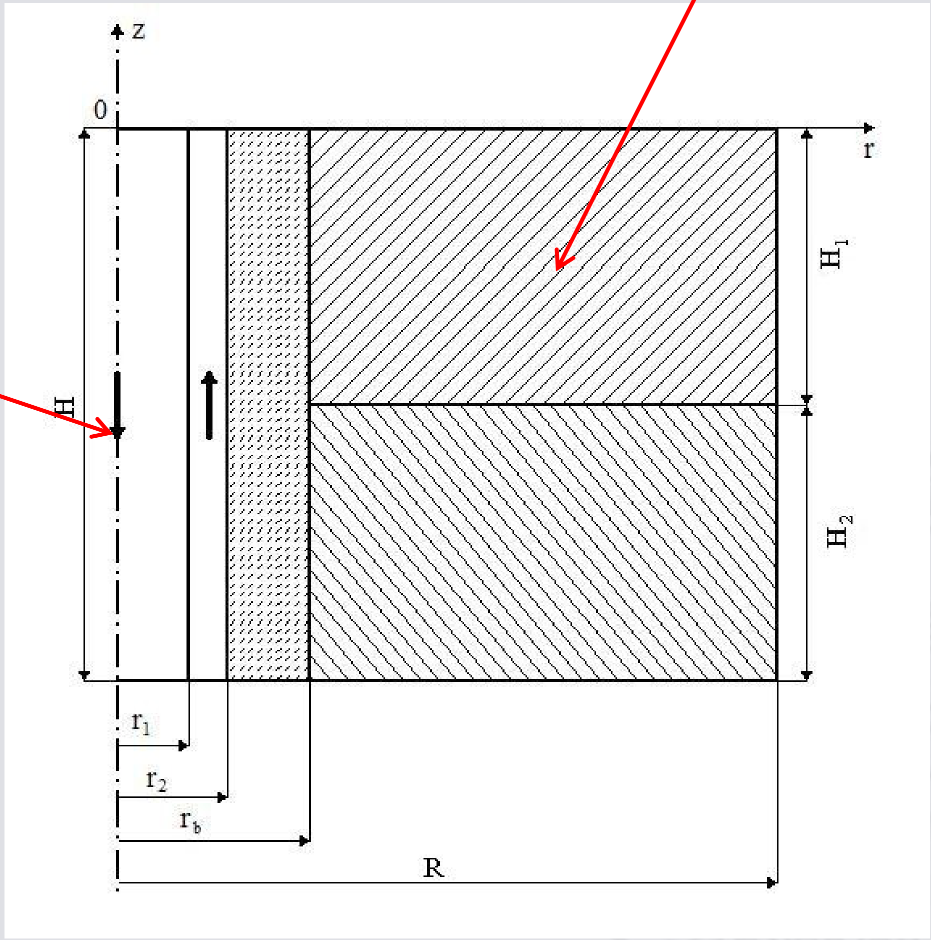
The U-tube configuration has been simulated by imposing that the temperature of the tube-side downward flow equals the temperature of the upward annular-side flow at the end of the heat transfer section.

$$T_o(H,t) = T_i(H,t)$$

Governing equations

A 2-D *Heat Conduction* model in the soil

A 1-D model, implemented by means of the *weak form formulation* in the fluid domain.

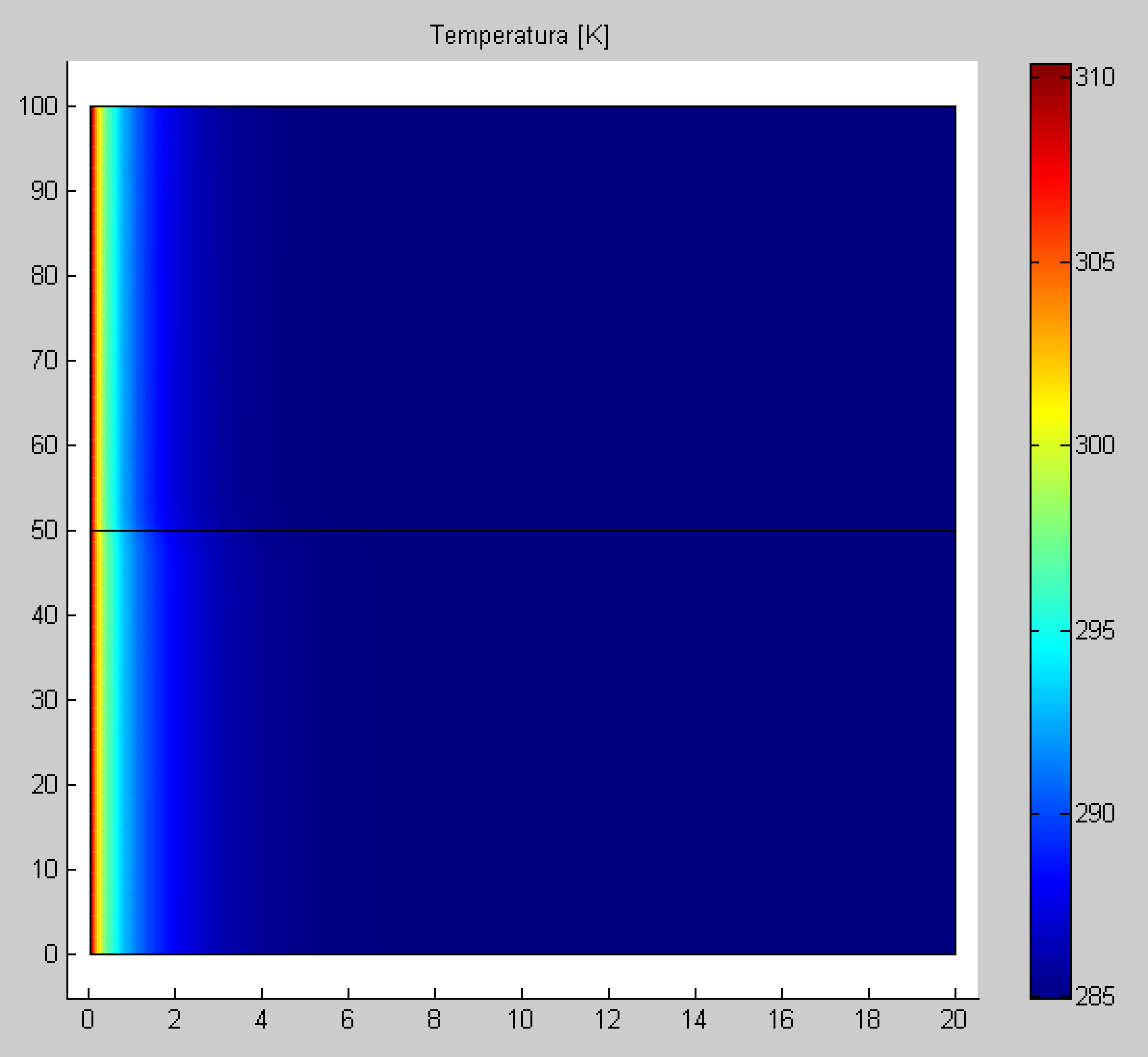


Geometry of the geothermal borehole system

Soil types

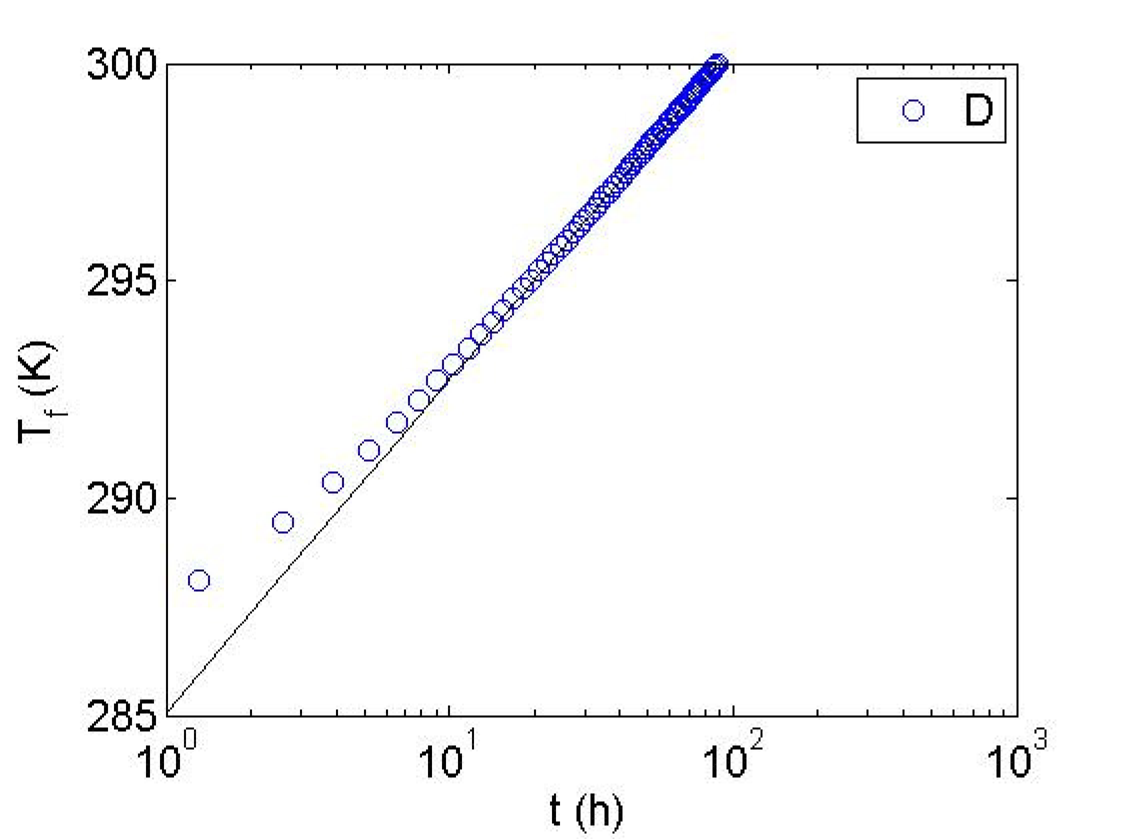
Type of soil	Composition	Thermal Conductivity (W/mK)	Volumetric Thermal Capacity (MJ/m^3K)
A	$H_1 = 0.2\ H$	2	2
	$H_2 = 0.8\ H$	4	2
B	$H_1 = 0.2\ H$	2	2
	$H_2 = 0.8\ H$	4	3
C	$H_1 = 0.5\ H$	1	2
	$H_2 = 0.5\ H$	1	3
D	$H_1 = 0.5\ H$	1	2,5
	$H_2 = 0.5\ H$	1	2,5

Results



Soil Temperature distribution

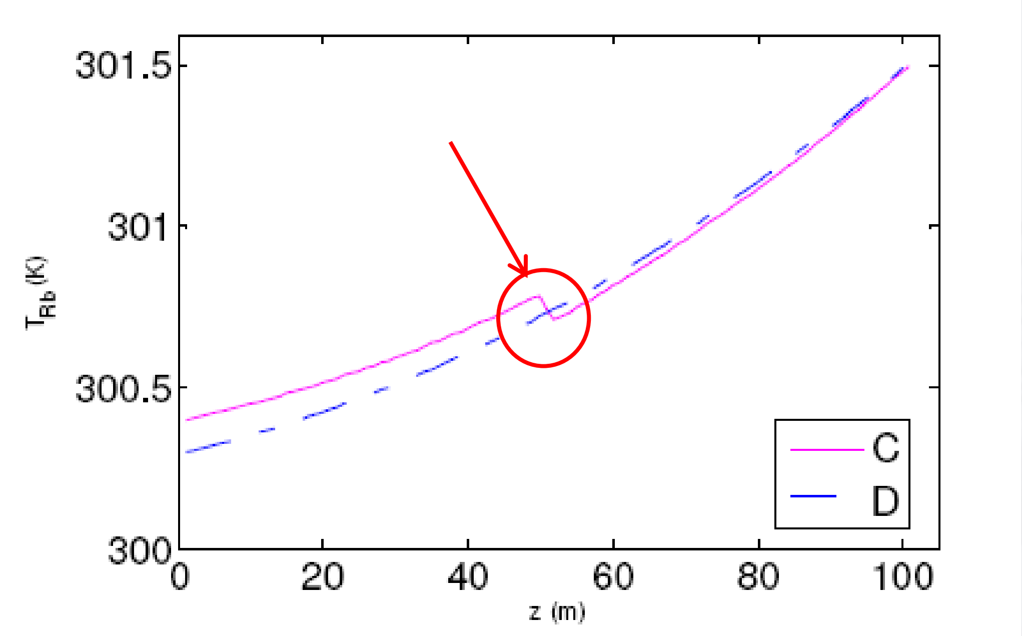
Results



Average fluid temperature versus time for soil tipe D

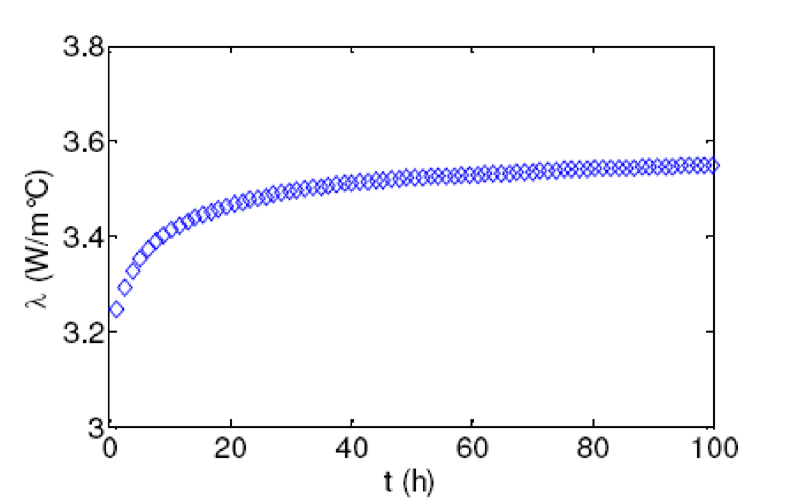
Results

The temperature distribution along the axial coordinate at the borehole-soil interface is reported in figure for cases C and D, describing respectively a non-homogenous and a homogeneous soils with equal mean volumetric heat capacity for a given thermal conductivity value.



Temperature axial distribution at the borehole-soil interface

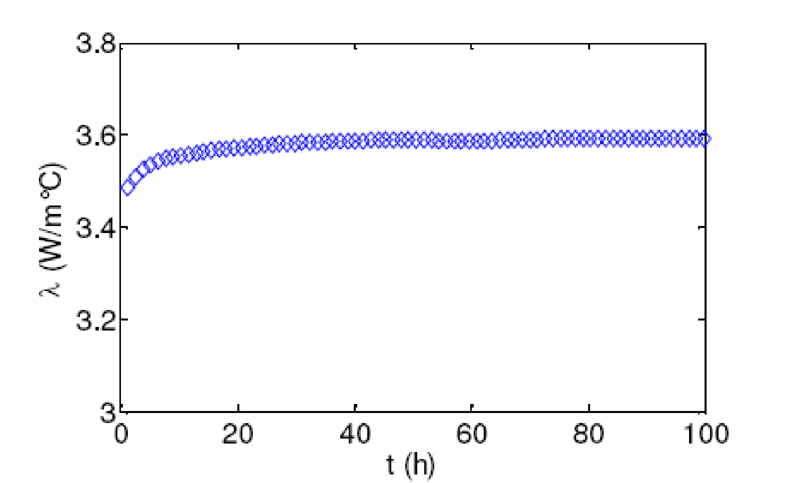
Results: Soil thermal conductivity



Case A

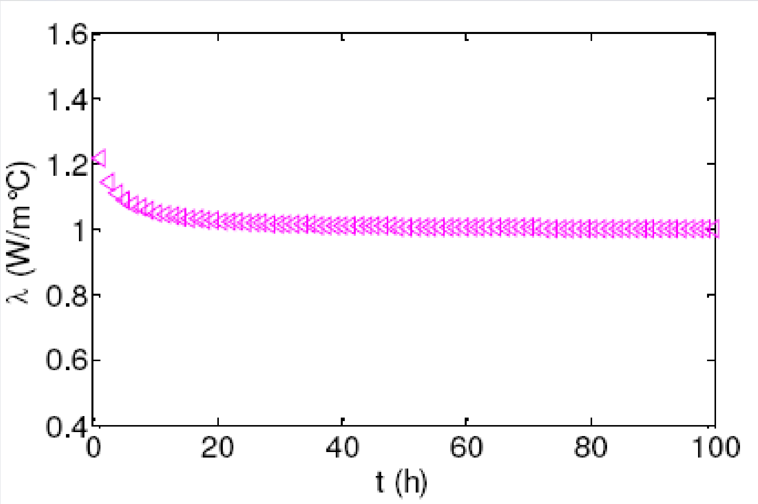
In case of non-homogeneous soil thermal conductivity, case A, and of both non-homogeneous thermal conductivity and volumetric heat capacity, case B, the estimated effective λ value approaches the value obtained by performing a mean, weighted according to the composition, of the values characterizing the single soil layer.

$$\lambda_{eq} = \frac{1}{H} \cdot \sum_i H_i \lambda_i$$



Case B

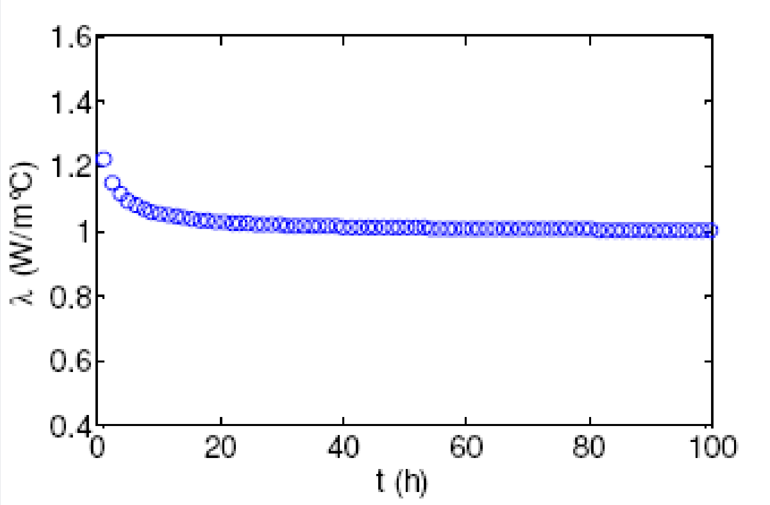
Results: Soil thermal conductivity



Case C

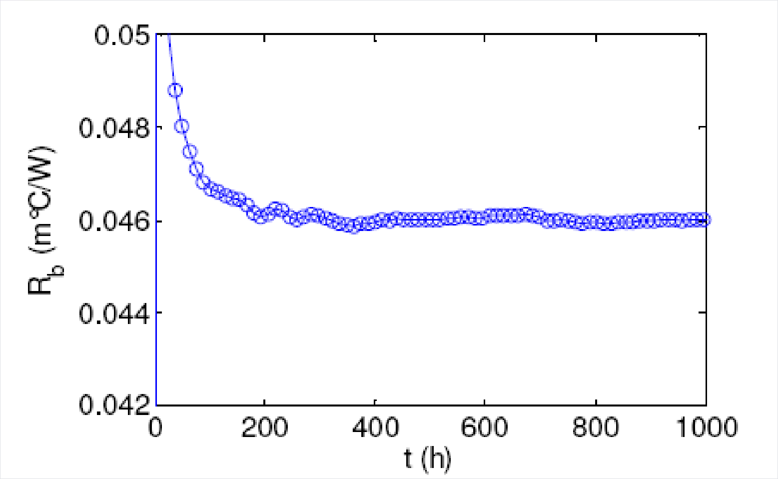
When considering the volumetric heat capacity non-homogeneity only, case C, the thermal conductivity is recovered exactly already after 10 hours after the beginning of the transient.

$$\lambda_{eq} = \frac{1}{H} \cdot \sum_i H_i \lambda_i$$



Case D

Results: Borehole thermal resistance

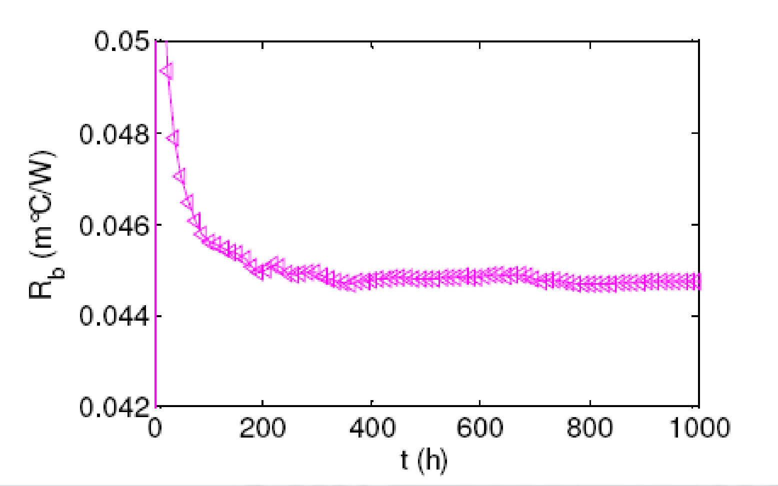


Case C

The borehole thermal resistance estimated according to the fitting procedure for cases C and D, describing respectively a non-homogenous and homogeneous soils with equal mean volumetric heat capacity for a given thermal conductivity value.

$$\alpha_{eq} = \frac{1}{H} \cdot \sum_i H_i \alpha_i$$

This approach provides a good approximation since, when the capacitive effects becomes negligible, the two asymptotic values assumed by the borehole thermal resistance of cases C and D differ by less than 3%.



Case D

Conclusions

In conclusion, the analysis confirms that, under certain hypothesis, the estimated properties resulting from the Thermal Response Test can be interpreted as effective values which approach the mean, weighted according to the soil composition, of the values characterizing the single ground layers.

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