Presented at the COMSOL Conference 2009 Milan

3D Simulation of the Thermal Response Test in a U-tube Borehole Heat Exchanger

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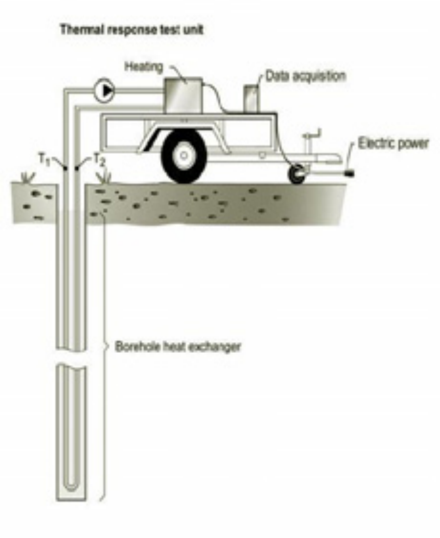
COMSOL CONFERENCE 2009
OCTOBER 14-16 2009, MILAN, ITALY

Thermal Response Test



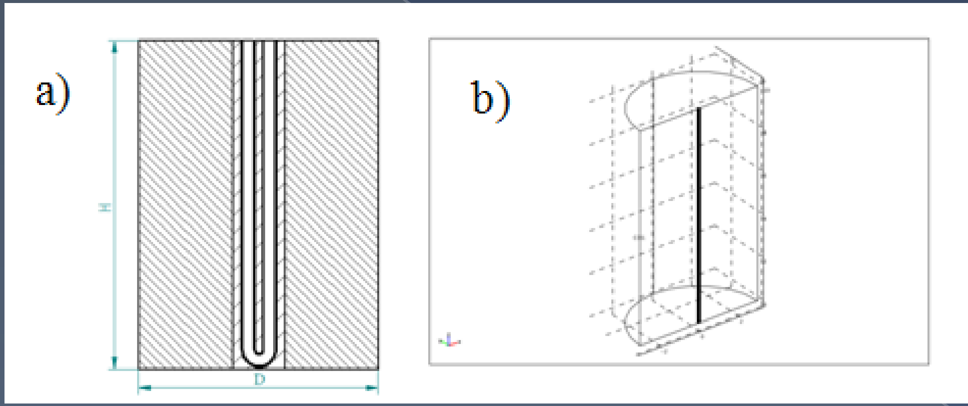
- Commonly used in GEOTHERMAL applications to restore the equivalent values of both the soil thermal conductivity (λ_{eq}) and the borehole thermal resistance (Rb_{eq}).

- The estimation procedure is based on the comparison of experimental TRT data with the solution of the equations describing the model's behaviour (i.e. Line Source Model, Cylinder Source Model).

Target

To discuss the capability of the Thermal Response Test based on the Line Source Model with regards to the characterization of borehole energy storage systems in real conditions of non-linear and non-uniform heat source.

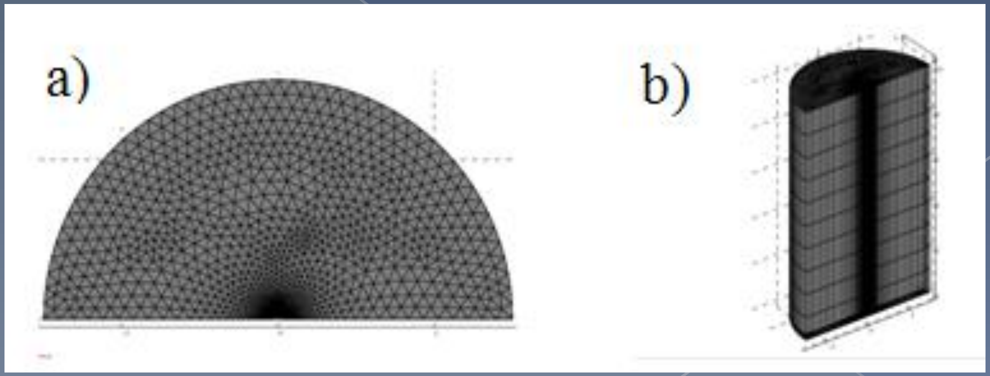
The simulated 3D geothermal energy storage system



Geothermal Energy Storage System's Geometry

3D transient conduction heat transfer problem within the soil, the borehole filling material and the HDPE tubes is coupled with the 1D convective problem within the carrier fluid

41080 prism meshing elements



a) Radial meshing; b) Axial meshing

Governing equations

$$\rho c_p \frac{\partial T}{\partial t} = \mathrm{div}(\lambda \nabla \mathrm{T})$$

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

$$-\lambda \frac{\partial T}{\partial r}\bigg|_{r=r_i} = h_o\left[T_{fluid}(z,t) - T(r_i,z,t)\right]$$ Boundary condition

Transient tri-dimensional heat transfer conduction governed by the Fourier equation is solved in the domain of the soil, the filling material and the HDPE tubes.

By assuming that the convection problem in both the tubes of the heat exchanger is one-dimensional

$$A\,\rho_f c_{pf}\left(\frac{\partial T_i}{\partial t} + u\,\frac{\partial T_i}{\partial z}\right) = h_o\left[T(r_i,z,t) - T_i(z,t)\right]$$

$T_i(z,0) = T_0$ Initial condition

Energy equation for the right-tube downward fluid flow

$$A\,\rho_f c_{pf}\left(\frac{\partial T_f}{\partial t} - u\,\frac{\partial T_f}{\partial z}\right) = h_o\left[T(r_i,z,t) - T_f(z,t)\right]$$

$T_f(z,0) = T_0$ Initial condition

Energy equation for the left-tube upward fluid flow

Governing equations (2)

The U-connection at the bottom of the pipe between the downward and upward fluid is here modelled by imposing for z=H that the mean temperature of the upward fluid equals the mean temperature of the downward fluid:

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

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

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

with ΔT constant over the whole temporal domain.

Results – Test Conditions

Main input data for the tested cases

Working Fluid Mass Flowrate	0.1 kg/s
Fluid density	1000 kg/m^3
Fluid specific heat	4186 J/(kg K)
Inlet-Oulet Fluid temperature difference	3.6 K
Convective Coefficient (Dittus-Boelter)	1960 W/(m^{2}K)
Soil density	1000 kg/m^3
Soil specific heat	2000 J/(kg K)
Soil thermal conductivity	**CASE A:** 2 W/(m K) **CASE B:** 3 W/(m K)
Fill density	1000 kg/m^3
Fill specific heat	1000 J/(kg K)
Fill thermal conductivity	0.9 W/(m K)
HDPE density	950 kg/m^3
HDPE specific heat	1900 J/(kg K)
HDPE thermal conductivity	0.48 W/(m K)

Results

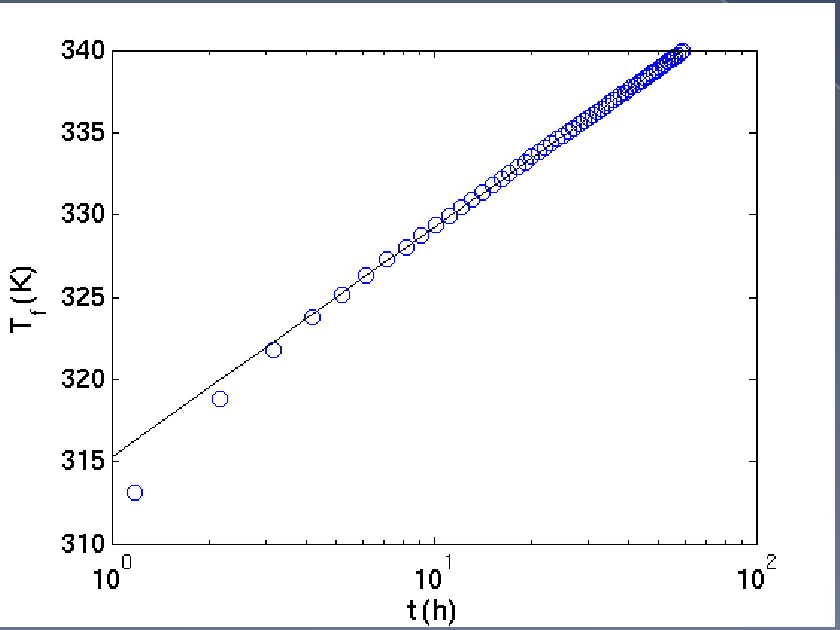
LINE SOURCE MODEL:

$T_f(t) = m + k \cdot \ln(t)$

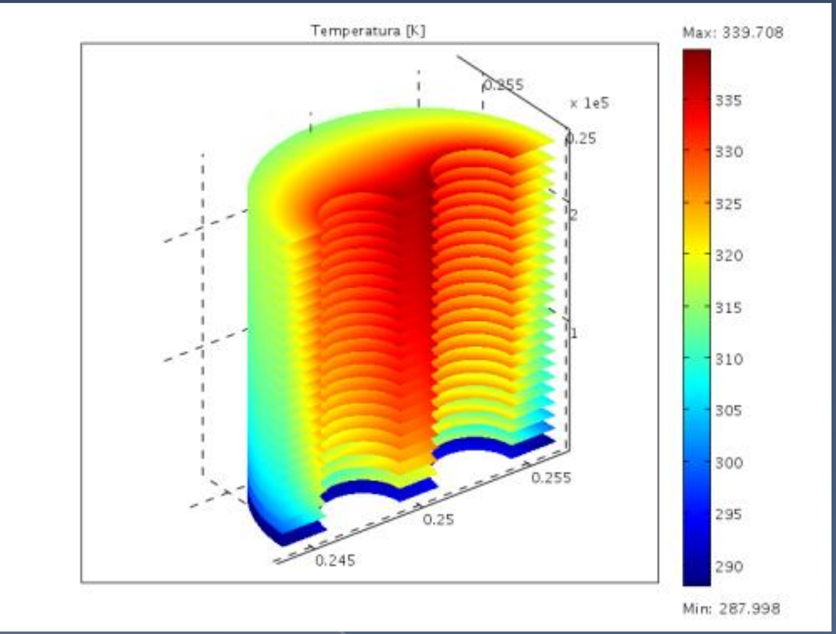
where:

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

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

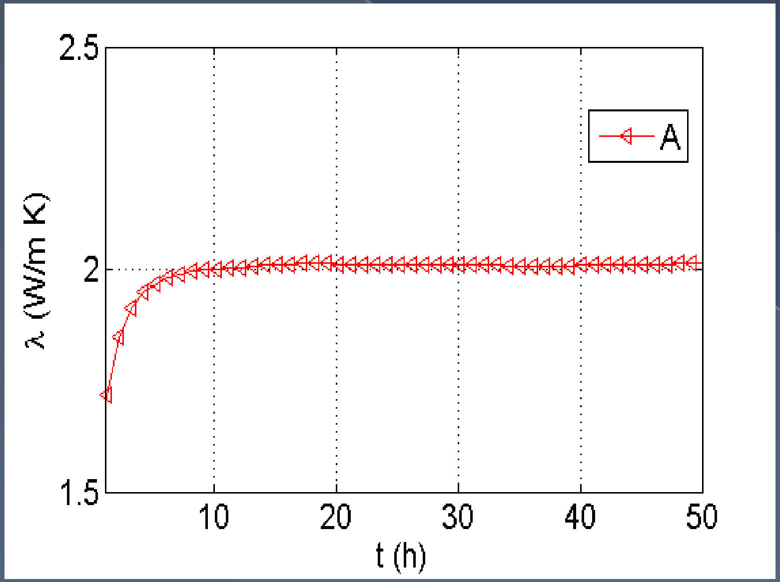


Average fluid temperature versus time for case A

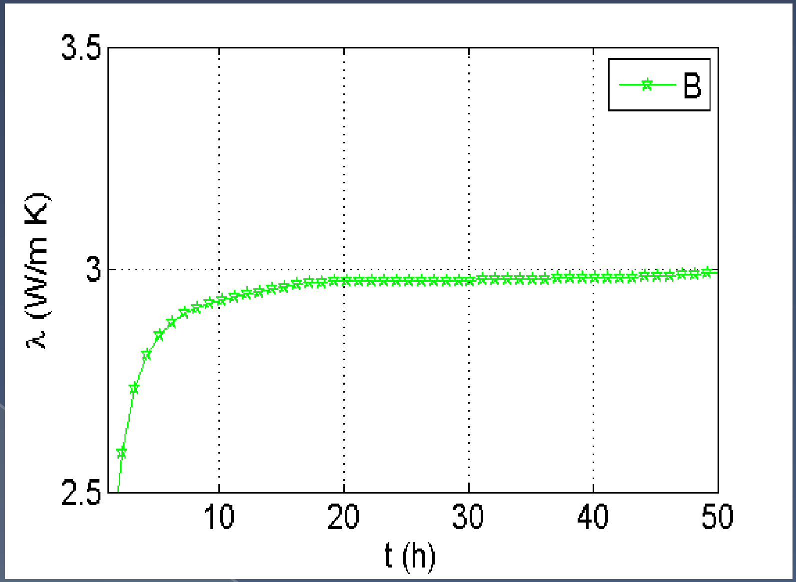


Temporal borehole temperature distribution at z=0

Results



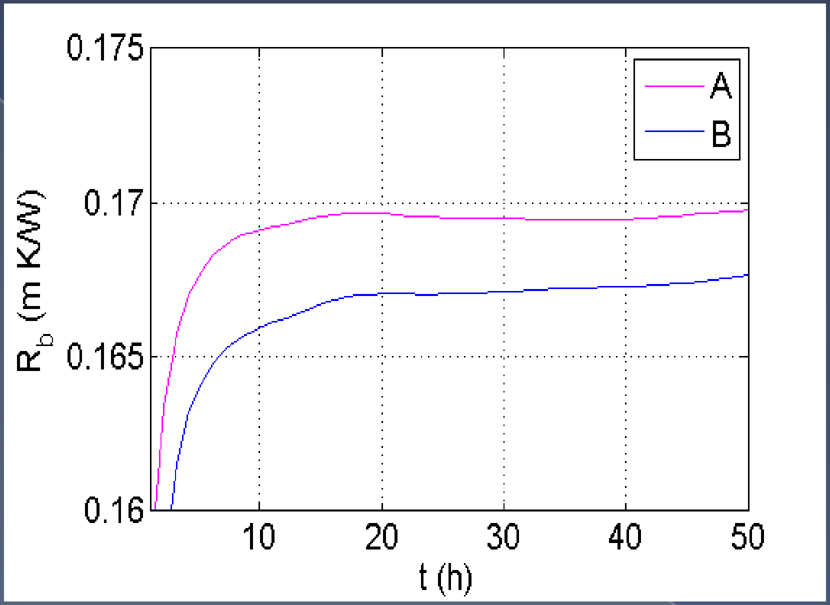
Estimated thermal conductivity for case A



Estimated thermal conductivity for case B

The Line Source Model satisfactory predicts the thermal conductivity of the soil, by restoring the parameter proper value already in the first 30 hours.

Results



Estimated borehole thermal resistance

- The two cases differ each other only for 1,5% for a variation of 50% of the soil thermal conductivity.
- They differ from the value numerically calculated in steady state regime for less than 5% (R_b=0.1625).

Conclusions

- The Line Source Model applied to the Thermal Response Test represents a sufficiently accurate approach also in the U-tube configuration.
- The 3D approach appears necessary when other more complex geometric configurations, or other phenomena have to be considered.