Thermal Response Test Use of a Borehole Heat Exchanger

ALEKSANDAR SALJNIKOV, DARKO GORIČANEC*,
DANIJELA DOBERŠEK*, JURIJ KROPE*, ĐORĐE KOZIĆ
Faculty of Mechanical Engineering,
University of Belgrade
Kraljice Marije 16, 11120 Belgrade 35,
SERBIA
* Faculty of Chemical Engineering,
University of Maribor
Smetanova 17, 2000 Maribor,
SLOVENIA

Abstract: - This paper outlines the determination of ground thermal properties by using a borehole heat exchanger and applying the thermal response test. Bedrock thermal conductivities and thermal resistance of the borehole heat exchanger were determined on the basis of the line source theory, which is recommended as simple and precise.

Keywords: Renewable energy, Geothermal energy, Heat Pumps, Borehole Heat Exchanger, Thermal Response Test

1 Introduction

Design of heat exchangers for underground use of thermal energy implies, beside the other parameters, knowledge on thermal properties of ground (thermal conductivity, thermal resistance of the borehole and temperature of the ground itself). Around the globe, various laboratory methods have been invented and used for determining these properties. An available effective method is - Thermal Response Test (TRT). Different results have been obtained related with the geographic position and composition of soil at given territories. TRT has been utilized since 1995, but the method itself, necessary equipment and the procedure are still being developed. For this method, stationary system was designed and constructed; later, in USA and Sweden, a mobile system was invented [1].

It was achieved by comparing the TRT method with the else common methods and stressing its merits. In the TRT itself, comparative analysis was performed on – Slope-Determining, Two-Parameter and Geothermal-Properties-Measurement – methods.

2 Methods for experimental determination of thermal conductivity λ

Determining the thermal conductivity *(λ)* and volume specific heat *(ρc_p)* is a complex task. Knowledge on both thermal properties is necessary for defining the depth and the number of boreholes when utilizing the software packages as GLHEPRO /Windows/ [2].

The following available methods for experimental determination of thermal conductivity λ can be used:

- soil and rock identification
- testing of drill cuttings
- using the *in situ* probes
- thermal response test (TRT).

2.1 Thermal response test

Performing the TRT in order to determine the thermal conductivity of ground, as well as thermal resistance of the borehole, was done in several countries and has yielded vastly different results depending on latitude, longitude, and soil composition at particular territory.

At Faculty of Mechanical Engineering, Beograd, currently a project is being realized that encompasses drilling the ground to 60 m in depth, and locating in the borehole a Borehole Heat Exchanger (BHE) i.e. a twofold U–pipe and eleven sensors (thermocouples), to measure temperature at eleven levels. In the goal to define the methodology of experimental determination of λ of ground.

3 Methodology of experimental determination of λ by using TRT

Reduction of data from the TRT is based on the Line Source Model (LSM). Ground heat conductivity and thermal resistance of the borehole are determined [3].

During the testing, that can last from one to seven days, temperature of surroundings and temperature of water at the BHE inlet and outlet are measured and on the basis of obtained results, thermal conductivity and thermal diffusivity are determined. Different types of BHE are tested as to determine the thermal resistance of the borehole.

Vertical borehole heat exchanger (BHE), globally considered, consists of three main components as it is shown in Figure 1 [4]:

- pipes (pipeline),
- hydro-insulation (bentonite) around the pipes,
- soil (ground) around the bentonite.

Besides these three components, figure shows the set-up that is connected with the mentioned U-pipe.

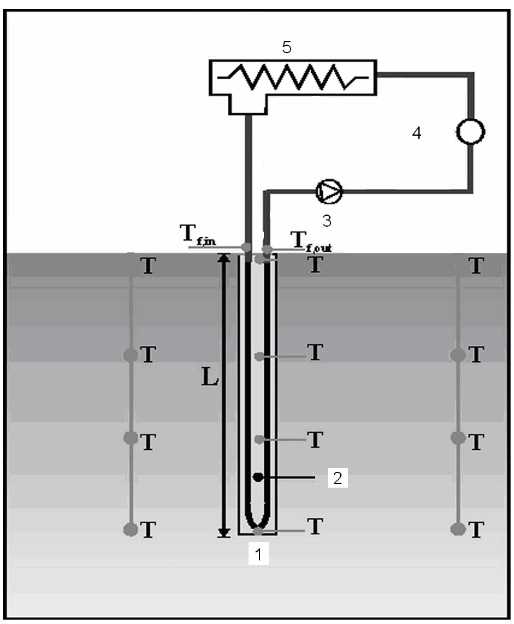

Figure 1: Schematic of the TRT test set-up (T-thermocouples; $T_{f,in}$, $T_{f,out}$-water intake and outflow temperatures; L-borehole depth; 1-borehole, 2-grout, 3-circulation pump, 4-flow meter, 5-electric heater) [5]

3.1 Line source model

The Line source model is based upon approximation of the borehole as a line source of heat, assuming that the inevitable errors of this approximation are small. When using this model one considers that initial soil temperature is constant, T_0. The fundamentals of the model had been set by J. Thomson (lord Kelvin) [3], by setting the so-called Kelvin's line source equation. This model is often used for determining soil thermal conductivity when dealing with vertical borehole heat exchangers. The general line source equation [5] that is used for computing the soil thermal conductivity is:

$$\Delta T_{(R,t)} = \frac{\dot{Q}}{4\pi\lambda L} \int_{\frac{r^2}{4at}}^{\infty} \frac{e^{-u}}{u} du \, . \quad (1)$$

Determination of effective ground thermal conductivity in given time, for approximately constant released heat and constant temperature change it can be established with equation:

$$\Delta T_{(R,t)} = \dot{Q} \cdot m_{TR} + \frac{\dot{Q}}{4\pi\lambda L}\left[\ln\left(\frac{4at}{R^2}\right) - C\right] + \frac{\dot{Q}}{4\pi\lambda L}\ln t \quad (2)$$

The first two terms at the right side of the equation do not change if the released heat is almost constant.

The only variable term is ln(t). The whole equation (2) is reduced to a simpler form by compressing the constants and ln(t) to a general linear form:

$$y = mx + b \quad (3)$$

where:
$y = \Delta T$ - temperature change,
b - constant in equation (3),
$m = Q/4a\lambda$, and $x = \ln t$.

A problem, often encountered in preparing the slope determination method using the experimental data, is - that for different time periods - one obtains different values of thermal conductivity.

3.2 Two variable parameters model

The ever increasing need for newer methods, for the determination of ground thermal properties, has led to some data adjustment where, as the most appropriate function, equation (2) is used - along the soil thermal conductivity and thermal resistance of the borehole. Therewith a new model was formed, of two variable parameters, for determining the main ground thermal properties. Analysis of these parameters is performed by using a commercial software "Origin 6" [6].

3.3 Cylindrical source model

The cylindrical source model is generally based upon approximating the U - pipe as a cylindric heat source [7]. For determination of ground thermal properties, the model uses a GPM code that has been developed at the Oak Ridge national laboratory. The code uses a data reduction method that is combined with a 1-D numerical model [8].

The cylindrical source model is conceived in the form of a cylindrical pipe, of given diameter and pipe wall thickness. Thermal resistances of the so formed model have the same value as the thermal resistances present in the real object (pipe).

The determination of thermal properties of ground (soil), by applying the cylindrical source model, starts with an equation, that is the analytical solution of the 2–D heat conduction equation:

$$\Delta T_g = T_{ff} - T_{ro} = \frac{q_{gc}}{\lambda_s L} G(z, p) \tag{4}$$

The variable quantities of „G" function in above stated equation (4), that is a relation for temperature change (temperature difference), can be determined from the relations that they are defined with:

$$z = \frac{a \cdot t}{r^2} \tag{5}$$

$$p = \frac{r}{r_0} \tag{6}$$

Obviously, the right side of the equation (5) is in fact the relation for the Fourier criterion. The form of equation (4) is a consequence of the assumed constant heat flux from the cylindrical heat source to the soil. However, because of the fact that in practice, during the experiments, it is not possible to attain a constant heat flux, equation (4) shall be modified and adjusted to the real conditions that are present in fact.

4 Slope determination method

By using the slope determination method the required thermal properties of soil are found. Time dependent quantities (measured during the method) are plotted in Fig. 2. The plot shows the behavior of variables that are used for data analysis. Changes of the input heat are obvious. As it is given by equation (3), thermal conductivity is interrelated with the slope of resulting line that is drawn on the plot of the average fluid temperature inside the RTB, with time as the abscissa.

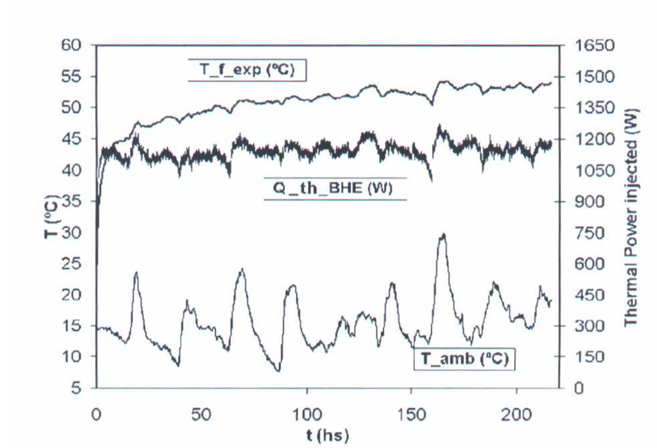

Figure 2: Time response of the system

Since during running this method the used values are roughly equal to real ones, only if observed in the lengthy time interval, the initial part of the gathered data is not considered. Thence, a TRT should not last less then the value of the following time criterion:

$$t \geq \frac{5r^2}{a} \tag{7}$$

5 Conclusion

Heat pump systems, using heat from the ground, for their economic feasibility and favorable influence onto the environment, can exert long term influence upon the energy policies of different countries.

Use of these systems reduces the consumption of fossil fuels for production of electric energy, as well as the level of flue gases (carbon-monoxide, carbon-dioxide, sulphur-dioxide and nitric oxides) emission.

If used widely globally, heat pump systems using heat from the ground could play vital role in reduction of pollution that leads to global warming.

Dimensioning such systems requires a knowledge on ground thermal properties that are determined by the Thermal Response Test (TRT) method.

Classical methods are simple and reliable. Accuracy of the results depends on the precision of conducting the TRT test (accuracy of temperature measurement, electricity supply of measuring apparatus, knowledge on ground temperature variation and - eliminating the meteorologic influences upon the system), and it is used because of its simplicity of application.

The measurement by using the mobile TRT set-up enables the determination of the required quantities *in situ*, and the Slope determination method yieldes satisfactory results. Based upon this, it is expected that TRT will become the standard procedure for determining ground thermal properties.

Nomenclature:

a	thermal diffusivity [m^2/s]
L	cylinder length [m]
m_{TR}	thermal resistance between the fluid and borehole wall [mK/W]
Q	heat flux on 1 m of borehole [W/m]
q	surface heat flux [W/m^2]
r	borehole radius [cm]
t	time [s]
T	temperature [°C]
$\Delta T_{(r,t)}$	temperature rise at radius r [°C]
$C = 0.5772$	Euler criterion [-]
λ	thermal conductivity [W/mK]
T_{ff}	temperature of the distant field,
T_{ro}	temperature of the cylinder wall,
T_g	temperature of ground,
q_{gc}	heat flux towards the ground,
λ_s	thermal conductivity of ground,

References:

[1] C. Eklöf, S. Gehlin *TED – A mobile equipment for thermal response test*, Master's Thesis 1996, Lulea University of Technology, Sweden

[2] Spitler, J.D., C. Marshall, R. Delahoussaye, M. Manicham. 1996. *Users Guide of GLHEPRO*, School of Mechanical and Aerospace Engineering, Oklahoma State University, Stillwater, OK

[3] Warren Adam Austin, *Development of an In Situ System for Measuring Ground Thermal Properties*, Ph D dissertation 1998, Oklahoma State University, Oklahoma, United States of America

[4] Saljnikov, A., Goričanec, D., Stipić, R., Krope, J., Kozić, Đ.: Design of an experimental test set-up for the thermal response test to be used in Serbia. *WSEAS transactions on heat and mass transfer*, Apr. 2006, vol. 1, iss. 4, pp. 481-487.

[5] A. Saljnikov, D. Goričanec, Đ. Kozić, J. Krope, R. Stipić: Choice of underground thermal energy storage system and thermal response test method to be used in Serbia. *WSEAS transactions on fluid mechanics*, June 2006, vol. 1, iss. 6, pp. 615-621

[6] Press, W., Flannery, B., Teukolsky, S., Vetterling, W., 1994. "*Numerical Recipes in FORTRAN- The Art of Scientific Computing*" (2nd Ed., pp. 436-448), New York: Press Syndicate of the University of Cambridge

[7] L.R. Ingersoll, O.J. Zobel, A.C. Ingersoll. 1948, 1954. *Heat Conduction with Engineering, Geological, and other Applications.* New York: McGraw-Hill

[8] P. Roth, A. Georgiev, A. Busso, E. Barrazza; First In Situ Determination of Ground Thermal Properties in Latin America, *Report of Department of Mechanical Engineering*, UTFSM, Valparaiso, Chille; Department of Physics, FaCENa, UNNE, Corrientes, Argentina, 2004