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Testul de răspuns termic pentru utilizarea eficientă a aplicațiilor geotermale în România

Thermal Response Test for the Efficient Use of Geothermal Applications in Romania

Virgil FLORESCU[1], Bahadir KIVANC[2], Tiberiu CATALINA[3]

[1] Technical University of Civil Engineering of Bucharest
122-124 Bvd Lacul Tei, Bucharest, Sector 2, Romania
E-mail: virgil.florescu@utcb.ro

2 Societatea Română Geoexchange,
str. Fabricilor nr. 2F, Oradea, Romania
E-mail: bahadir.kivanc@phd.utcb.ro

[3] Technical University of Civil Engineering of Bucharest
122-124 Bvd Lacul Tei, Bucharest, Sector 2, Romania

[3]Societatea Română Geoexchange,
str. Fabricilor nr. 2F, Oradea, Romania
E-mail: tiberiu.catalina@gmail.com

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Abstract. The Thermal Response Test – abbreviated as TRT – is a standardized procedure for geothermal heat pump systems with closed-loop heat exchangers. The test enables the determination of key physical properties of the ground – thermal conductivity and borehole thermal resistance – which are essential for the correct sizing of the ground heat exchanger system, ensuring it meets the requirements of the building's HVAC system. Additionally, the TRT provides valuable information regarding the technical and financial effort required for the drilling operation.

Keywords: Thermal Response Test, TRT, geothermal heat pumps, ground heat exchangers

1 Principle of the method

The thermal response test is performed for closed-loop heat exchangers. In most cases, the thermal response test is carried out by injecting or extracting a constant heat flux per unit length into the ground. Electric resistances (connected according to the borehole depth) are typically used to generate heat, as this method allows for easier monitoring of operating parameters. In some cases, a gas boiler can also be used. The

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thermal response of the ground is determined by measuring the temperature difference ΔT between the supply and return lines of the circuit. The average temperature of the fluid is:

$$T_b=(T_{wi}+T_{wo})/2 \tag{1}$$

The equation that describes the evolution of the average temperature T_b as a function of the thermal load after the heat generator is started is usually derived from the line source model and has the form:

$$T_b - T_0 = \frac{q}{4\pi\lambda} E\left(\frac{r_b^{\ 2} S_{VC}}{4\lambda t}\right) + qR_b \tag{2}$$

For large time values (t > 5–10 hours), the equation can be simplified to a logarithmic function, which is commonly used in the analysis of Thermal Response Test (TRT) data. The simplified form is:

$$T_b - T_0 = \frac{q}{4\pi\lambda}\left[\ln\left(\frac{4\lambda t}{S_{VC} r_b^{\ 2}}\right) - 0.5772\right] + qR_b \tag{3}$$

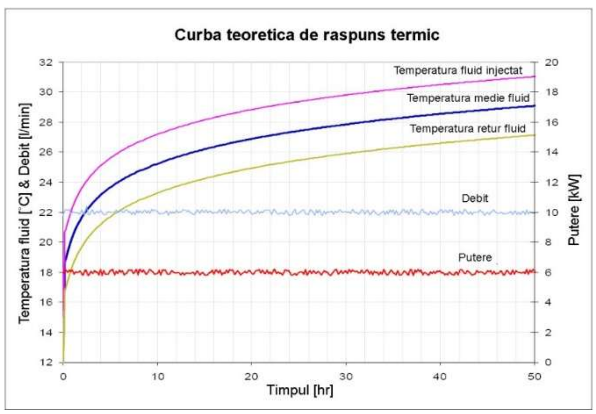


*Figure 1-1. **Parameters Monitored During the Thermal Response Test (TRT) [1]***

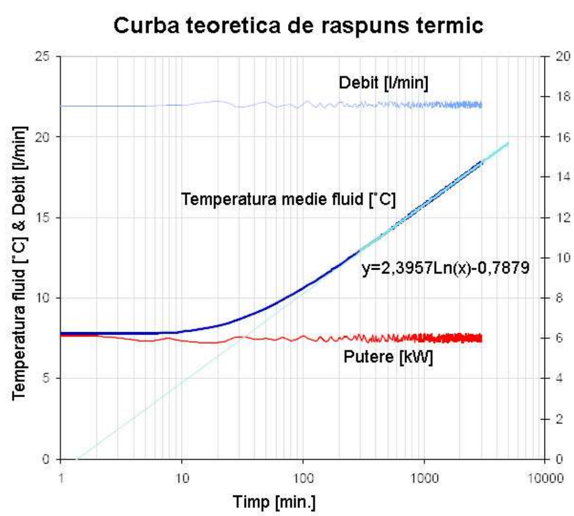


*Figure 1-2. **Theoretical Thermal Response Curve [1]***

The linear interpolation equation describing the variation of temperature as a function of the natural logarithm of time is:

$$y = A \ln(t) + B \qquad (4)$$

It can be observed that determining the coefficient A (the slope of the line) is sufficient to determine the thermal conductivity of the analyzed ground.

$$A = q / 4 \pi \lambda \qquad (5)$$

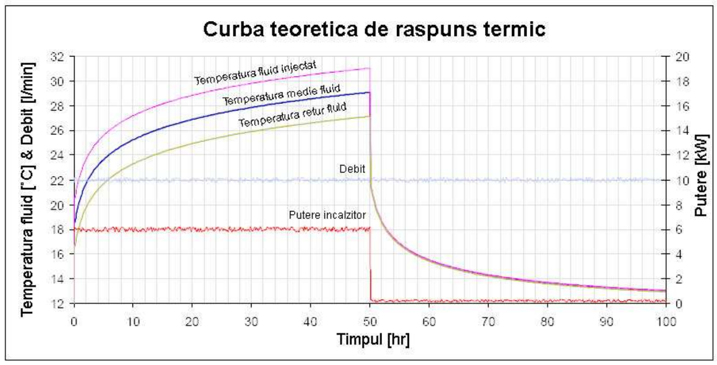


Figure 1-3. ***Theoretical thermal response curve after stopping the heating [1]***

The thermal response test provides the results:

- Thermal conductivity of the ground λ
- Thermal resistance of the borehole R_b
- Additionally, it provides the contractor with information regarding the level of effort required for the execution and outfitting of the borehole

In accordance with the guidelines related to TRT published by GSHPA (Ground Source Heat Pump Association) [2], ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers), and IEA (International Energy Agency), the Thermal Response Test must comply with the following conditions:

- Test duration over 36 hours (according to GSHPA), but preferably over 50 hours (according to IEA);
- Constant heat flux injected at a level of 50–80 W/m of borehole;
- Constant heat flux extracted at a level of 20–50 W/m of borehole;
- The fluid flow inside the heat exchanger pipes must occur under turbulent flow conditions;
- The test should be conducted at least 5 days after the completion of the drilling;
- The testing equipment should be placed as close as possible to the borehole, and the connections to its pipes must be thermally insulated to limit heat losses to a value below 2%;
- If the test needs to be repeated, it should be done after an interval of 10 to 14 days following the completion of the first test.

Forajul experimental realizat are adâncimea de 50 m, diametrul de 160 mm, și este dotat cu un schimbător de căldură cu pământul de tip double-U, conducta având diametrul de 32 mm.

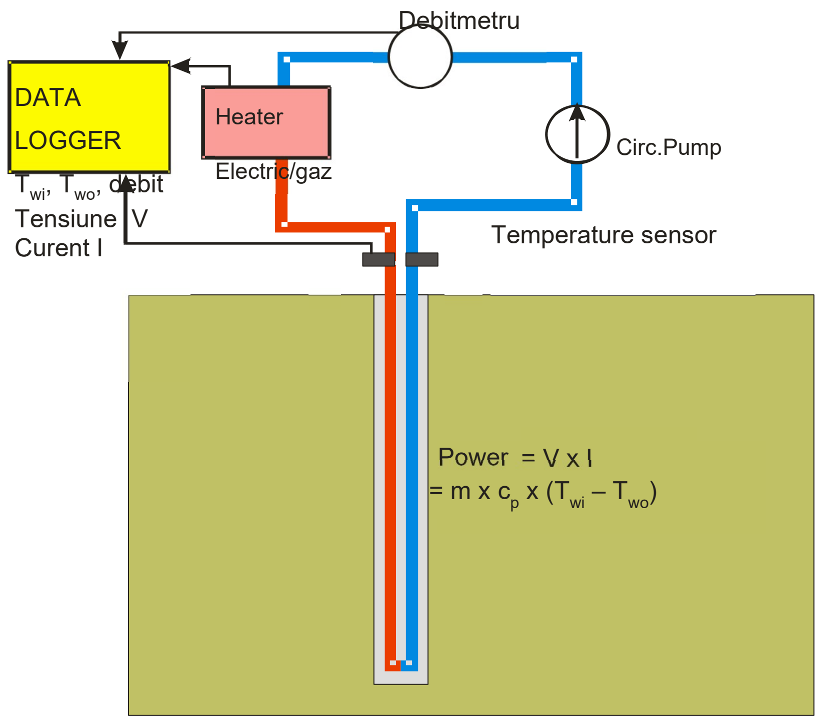


Figure 1-4. ***The principle of the Thermal Response Test [1]***

2 Experimental equipment

The determinations were carried out using the mobile geothermal laboratory – consisting of the following equipment:

- GeoCube – Portable unit for measuring thermal conductivity (TC), thermal response (TRT) for different soil types, as well as for determining the BTR factor (Borehole Thermal Resistance)
- 3x16 mm² cable for the electrical supply of the resistors in the GeoCube unit from an electrical panel located very close to the experiment;
- Specialized software – TC/TRT Software and Ground Loop Design Software.


Figure 2-1. ***GeoCube Equipment***

3 Drilling Equipment Used in the GEO4CIVHIC Project

To enable the installation of vertical heat exchangers in the built environment, the objectives of the drilling equipment were as follows:

- Capable of installing U-type, double U-type, and W-type heat exchangers
- Capable of accessing and operating in confined and small spaces in cities and villages
- Designed to have a minimal environmental footprint in terms of emissions and noise generated by the equipment
- Provides safe and less tiring conditions for rod operation (loading and unloading), as well as a user-friendly system for operating and handling the equipment

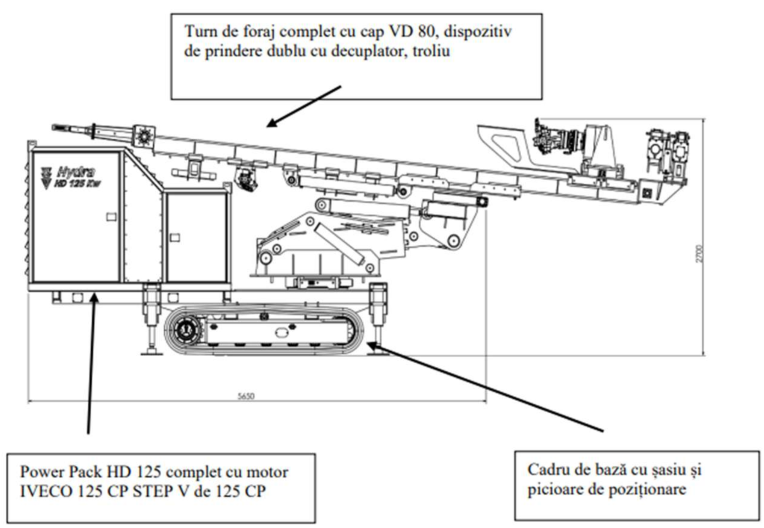


Figure 3-1. The main systems of the drilling machine are:

The main systems of the drilling machine are:

- **Drilling system** – includes the spindle, drill rods, drill bit, and rotation mechanism for the actual digging.
- **Feed and retract system** – allows the up and down movement of the drill rods and bit, controlling the drilling depth.

- **Hydraulic or pneumatic system** – provides the energy needed to operate the spindle, feed systems, and other components.
- **Cooling and lubrication system** – ensures cooling and lubrication of the drill bit and rods, usually by circulating drilling fluid (water or special solutions).
- **Cuttings removal system** – helps efficiently remove the excavated material (cuttings) from the borehole.
- **Control and monitoring system** – control panel, instruments for measuring depth, pressure, rotation, and other essential parameters.
- **Stabilization and positioning system** – ensures the stability of the drilling machine during operation, e.g., supports and anchors.

The equipment shown in Figure 3-1 is capable of drilling both vertically and horizontally at angles between 15º and 30º for the installation of coaxial probes, allowing the total length to increase substantially. Additionally, the mast can rotate 90º to the left or right. This feature enables the equipment to drill up to 3 meters to the left or right from the center of the machine. The drilling diameter used was 160 mm (Figure 3-2).

Figure 3-2Driling head 160 mm

With the new drilling method, during drilling in soils containing clay and sand, a bentonite-water mixture was used simultaneously as a composite material to stabilize the borehole walls (Figure 3-3).

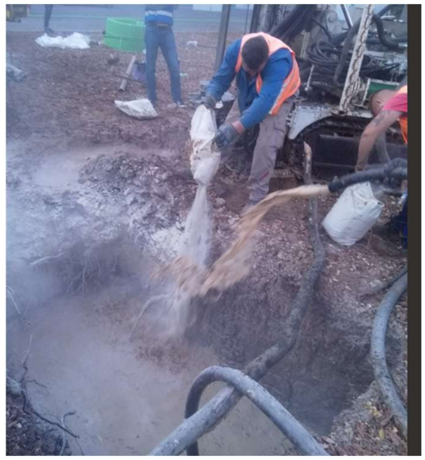


Figure 3-3. Bentonite and water mixture for borehole wall stabilization

In the below link, you can see all the steps carried out for the drilling and obtaining data about the thermal response test (TRT) performed at Romexpo. https://photos.google.com/share/AF1QipMgogCQOxrtWRME6q1OTayzJCe_ql9_ckC4uvkZ_jPhBJCcTOeP8nblC4SSI7BWbg?pli=1&key=bFBDWDVfTGE5Z04tSWpYTVRTZFh3NWlKTlo1bjln

4 In situ determination results

Following the processing of the experimental data, the following results were obtained:

- Thermal conductivity 1.71 [W/m*K]
- Thermal diffusivity 0.073 [m^2/zi]
- Average heat flux 49.2 [W/m]
- Borehole thermal resistance 0.19 [m*K/W]
- Average flow rate 0.61 [l/s]
- Test duration 12 [h]
- Calculation interval 1.5 – 13.5 [ore]
- Unperturbed ground temperature 12.9 [°C]

Thermal Conductivity Report **- 12/1/2019**

Project Name: Testare put 50 m RomExpo

Project Address: Dd. Marasti nr. 65-67

City: Bucuresti **State:** Romania **Zip:**

Prepared By:.Ing. Bahadir Kivanc

Email: bahadir.kivanc@phd.utcb.ro **Phone:** +40720 003 074

Drill Date 11/19/2019

TC Test Date(s) 11/25/2019 >> 11/29/2019

Client Name: UTCB

Address Line 1: Bd. Lacul Tei nr. 122-124

Address Line 2:

City: Romania **Phone:**

State: **Fax:**

Zip: **Email:**

Calculation Results

Thermal Conductivity (W/(m*K)) :	**1.71**
Thermal Diffusivity (est.) (m^2/ day) :	**0.073**
Average Heat Flux (W/m) :	**49.2**
BH Thermal Resist (BTR) (m*K/W) :	**0.19**
Average Flow Rate (L/s) :	**0.61**
Test Duration (hr) :	**12**
Calculation Interval :	**1.5 - 13.5 Hours**

Borehole Input Parameters

Undisturbed Ground Temperature (°C) :	**12.9**	(Auto-Estimated)
Depth (m) :	**50**	
Borehole Diameter (mm) :	**160.0**	
Pipe Size:	**1 1/4 in. (32 mm)**	
Grout Thermal Conductivity (W/(m*K)) :	**2.10**	
Drilling Method :	**Standard**	
Drilling Time (hr) :	**10.0**	

Diffusivity Input Parameters

Soil/Rock Specific Heat - Dry (kJ/(K*kg)) :	**0.837**
Soil/Rock Density - Dry (kg/m^3) :	**1601.8**
Moisture (0-100) (%) :	**15.0**

Flow Rate Input Parameters

TC Unit Model Name	**GeoCube Standard**

Figure 4-1. Geocube final results

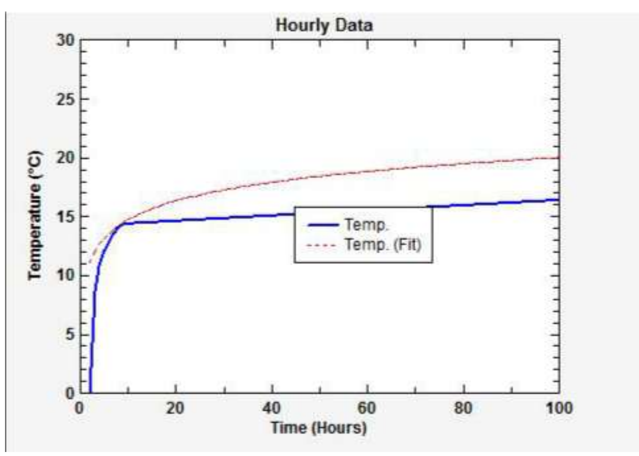
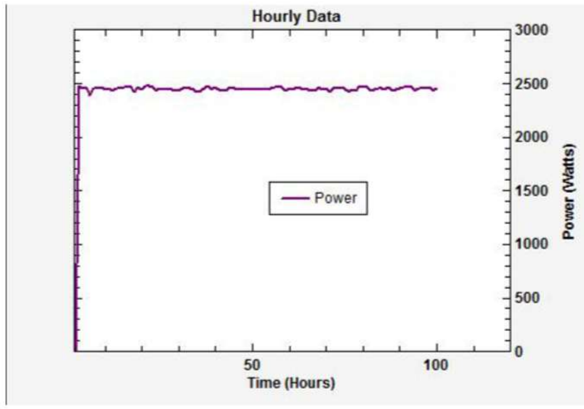
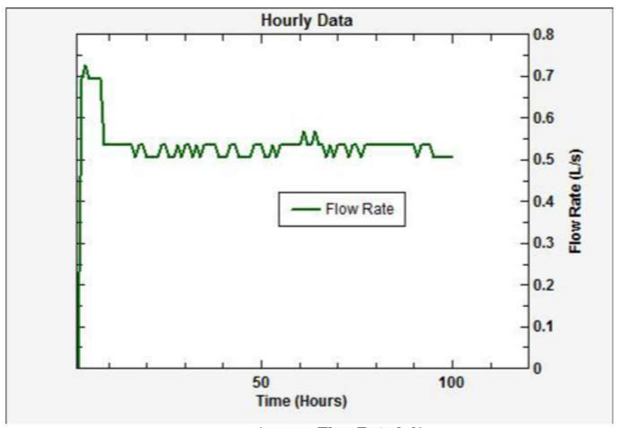


Figure 4-2. Variation of temperature in the borehole during the TRT (Thermal Response Test)



Average Power 2457.8 Watts

Figure 4-3. Variation of the injected power in the borehole during the TRT (Thermal Response Test)



Average Flow Rate 0.61

Figure 4-4. Variation of the flow rate during the Thermal Response Test (TRT)

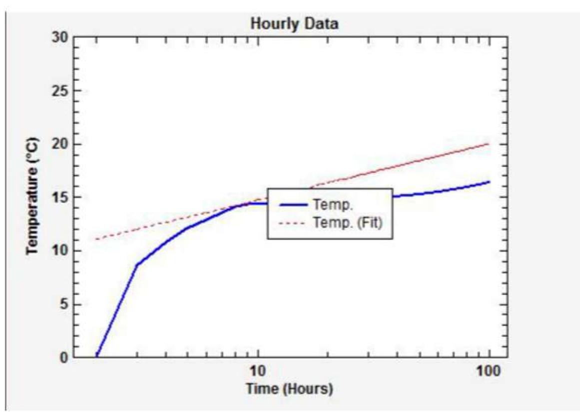


Figure 4-5. Variation of temperature as a function of the natural logarithm of time during the Thermal Response Test (TRT)

5 Conclusions

The in situ measured value of the thermal conductivity – 1.71 [W/m·K] – represents an average value over the depth of the 50-meter lithological column (up to which the test borehole was drilled). According to [5], this lithological column is composed of the following layers:

- Layer of topsoil
- Layer of Bucharest clays
- Layer of Colentina sands and gravels
- Layer of intermediate clays
- Layer of intermediate sands

If the sizing calculation of the ground heat exchanger were to be performed based solely on the thermal conductivity values extracted from Table 1, the degree of uncertainty in the results would be extremely high, as the range of thermal conductivity values is very wide, spanning from 0.4 [W/m_K] (for dry sand) to 2.4 [W/m_K] (for saturated clay and sand). The calculation error for the total required length of the ground heat exchanger is approximately ±10%, an error which may lead to the following consequences:

- **Undersizing of the ground heat exchanger** – if the thermal conductivity of the ground is assumed to be greater than 1.71 [W/m*K] – leading to immediate effects such as the failure to meet the technical and comfort parameters of the HVAC system based on geothermal heat pumps, or, conversely...
- **Oversizing of the ground heat exchanger** – if the thermal conductivity of the ground is assumed to be less than 1.71 [W/m*K] – resulting in immediate effects such as increased costs for its installation by tens, or even hundreds of thousands of euros, depending on the installed capacity of the HVAC system based on geothermal heat pumps.

Tabel 1.

Thermal conductivity and specific heat capacity according to VDI 4640 [4]

	Type of rock	Thermal conductivity [W/m.K]		Specific heat capacity [kWh/m³.K]	Density [10³ g/m³]
		Range	Recommended value		
Unconsolidated	Dry clay/silt	0,4÷1,0	0,5	0,42÷0,44	1,8÷2,0
	Saturated clay/silt	1,1÷3,1	1,8	0,55÷0,78	2,0÷2,2
	Dry sand	0,3÷0,9	0,4	0,36÷0,44	1,8÷2,2
	Wet sand	1,0÷1,9	1,4	0,28÷0,61	1,9÷2,2

	Type of rock	Thermal conductivity [W/m.K]		Specific heat capacity [kWh/m³.K]	Density [10³ g/m³]
		Range	Recommended value		
	Saturated sand	2,0÷3,0	2,4	0,61÷0,78	1,9÷2,3
	Gravel/cobble, dry	0,4÷0,9	0,4	0,36÷0,44	18÷2,2
	Gravel/cobble, saturated	1,6÷2,5	1,8	0,61÷0,72	1,9÷2,3
	Fill/clay (fat clay)	1,1÷2,9	2,4	0,42÷0,69	1,8÷2,3
	Peat/weak lignite (woody brown coal)	0,2÷0,7	0,4	0,14÷1,06	0,5÷1,1
Sedimentary rocks	Clay/silty (fine sandstone)	1,1÷3,4	2,2	0,58÷0,67	2,4÷2,6
	Sandstone	1,9÷4,6	2,8	0,50÷0,72	2,2÷2,7
	Conglomerate/ breccia	1,3÷5,1	2,3	0,50÷0,72	2,2÷2,7
	Marna	1,8÷2,9	2,3	0,61÷0,64	2,3÷2,6
	Limestone	2,0÷3,9	2,7	0,58÷0,67	2,4÷2,7
	Dolomite	3,0÷5,0	3,5	0,58÷0,67	2,4÷2,7
	Dolomitic rocks (anhydrite)	1,5÷7,7	4,1	0,55	2,8÷3,0
	Dolomitic rocks (gypsum)	1,3÷2,8	1,6	0,55	2,2÷2,4

Thermal Response Test (TRT) is therefore recommended for geothermal heat pump systems with a total thermal power greater than 50 kW, allowing the acquisition of real technical information directly from the project implementation site. Performing the TRT can save significant financial resources—both by avoiding unnecessary additional drilling and by meeting the heating and cooling demands of the consumer with high energy efficiency.

The in-situ results obtained through the TRT must be used with great caution, as practical implementations need to correspond to the physico-mathematical model used for interpreting the experimental results from the TRT. Since the experimentally determined thermal conductivity represents an average value over the entire borehole length, this value can be applied for similar depths of ground heat exchangers. Also, the borehole thermal resistance value cannot be extrapolated to energy piles, because the boundary geometric conditions differ due to the different length-to-diameter ratio, and the applicable physico-mathematical model is that of an infinite cylindrical sourceunlike ground heat exchangers where the physico-mathematical model used is that of an infinite line source.

6 Standard Finite Line Source Model (FLS) (H.S. Carslaw, J.C. Jaeger, 1959)

Traditionally, heat transfer in the porous soil medium without groundwater flow is described by the heat conduction equation as follows (H.S. Carslaw, J.C. Jaeger, 1959):

$$\rho c \frac{\delta T}{\delta t} - \nabla * (\lambda \nabla T) = 0 \qquad (6.1)$$

where:

- ρ is the density of the soil [kg/m³],
- c is the specific heat capacity of the soil [J/kg·K],
- T is the temperature [°C or K],
- t is time [s],
- k is the thermal conductivity of the soil [W/m·K],
- Q is the internal heat source term [W/m³].

$$\rho c = n\rho_w c_w + (1-n)\rho_s c_s \qquad (6.2)$$

λ – Thermal conductivity [W/m·K]
ρc – Volumetric heat capacity of the porous medium
$\rho_s c_s$ – Weighted average of the solids in the aquifer medium
$\rho_w c_w$ – Weighted average of the water in the aquifer medium

The solution of the partial differential equation for heat transfer from a source in a porous medium with an initial uniform temperature T_0 is given by the relation:

$$\Delta T(x, y, z, t) = \frac{Q}{4\pi\lambda} erfc\left[\frac{r}{\sqrt{4at}}\right] \qquad (6.3)$$

The temperature difference in the borehole, ΔT=T0−T, where T0 is the initial uniform temperature and T is the local temperature, is related to the heat Q extracted or injected from the borehole. The thermal diffusivity is defined as (a=$\frac{\lambda}{\rho c}$), where λ is the thermal conductivity and ρc is the volumetric heat capacity of the porous medium. The distance $r = \sqrt{x^2 + y^2 + (z - z')^2}$ to the heat source, located along the z-axis at coordinates (0,0, z′)

The Finite Line Source (FLS) model can be expressed as follows (H.Y. Zeng, N.R. Diao, Z.H. Fang, 2002): (D. Marcotte, P. Pasquier, F. Sheriff, M. Bernier, 2010), (L. Lamarche, B. Beauchamp, 2007).[6],[7]

$$\Delta T_{FLS}(x, y, z, t) = \frac{q_L}{4\pi}\left[\int_0^H \frac{1}{r} erfc \frac{1}{\sqrt{4at}} dz' - \int_{-H}^0 \frac{1}{r} erfc \frac{r}{\sqrt{4at}} dz'\right] \qquad (6.4)$$

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