Geothermics 61 (2016) 1–11

Contents lists available at ScienceDirect

Geothermics

journal homepage: www.elsevier.com/locate/geothermics

Comparison of different methods for ground thermal properties determination in a clastic sedimentary environment

Vladimir Soldo[a,*], Staša Borović[b], Leon Lepoša[a], Luka Boban[a]

[a] University of Zagreb—Faculty of Mechanical Engineering and Naval Architecture, Ivana Lucica 5, HR-10000 Zagreb, Croatia
[b] Croatian Geological Survey, Sachsova 2, HR-10000 Zagreb, Croatia

ARTICLE INFO

Article history:
Received 19 June 2015
Received in revised form 27 August 2015
Accepted 28 December 2015

Keywords:
Ground thermal properties
Thermal response test
Distributed thermal response test
Direct thermal properties measurement
Borehole heat exchanger
Clastic sediment

ABSTRACT

Energy Strategy of the Republic of Croatia by 2020 relies on renewable energy resources as one of the main priorities. The use of geothermal energy sources is specifically encouraged. Within the research project "Research and the Promotion of the Use of Shallow Geothermal Potential in Croatia", an improved method, the so called distributed thermal response test (DTRT) has been applied on a 100 m deep borehole heat exchanger (double U pipe) within a borehole of 152 mm outer diameter. The fundamental difference from the thermal response test (TRT) is the measurement of the carrier fluid temperature along the borehole heat exchanger (BHE) using an optic fiber cable placed inside the BHE pipes. Hence, in DTRT vertical distribution of the ground thermal conductivity and borehole thermal resistance are determined along the borehole heat exchanger. The undisturbed ground temperature profile along the BHE was also determined using this method. The work presented in this paper shows measurements from the borehole heat exchanger installation located in the city of Osijek, and determination of the ground thermal conductivity for specific geological settings using three different approaches: DTRT, TRT and direct measurement of sediment thermal properties. In a fluvial sedimentary sequence found in Osijek the discrepancy of DTRT and TRT results are 3.65% for thermal conductivity and 2.25% for borehole thermal resistance, while comparison of weighted averaged ground thermal conductivity results of DTRT and the direct thermal measurement yielded difference of 8.74%.

1. Introduction

Heat pumps coupled with closed-loop borehole heat exchangers (BHE) have been investigated theoretically and experimentally in the past few decades. Numerous reports show that such systems should be designed using complex mathematical simulations (Deroute et al., 2015; Eskilson, 1987; Ruševljan et al., 2009) that have to be performed not only for peak building loads, but also for building loads that are calculated throughout the whole year. The long-term (years and decades) performance of BHEs is highly dependent on the balance between heat extraction during the heating period and heat injection into the ground surrounding the borehole during the cooling period (Luo et al., 2015).

Theoretical models are mostly based on the assumption of a homogeneous and isotropic ground, which rarely occurs in reality. Thermal processes between BHE and the ground can be better interpreted if the undisturbed ground temperature and the borehole wall temperature are measured. Different methods and reports on measurements of the temperature along the BHE are available in literature (Esen et al., 2009; Gao et al., 2006; Soldo et al., 2011). Martos et al. (2011) presented a novel sensors system based on autonomous wireless sensors to measure the temperature of the heat transfer fluid along a borehole heat exchanger. Ouzzane et al. (2015) have developed two different correlations for the undisturbed ground temperature prediction. Fujii et al. (2006, 2009), Acuña et al. (2008) and Acuña and Palm (2008, 2010) presented a new technique for the measurement of temperature in the boreholes: fiber optic cables for measuring the temperature of the heat carrier fluid, groundwater and the borehole wall, are installed along the test boreholes. The biggest advantage of using optic cables is the possibility of measuring fluid temperature in intervals of up to one meter along the full length of the borehole, and estimating the local thermal conductivity along the length of BHE.

For many years the performance of BHEs as well as the determination of thermal conductivity of the ground and borehole thermal resistance have been evaluated by the thermal response test—TRT (Gehlin, 2002; Gehlin and Hellström, 2003; Sanner et al., 2005,

* Corresponding author.
E-mail addresses: vladimir.soldo@fsb.hr (V. Soldo), sborovic@hgi-cgs.hr (S. Borović), leon.leposa@fsb.hr (L. Lepoša), lboban@fsb.hr (L. Boban).

http://dx.doi.org/10.1016/j.geothermics.2015.12.010
0375-6505/

Nomenclature

a	Ground thermal diffusivity (m^2/s)
c	Specific heat capacity (J/(kgK))
C_ρ	Volumetric heat capacity ($MJ/(m^3K)$)
q	Heat injection rate per length of the borehole (W/m)
r	Radial distance (m)
R_b	Borehole thermal resistance (K m/W)
t	Time (s)
v	Volumetric flow rate (m^3/s)

Greek symbols

γ	Eulers constant, ($\approx$ 0,5772)
ϑ_f	Fluid temperature (°C)
ϑ_o	Undisturbed ground temperature (°C)
$\Delta\vartheta_s$	Section fluid temperature difference (°C)
λ	Ground thermal conductivity (W/(m K))
ρ	Fluid density (kg/m^3)
σ	Standard deviation (−)

2007, 2013), although alternative indirect methods have been proposed (Rohner et al., 2005, 2008). Alonso-Sánchez et al. (2012) applied the gamma ray log combined with needle probe for determination of ground thermal properties. Moghaddam and Bårman (2015), Raymond and Lamarche (2014) and Raymond et al. (2015) have recently showed a novel thermal response test using heating cables.

In this research an improved method for evaluation of local thermal conductivity in the ground and thermal resistance of a borehole heat exchanger was used, in order to make further investigations. The method is known as distributed thermal response test (DTRT) (Acuña et al., 2008; Soldo et al., 2015) and enables the measurement of undisturbed and disturbed ground temperature profiles along the BHE using optic fiber cables. Geological supervision was performed along with drilling procedure of a 100 m deep experimental borehole and installation of optic fiber cables. Soil sampling and ground properties determination were carried out in order to determine geothermal potential and thermal properties of shallow geological formations in characteristic regions throughout the Republic of Croatia. The work presented in this paper shows measurements from the borehole heat exchanger installation located in the city of Osijek, Croatia, and determination of ground thermal properties for specific geological settings using three different approaches.

2. Geographical and geological settings

Croatia is situated at the junction of major European tectonic units: the Dinarides and the Pannonian Basin System (PBS). It is distinctively divided into northeastern Pannonian part and the southwestern Dinaridic part (Fig. 1a). Northeastern part of Croatia represents the south-western margin of the Pannonian Basin System (PBS), and the majority of Croatian deep geothermal potential is concentrated there. It is characterized by a high average geothermal gradient (49 °C/km) and surface heat flow (76 mW/m^2). In comparison, the Dinaridic part has a low average geothermal gradient (18 °C/km) and surface heat flow (29 mW/m^2) (EIHP, 1998).

However, shallow geothermal potential does not have to be congruent with conventional, i.e., deep geothermal characteristics because boreholes for ground-source heat pump utilization are usually drilled to a depth of 100 m, which is why that borehole depth was chosen in the scope of the project. Relevant thermal parameters for utilization of ground-coupled heat pumps also vary between the Pannonian and the Dinaridic parts of Croatia. The Pannonian part is characterized by a several kilometers thick clastic sedimentary sequences of Paratethys (Velić et al., 2012), while the Dinaridic part is dominated by thick platform carbonate sequences, mostly limestone (Korbar, 2009).

In accordance with diverse genesis and lithology of the regions, different ground thermal parameters were also anticipated. As mentioned in the introduction, the borehole in which the research was conducted is situated in Osijek, a city on the Drava River bank (Fig. 1b). Both Drava and nearby Danube River are large meandering rivers and the geological conditions found in a 100 m deep borehole are a product of such sedimentary environment. According to Magaš (1987a,b), the total surface area of Osijek city is covered by Pleistocene loess sediments (sandy silt, clay and clay with organic material) up to a maximum depth of 12 m.

Middle to Upper Pleistocene sediments are found below those deposits. During exploratory drilling for hydrocarbon research their thickness was determined to be around 800 m. They consist predominantly of sand with thin clay intercalations in the deeper parts. Gravel occurrences have also been found. All of those characteristics suggest a high energy fluvial environment (Jagačić, 1963). This type of sedimentary environment is exemplified in Fig. 2 where the main sedimentary forms are visible. Typical channel sediments consist of bedload (gravels and sands), while the floodplain and oxbow lakes consist mostly of suspended load (finer particle sediments—clay and silt), with a lot of carbonized and non-carbonized organic matter (e.g., wood fragments, peat, coal). Based on previous research and known regional geological settings, all of the mentioned sediments were expected to be found in the Osijek borehole, since it is known that the sedimentation in such environments is laterally and vertically variable due to river channel migration (Allen, 1992).

Deeper geological formations will not be described here, since they are seated too deeply to be relevant in the context of borehole heat exchanger installations.

3. Methodology

3.1. The borehole heat exchanger installation

As a part of the implementation of the project titled "Research and the Promotion of the Use of Shallow Geothermal Potential in Croatia", a 100 m deep test borehole with the outer diameter of 152 mm was drilled next to the Technical school Osijek (Table 1). During the drilling, core determination and thermal parameter measurements were carried out.

Together with the BHE in the form of a double polyethylene U-pipe (32 × 2.9 mm), the optic fiber cable was inserted into the borehole (Table 1, Fig. 3). The vertical position of the heat exchanger in the borehole has been ensured using a steel tube which was inserted between the pipes of the heat exchanger and connected to the weight during the probe installation. Steel tube was also used as an injection tube for borehole grouting. The spacers were placed at distances of 2 m in order to center the probe in the borehole and to maintain the distance between the PE pipes.

After the installation of borehole heat exchanger and optic fiber cables, the borehole was filled with grouting material manufac-

Table 1
Borehole characteristics.

Borehole depth (m)	100
Borehole radius (mm)	152
Heat exchanger type	Double U-pipe, PEHD 100
Outer pipe diameter (mm)	32
Inner pipe diameter (mm)	26.2
Grouting material	GeoSolid 235 (Fischer)
Carrier fluid	Water