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Research paper

The influence of the ground coupled heat pump's labor on the ground temperature in the boreholes – Study based on experimental data

Natalia Fidorów*, Małgorzata Szulgowska-Zgrzywa [1]

Chair of Air Conditioning, Heating, Gas Engineering and Air Protection (W7/K3), Faculty of Environmental Engineering, Wrocław University of Technology, Norwida Str. 4/6, 50-373, Wrocław, Poland

HIGHLIGHTS

- Whole year monitoring of ground coupled heat pump boreholes has been conducted.
- During heating season the boreholes cooled down by 0.3 K–1.1 K on average.
- In the summer two among five boreholes have been actively regenerated.
- Temperature of borehole regenerated by solar collectors has risen by 0.2 K.
- Temperature of borehole regenerated by free-cooling has returned to prior state.

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ABSTRACT

The paper presents the results of observations made during whole year monitoring of the temperature of the 78 m deep boreholes. The boreholes serve as lower heat source for ground coupled heat pump used as one of heating sources in Energy Technology Center in Świdnica (Poland). Two of those boreholes were regenerated during warm season by free-cooling system and heat from solar collectors. It has been observed that the boreholes temperature changes along with the outdoor temperature changes during heat pump labor. During the heating season the heat source has cooled down by 0.3–1.1 K in comparison to the starting point. The temperature of non-regenerated borehole was lower by 0.4 K in the beginning of the next heating season in comparison to the former one. The temperature of borehole regenerated by free-cooling (63% of returned energy) has been kept the same, and the temperature of borehole regenerated by solar collectors (99% of returned energy) has risen by 0.2 K in comparison to the point before former heating season.

1. Introduction

Heat pumps are nowadays commonly used for heating and cooling in residential, commercial and public buildings. In this article issues concerning ground as an energy source, are discussed. The most popular way of extracting heat from the ground is to use the vertical or horizontal ground heat exchanger with intermediary agent. Vertical heat exchangers are usually boreholes between 15 and 180 m deep filled with solid medium (for example bentonite) with high-density polyethylene pipes joined together at the bottom [1]. According to the sources [1–3] ground is a suitable source for heat pump based heating sources. The vertical heat exchangers distinguish itself with practically constant flow temperature in short periods and only slightly changeable flow temperature during heating season [4]. Boreholes may be used for cooling purposes and act as an energy sink for a heat pump or free-cooling system [5]. In climatic conditions of most European countries the temperature of the ground changes seasonally near the surface because of the atmospheric influences, it becomes more stabilized with the depth and remains constant from about 10 to 15 m underground [3,6]. During the heat pump operation the temperature of the ground fall or rise around the heat exchanger as the boreholes might be used for both heating and cooling. If the thermal balance of the source is not to be disturbed, the ground should return to the previous state by the influences of surrounding environment or the geothermal energy. If the level of energy extraction is high, it is right to load the

* Corresponding author. Tel.: +48 71 320 31 09; fax: +48 71 320 35 32.
E-mail addresses: natalia.fidorow@pwr.edu.pl (N. Fidorów), malgorzata.szulgowska@pwr.edu.pl (M. Szulgowska-Zgrzywa).
[1] Tel.: +48 71 320 31 09; fax: +48 71 320 35 32.

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Nomenclature

B1, B3, B5	borehole number 1, 3 and 5
COP	coefficient of performance
Q	energy, kWh
R	yearly active regeneration coefficient of borehole
TB1, TB3, TB5	the temperature of borehole no 1, 3 and 5, °C
TS(2) − TS(77)	the temperature sensor located at the specified depth (in meters) of borehole, °C
T	temperature, °C

Greek symbols

Δ	difference
η	temperature efficiency of borehole regeneration
τ	date

Subscripts

avg	average
e	external
HP	heat pump
G	energy taken from the ground
R	energy transferred to the ground
I	first period of analysis
II	second period of analysis
m	number of ground sensor

boreholes, for example with energy from sun, while they are not operated for heating [3]. Depending on the source authors claim that after the period of initial quick temperature changes, the ground will achieve new balance state and the source would not "thermally collapse" [6] or the borehole temperature will be changing during whole period of exploitation and the balance will be established if the energy is alternately extracted and delivered to the ground [7] and that the thermal imbalance of the source is not desirable [8,9]. Regardless, all authors agree that the lower the source temperature, the worse the heat pump performance for heating and avoiding ground cool down brings the benefits. Heat exchange around the borehole is complex and depends on simultaneous processes. First of them is the significant temperature drop in the nearest surrounding of borehole during heat pump performance. Then the radial ground cooling occurs in the distance of a few meters around the borehole forming the temperature funnel and the global ground exchangers area cooling down happens on the substantial distance of 10 or more meters while long exploitation (25–30 years) [6,7].

There are few sources presenting measured temperature profiles in boreholes serving as heat sources, especially during the heat pump labor. In Ref. [10] the ground temperature alternations in 110 m deep borehole during operation of the heat pump for cooling in Turkey were presented. In Ref. [11] some temperature measurement of the undisturbed ground for 98 m borehole was done. In Refs. [12,13] authors give some profile measurement results from ground response tests. In Ref. [14], some research that showed the usefulness of the ground temperature measurement along whole borehole during ground response test has been introduced, because the brine temperature monitoring does not give enough information about heat pump's low-enthalpy energy source future performance. In works [15] and [16] the usefulness of ground temperature profile as the base for heat pump labor modeling and ground response test conduction has been taken under discussion. Authors of this paper have the same point of view and that's why they chose to present the full heat pump's lower heat source monitoring, including the heat extraction in heating season 2012/2013 and heat injection in summer 2013, in the article.

2. Experimental and measurement site

In the paper the results of research conducted for ground source heat pump installation with low-enthalpy energy source regeneration possibility has been presented. The aim of the experiment was to check, during in-situ research, if the active regeneration will change the heat source temperature significantly in comparison to the system without balancing the energy extracted during the winter. The site is located in town Świdnica in Poland (latitude 50°51″ N, longitude 16°29″ E). Heat pump (nominal thermal power - 17 kW; COP 4.4 for 0/35 °C) using boreholes as low enthalpy energy source is one of three main energy sources for Energy Technology Centre (CTE) building. The heat source consists of five boreholes 78 m deep each. The heat exchanger is the single U-pipe (PE 40 × 4.0 mm) surrounded by bentonite filler, the temperature sensors are installed on the surface of additional pipe in the bentonite. The heat transferring agent is propylene glycol solution in water (1032 kg/m^3, 3900 kJ/(kg K), concentration 34%). Three of boreholes cannot be actively regenerated. Two others may be regenerated during summer time; borehole no 1 with waste heat from free-cooling performed by cooler in air handling unit and borehole no 5 with the energy from 6 m^2 of solar collectors with the thermal peak power of 5 kW.

The ground structure profile for all boreholes is similar and has been also presented in Fig. 1. The stages of experiment are described in Table 1. Three among five boreholes that create lower heat source, has been equipped with measurement sets. The brine volumetric flow as well as flow and return temperatures of the borehole are measured. Endress&Hausner Proline PROMAG 10P25 electromagnetic flow meters (1% accuracy) and Endress&Hausner Omnigrad M TST90 coupled temperature sensors (accuracy of temperature difference measurement of ±0.05 K and individual sensor accuracy of $\pm(0.15 + 0.002 \cdot |t|)$ °C) have been used. Vertical heat exchangers have been equipped with 16 ground temperature sensors each; the sensors are located along the borehole every 5 m. The temperature sensors used are Pt 1000 type, class B (permissible deviation ±0.3 K, standard deviation for B type measurement is 0.17 K). Temperature sensors are located about 10 cm from the polyethylene pipe (in bentonite used for filing the space between the pipe and the ground). All measurements taken are recorded every minute.

During the experiment, after 20th December 2012, the data recording of two temperature sensors (TS(37)B1 and TS(47)B3) failed. It was decided to complete missing data in temperature profiles with values calculated from functions determined basing on the measurements before the failure and after the repair. Similar situation occurred with the temperature sensor TS(32)B3 from 5th May to 7th August 2013, and the missing data has also been complemented.

3. Results and discussion

3.1. Vertical temperature profiles

In the beginning of heating season a measurement of the initial temperature profile (before heat pump launching) has been carried out. The measurements have been conducted for 7 days and didn't show significant ground temperature changes under the influence of external conditions. In Fig. 2 it can be seen that on the depth of 37 m a groundwater flow occurs. The measurements taken during the season confirm this theory, showing the specificity of borehole