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Measurement and analysis of temperature changes of ground massif with Slinky heat exchanger

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Abstract. The article is describing temperature changes in the ground massif with Slinky heat exchanger. The exchanger serves as a heat source for a heat pump which is used for cold water warming and a heating of the administration building. The aim of the research is to analyse the influence of the Slinky heat exchanger to the temperature of the ground massif while extracting heat energy at the beginning and during the heating season, as well as beyond it. The temperature process of the ground massif is described near the exchanger, on a reference lot in burial depth of the heat exchanger and also in a depth of 0.2 m. The energy potential of the ground massif was evaluated using the temperature differences of ground massif in the area of the Slinky heat exchanger at the beginning and at the end of the heating season.

Key words: ground massif, heat source, heating season, Slinky heat exchanger.

INTRODUCTION

We live in a time when the use of alternative energy sources gets more and more into the foreground. Heat pumps are devices that can effectively use these resources. It can draw a heat from land, air and water, but it can also utilize a secondary heat. These heat sources for heat pump evaporators are used in both residential and civil construction and in agriculture. They can be used for heating of stables for breeding sows with piglets, fattening of broiler chickens to heat water for technological purposes, drying crops, etc.

In South Korea at the Seoul National University the cost of heating greenhouses was solved (Ha et al., 2011). At the Saint Mary's University in Canada and at the Hokkaido University in Japan the issue of heating water in production ponds, grain drying and pasteurization of milk has been addressed (Tarnawski et al., 2009). At the Geriz University and at the Ege University in Turkey a usage of gas engine driven heat pump during drying of medicinal and aromatic plants was verified (Gungor et al., 2011).

Heat pumps ground – water use two sources of low potential heat energy which is drawn by heat exchangers. There are called rock massif and ground massif (ground massif is the rock to a depth of 2 m). Exchangers are installed vertically or horizontally. It consists of polyethylene pipes of different diameters and lengths. This depends mainly on the required performance.

Vertical heat exchangers are using the internal performance of the Earth using polyethylene pipe in the shape of 'U' in which a cooling medium is flowing (Petráš, 2008). The space in the borehole around the pipes is filled with a suitable material to provide good contact between the pipe and the massif and to reduce thermal resistance (Florides & Kalorigou, 2007).

Horizontal heat exchangers are mainly using thermal energy that is naturally accumulated in the surface ground massif as a result of the incident solar radiation (Petráš, 2008). With horizontal exchanger the flow of heat is used. Heat comes from above and it is received by upper layer of the Earth from direct and indirect solar energy (radiation, rain, etc.). 98% of the energy draws horizontal heat exchanger from a layer of ground massif that is above it. Only 2% of the energy is taken from the ground massif under the exchanger. This heat exchanger can be considered as a sizable solar collector with low efficiency, which is complemented by a huge heat accumulator (surface) with an annual cycle of charging and discharging.

MATERIALS AND METHODS

Experimental measurements were carried out in Prague - Dolní Měcholupy within the company Veskom spol. s r.o. The altitude of Prague is 258 m. In this area the average temperature during the heating season is 4°C and the outside temperature for calculation is considered -12°C. The measurement of 5 vertical heat exchangers is taking place there, as well as 1 horizontal exchanger and 1 Slinky exchanger. Overall 9 vertical heat exchangers, 2 horizontal exchangers and 2 Slinky heat exchangers are the heat source for heat pumps which are used for water heating and heating of administration building with floor age of 1,480 m^2. Exchangers were put into operation in August 2008.

Slinky heat exchanger was made of polyethylene pipes PE 100RC 32 x 2.9 mm. Slinky with a total length of 200 m is installed at a depth of 1.5 m, 53 coils rolled in a circle. It is not stored in the bed of sand. The ground massif to a depth of 2 m is dark brown sandy-clay loam. In the heat exchanger a cooling liquid mixture of 33% ethanol and 67% water is used. Fig. 1 shows in placement scheme of sensors that measure the temperature of the ground massif.

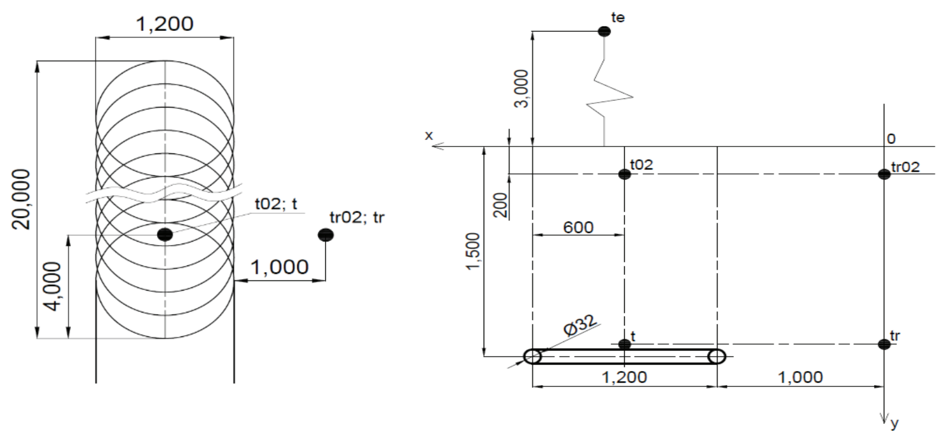

Figure 1. Scheme of Slinky heat exchanger and location of the temperature sensors.

Designation of the temperature sensors is as follows:
t – temperature sensor located at a depth of 1.5 m in the vicinity of the heat exchanger ([°C]); t_r – reference temperature sensor located 1.0 m from the heat exchanger

at a depth of 1.5 m (°C); t_{02} – temperature sensor located at a depth of 0.2 m above the heat exchanger (°C); t_{r02} – reference temperature sensor located 1.0 m from the heat exchanger at a depth of 0.2 m (°C); t_e – sensor ambient temperature located at a height of 3.0 m above the surface (°C).

Temperatures of the ground massif and the ambient air are recorded from 1 March 2011 every 15 minutes.

RESULTS AND DISCUSSION

According to Czech legislation heating season lasts from 1 September to 31 May of the following year. Supply of thermal energy is initiated in heating season, when the average daily temperature of outside air in the relevant locality is below 13 °C in two consecutive days and the evolution of the weather cannot be expected to increase the temperature above 13 °C for the following day.

The average daily air temperature t_{ed} is calculated by the Eq. 1:

$$t_{ed} = 0.25 \cdot (t_7 + t_{14} + 2 \cdot t_{21}). \qquad (°C) \qquad (1)$$

where: t_7 – temperature at 7:00 a.m. (°C); t_{14} – temperature at 2:00 p.m. (°C); t_{21} – temperature at 9:00 p.m. (°C).

Fig. 2 shows temperatures of the ground massif at about 3 p.m. and the average daily air temperature in the period from 1 September 2013 to 31 May 2014.

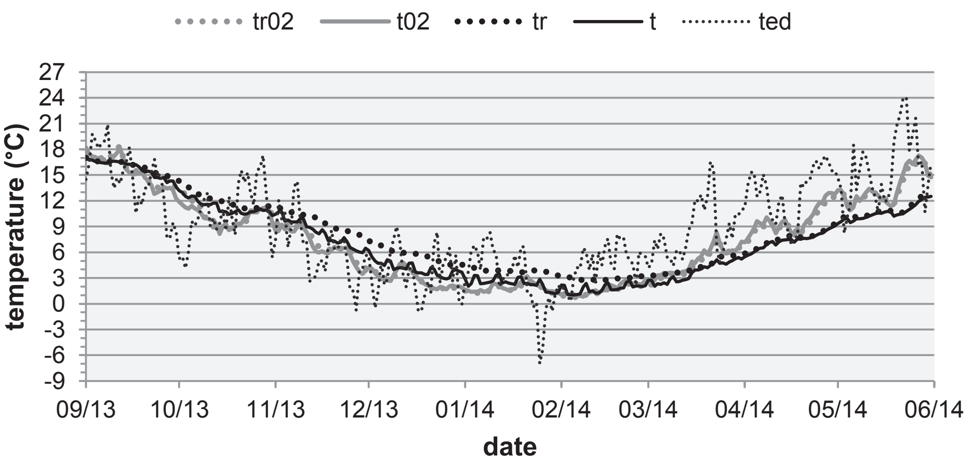

Figure 2. Temperatures of the heating season 2013/2014.

There is only a slight delay of the temperature course of t_{02} at the depth of 0.2 m with respect to air temperatures above the ground massif. A higher delay and a slight reaction to the ambient air temperature were seen for the temperature t at a depth of 1.5 m. The generally known fact that due to a low value of the coefficient of thermal conductivity of the ground massif and a high specific heat capacity, the amplitudes of temperature changes of the ground massif decrease with the depth of the ground massif when compared to the air temperature above its surface, is valid even during the transfer of the heat flow from the ground massif by the installed heat exchanger. The temperature of the ground massif t_{02} at a depth of 0.2 m above the heat exchanger is influenced particularly by the temperature and speed of the surrounding air, the intensity of incident solar radiation, and falls of rain and snow (Neuberger et al., 2014).

The temperature course of t_{ed} shows that the heating season 2013–2014 lasted from 19 September 2013 to 20 April 2014. In this time period the temperature of the ground massif t gradually decreased from 16.07°C to the minimum value of 0.65°C. This minimum temperature was recorded at 10 a.m. on 5 February 2014. The Eq. 2 in this period is as follows:

$$t = 3\cdot10^{-6}\cdot d^3 - 2\cdot10^{-4}\cdot d^2 - 12.47\cdot10^{-2}\cdot d + 15.23. \quad (R^2=0.979) \quad (°C) \qquad (2)$$

where d – number of days from the beginning of the heating season 2013–2014, i.e. from 19 September 2013.

The minimum temperature difference between the temperature t_r which was measured 1.0 m from the heat exchanger at a depth of 1.5 m and the temperature at a depth of 1.5 m in the vicinity of the heat exchanger t was 0.04 K. The maximum temperature difference was recorded 4 December 2013 with a value of 3.17 K. During the heating season 2011–2012 the lowest temperature of the ground massif t was measured 13 February 2012 (Neuberger et al., 2014). In the season 2012–2013 was this temperature recorded 29 March 2013.

The Eq. 3 of the reference temperature of the ground massif at a depth of 1.5 m t_r has following forms:

$$t_r = 3\cdot10^{-6}\cdot d^3 - 4\cdot10^{-4}\cdot d^2 - 9.79\cdot10^{-2}\cdot d + 15.47. \quad (R^2=0.989) \quad (°C) \qquad (3)$$

where d – number of days from the beginning of the heating season 2013–2014, i.e. from 19 September 2013.

Fig. 2 shows a gradual increase of the temperature of the ground massif t and the reference temperature t_r in the period from 21 April to 31 May 2014. Eq. 4 and Eq. 5 in this time period are as follows:

$$t = 2\cdot10^{-4}\cdot d^3 - 13.4\cdot10^{-3}\cdot d^2 + 34.62\cdot10^{-2}\cdot d + 6.87. \quad (R^2=0.969) \quad (°C) \qquad (4)$$

$$t_r = 2\cdot10^{-4}\cdot d^3 - 15.5\cdot10^{-3}\cdot d^2 + 38.11\cdot10^{-2}\cdot d + 6.96. \quad (R^2=0.969) \quad (°C) \qquad (5)$$

where d – number of days from 21 April 2014.

In this time period the temperature of the ground massif t gradually increased from 7.58°C to 12.73 °C.

The energy potential of the ground massif was evaluated from temperature differences of the ground massif in the vicinity of the Slinky heat exchanger Δ*t* at the beginning and at the end of the heating season. Table 1. shows temperature differences at the beginning and at the end of four consecutive heating seasons.

Table 1. Temperature differences of the ground massif at the beginning and at the end of heating season

Start of heating season	Date	*t*(°C)	Δ*t*(K)
2010–2011	30 August 2010	18.40	
			-0.94
2011–2012	30 August 2011	17.46	
			0.2
2012–2013	30 August 2012	17.66	
			-0.72
2013–2014	30 August 2013	16.87	
End of heating season	**Date**	***T*(°C)**	**Δ*t*(K)**
2010–2011	1 May 2011	9.8	
			-1.04
2011–2012	1 May 2012	8.4	
			-0.37
2012–2013	1 May 2013	7.67	
			1.69
2013–2014	1 May 2014	9.36	

Temperature differences of the ground massif at the beginning and at the end of heating seasons are within the range of measurement accuracy. These temperature differences shows that ground massif with Slinky heat exchanger, under the climatic conditions and the quantity of heat, can be considered as a stable energy source for heat pumps.

CONCLUSIONS

The course of temperature ted shows that the heating season 2013–2014 lasted from 19 September 2013 to 20 April 2014.

During this time period temperatures of the ground massif at a depth of 1.5 m were higher than temperatures of the ground massif at a depth of 0.2 m. After this time period the situation is reversed. Temperatures of the ground massif at the depth of 0.2 m react to changes of air temperatures.

The temperature of the ground massif *t* and the reference temperature of the ground massif t_r are described by Eqs. (2) to (5).

The temperature of the ground massif at a depth of 1.5 m in the vicinity of the Slinky heat exchanger during the heating season didn't achieve negative values. The minimum measured value was 0.65 °C.

Temperature differences Δ*t* at the beginning and at the end of heating seasons (Table 1.) did not exceed 2 K.

From results of temperature in the ground massif t at the beginning and at the end of each heating season the ground massif has sufficient potential energy and can be considered as a stable energy source for heat pumps.

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