GROUND MASSIF AS A HEAT SOURCE FOR HEAT PUMP

M. Šeďová

Department of Mechanical Engineering, Faculty of Engineering, Czech University of Life Sciences Prague, Czech Republic

Abstract
The article is describing ground massif as a heat source for heat pump. In the ground massif is stored a horizontal heat exchanger. The heat pump 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 heat exchanger on the ground massif temperature while extracting heat energy at the beginning and during the heating season 2014 – 2015. Temperatures are measured near the exchanger and on a reference lot in a burial depth of the heat exchanger. In the article are described subsurface temperatures in a depth of 0.2 m also. The energy potential of the ground massif was evaluated using the differences of temperatures of the ground massif in the area of the heat exchanger at the beginning and 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.

The aim is to analyze the temperature changes of the ground massif with Slinky heat exchanger in consecutive heating season. Another aim to determine whether the ground massif is able to regenerate sufficiently out of heating season and whether a stable energy source for heat pumps.

MATERIALS AND METHODS

Experimental measurements were carried out in Prague – Dolní Měcholupy within the company Veskom spol. sr.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 was made of pipes PE 100RC 32 x 2.9 mm. This heat exchanger is installed at a depth of 1.5 m. Its total length is 200 m and it is formed by 53 loops. 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.

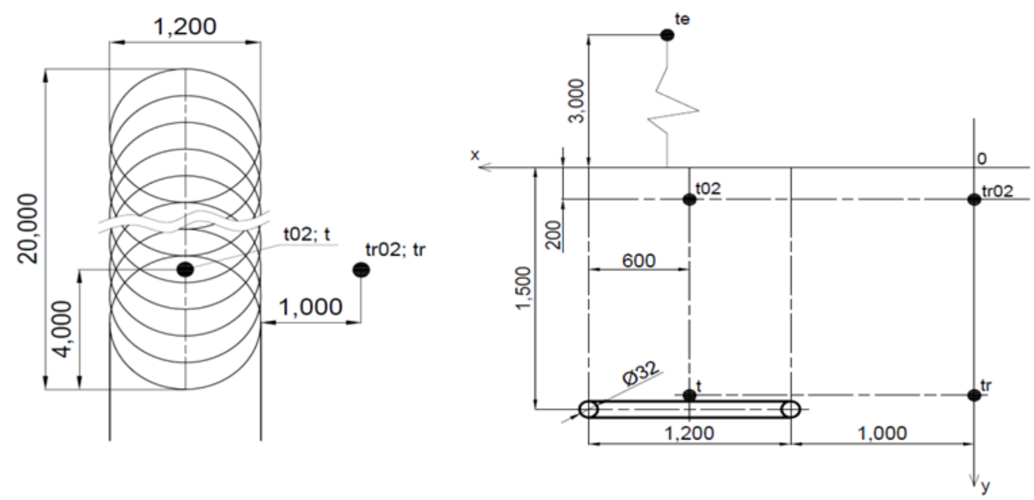

Fig. 1. – Scheme of Slinky heat exchanger and placement of temperature sensors

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

Czech legislation states that 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 according to the Eq. 1.

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

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]
The average daily air temperature and temperatures of ground massif at about 3 p.m. in the period from 1 September 2014 to 31 May 2015 are shown in Fig. 2.

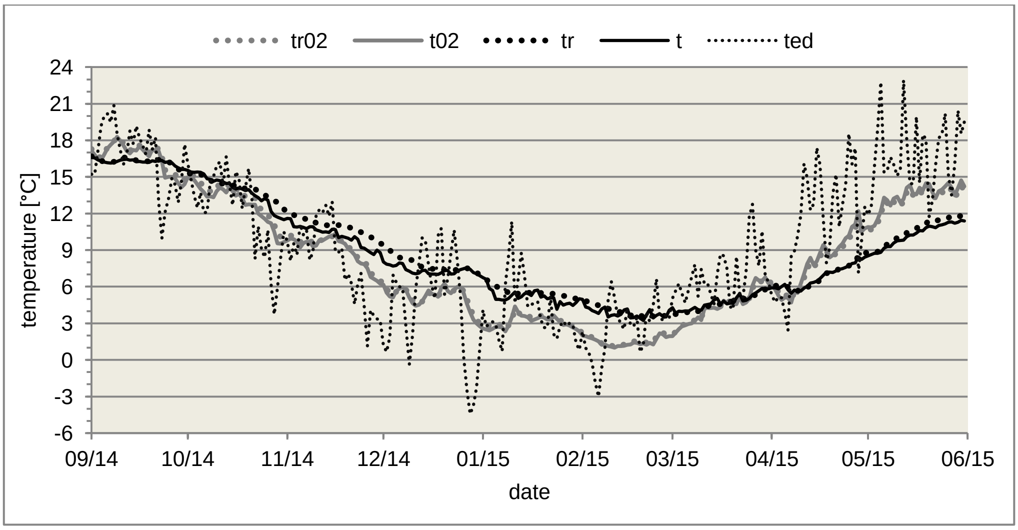

Fig. 2. – Course of the temperatures in the heating season 2014 - 2015

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 2014–2015 lasted from 21 October 2014 to 2 May 2015. In this time period the temperature of the ground massif t gradually decreased from 14.07°C to the minimum value of 2.77°C. This minimum temperature was recorded at 2 a.m. on 20 February 2015. The Eq. 2 in this period is as follows:

$$t = 2\cdot10^{-6}\cdot d^{3} + 9\cdot10^{-5}\cdot d^{2} - 11.49\cdot10^{-2}\cdot d + 13.15. \quad (R^2=0.973) \quad [°C] \quad (2)$$

where: d – number of days from the beginning of the heating season 2014–2015, i.e. from 21 October 2014.

The maximum 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 recorded 1 December 2014 with a value of 2.02 K. During the heating season 2013 - 2014 the lowest temperature of the ground massif t was measured 5 February 2014 (ŠEĎOVÁ ET AL., 2015). In the season 2014–2015 was this temperature recorded 28 March 2015.

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

$$t_r = 3\cdot10^{-6}\cdot d^{3} - 1\cdot10^{-4}\cdot d^{2} - 10.74\cdot10^{-2}\cdot d + 13.81. \quad (R^2=0.986) \quad [°C] \quad (3)$$

where: d – number of days from the beginning of the heating season 2014–2015, i.e. from 21 October 2014.

Fig. 2 shows a gradual increase of the temperature of the ground massif t and the reference temperature $t_r$in the period from 3 May to 31 May 2015. Eq. 4 and Eq. 5 in this time period are as follows:

$$t = 1\cdot10^{-4}\cdot d^{3} - 8.1\cdot10^{-3}\cdot d^{2} + 23.52\cdot10^{-2}\cdot d + 8.30. \quad (R^2=0.962) \quad [°C] \quad (4)$$

$$t_r = 1\cdot10^{-4}\cdot d^{3} - 7.1\cdot10^{-3}\cdot d^{2} + 24.57\cdot10^{-2}\cdot d + 8.43. \quad (R^2=0.970) \quad [°C] \quad (5)$$

where: d – number of days from 3 May 2015.

In this time period the temperature of the ground massif t gradually increased from 8.65°C to 11.73°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 Δt at the beginning and at the end of the heating season. Tab. 1.and Tab. 2. show temperature differences at the beginning and at the end of five consecutive heating seasons.

Tab. 1. – Temperature differences of the ground massif at the beginning of heating season

Start of rating season	Date	t[°C]	Δt[K]
2010 - 2011	30 August 2011	18.40	
			-0.94
2011 - 2012	30 August 2012	17.46	
			0.2
2012 - 2013	30 August 2013	17.66	
			-0.72
2013 - 2014	30 August 2014	16.87	
			-0.27
2014 - 2015	30 August 2015	16.60	

Tab. 2. – Temperature differences of the ground massif at the end of heating season

End of rating season	Date	t[°C]	Δt[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	
			-0.82
2014 - 2015	1 May 2015	8.54	

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 t_{ed} shows that the heating season 2014 - 2015 lasted from 21 October to 2 May 2015.

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).

Temperature differences Δt at the beginning and at the end of heating seasons (Tab. 1., Tab. 2.) did not exceed 2 K.

The measurement results show that the highest temperatures of ground massif at the depth of 1.5 m are achieved in mid-August. In the regeneration period of Slinky heat exchanger before the heating season 2014 - 2015 it occurred 13 August 2014.

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.

REFERENCES

1. FLORIDES, G., KALORIGOU, S.: Ground Heat Exchangers: A Review of Systems, Models and Applications. Renewable Energy, 32, 2007: 2461–2478.
2. GUNGOR, A., ERBAY, Z., HEPBASLI, A.: Exergoeconomic Analyses of a Gas Engine Driven Heat Pump Drier and Food Drying Process. Applied Energy, 88, 2011: 2677–2684.
3. HA, T., LEE, I. ., HWANG, H., HONG, S., SEO, I., BITOG, J. P.: Development of an Assessment Model for Greenhouse Using Geothermal Heat Pump System. In: American Society of Agricultural and Biological Engineers Annual International Meeting 2011. pp. 2105–2114, Louisville, Kentacky, USA.
4. NEUBERGER, P., ADAMOVSKÝ, R., ŠEĎOVÁ, M.:Temperatures and Heat Flows in a Soil Enclosing a Slinky Horizontal Heat Exchanger. Energies, 7, 2014: 972–987.
5. PETRÁŠ, D.: Low-temperature heating and renewable energy. JAGA group, Bratislava, 2008 (in Czech).
6. ŠEĎOVÁ, M., NEUBERGER, P., ADAMOVSKÝ, R.:Measurement and analysis of temperature changes of ground massif with Slinky heat exchanger. Agronomy Research, 13, 2015: 533 - 538.
7. TARNAWSKI, V., LEONG, W. H., MOMOSE, T., HAMADA, Y.:Analysis of Ground Source Heat Pumps with Horizontal Ground Heat Exchangers for Northern Japan. Renewable Energy, 34, 2009: 127–134.

Corresponding author:
Ing. Michaela Šeďová, Department of Mechanical Engineering, Faculty of Engineering, Czech University of Life Sciences Prague, Kamýcká 129, Praha 6, Prague, 16521, Czech Republic, phone: +420 22438 3174, e-mail: sedova@tf.czu.cz