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Theoretical and Experimental Research Regarding the Soil Thermal Response

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Abstract

The geothermic energy of the soil can be valued by means of heat pumps, which reduce the fossil fuel consumption, noxes and greenhouse gas effect. The quantity of heat that can be extracted from the soil depends on its properties. The experimental installation for testing the thermal response of the soil is capable to inject in the well a constant thermal flow and measure the thermal response of the soil through the continuous determination of water temperature that enters and leaves the well

Key words: *renewable, heat, pump, soil*

Introduction

An important renewable source of energy is the geothermic energy of the soil, found in the superficial layers of the ground less than 200 meters deep. The temperature of this layer is between 10 and 30^{o}C and is constant beginning with 10 meters deep.

This type of energy can be valued by means of heat pumps and used for heating dwellings or to prepare hot running water.

In the warm season we can insert the heat obtained from cooling the dwellings in the soil.

The heat pumps that use the geothermal energy from the earth surface present high performance coefficients (3,5-4,5), so that their use brings about the reduction of fossil fuel consumption, of noxes and greenhouse gas effect.

Thermodynamics Properties of Soil

The quantity of heat that can be extracted from the soil depends on its properties. The properties that influence the thermal power extracted or introduced in the soil are:

λ [W/(mK)] – thermal conductivity of the soil

ρ [kg/m^3] – soil density

c [J/(kg·K)] – specific heat of the soil

$d = \dfrac{\lambda}{\rho c}$ – thermal diffusivity of the soil

R_b – thermal resistance of the soil

The knowledge of this measure allows a correct process design of the heating/cooling systems with heat pumps soil-water or soil-air.

Because of the complexity of local factors that influence these properties (pressure, humidity, the structure of the rocks, etc.) the thermodynamics properties of the soil cannot be directly determined. The method that allows us to determine indirectly in site the thermodynamics properties of the soil is called the thermal response of the soil.

The Thermal Response of the Soil

The majority of heat exchangers introduced into the soil are composed from polyethylene tubes introduced in the vertical well (figure 1).

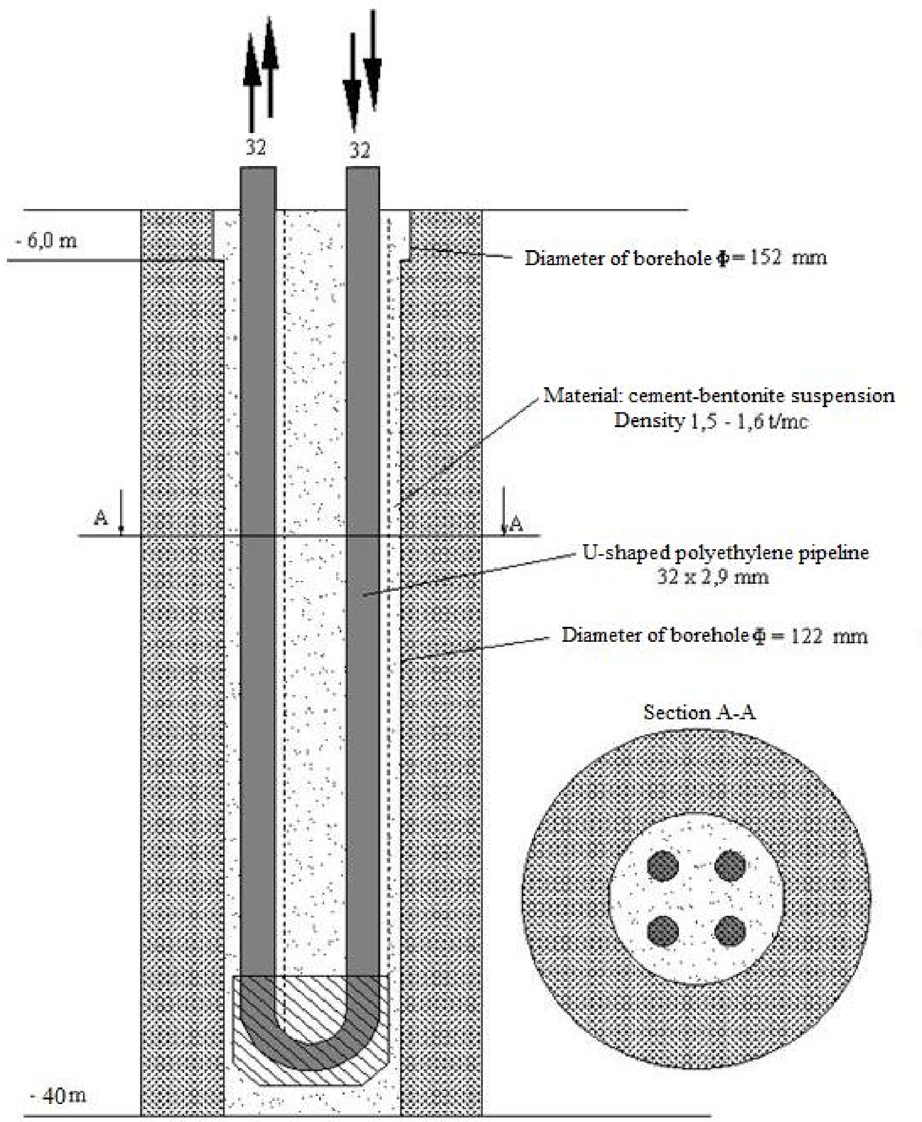

Fig. 1. Polyethylene tubes introduced in the vertical well

Due to the geometrical configuration of the well and of the heat exchanger, as well as the depths between 50 and 200 meters, we accept the assumption that the thermal interaction between soil and well is plan radial.

The method of measurement consists in injecting for a long period of time (40 – 70 hours) of a constant thermal flux in the polyethylene tubes from the drill well (figure 2).

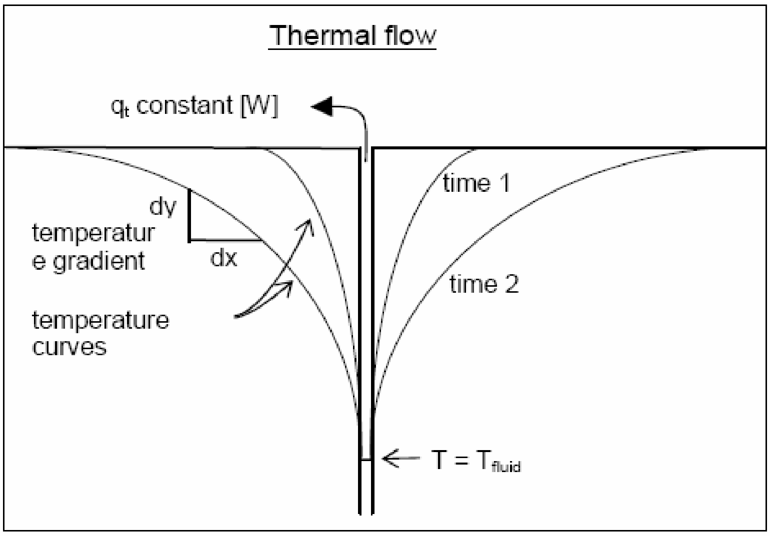

Fig. 2. Injecting a thermal flux in the polyethylene tubes

The thermal fluxes injected into the soil change the temperature around the well. The equation that describes this phenomenon is the thermal diffusivity equation, which in cylindrical coordinates bears the expression

$$\frac{\partial T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} = \frac{\aleph}{\lambda}\frac{\partial T}{\partial \tau} \tag{1}$$

Considering the well as a “warm line” as compared with the surrounding soil, the solution of the thermal diffusivity equation is

$$T(r,\tau) = T_0 + \frac{q}{4\pi\lambda}\int_0^{\tau}\frac{e^{-\frac{r^2}{4a\tau}}}{\tau}d\tau = T_0 + \frac{q}{4\pi\lambda}W(u) \tag{2}$$

Let us consider the measure *u*

$$u = \frac{r^2}{4a\tau} \tag{3}$$

In these conditions the function *W (u)* has the following expression

$$W(u) = \int_u^{\infty}\frac{e^{-u}}{u}du \tag{4}$$

By progressive development an approximated solution can be obtained

$$W(u) = -\gamma - \ln u + u - \frac{u^2}{2\cdot 2!} + \frac{u^3}{3\cdot 3!} + \frac{u^4}{4\cdot 4!} + \ldots\ldots \tag{5}$$

In the expression above, $\gamma \approx 0{,}5772$ is called the Euler constant.

For increased time elements, $\gamma \rightarrow \infty$, $u = \frac{r^2}{4a\tau} \rightarrow 0$ and $W(u) \approx -\gamma - \ln u$ result.

A 10% error for the thermal response tests of the soil is generally accepted.

In these conditions, the expression of soil temperatures in time and space around the well, can be assumed by the relation

$$T(r,\tau) = T_0 + \frac{q}{4\pi\lambda}\left[\ln\left(\frac{4a\tau}{r^2}\right) - \gamma\right] \tag{6}$$

for $\gamma > \dfrac{5r^2}{\alpha}$.

Determination of Soil Properties as a Consequence of Experimental Measurement

Inside the Renewable Source of Energy laboratory a pilot plant for testing the thermal response of the soil is under construction, figure 3. This is composed of a heat pump air – water that generates hot water, a circulation system provided with a pump with revolution controlled by detectors and a data acquisition system.

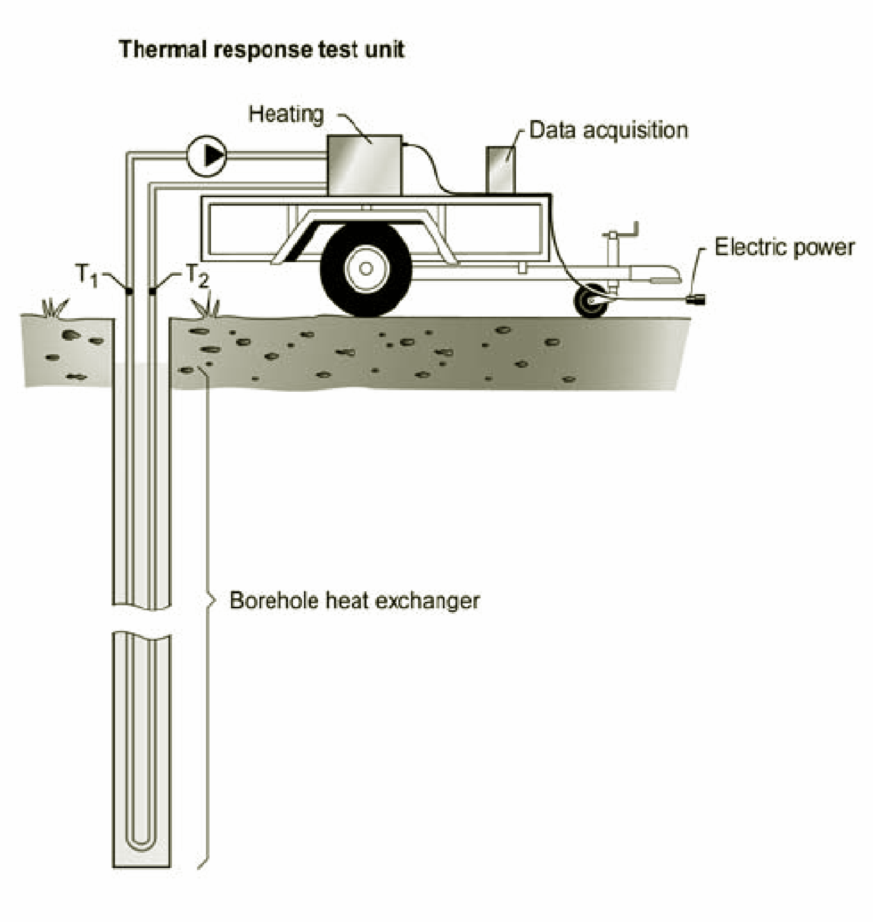

Fig. 3. Thermal response test unit

This experimental installation is capable to inject in the well a constant thermal flow and measure the thermal response of the soil through the continuous determination of water temperature that enters and leaves the well.

Figure 4 presents a chart with a test made with the experimental plant

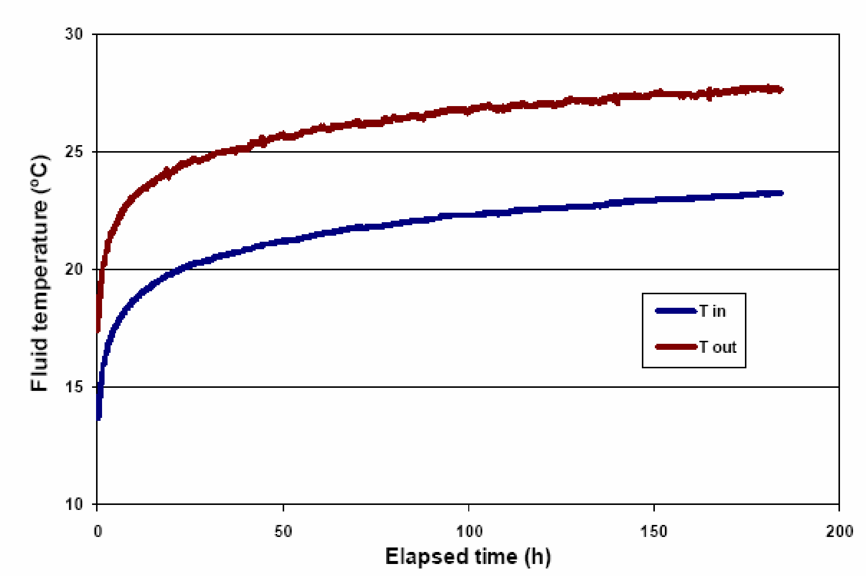

Fig. 4. Water temperature that enters and leaves the well

If the curve representing the thermal response is represented in logarithmic coordinates, figure 5, it is possible to determine the linear part gradient of the curve.

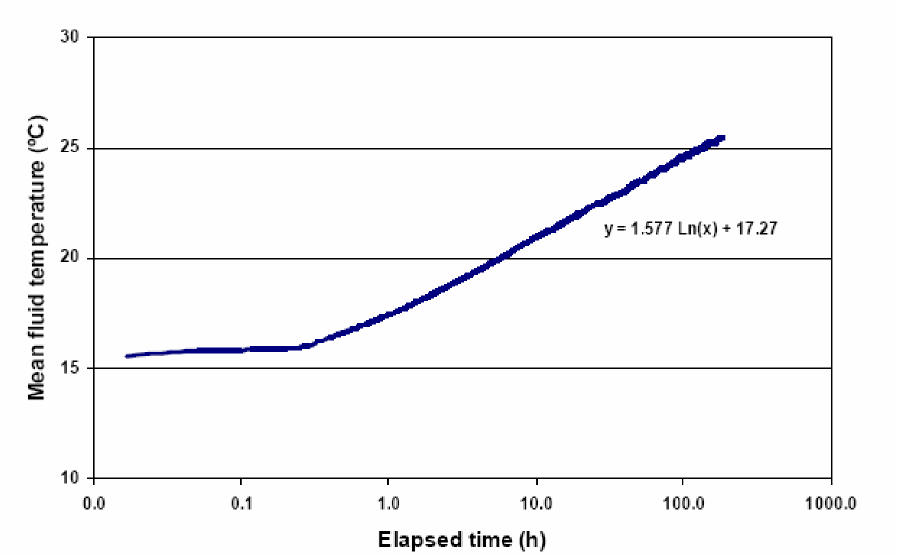

Fig. 5. Determination of the linear part gradient of the curve

Let us consider k this gradient and based on this value we can determine the effective conductivity of the soil with the formula

$$\lambda_{ef} = \frac{\dot{q}}{4\pi k} \tag{7}$$

where $\dot{q}$ represents the constant thermal flow, introduced into the plant.

Let us consider r_0 the well radius, T_f the formation temperature and T_0 the temperature from the well at time τ. The thermal effective resistance, R_b, can now be determined with

$$R_b = \frac{1}{q}\left(T_f - T_0\right) - \frac{1}{4\pi\lambda}\left[\ln(\tau) + \ln\left(\frac{4a}{r_0^2}\right) - \gamma\right] \tag{8}$$

Conclusions

The thermal energy production of heat pumps that use geothermic energy from the ground, depends on the correct dimensioning of heat exchanger introduced into the soil.

The testing method of thermal response allows us to determine indirectly, by measurement realized in geothermal wells, the effective conductivity of the soil.

An accurate determination of this measure allows a correct process design of geothermic wells that in practice is translated into a reduction of necessary cost for geothermic wells accomplishment.

References

1. Allan, M.L., Kavanaugh, S.P. –*Thermal conductivity of cementitious grouts and impact on heat exchanger length design for ground source heat pumps*, International Journal of HVAC&R Research, Vol. 5, (2), 1999;
2. Allan, M.L., Philippacopoulus, A.J. – *Thermally Conductive Cementitious Grouts for Geothermal Heat Pumps*, FY 1998 Progress Report, BNL 66103, 1998
3. Kakas, S., Bergles, A.E., Mayinger, F. - *Heat Exchangers: Thermal-Hydraulic Fundamentals and Design*, McGraw-Hill, 1981
4. Neacşu, S., Trifan, C., Albulescu, M., Eparu, C., IONESCU, E.M. - *Analysis on energy available in soil to be used for heating dwelling places,* CNEI, Bacău, 2005
5. Neacşu, S., Trifan, C., Albulescu, M. - *Răspunsul termic al solului în cazul utilizării pompelor de căldură* Conferința națională de termotehnică cu participare internațională, Ediția XVI-a, Vol 2, Ploieşti, 2007,
6. Rybach, L., Sanner, B. - *Ground-Source heat pump systems the European experience*, Institute of Applied Geosciences, Giessen, Germany
7. Sanner, B. – *Earth threat Pumps and Underground Thermal Energy Storage in Germany,* Proc. World Geothermal Congress 1995:2167-2172, 1995
8. Sanner, B. –*Prospects for Ground-Source Heat Pumps in Europe*, Newsletter IEA Heat Pump Centre, 17/1, 1999.

Cercetări teoretice şi experimentale privind răspunsul termic al solului

Rezumat

Energia geotermică a solului poate fi valorificată cu ajutorul pompelor de căldură, care reduc consumul de combustibili fosili, noxe şi gaze cu efect de seră. Cantitatea de căldură care poate fi extrasă din sol depinde de proprietățile acestuia. Instalația experimentală pentru testat răspunsul termic al solului este capabilă să injecteze în puț un flux termic constant şi să măsoare răspunsul termic al acestuia prin determinarea permanentă a temperaturii apei care intră şi iese din puț.