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EXPERIMENTAL DETERMIINATION THERMAL CONDUCTIVITY OF DOLOMITIC LIMESTONE

Introduction

The origin of geothermal energy is in the hot core of the Earth. Due its inexhaustible potential, it is also included among renewable sources. Renewable sources are, from the point of view of national economies, domestic resources that have the potential to replace and in the future, in certain applications, completely dispose of fossil fuels. These sources already offer the opportunity to significantly diversify energy sources in each country. Their development is also seen as an important tool to protect the national economy from future shocks from the rise in imported fuel prices and the cost of environmental damage [1].

Heat from the Earth's rock is obtained from deep boreholes of 100 m to 300 m. Systems for acquiring natural thermal energy from the ground are referred to as ground (wells) – water, i.e. that the rocks are the source of thermal energy that is pumped from the rocks through a circulating antifreeze mixture into a hermetically sealed collector. The heat pump produces a heat output of up to 65°C through the compressor, which is sufficient for the hot water heating system or for hot water heating [2].

Limestone and dolomite make up four fifths of all sediments on the Earth's surface. The transition between dolomite and limestone is not sharp, and thus is form a dolomitic limestone – a rock made of dolomite and a predominant limestone. Dolomite is a rock of sedimentary origin. It consists predominantly of a mineral of the same name. It is formed by settling of $CaMg(CO_3)$ in hypersalinic aqueous medium, but more often it results from dolomitization of settled limestones [3]. In Slovakia and especially in the Žilina region there is a large number of sites on dolomitic limestone, so it is necessary to know the properties of these rocks in what composition they occur in nature.

The course of the temperature field in the rock mass can be determined by direct field measurements and analytical calculations. Mostly on-site measurement results provide input data for analytical calculation. On the other hand, the analytical calculation applies to the ideal body, and the information thus obtained provides a sort of temperature field course. By comparison, we can determine whether the temperature field in a rock mass based on the calculations is real or is loaded by errors (in measurements, in ignorance of structural - texture parameters, moisture and other aspects of material and mass) [4].

Thermal conductivity determination

We can measure thermal conductivity in several ways. These methods are primarily determined by the thermal mode in which the measurement is performed. The most frequent measurement is in stationary or non-stationary mode. For both methods, a number of specific methods have been developed in practice and are being used successfully. In general, stationary methods of measurement are suitable for thermally conductive materials, and non-stationary methods are more suitable for thermal insulators [5].

At present, the method of measuring the thermal conductivity of dry materials by means of non-stationary heating is being gradually applied. The advantages of this measurement method include short measurement time, simplicity of operation, measuring device, but also determination of the influence of moisture on material samples on their thermal conductivity. Based on the above facts, the thermal conductivity of dolomitic limestone was measured using a non-stationary method – the principle of the heated wire method.

The heated wire method is amongst non-stationary methods, the principle of which is to measure the temperature rise at a defined distance from the linear (line) heat energy source or the constant power per unit length in the volume of the measured material. The mathematical model assumes the ideal, endlessly long line heat source, in this case the heated wire, which is surrounded by an endless, homogeneous and isotropic environment with constant temperature. If a heat source with a constant output per unit of length q starts to operate at time τ = 0, a radial heat flow will occur in the material around the source. If the temperature variables are independent of the temperature in the range of temperature changes caused by the effect of the heat source, then the temperature increase ΔT (r, t) at the distance r from the heat source is valid [6].

$$\Delta T(r,t) = \frac{q}{4\pi\lambda} \ln \frac{4\alpha\tau}{r^2\gamma}, \quad \mathrm{K}$$

The thermal conductivity λ is determined from the relationship of the linear dependence of the temperature increase ΔT to the logarithm of time $\ln\tau$ according to the relation:

$$\lambda = \frac{q}{4\pi SP}, \quad \mathrm{W \cdot m^{-1} \cdot K^{-1}}$$

Experiment

The determination of the thermal conductivity of dolomitic limestone results from the determination of the thermal field. Measurement of the temperature field was carried out in laboratory at the University of Žilina on the sample of stone – dolomitic limestone from stone quarry in Varín near Žilina city.

In figure 1 is a schematic diagram of measuring the temperature field of a dolomitic limestone sample. The sample has one vertical hole with a diameter of 30 mm and a length of 800 mm and three horizontal holes of 12 mm in diameter and 300 mm in length. In to a horizontal hole is inserted in bentonite cover heating rod of 17 mm diameter plugged to a laboratory DC power supply which supplies a constant heat output of 100 W.

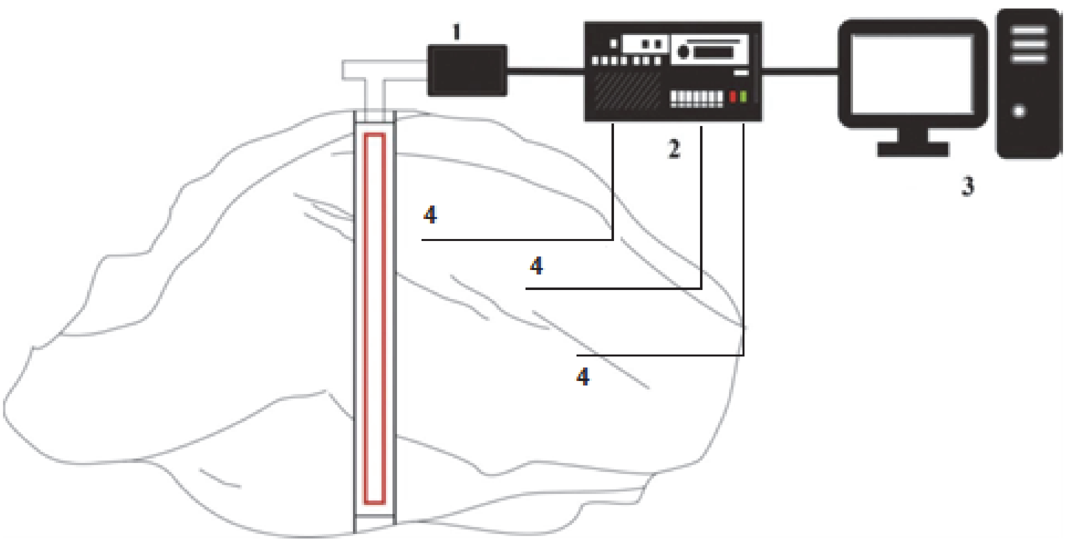

FIGURE 1. Schema of the temperature field measurement: 1 – Laboratory DC power supply, 2 – Measuring unit, 3 – computer, 4 – Temperature sensors

The principle of thermal conductivity measurement by the heated wire method is that heat samples are transmitted to the analysed sample pulses and the subsequent temperature dependence of the temperature response of the material. The heat flux is generated by dissipated electrical power in the resistance of the probe, which is the heat conduction associated with the laboratory material. Resistance temperature is sensed by a semiconductor sensor.

The temperature field was measured using NiCr - Ni thermocouples placed in horizontal holes and on the surface of a rock sample at different levels and at different distances from the heater. Ambient temperature was also measured. The temperature measurement interval was set to 1 minute in order to measure possible thermal effects during the measurement. The whole sample was enveloped circumferentially by thermal insulation from mineral wool 10 cm thick to prevent the influence of heat flow due to ambient temperature fluctuations.

Results

A steady 100 W heat flux was supplied to the sample within 50 hours (3000 minutes), which was sufficient time to dissipate the heat throughout the sample. In figures 2 and 3 are the results of measuring the temperature field in a sample of dolomitic limestone at a delivered heat output of 100 W.

Figure 2 shows the effect of the outside temperature on the temperature of the surface of the stone, where partial stabilization of the temperature is seen after 1500 minutes and completely after 3000 minutes.

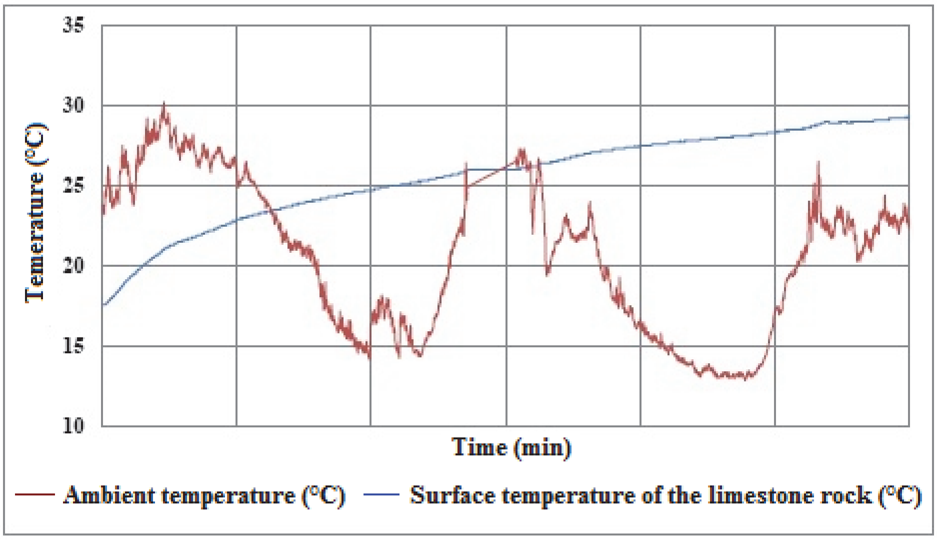

FIGURE 2. *Dolomitic limestone surface temperature course and ambient temperature course*

In figure 3 is the temperature flow in the individual probes located in the sample. The red colour shows the temperature of the probe at a distance of 150 mm from the heat source. The green colour shows the temperature of the probe at a distance of 300 mm from the heat source. The blue colour shows the temperature of the probe at a distance of 550 mm from the heat source. The temperature course inside the sample were mainly influenced by heat from the heat source where it is seen that with increasing distance from the heat source the temperature decrease and partly from the ambient temperature when during the day the temperature increase was faster than during the night.

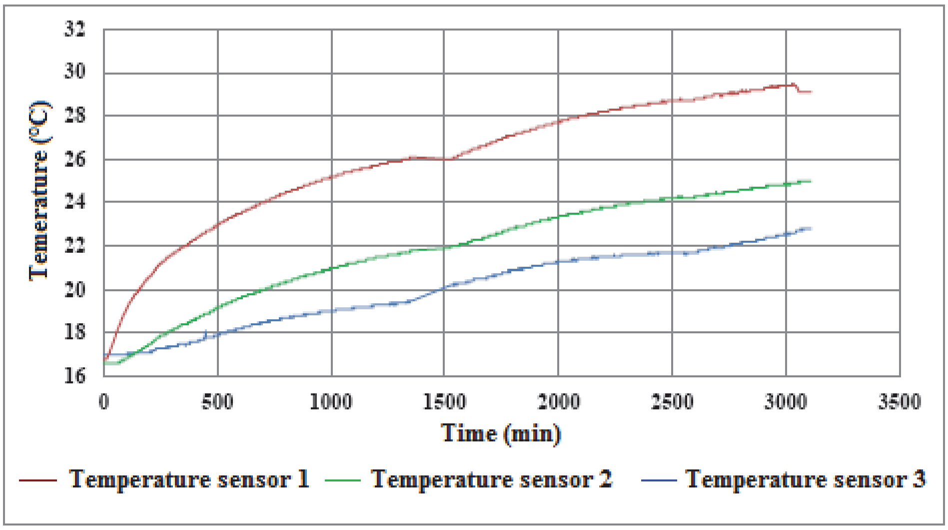

***FIGURE 3.** Temperature course in the dolomitic limestone sample*

Calculation of the thermal conductivity of the dolomite limestone results from the theory of the heated wire method and the directives of the trend logarithmic curve determined according to the measured temperatures of the sample.

$$\lambda = \frac{q}{4\pi SP} = \frac{125}{4\pi 1.786} = 5.56\ \mathrm{W \cdot m^{-1} \cdot K^{-1}}$$

The measured heat flux is determined as the ratio of heat that is delivered (withdrawn) during the measurement and the depth of the hole in which the heater body is located. The amount of heat was determined as the product of the supplied current and the el. with a 100 W power output. The hole for the heater is 0.8 m:

$$q = \frac{Q}{H} = \frac{100}{0.8} = 125\ \mathrm{W \cdot m^{-1}}$$

Ražnievič [7] states thermal conductivity value of the dolomite limestone to be 2.268 $\mathrm{W{\cdot}m^{-1}K^{-1}}$ and Ochaba [8] states thermal conductivity value of the dolomite limestone in range from 4.19 $\mathrm{W{\cdot}m^{-1}K^{-1}}$ to 6.28 $\mathrm{W{\cdot}m^{-1}K^{-1}}$.

Conclusion

The aim of the experiment was to determine the thermal conductivity of the dolomite limestone rock origin from the nature in the Žilina region, which could represent a potential renewable energy source for low temperature heating technologies. Experimental determination of the thermal conductivity of the dolomite limestone by the heated wire method revealed a value of 5.56 $\mathrm{W{\cdot}m^{-1}K^{-1}}$. This value has been compared to the values given in the tables of the thermophysical properties of the Earth's rocks in several sources and can be considered relevant.

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Acknowledgment

This publication is the result of the project implementation: Device for the use of low-potential geothermal heat without forced circulation of the heat carier in deep boreholes, ITMS 26220220057 supported by the Operational Programme Research and development funded by the ERDF.