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USING SELECTED TRANSIENT METHODS FOR MEASUREMENTS OF THERMOPHYSICAL PARAMETERS OF BUILDING MATERIALS

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This article deals with thermophysical properties of red and white bricks. If we want to protect the high standard of quality building materials, we need to know the physical parameters which can evaluate the quality. The most important for building materials are mainly thermophysical, mechanical parameters and parameters which can determine the structure of materials. The article presents results of thermophysical parameters measurements of red and white bricks during the temperature stabilization for different values of moisture content. For our measurements, we have chosen a hot wire method and a dynamic plane source method. Both methods are classified as transient methods and they are very convenient for measurements of thermophysical parameters of materials with a compact structure. The results of measurements show that temperature and moisture content have a significant effect on thermophysical parameters of bricks.

Keywords: thermal conductivity, temperature, moisture content, building material, brick

Material research and the rapid industrial development create a demand for experimental methods that give reliable data of thermophysical properties of materials in a short time. A great number of experimental techniques have appeared in literature so far. Methods differ in basic principles of measurement, in the number of thermophysical properties they allow estimating simultaneously, and they differ in suitability to test different materials and under various experimental conditions (Božiková, 2012).

Transient methods – the dynamic plane source method (DPS) and the hot wire method (HW) were used for our measurements. Transient methods represent a large group of techniques where measuring probes, i.e. the heat source and the thermometer, are placed inside the sample. This experimental arrangement suppresses the sample surface influence on the measuring process, which can be described as follows. The temperature of the sample is stabilized and made uniform. Then, dynamic heat flow in the form of a pulse or step-wise function is generated inside the sample. The thermophysical parameters of the sample can be calculated from temperature response to this small disturbance (Kubičár et al., 2000). The article presents the measurements of thermophysical parameters of selected bricks during the temperature stabilization for moisture content 11 % and 16.5 %.

Material and methods

For the first series of measurements, we choose the hot wire method (Figure 2). The simple measurement consists in measuring the temperature rise vs time evaluation of an electrically heated wire embedded in the tested material. Thermal conductivity is derived from the resulting change in temperature over a known time interval.

The ideal analytical model assumes an ideal – infinitely thin and infinitely long line heat source (hot wire), operating in an infinite, homogeneous and isotropic material with a uniform initial temperature. If the hot wire is heated for the time $t = 0$ with constant heat flux q per unit wire length, radial heat flow around the wire will occur. The temperature rise $\Delta T(r, t)$ in any distance r from the wire as a function of time is described by a simplified equation (Carslaw et al., 1999; Božiková, 2012):

$$\Delta (r, t) = \frac{q}{4\pi\lambda} \ln \frac{4at}{r^2 C} \quad (1)$$

where:
λ – thermal conductivity
a – thermal diffusivity
$C = \exp(\gamma)$, with γ being Euler's constant

Thermal conductivity is calculated from the slope S of temperature rise $\Delta T(r, t)$ vs the natural logarithm of time $\ln t$ evolution using the formula:

$$\lambda = \frac{q}{4\pi S} \quad (2)$$

Several corrections have been introduced to account for the heat capacity of the wire, thermal contact resistance between the wire and the test material, the finite dimension of the sample, and the finite dimension of the wire embedded in the sample (Liang, 1995).

For the second series of measurements, we choose the dynamic plane source method (Figure 1). This method is based on using an ideal plane sensor (*PS*). The PS sensor acts both as a heat source and temperature detector. The plane source method is arranged for one-dimensional heat flow into a finite sample.

The theory considers ideal experimental conditions – an ideal heater (negligible thickness and mass), perfect thermal contact between the PS sensor and the sample, zero thermal resistance between the sample and the material surrounding the sample, and zero heat losses from the lateral surfaces of the sample (Karawacki et al., 1992).

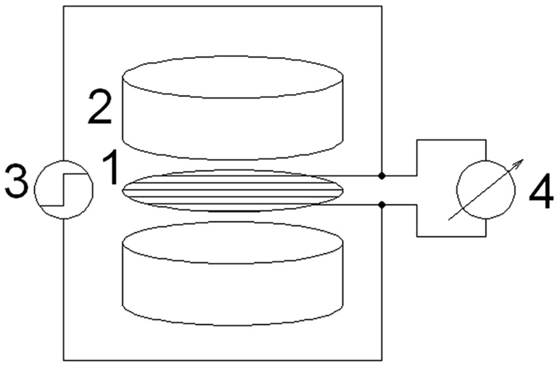

Figure 1 Dynamic plane source method
1 – PS sensor, 2 – samples, 3 – current source, 4 – millivoltmeter
Source: Malinarič, 2007

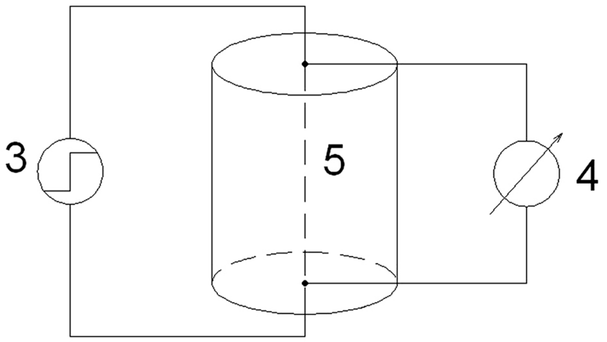

Figure 2 Hot wire method
3 – current source, 4 – millivoltmeter, 5 – heat source and thermometer

If q is the total output of power per unit area dissipated by the heater, then temperature increase as a function of time is given by:

$$\Delta T(x,t) = 2\frac{q\sqrt{at}}{\lambda}\, ierf\left(\frac{x}{2\sqrt{at}}\right) \qquad (3)$$

where:

a – thermal diffusivity
λ – thermal conductivity of the sample
ierf – error function

We consider the PS sensor placed between two identical samples having the same cross section as the sensor in the plate $x = 0$. Temperature increase in the sample as a function of time conforms to:

$$T(0,t) = \frac{q\sqrt{a}}{\lambda\sqrt{\pi}}\sqrt{t} \qquad (4)$$

which corresponds to linear heat flow into an infinite medium (Karawacki et al., 2001). Measured samples were placed in laboratory storage boxes at temperature 5 °C and 90 % air moisture content during 24 hours before measurement, and relations of thermal conductivity to temperature were measured during the temperature stabilization of samples. All measurements were made in laboratory settings. The measurement was performed for the red brick and white brick with moisture content 11 % and 16.5 %.

For the first series of measurements, we choose the HW method. It was applied to all the samples. There was also made the second series of measurements using the DPS method for all the samples of bricks.

Results and discussion

We have obtained the values of thermal conductivity for white brick with moisture content 11 % and 16.5 %, as presented in Figs 3 and 4. Samples were measured in temperature range from 9 °C to 26 °C. All presented values were obtained as arithmetic averages from thirty measurements for every temperature. Graphic relations for red brick with the same moisture content during the temperature stabilization are shown in Figs 5 and 6. Values of thermophysical parameters obtained by the HW and DPS method are in a great agreement with values presented in literature.

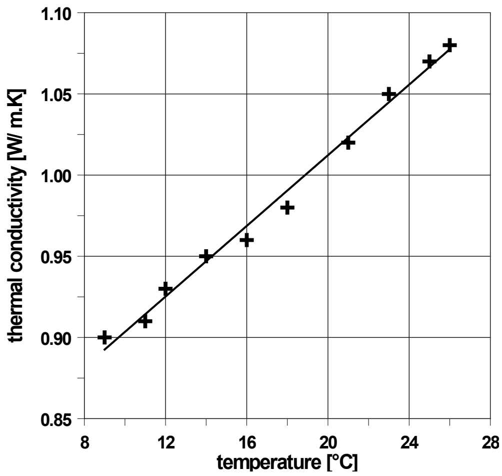

Figure 3 Relations of thermal conductivity to temperature for white brick with moisture content 11 %

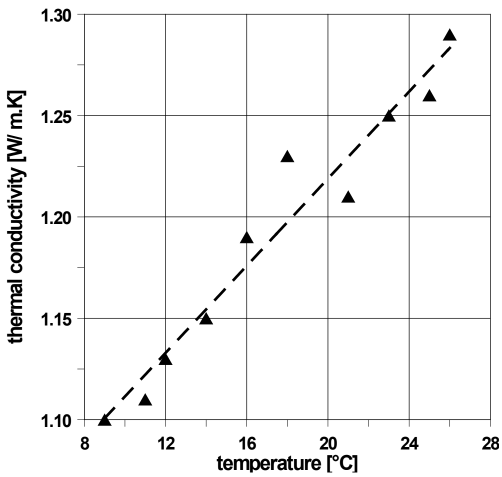

Figure 4 Relations of thermal conductivity to temperature for white brick with moisture content 16.5 %

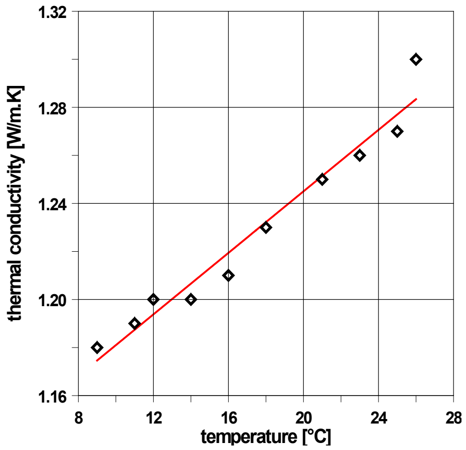

Figure 5 Relations of thermal conductivity to temperature for red brick with moisture content 11 %

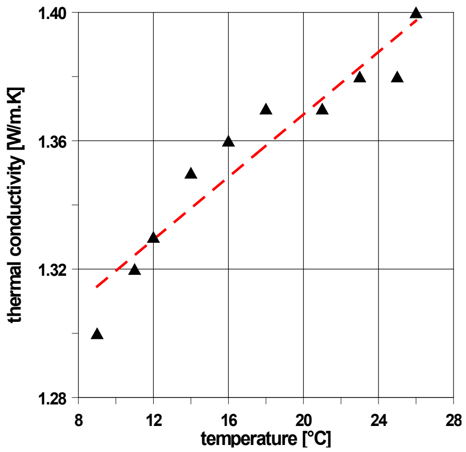

Figure 6 Relations of thermal conductivity to temperature for red brick with moisture content 16.5 %

Conclusion

The measuring process is usually influenced by effects of measurement settings, so consideration on experimental arrangement and characteristics of samples which can determine the data reliability is necessary.

Data reliability can be improved by performing comparison measurements using various methods. Comparison measurements are the key strategy to improve the data reliability. There is also a relation between the real and ideal experimental arrangement. A deviation from the ideal model is caused by technical concepts of measuring probes and by the actual sample size. The actual structure of probes and samples is characterized by appropriate limit and initial conditions. Results of temperature functions are different, more complicated in comparison to ideal ones. Then, deviations from ideal models can be characterized by correction factors. The form of correction factors can be obtained by the theoretical analysis of real experimental arrangement (Kubičár et al., 1997). Several corrections have been introduced according to Assael et al. (1992) for the heat capacity of the probe, thermal contact resistance between the probe and the test material, the finite dimension of the sample, and the finite dimension of the probe embedded in the sample.

The study of relationships between thermal conductivity and temperature, the results of which are shown in Figs 3–6, demonstrate linear increasing relations between thermophysical parameters and temperature during the temperature stabilization of the samples for red brick and white brick with moisture content 11 % and 16.5 %. For data reliability protection, there were performed series of measurements for every point in graphical characteristic with hundred measurements, and results were obtained as averages. Based on presented results, it is necessary to have knowledge of the dependence of thermophysical parameters on the temperature and moisture content of building materials if we need to protect the quality during manipulation, processing and using.

References

ASSAEL, M. J. – WAKEHAM, W. A. 1992. Measurement of the transport properties of fluids. In International Journal of Thermophysics, vol. 13, 1992, pp. 223–229.

BOŽIKOVÁ, M. 2012. Application of thermophysical measurement methods for detection of selected bio-based materials thermophysical properties : habilitation thesis. Nitra : SUA.

BOŽIKOVÁ, M. 2005. Some chosen thermophysical parameters of apples and applesauce. In Acta Technologica Agriculturae, 2005, no. 4, pp. 89–92.

CARSLAW, H. S. – JEAGER, J. C. 1999. Conduction of heat in solids. 2nd ed. Oxford : Oxford University Press, 1999, pp. 482–484.

KARAWACKI, E. – SULEIMAN, B. M. – UL-HANG, I. – Nhi, B. T. 1992. An extension to the dynamic plane source technique for measuring thermal conductivity, thermal diffusivity and specific heat of solids. In Review of Scientific Instruments, 1992, 63, pp. 4390–4397.

KARAWACKI, E. – SULEIMAN, B. M. 2001. Dynamic plane source technique for study of the thermal transport properties of solids. In High Temperatures – High Pressures, 2001, 23, pp. 215–223.

KUBIČÁR, Ľ. – BOHÁČ, V. 1997. Dynamic methods of measuring thermophysical parameters. In Pittsburgh Conference. Pitsburgh Press, 1997, pp. 2–16.

KUBIČÁR, Ľ. – BOHÁČ, V. 2000. Transient methods for the measurement of thermophysical properties. In Thermophysics 2000. Nitra : FNS CPU, 2000, pp. 39–47.

LIANG, X. G. 1995. The boundary induced error on the measurement of thermal conductivity by transient hot wire method. In Measurement Science and Technology, 1995, 6, pp. 467–471.

MALINARIČ, S. 2007. Uncertainty analysis of thermophysical property measurements of solids using dynamic methods. In International Journal of Thermophysics, vol. 28, 20007, no. 1, pp. 20–32.

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