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HOT WIRE AND HOT PLATE APPARATUSES FOR THE MEASUREMENT OF THE THERMOPHYSICAL PROPERTIES

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Key words and phrases: dynamic hot plate method; transient hot wire method; thermal conductivity; thermal diffusivity; effusivity; uncertainty.

Abstract: The paper deals with the measurement of the thermal conductivity using the hot wire method and the thermal conductivity, the effusivity and the thermal diffusivity using the dynamic plate source method. The hot wire apparatus for measurement of the thermal conductivity and the hot plate apparatus for measuremant of the thermal conductivity, the effusivity and the thermal diffusivity of materials are described here. The theory of the hot wire as well as the dynamic plate source method is summarized and uncertainties of the experimental apparatuses are given here in details. Both apparatuses are used for measurement of the thermophysical properties of the plastic material BRALEN SA 200-22. The measurements were performed at room temperature, on air, under atmospheric pressure.

Nomenclature

a - thermal diffusivity $[\mathrm{m^2s^{-1}}]$;
c - specific heat $[\mathrm{Jkg^{-1}K^{-1}}]$;
e - effusivity $[\mathrm{Ws^{1/2}K^{-1}m^{-2}}]$;
I_0 - current $[\mathrm{A}]$;
k - coverage factor;
K - slope;
L - sample length $[\mathrm{m}]$;
q_l - heat flux a unit length of the wire $[\mathrm{Wm^{-1}}]$;
q_s - heat flux a unit area of the plane source $[\mathrm{Wm^{-2}}]$;
r - distance $[\mathrm{m}]$;
r_s - sample radius $[\mathrm{m}]$;
R_0 - resistance of the plane source $[\Omega]$;
t - time $[\mathrm{s}]$;
T, T_0 - temperature [°C];
ΔT - temperature rise [°C];
U - expanded uncertainty [%];
$u_c(y)$ - combined standard uncertainty [%];
x - position $[\mathrm{m}]$;
Y - measurand;
α - resistivity temperature coefficient $[\mathrm{K^{-1}}]$;
γ - Euler's constant [0.5772];
λ - thermal conductivity $[\mathrm{Wm^{-1}K^{-1}}]$;
Θ - characteristic time $[\mathrm{s}]$;
ρ - density $[\mathrm{kgm^{-3}}]$

Introduction

The transient hot wire method is one of the most popular methods for measurement of the thermal conductivity of solids, liquids, gases and loose materials [1, 2, 3]. The method is based on the measurement of the temperature rise in a define distance from a linear heat source (hot wire) embedded in the test material. If the heat

source is assumed to have a constant and uniform output along the length of the test sample, the thermal conductivity can be derived directly from the resulting change in the temperature over a know time interval [4].

The dynamic plate source method is a suitable method for the measurement of the effusivity, the thermal conductivity and the thermal diffusivity of solids [5]. The method uses a plane heat source (hot plate), which acts both as the heat source and the temperature detector. The hot plate is sandwiched between two equal samples of finite length. The outer (rear) surface of the sample is in good contact with a very good heat conducting material (heat sink) kept at constant temperature. This creates constant temperature boundary condition at the rear face of the samples. The experiment is proposed so the hot plate has the same shape as the samples cross profile, then the method assumes a one-dimensional heat flow across the samples.

The main features that distinguish the dynamic plate source method from the transient hot wire method [6] can be summarized as: dynamic plate source method uses the plane source as a heater and a thermometer, simultaneously, it considers that the sample is treated as a finite medium, while hot wire method is restricted only to the time region where the sample is regarded as an infinite medium, dynamic plate source method gives more than one thermophysical property from a single measurement, the one-dimensional heat flow of the dynamic plate source method that creates a possibility of studying an anisotropic media is a significant advantage over hot wire method.

The reliability of measurement of a thermopysical property confirms a quantitative statement of its uncertainty that accompanies it. General rules for evaluating and expressing uncertainty in measurement, which can be followed at various levels of accuracy, have been established as the GUM method (Guide to the Expression of Uncertainty in Measurement) [7, 8]. The method has been adopted by various regional metrology and related organizations worldwide.

Classification of uncertainty components

Every measurement is affected by measurement errors that cause the difference between the measured value of the estimated property and its true value. The uncertainty of the result of a measurement consists of several components, which may be grouped into two categories according to the method used to estimate their values:

Type A standard uncertainties are those evaluated by the statistical analysis of series of observations,

Type B evaluation of standard uncertainty is usually based on scientific judgment using all the available relevant information, which may include previous measurement data.

All the individual uncertainties of the measurement result can be combined. The combined standard uncertainty $u_c(y)$ of a measurement result y is obtained by combining the individual standard uncertainties u_i arising from a Type A or a Type B evaluation. Taking a first order Taylor series approximation of the measurement equation $Y = f(x_1, x_2, ..., x_N)$ the equation referred to as the law of propagation of uncertainty can be received in the form

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 u_i^2 + 2 \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \frac{\partial f}{\partial x_i} \frac{\partial f}{\partial x_j} u_{i,j} \, . \qquad (1)$$

The partial derivatives of f with respect to the x_i are sensitivity coefficients, u_i is the standard uncertainty associated with the input estimate x_i; and $u_{i,j}$ is the estimated covariance associated with x_i and x_j. If the probability distribution characterized by the measurement result is approximately normal (Gaussian), then it is believed with an approximate level of confidence of 68 % that the measurement result can be written as $Y = y \pm u_c(y)$.

The expanded uncertainty U is the measure of uncertainty which can be obtained by multiplying $u_c(y)$ and by a coverage factor k and it is confidently believed that $Y = y \pm U$. When the normal distribution applies and u_c is a reliable estimate of the standard deviation of y, $U = 2u_c$ (i.e., $k = 2$) defines an interval having a level of confidence of approximately 95 % and when $U = 3u_c$ (i.e., $k = 3$) a level of confidence is greater than 99 %.

Principle of the hot wire method

The ideal analytical model assumes an ideal - infinite thin and infinite long line heat source (hot wire), operating in an infinite, homogeneous and isotropic material with uniform initial temperature T_0. Since the zero time $(t = 0)$ the wire is uniformly heated and the radial heat flows around the wire. If the wire produces a constant heat flux q_l per unit wire length the temperature rise $\Delta T(r,t)$ in any distance r from the wire as a function of time is described by the simplified formula [9]

$$\Delta T(r,t) = \frac{q_l}{4\pi\lambda} \ln \frac{4at}{r^2 C} \quad . \tag{2}$$

Here λ is the thermal conductivity, a the thermal diffusivity and $C = \exp(\gamma)$, with γ the Euler's constant. Eq. (2) is the working equation for the thermal conductivity calculation. The thermal conductivity is calculated from the slope K of the temperature rise $\Delta T(r,\ t)$ vs. the natural logarithm of the time ln t evolution from

$$\lambda = \frac{q_l}{4\pi K} \quad . \tag{3}$$

The Eq. (2) is valid only when the condition $r^2 / 4at << 1$ is fulfilled; for a sufficient long time t larger than certain minimum time $t_{\min}$ and for a small distance r. In a real experiment the minimum time $t_{\min}$ depends on the diameter of the wire, on the heat capacity of the wire and on the thermal contact resistance between the hot wire and the sample and the thermal contact resistance between the hot wire and the temperature sensor. In addition every sample has finite dimensions and since the heating caused by the wire will be perceivable after some time on the sample surface, the time range within which the temperature rise vs. time corresponds to Eq. (2) is also limited. Both times, the minimum time $t_{\min}$ and the maximal time $t_{\max}$ can be estimated analytically [10] or they could be found by an interactive searching. Fig. 1 presents the typical experimental temperature rise vs. time evolution obtained on the plastic sample made of polyethylene BRALEN SA 200-22.

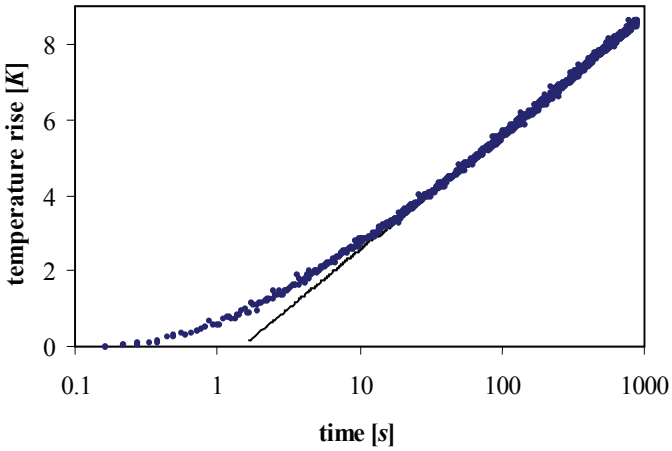

Fig. 1 Typical experimental temperature rise vs. time data and its least-squares-fit from the measurement of the thermal conductivity on the plastic sample

Experimental hot wire apparatus

There are known different modifications of the transient hot wire method. They differ accordingly to the type and place of the temperature sensor of measuring the temperature increase employed: the resistance technique [11], the standard (cross) technique [12], the parallel wires technique [13], and the probe modification of the hot wire method [14].

The used experimental apparatus allows the determination of the thermal conductivity of solids, powders and granular materials at the temperatures between 20 – 1200°C. Currently it allows utilizing one of two measurement techniques: standard cross wire technique and the probe modification of the hot-wire method. In each of these arrangements a platinum wire 0.1 - 0.35 mm in diameter (Heraeus) or a kanthal wire (Bulten Kanthal AB) 0.1 - 0.4 mm in diameter acts as the linear heat source. Their choice depends upon the measured material and upon the temperature range of the measurement.

In the cross technique, the wire cross consists of the linear heat source and of the spot welded thermocouple, *K* type made from Ni-NiCr wires (Heraeus) or *S* type – *PtRh* 90/10 % diameter (Heraeus), which acts as the temperature sensor. The hot spot of the thermocouple is in direct contact with the heating wire. In order to eliminate axial outer boundary effect it is placed in the center of the sample. The cold junction is put on the reference place in the Dewar cup at 0 ºC.

The probe method utilized the simple cylindrical probe of the original construction, which consists of a heating wire and the temperature sensor, both placed in a ceramic microcapillary (Degussa) [10]. The heating wire is located in the first hole and temperature sensor – the spot welded thermocouple is in the second one. The measurement point (the hot spot) is placed near the center of the probe.

In the case of the measurement of a solid material, the wires or the probe are embedded in ground grooves between two equally sized samples. Powders and granular materials are held in an iron container, with appropriate dimensions, so that wires or probe cross the center of the container.

Fig. 2 presents the block diagram of the apparatus. The current through the hot wire is produced by the stabilized regulated direct current supply Z-YE-2T-X (Mesit) operated by PC via a remote control unit JDR-1 (Mesit). The choice of optimal current

depends upon the sample thermal properties and dimensions, so that a temperature rise of 5 – 10ºC is produced. A high-resolution data acquisition board PCL-818HG (Advantech) with the lock-in-pre-amplifier Z-35 (Metra) is employed for the serial measurements of the transient *emf* of the thermocouple, and the transient voltage corresponding to the temperature rise. A proportional feedback temperature controller regulates the temperature stability of the electro-resistive furnace. The apparatus allows measurements in air under atmospheric pressure.

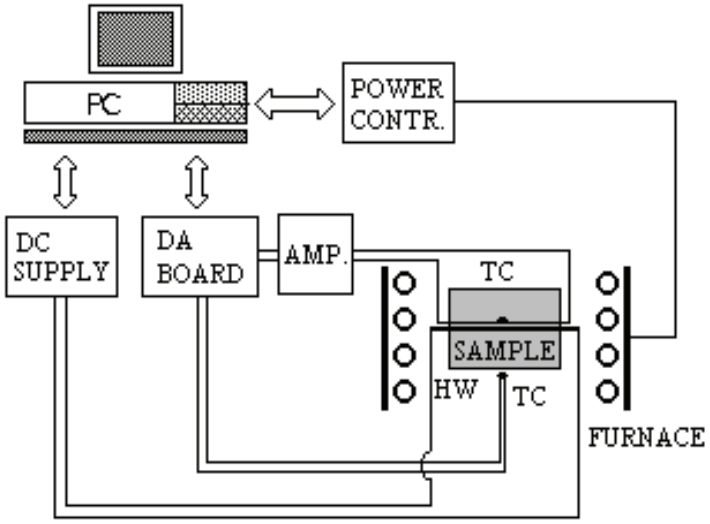

Fig. 2 Block diagram of the hot wire apparatus

Principle of the dynamic plate source method

The ideal theory considers an ideal flat heater - the homogenous hot plate of negligible thickness and mass that is in perfect thermal contact with the front face of the sample. They assume to have an ideal thermal contact (zero thermal contact resistance) between the sample and the temperature stabilizer - the block of very good heat conducting material (heat sink) as well as no heat exchange (zero heat losses) between the lateral surfaces of the sample and the surrounding environment is considered in order to have a one-dimensional heat flow [5].

We consider the ideal plane heat source at $x = 0$ placed between two identical disc-shaped samples of the thickness L made from measured materials. The samples occupy the region $-L < x < L$. Rear faces of the samples at $x = -L$ and $x = L$ are kept at constant temperature being in a perfect contact with the temperature stabilizer made of a high conducting material.

If the system has zero initial temperature T_0 and if q_s is the total output of power a unit area dissipated by the heater, then the temperature increase as a function of time is given by [5]

$$\Delta T(x,t) = \frac{q_s L}{\lambda\sqrt{\pi}} F(\Theta, t) \ , \tag{4}$$

where

$$F(\Theta,t) = \sqrt{\frac{t}{\Theta}}\left[1 + 2\sqrt{\pi}\sum_{n=1}^{\infty}\xi^n \mathrm{ierfc}\left(n\sqrt{\frac{\Theta}{t}}\right)\right] \ , \tag{5}$$

$$\xi = \left(\frac{\lambda}{\sqrt{a}} - \frac{\lambda_{Al}}{\sqrt{a_{Al}}} \right) \Big/ \left(\frac{\lambda}{\sqrt{a}} + \frac{\lambda_{Al}}{\sqrt{a_{Al}}} \right) \quad . \tag{6}$$

Here $\Theta = L^2 / a$ is the characteristic time of the sample, ierfc is the error function integral [9], λ_{Al} and a_{Al} is the thermal conductivity and the thermal diffusivity of the temperature stabilizer - heat sink (aluminum). The desired thermophysical properties of the test material can be obtained from the temperature rise $\Delta T(t)$ vs. time t evolution (Fig. 3).

For small times - $0 < t < 0.3\ \Theta$ the Eq. (4) yields

$$T(0,t) = \frac{q_s \sqrt{a}}{\lambda \sqrt{\pi}} \sqrt{t} \quad , \tag{7}$$

which corresponds to the linear heat flow into an infinite medium [9]. The slope of the temperature rise $\Delta T(x, t)$ vs. square root time $\sqrt{t}$ evolution gives the effusivity e of the measured material [15]

$$e = \frac{\lambda}{\sqrt{a}} = \sqrt{\rho\, c\, \lambda} \quad , \tag{8}$$

where ρ is the density and c is the specific heat of the sample material.

In the case of an ideal heat sink $(\zeta = -1)$ the equations (4) and (5) we can be simplified as

$$\Delta T(x,t) = \frac{q_s L}{2\lambda} \left[1 - \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left(- \frac{(2n+1)^2 \pi^2 t}{4\Theta} \right) \right] \quad . \tag{9}$$

For large times $t > 2\Theta$ [16] the temperature rise conforms the formula

$$\Delta T(x,t) = \frac{q_s L}{2\lambda} \quad , \tag{10}$$

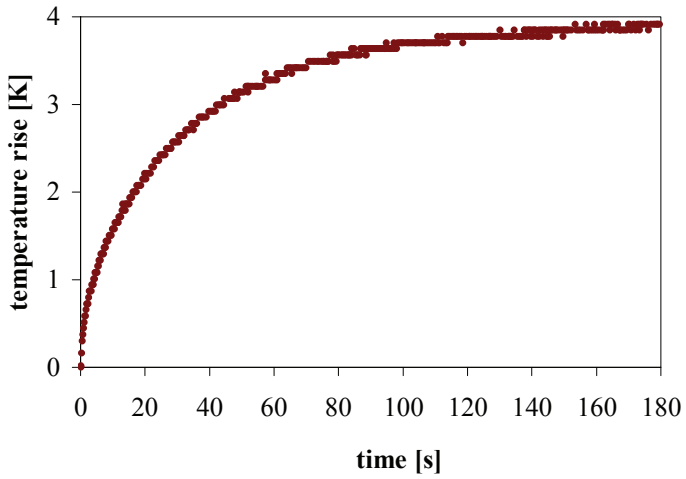

Fig. 3 Experimental temperature rise of the hot plate sensor as a function of the time measured on the sample of BRALEN SA 200-22

that can be easily used for the thermal conductivity λ estimation. The thermal diffusivity *a* can be calculated from the effusivity *e* and the thermal conductivity λ values using the equation

$$a = \left(\frac{\lambda}{e}\right)^2 \quad . \tag{11}$$

Experimental hot plate apparatus

The plane heat source (supplied by Institute of Physics, SAS Bratislava) is made of a 23 μ*m* thick Ni foil, protected from both sides by an insulating layer made of 25 μ*m* thick kapton. It is placed between two identical disc-shaped samples having the same cross section profile as the heater surface. The rear surfaces of the samples are connected to stabilizer bocks (heat sinks). They are made of sufficiently thick disks of a very good heat conducting material (aluminum). The plane heat source serves both as a heat source and as the resistance temperature detector. The thermophysical properties of the test material are estimated analyzing the measured temperature rise vs. time evolution subjected by the application of the step heating by flowing the electrical current through the hot plate source. The temperature variation at the hot plate sensor is determined by measuring the change of the voltage $\Delta U(t)$ across the source

$$\Delta U(t) = I_0 R_0 \alpha \Delta T(t) \quad , \tag{12}$$

where I_0 is the heating electric current, R_0 is the initial resistance of the hot plate and α is the temperature coefficient of resistivity of the nickel. Fig. 4 presents the schematic view of the experimental apparatus. The heating current flowing through the heat source is produced by the direct current power source BS 575 (Tesla). The voltage variation across the sensor is measured by the PCL-818HG (Advantech) data acquisition board. The apparatus is controlled by the PC.

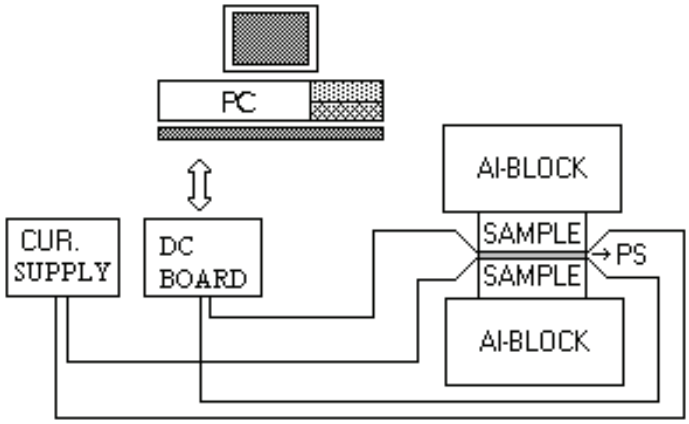

Fig. 4 Schematic view of dynamic hot plate apparatus

Experimental results

The measurements have been performed on the plastic samples made of low-density polyethylene BRALEN SA 200-22.

In the hot wire method, the 'wire cross' was embedded between two sample blocks of 50 × 100 × 100 mm. The thermal contact was improved using the silicon sink

compound paste (Dow Corning 340). Measurements were performed utilizing two different currents – 0.6 and 0.7 A.

In the dynamic plate source method, the plane source was embedded between two identical the disc shaped samples of 30 mm in diameter. The total thickness of the samples was $2L = 76$ mm, the resistance of the hot plate was about $R_0 = 1.221\ \Omega$ and the temperature coefficient of the resistivity of the sensor was $4.7\ 10^{-3}\ K^{-1}$. The measurement were performed utilizing currents – 0.4 A, 0.5 A and 0.6 A. The thermal contacts between the plane source and the samples, the samples and the heat sinks were improved using the silicon sink compound paste. All measurements were performed at room temperature, on air, under atmospheric pressure.

Achieved results of the thermal conductivity using the hot wire apparatus and results of the thermal conductivity, effusivity and thermal diffusivity using the hot plate apparatus are summarized in the Table 1. Each value presented there is calculated as the average of five independent measurements.

The achieved thermal conductivity results are compared with the reference values obtained on the heat flow meter in the Austrian Research Centers in Seibersdorf. The Table 1 shows very low dispersion of results as well as a very good agreement with the reference values λ_{ref} .

Table 1

Experimental results
(λ_{THW} – the thermal conductivity measured by the hot wire method, λ_{DPS} - the thermal conductivity measured by the dynamic plate soure method, λ_{ref} - the reference thermal conductivity, *e* – the effusivity, *a* – the thermal diffusivity calculated from λ_{DPS} and *e*).

	λ_{THW} [$Wm^{-1}K^{-1}$]	λ_{DPS} [$Wm^{-1}K^{-1}$]	λ_{ref} [$Wm^{-1}K^{-1}$]	*e* [$Ws^{1/2}K^{-1}m^{-2}$]	*a* [$m^{-2}s^{-1}$]
BRALEN SA 200-22	0.315	0.316	0.317	845.4	1.410
Mean square deviation	± 0.004	± 0.002		± 6.9	± 0.023
Standard deviation	2.1 %	1.2 %		1.5 %	3.5 %

Uncertainty analysis of the hot wire apparatus

The thermal conductivity is in the case of the transient hot wire method obtained calculating the slope of the measured temperature rise vs. time evolution in logarithmical scale over a defined time. The sources of uncertainties in the thermal conductivity measurement are connected with the measurement of the temperature, the stability of the time scale and the stability of the power supply. The main sources of the non-measurement errors are caused by differences between the assumptions of the ideal analytical model and the real experimental conditions i.e., that the heating wire has finite non-zero diameter and the real heat capacity, that there are thermal barriers between the wire and the sample; between the temperature sensor and the wire, that the sample and the wire have finite dimensions and that there the heat exchange between the sample outer surface may occur. The random component of the uncertainty is evaluated statistically analysing the repeated measurement.

Type A uncertainty is represented with the relative standard deviation value that is in our case equal to 2.08 % (Table 1).

The main sources of the Type B uncertainty are the measurement errors connected with the temperature measurement, the time base stability and the stability of the power supply. The temperature is measured using the K type thermocouple Manufacturer specifies the typical accuracy better than 0.4 % of the measured value. If we take account of the uncertainties of the thermocouple *emf* measurement and uncertainty of the PCL-818HG data acquisition board manufacturer that is of order of 0.08 % we may guess the uncertainty of the temperature measurement at value 0.5 %. It is supposed that the effect causes mainly systematic error in the temperature measurement. We can guess that this error influences the uncertainty of the thermal conductivity at the level of about 0.1 %. The time base is based on the PCL-818HG data acquisition board time system. The manufacturer specifies the stability and the uncertainty better than 0.01 %. The influence is so small that we do not have to consider it as a source of the thermal conductivity uncertainty. The current is produced by the stabilized power source Z-YE-2T-X working in the stabilized current supply mode. Manufacturer specifies the current stability at level of 0.05 %. The influence on the thermal conductivity uncertainty is then 0.1 %.

Non-measurement errors: deviations of real experimental conditions from those considered in the ideal analytical model as initial and boundary conditions cause deformation of the temperature rise curve.

Non-linearity of the initial part of the data is caused by finite radius and non-zero heat capacity of the wire and similar influence has also an effect of the thermal contact resistance between the hot wire and the sample and resistance between the hot wire and the temperature sensor. This phenomenon is overcame finding the minimum time $t_{\min}$ which corresponds to the beginning of the linear part of the curve. It is difficult to evaluate the influence of these errors on the uncertainty of the thermal conductivity estimation. We try to eliminate these effects experimentally (using of thin wires, by improvement of the thermal contact using a silicon paste). Because of the way of the data reduction based on the checking of the least-squares fit of the data to the analytical model, we suppose that uncertainty is included in the random uncertainty (presented as the A Type).

Deformation of the end of experimental curve is caused mainly as a result of finite dimensions of the sample and finite length of the hot wire. Similarly like the time $t_{\min}$, the maximal time $t_{\max}$ is found by an interactive searching. To eliminate the other boundary effects experimentally we use relatively large samples. We eliminate the influence of the finite length of the hot wire by the measurement of the temperature evaluation in the centre of the sample. We consider that the influence of the accuracy of the measurement on these effects is in our case negligible.

All the A and B Type components of the uncertainty are considered to be independent. Using the law of uncertainty propagation (Eq. 1) we can assure the combined standard uncertainty of the thermal conductivity better than 3.3 %.

Uncertainty analysis of the dynamic hot plate apparatus

The sources of the uncertainty of the thermal conductivity and of the effusivity measurement are connected with measurement of the voltage evolution over the hot plate, stability of the time axis and stability of the power supply. The sources of the non-measurement errors are originated, as for the hot wire apparatus, by differences between the real experimental conditions and the theoretical assumptions of the ideal analytical model. In a real experiment the hot plate has non-zero thickness and mass; there is not a perfect thermal contact between the plate source and the sample; non-zero thermal contact resistance may cause a possible thermal barrier between the sample and the heat sink; heat losses from the lateral surfaces of the sample may be significant.

Type A uncertainty is expressed by the relative standard deviation value for the thermal conductivity 1.19 %, for the effusivity 1.50 % and for the thermal diffusivity 3.46 % as written in the Table 1.

Measurement errors (Type B) are connected with voltage measurement, time base stability and power supply. The voltage over the hot plate is measured using the PCL-818HG data acquisition board. Manufacturer specifies the typical accuracy 0.08 % the measured value, what causes the uncertainty of the thermal conductivity and effusivity is about 0.1 %. The time base is based on the PCL-818HG data acquisition board time system, same as in the hot wire apparatus, with the uncertainty better than 0.01 %. The influence is so small that we do not have to consider it as a source of the thermal conductivity and effusivity uncertainty. The current is produced by the stabilized power source BS 575. Manufacturer specifies the current stability at level of 0.05 %. The influence on the thermal conductivity and thermal effusivity uncertainty is then 0.1 %.

Non-measurement errors: deviations of the real experimental conditions from the ideal analytical model (non-ideal heater, thermal resistance between the heater and the sample and between the rear surface of the sample and the heat sink, heat losses from the lateral sides of the sample).

The influence of the thermal inertia of the hot plate heater and the thermal contact resistance between the plate and the samples influence only the initial part of the experimental data. This negative influence can be neglected after a few seconds, when a straight line portion of the curve $\Delta T(t)$ against $\sqrt{t}$ occurs. It is impossible directly evaluate the uncertainty of the effusivity estimation caused by these effects. We try to eliminate these negative effects experimentally by using of the plate source as thin as possible and by improving the thermal contact using a silicon paste.

The thermal contact resistance between the rear surface of the samples and the heat sinks influences later parts of the experimental data. The effect can be eliminated by making the rear surface of the sample and heat sink sufficiently flat and by improving the thermal contact between the sample and the heat sink using a silicon paste. Heat losses from the lateral sample surface depend [5] on the thermal properties of the material of the sample and on the sample thickness to sample radius L / r_s ratio. The optimal is keeping the ratio as small as possible. We consider that the influence of the accuracy of the measurement on these effects is in our case negligible.

Accordingly to the Eq. 1 we can assure that the combined standard uncertainty of the thermal conductivity is 1.4 %, the effusivity is 1.7 % and the thermal diffusivity is better than 4.0 %.

Conclusions

The paper confirms reliability of the transient hot wire and the dynamic hot plate method apparatuses for the measurement of the thermal conductivity and the effusivity of a low thermal conductive material.

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Устройства для измерения термофизических свойств, использующие проволочный и плоский нагреватели

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Ключевые слова и фразы: динамический метод плоского нагревателя; метод мгновенного нагрева проволочным нагревателем; нечеткость; теплопроводность; температуропроводность; тепловая активность; погрешность измерений.

Аннотация: Рассматривается измерение теплопроводности с использованием метода нагрева проволочным нагревателем, а также теплопроводности, коэффициента тепловой активности и коэффициента температуропроводности с использованием динамического метода плоского нагревателя. Описываются устройство для измерения теплопроводности материалов с использованием проволочного нагревателя, устройство измерения теплопроводности, коэффициента тепловой активности и коэффициента температуропроводности с использованием плоского нагревателя. Приведены теория использования метода мгновенного нагрева проволочным нагревателем и теория применения динамического метода плоского нагревателя. Дано детальное описание источников погрешностей экспериментальных устройств, Оба устройства используются для измерения теплофизических свойств пластикового материала BRALEN SA 200-22. Измерения были выполнены при комнатной температуре, на воздухе, под атмосферным давлением.

Draht- und Flachheizungsgeräte für die Messung der wärme-physikalischen Eigenschaften

Zusammenfassung: Es wird die Messung der Wärmeleitfähigkeit mit der Benutzung der Heizungsmethode mit Hilfe vom Drahterhitzer und auch der Wärmeleitfähigkeit, des Koeffizientes der Wärmeaktivität und des Koeffizientes der Temperaturleitfähigkeit mit der Benutzung von dynamischer Methode des Flacherhitzers betrachtet. Es werden die Errichtung für die Messung der Wärmeleitfähigkeit, des Koeffizientes der Wärmeaktivität und des Koeffizientes der Temperaturleitfähigkeit mit der Benutzung vom Flacherhitzer beschrieben. Es sind die Theorie der Anwendung der Methode der momentanen Heizung mit dem Drahterhitzer und die Theorie der Verwendung der dynamischen Methode des Flacherhitzers angeführt. Es ist die Detailbeschreibung der Fehlerquellen der Experimentell-einrichtungen gegeben. Die beiden Einrichtungen werden für die Messung der wärme-physikalischen Eigenschaften des Kunststoffes BRALEN SA 200-22 benutzt. Die Messungen wurden bei der Raumtemperatur, an Luft, unter dem Luftdruck durchgeführt.

Dispositif pour la mesure des propriétés thermphysiques qui utilisent des réchauffeurs plat et à fil

Résumé: On étudie la mesure du transfert de chaleur avec l'utilisation de la méthode du chauffage par le réchauffeur à fil, ainsi que du transfert de chaleur, du coefficient de l'activité thermique et du coefficient du transfert de température avec l'utilisation de la méthode dynamique du réchauffeur plat. On décrit le dispositif pour la mesure du transfert de chaleur avec l'utilisation du réchauffeur à fil, le dispositif de la mesure du transfert de chaleur, du coefficient de l'activité thermique et du coefficient du transfert de température avec l'utilisation du réchauffeur plat. On cite la théorie de l'utilisation de la méthode du chauffage instantanné par le réchauffeur plat. On donne la description détaillée des sources des erreurs des dispositifs d'expériment. Les deux dispositifs sont utilisés pour la mesure des propriétés thermphysiques de la matière plastique BRALEN SA 200-22. Les mesures ont été faites avec la température ordinaire de l'air, sous la pression atmosphérique.