Thermal Effusivity Estimation of Polymers in Time Domain

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An accurate knowledge of thermophysical properties is very important, for example, to optimize the engineering design and the development of new materials for many applications. Thermal effusivity is a thermal property which presents an increasing importance in heat conduction problems. This property indicates the amount of thermal energy that a material is able to absorb. The estimation can be done by simulating a transient heat transfer model. In this case a one-dimensional semi-infinite thermal model is used. A resistance heater in contact with the sample generates a heat pulse. Variations of temperature and heat flux are measured simultaneously on the top surface of the sample. In this work, thermal effusivity is estimated in time domain through the minimization of the objective function, defined as the square difference between experimental and theoretical temperatures. The golden section technique is used for minimizing this objective function. A sensitivity analysis and a comparison between the semi-infinite and the finite models were also done to define the number of points to be used in the estimation. Measurements were carried out with three different polymers: polymethyl methacrylate, polyvinyl chloride and polyethylene. In all cases studied the results are in good agreement with literature. In addition, an uncertainty analysis is also presented.

Keywords: *heat conduction, experimental methods, optimization, thermal effusivity*

Introduction

The knowledge about thermophysical properties of materials is even more necessary to make its correct application in engineering processes. Thermal conductivity, λ, thermal diffusivity, α, and thermal effusivity, b, are three important properties in heat conduction problems. Due to their importance, several methods have been developed to determine their values with accuracy and reliability. The methods which involve transient heat transfer stand out because they have an easy implementation, lower costs and shorter measurement time. In these methods a signal is generated, usually an impulse or a periodic function or a step-function, on the surface of the sample. The variations of temperature and heat flux are used to calculate the property. Blackwell (1954) presented the hot wire technique to measure thermal conductivity. A wire used as heater and temperature sensor is inserted inside the sample. A heat pulse is generated and the heat flux and temperature variations are measured. A disadvantage is that it is a destructive method because a hole has to be made in the sample. Also, it cannot be used in metals because of the thermal contact resistance and the short time for measurement. This method presents good results for insulation materials. Santos et al. (2004) and Carvalho et al. (2006) used it to measure thermal conductivity of polymers. To measure thermal diffusivity, Parker et al. (1961) developed the flash method. Since then it has been used several times and received improvements, as made by Sheindlin et al. (1998) and Min, Blumm and Lindemann (2007). Additionally, it is the most used method to measure thermal diffusivity of different kinds of materials. As an example, Iguchi, Santos and Gregório (2007) measured α of polymers and Blumm, Lindemann and Min (2007) measured α of water and ethylene glycol. The method consists in generating a high intensity energy pulse in a short time on the top surface of a thin sample. The variations of temperature are measured in the bottom face. Using a temperature versus time curve the thermal diffusivity can be calculated. The photoacoustic techniques have widely been used to measure thermal effusivity. These techniques can be used in many kinds of materials, including liquids, as in the work of Dadarlat et al. (2008). As shown by Benedetto and Spagnolo (1988), the technique is based on the measurement of sound wave intensity or phase. These waves are generated by any type of radiation absorbed by the material. A microphone is used to detect them. Generally, the radiation source is a light beam. To avoid the reflection, the surface of the sample must be opaque with a black paint with known thermal properties. The aforementioned techniques are restricted to laboratorial experiments.

The majority of the work in the literature has estimated the thermal effusivity by using the thermal quadrupole theory (Krapez, 2000; Defer, Antczak and Duthoit, 2001; Antczak et al., 2003; Antczak et al., 2007 and Lima e Silva and Lima e Silva, 2010). In this case the frequency domain is used and it is necessary that the heat flux and the temperature difference $\Delta T = T(x,t) - T(x,0)$ signals drop to zero after heating is off. In the frequency domain, to determine the thermal properties accurately, an impulse or periodic signal must be used and only few points can be used in the estimation procedure. In addition, it is very difficult to estimate temperature dependent thermophysical properties. Thus, to avoid these difficulties, the objective of this work is to estimate the thermal effusivity of large thickness samples in time domain. To achieve this, the same temperature and heat flux data used in Lima e Silva and Lima e Silva (2010) are used in this work to estimate the thermal effusivity of three different polymers: polymethyl methacrylate (PMMA), polyvinyl chloride (PVC) and polyethylene (PE). A semi-infinite and one-dimensional thermal model is used. In this case the medium depends only on its thermal effusivity. In this thermal model, Green's functions are used to solve the heat diffusion equation. This solution allows for calculating the theoretical temperature through numerical methods. The solution of the problem is achieved in time domain which allows a larger number of points to be used in the estimation procedure. To solve the problem, the minimization of an objective function was done. This function is defined as the square difference between experimental and theoretical temperatures. The golden section technique was used to minimizate the function (Vanderplaats, 2005). A sensitivity analysis and a comparison between the semi-infinite and finite models were carried out to choose the number of points to be used. The results are in good agreement with literature. This methodology represents a good alternative to estimate the thermal effusivity in *in situ* applications.

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Nomenclature

B = *thermal effusivity* ($W\ s^{1/2}\ K^{-1}\ m^{-2}$)
F = *objective function* (K^2)
L = *sample thickness* (m)
n = *number of points used in estimation*
S_b = *sensitivity coefficient* ($m^2\ K^2\ W^{-1}\ s^{-1/2}$)
t = *time* (s)
T = *theoretical temperature* (K)
T_0 = *initial temperature* (K)
T_e = *experimental temperature* (K)
U_b = *thermal effusivity uncertainty*
U_{data} = *data acquisition system uncertainty*
U_e = *experimental temperature uncertainty*
$U_{H.F.}$ = *heat flux uncertainty*
$U_{H.T.}$ = *heat flux transducer uncertainty*
U_{num} = *numerical uncertainty*
U_{obj} = *objective function uncertainty*
U_R = *thermal contact resistance uncertainty*
U_{theo} = *theoretical temperature uncertainty*
U_{therm} = *thermocouple uncertainty*
x = *dimension* (m)

Greek Symbols

α = *thermal diffusivity* ($m^2\ s^{-1}$)
λ = *thermal conductivity* ($W\ m^{-1}\ K^{-1}$)
ϕ = *heat flux* ($W\ m^{-2}$)
$\phi_1(t)$ = *heat flux measured* ($W\ m^{-2}$)

Subscripts

b = *relative to thermal effusivity*
data = *relative to data acquisition system*
e = *relative to experimental measurement*
H.F. = *relative to heat flux*
H.T. = *relative to heat transducer*
num = *relative to numerical solution*
obj = *relative to objective function*
R = *relative to thermal contact resistance*
theo = *relative to theoretical temperature*
therm = *relative to thermocouple*
0 = *relative to initial time*
1 = *relative to frontal surface*

Formulation of the Problem

Semi-infinite thermal model

The one-dimensional thermal model used is presented in Fig. 1. A semi-infinite solid is subjected to a heat flux on the top surface. The temperature measurement is on the same surface.

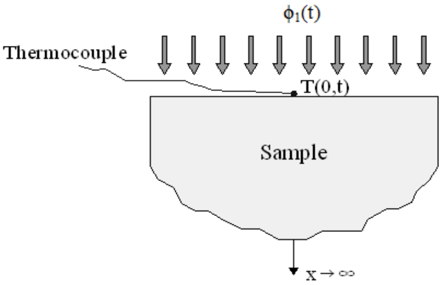

Figure 1. Semi-infinite sample subjected to a heat flux.

In this case, the heat diffusion problem can be described as:

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{1}$$

The boundary and initial conditions are:

$$\varphi(0,t) = \lambda \left.\frac{\partial T}{\partial x}\right|_{x=0} = \varphi_1(t) \tag{2}$$

$$T(x,t)_{x\to\infty} = T_0 \tag{3}$$

$$T(x,0) = T_0 \tag{4}$$

where $\phi_1(t)$ is the heat flux measured on the sample surface and T_0 is the initial temperature.

Several methods can be used to solve Eqs. (1)-(4) in order to obtain the temperature solution. For example, Green's functions– GFs (Beck et al., 1992) and Laplace Transform (Özisik, 1993) are classical methods that can be used. In this work the GFs were chosen because a lot of problems are solved using this method. The same GFs for a given geometry and a given set of homogeneous boundary conditions is a building block of the temperature distribution resulting from: (a) space variable initial temperature distribution, (b) time- and space-variable boundary conditions, and (c) time- and space-variable volume and energy generation. Many GFs have been derived and are tabulated in Beck et al. (1992), so the derivation of GF may be omitted in many cases. Two and three-dimensional GFs can be found for transient cases by simple multiplication of one-dimensional GFs for the rectangular coordinate system for most boundary conditions, etc. In this sense the solution of the temperature problem presented in Eqs. (1)-(4) was obtained by using GFs solution for one-dimensional rectangular coordinates as (Beck et al., 1992).

$$T(x,t) = \int_{x'=0}^{L} G_{X20}(x,t|x',0).F(x')dx' + \alpha \int_{\tau=0}^{t} \frac{\phi_1(\tau)}{\lambda} G_{X20}(x,t|x',\tau)d\tau \tag{5}$$

where α is the thermal diffusivity, λ is the thermal conductivity and $F(x')$ is the initial temperature distribution. The GF G_{X20} was found in Beck et al. (1992) as:

$$G_{X20}(0,t|0,\tau) = [\pi\alpha(t-\tau)]^{-1/2} \tag{6}$$

After some manipulations, the solution of temperature on the top surface $T(0,t)$ of a semi-infinite medium can be written as:

$$T(0,t) = T_0 + \frac{1}{b.\pi^{1/2}}.\int_0^t (t-\tau)^{-1/2}.\phi_1(\tau)d\tau \tag{7}$$

where b is the thermal effusivity, defined as the relation between the thermal conductivity, λ, and the square root of the thermal diffusivity, α. The thermal effusivity of the material is a measure of its ability to exchange thermal energy with its surroundings.

$$b = \frac{\lambda}{\alpha^{1/2}} \tag{8}$$

Equation (7) may be used to approximate the transient temperature response of a finite solid, such as a thick slab. This equation was solved numerically by the trapezoid rule method (Ruggiero and Lopes, 1996).

Thermal effusivity estimation

The thermal effusivity is estimated by minimizing an objective function. This function is defined as the square difference between experimental, T_e, and theoretical, T, temperatures, defined as:

$$F = \sum_{i=1}^{n} [T_e(i) - T(i)]^2 \tag{9}$$

where n is the number of points used. To minimize the objective function (Eq. (9)), the Golden Section method (Vanderplaats, 2005) is used to determine the thermal effusivity.

Definition of the number of points used

A sensitivity analysis and a comparison between the semi-infinite and the finite models were done in order to choose the number of points n to be used in the estimation procedure. Values of thermal effusivity from literature were used to carry out these analyses. The values for PVC were obtained from Larbi Youcef et al. (2010), for PMMA from Roger et al. (1995), and for PVC from Jannot and Meukam (2004) (Table 1).

Table 1. Literature values used in the sensitivity analysis and in the comparison between semi-infinite and finite models.

Sample	***b*** **(W s$^{1/2}$ K^{-1} m^{-2})**
PVC	408
PMMA	566
PE	888.6

Sensitivity analysis

The sensitivity coefficient, S_b, is defined as the first derivative of the temperature (Eq. (7)) with respect to the b parameter. The trapezoid rule method (Ruggiero and Lopes, 1996) was used to solve Eq. (10) numerically by using the experimental data of the heat flux $\phi_1(t)$ and the reference values of b (Table 1).

$$S_b = \frac{dT}{db} = -\frac{1}{b^2.\pi^{1/2}} \cdot \int_0^t (t-\tau)^{-1/2}.\phi_1(\tau)d\tau \tag{10}$$

Equation (10) shows that S_b depends on the heat flux, the value of b, and the time steps. Figure 2 shows the behavior of S_b for each sample. It can be observed in this figure that for PE, S_b becomes constant for times higher than 2000 s. In Fig. 2, a little contribution is given to the estimation procedure for times higher than 2640 s for PVC and 3500 s for PMMA. PVC presents the highest values of S_b in Fig. 2. This happens because PVC has the smaller value of b and the smaller time step.

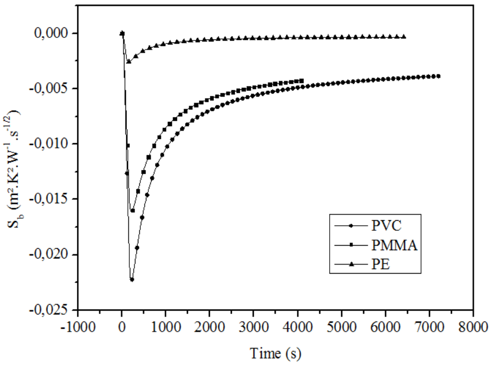

Figure 2. Sensitivity coefficients related to b for PMMA, PVC, and PE.

Comparison between semi-infinite and finite models

As already mentioned, the semi-infinite model must be used for the determination of b. In this work, the samples used are finite with a thickness of L = 50 mm. However, under certain conditions of time, the thermal behavior of a finite medium of thickness L can be considered identical to the semi-infinite medium (Beck et al., 1992). In addition, this behavior tends to be the same when the thickness and heat diffusion time are short. In order to verify this condition, a comparison between a finite model and a semi-infinite model is done for the calculated temperatures on the top surface. The finite model was given by a one-dimensional model with heat flux imposed on the top surface and insulation on the other surface (Fig. 3). For this case the heat diffusion (Eq. (1)) was used with the following boundary and initial conditions:

$$\varphi(0,t) = \lambda \left.\frac{\partial T}{\partial x}\right|_{x=0} = \varphi_1(t) \tag{11}$$

$$\frac{\partial T(L,t)}{\partial x} = 0 \tag{12}$$

$$T(x,0) = T_0 \tag{13}$$

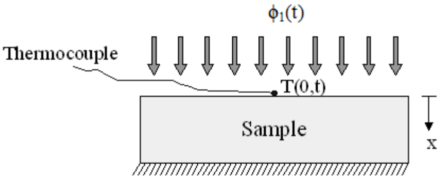

Figure 3. Finite thermal model.

The problem of Fig. 3 is solved numerically by approximating the heat diffusion equation in finite differences through explicit method. This procedure was validated with exact solution obtained by Lima e Silva, Duarte and Guimarães (1998). Literature values of α and λ for PVC (Crawford, 1998), for PMMA (Miller and Kotlar, 1991) and for PE (Guimarães, Philippi and Thery, 1995) were used. The difference between the two models is analyzed and the moment the difference begins to increase is determined. At this point the hypothesis of semi-infinite medium is no longer valid. Figure 4 shows the difference between finite and semi-infinite models for PMMA, PVC, and PE samples. In this figure the discrepancy between the semi-infinite and finite models for short times happens due to the difference of the models. This probably occurs because the semi-infinite model is based on the hypothesis of the larger the sample, the higher the temperature for this model. This discrepancy happens only when the heater is on and it will be considered in the uncertainty analysis presented forward. In Fig. 4, it can be seen that for times higher than the values mentioned before for PVC, PMMA, and PE the finite model can not be considered semi-infinite.

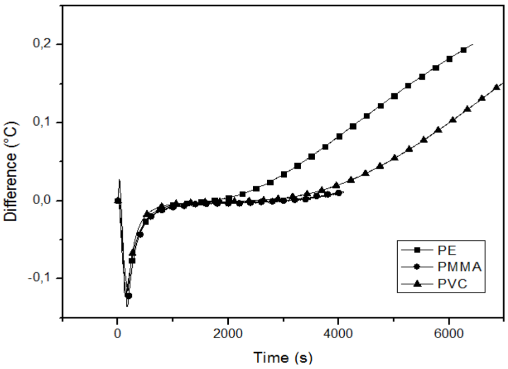

Figure 4. Difference between finite and semi-infinite models.

Thermal Contact Resistance Influence

In heat conduction problems involving compound systems, in which the conduction occurs from a material to another, the thermal contact between them has great importance. Usually, a perfect thermal contact is assumed, but this does not occur in practice due to lack of flatness, the roughness of the samples, and the insertion of sensors such as thermocouples. These spaces are occupied by air, which causes a drop in temperature on the surface of the sample. So heat transfer occurs through the real contact area and the gaps. To determine the influence of thermal contact resistance in the experiments, an air layer of 0.01 mm thick between the transducer and the sample, as shown in Fig. 5, was simulated. Lima e Silva (2000) showed that on center of the heat transducer and the surrounding area, heat transfer can be considered one-dimensional.

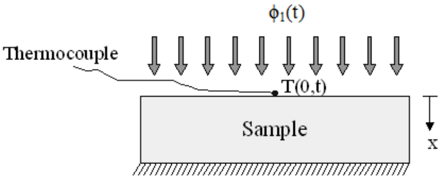

Figure 5. Model adopted to analyze thermal contact resistance influence.

To determine the influence of the air layer, the temperatures on the surface of the transducer and the sample were compared (Fig. 6a). These temperatures were calculated for PVC (thermal effusivity from Table 1) by using experimental data of heat flux. Figure 6a shows that the difference between these temperatures increased with the rise of heat flux. However, for an air layer of only 0.01 mm the largest difference found was only 0.103°C (Fig. 6b). It represents an error of only 0.32%. So the effect of thermal contact resistance can be despised in thermal effusivity estimation. In addition, to reduce the contact resistance the heat transducer is placed under pressure with a thermal paste.

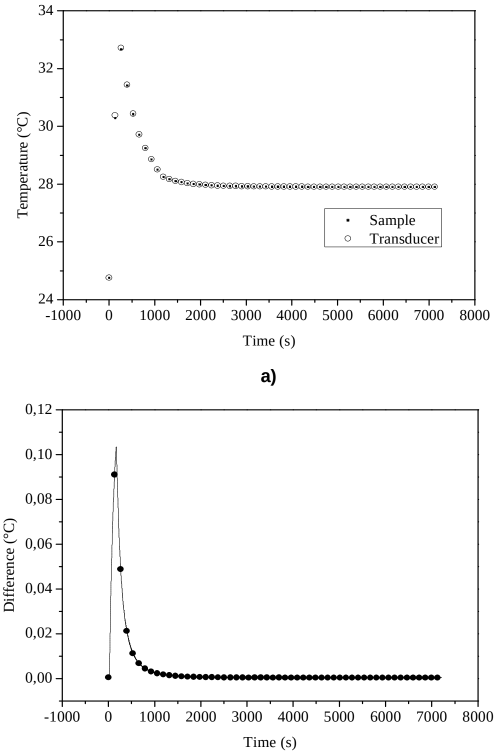

Figure 6. a) Temperature evolution on the heat transducer and on the PVC sample; b) Difference between temperatures on the heat transducer and on the sample.

Experimental Procedure

Figure 7 shows a diagram of the assembly made to perform the thermal effusivity estimation of three polymers: PMMA, PVC and PE. The samples have dimensions of 305 x 305 x 50 mm. The lateral dimensions are larger than the thickness to ensure a uniform and one-dimensional heat flux on their surfaces. The heater used has the same lateral dimensions and a thickness of 1.4 mm. Its electrical resistance is 22 Ω. This heater was connected to a digital power supply to provide a heat pulse of 40 V (dc) for all samples. The time duration of heating was approximately 150 s for PVC and PMMA samples and 90 s for PE. To measure the heat flux a transducer with dimensions of 50 x 50 x 0.3 mm (Leclerq and Thery, 1983) was used. This transducer is based on measurements of temperature difference. It employs the same gradient layer principle which is used in direct calorimeter. Technological developments have demonstrated the feasibility of using very thin metallic foils to form thermoelectric junctions. Thermoelectric junctions are made with the help of metallization and photoetching. These techniques made possible the construction of heat flowmeters of large dimensions and extreme thicknesses of 0.1 mm. The sensitivity of these flowmeters is high due to the considerable increase in the number of thermoelectric junctions per unit area. A linear response was used in the calibration process of the heat flux transducer (Lima e Silva, 2000). This transducer is very thin and was made of copper which presents a high thermal conductivity. A thermal grease of high thermal conductivity was also used to reduce the contact resistance. Guimarães (1993) and Lima e Silva (2000) presented a detailed study on heat flux measurements using heat transducer and mentioned that the effects of contact resistance and non one-dimensional heat flux can be negligible for the experimental conditions of this work. The temperature measurement on the contact surface is made through a K type cable thermocouple (30

AWG). This thermocouple was calibrated in a portable calibration bath ERTCO with a stability of ± 0.01ºC. The thermocouple was attached on the side of the heat transducer with the same thermal grease previously mentioned. Weights were used on the top of the isolated assembly to improve the contact between the components. Signs of heat flux and temperature are acquired by an acquisition system HP Series 75000 controlled by a computer. The sensors were attached on the middle of the sample. In Fig. 7, an oven which does not control the temperature was only used to minimize the convection influence and the variation of the ambient temperature over the sample. The sample was all isolated and Lima e Silva (2000) showed that for these conditions the convection can be neglected.

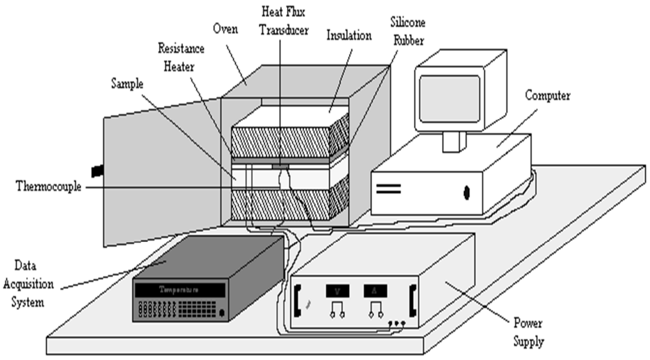

Figure 7. Scheme of the experimental apparatus.

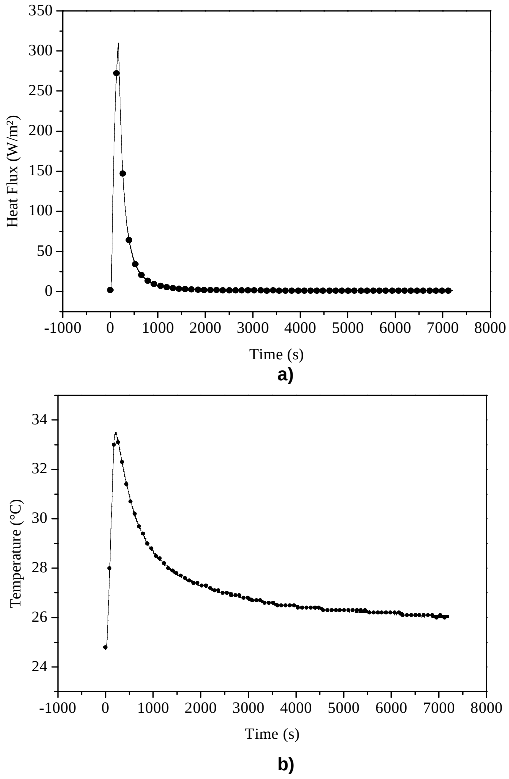

Figure 8. a) Heat flux evolution; b) Temperature evolution.

Results

Table 2 shows the number of experiments carried out, the time interval of acquisition, and the number of points measured and used in the thermal effusivity estimation for PVC, PMMA, and PE samples. The difference between the procedures is due to the fact that the data were obtained from three different articles, for PE (Guimarães, Philippi and Thery, 1995), for PMMA (Lima e Silva, Duarte and Guimarães, 1998) and for PVC (Lima e Silva, Tiong and Guimarães, 2003). Since the equipment is the same, the authors made use of these experiments from the mentioned articles. A number of experiments were done in order to obtain reliable estimates of standard deviation and average of the data. According to the literature this number has to be at least 20 experiments (Holman, 2001).

Table 2. Number of experiments, time interval, points measured and used in the thermal effusivity estimation.

Sample	Experiments	Time Interval (s)	Total Points	Points Used
PVC	51	0.88	8192	3000
PMMA	42	1.00	4097	3500
PE	21	6.25	1030	320

In all experiments the heat flux and the temperature evolution have the same behavior, as shown in Fig. 8. An impulse signal of heat flux imposed on the sample surface results in temperature increase. After this impulse, temperature begins to decrease.

The results of thermal effusivity estimation are shown in Table 3. The values of *b* presented are an average of the values found in all experiments for each sample. The term “Difference” (Diff.) in Table 3 represents a comparison between *b* estimated in this work and *b* from literature (Table 1). There is a significant variation in the values of *b* from literature for these materials. The “Standard Deviation” (SD) represents the difference observed among the experiments carried out with each sample. Table 3 presents different values of the Standard Deviation for each sample. The difference between them is explained by the higher number of experiments for PVC as well as the shortest time step.

Table 3. Average thermal effusivity, standard deviation and comparative difference with literature values.

Sample	b ($W\ s^{1/2}\ K^{-1}\ m^{-2}$)	Literature ($W\ s^{1/2}\ K^{-1}\ m^{-2}$)	SD (%)	Diff. (%)
PVC	437	408	1.01	6.64
PMMA	522	566	2.44	7.77
PE	860	888.6	3.30	3.21

Uncertainty Analysis

Uncertainty can be described as a portion of the measurement that cannot be considered as a true value. Each time a measurement is taken it depends upon a mechanical, electrical or visual point of reference to assign an appropriate value. These values, no matter how carefully they are obtained, contain some uncertainty (Taylor, 1997). The uncertainties are used to evaluate the precision of the result. That is why it is important to keep low values for them. In this work the procedure to determine the uncertainty in the estimation of *b* is based on linear propagation of uncertainties of the variables, heat flux and temperature, and the numerical calculus of these signals. The hypothesis of linear propagation is used because the objective function is based on the difference between experimental and theoretical temperatures. The uncertainty for experimental temperature U_e is obtained from the uncertainties of the data acquisition system U_{Data}, the thermocouple U_{Therm} and the thermal contact resistance U_R.

$$U_{Exp}^2 = U_{Data}^2 + U_{Therm}^2 + U_R^2 \tag{14}$$

The uncertainty of theoretical temperature is calculated from the uncertainties of the heat flux $U_{H.F}$ and the error of the numerical calculus with the trapezoid rule U_{Num}.

$$U_{Theo}^2 = U_{H.F.}^2 + U_{Num}^2 \tag{15}$$

The uncertainty of the heat flux can be determined from the uncertainties of the heat transducer $U_{H.T.}$ and the data acquisition system U_{Data}.

$$U_{H.F.}^2 = U_{Data}^2 + U_{H.T.}^2 \tag{16}$$

Combining Eqs. (14)-(16), the total uncertainty of the objective function can be calculated as:

$$\begin{aligned} U_{Obj}^2 = U_{Exp}^2 + U_{Theo}^2 = 2.U_{Data}^2 + U_{Therm}^2 \\ + U_{H.T.}^2 + U_R^2 + U_{Num}^2 \end{aligned} \tag{17}$$

The value for the uncertainty of the data acquisition system is based on an operation range between 20 and 35°C, auto-zero in position on with the Number of Power Line Cycle (NPLC) = 1, range of 125 mV with one hour of warm up.

$$U_{Data} = 1.00\% \tag{18}$$

The estimation of the thermocouple uncertainty is based on the calibration of the thermocouple and on the maximum value of the measured temperature difference that was approximately 9.0°C. The thermocouple was calibrated in a bath calibrator (Thermometry Calibration System) with a maximum fluctuation of 0.1°C.

$$U_{Therm} = 1.13\% \tag{19}$$

The uncertainty resultant of the thermal contact resistance is estimated with the maximum difference between the temperatures on the transducer and on the sample surface with an 0.01 thick air layer. This difference is 0.103°C, which results in an uncertainty of:

$$U_R = 0.32\% \tag{20}$$

The uncertainties U_{Therm} and U_R are considered constant because they represent the maximum uncertainties observed during the experiments.

The uncertainty of the heat transducer is estimated from its previous calibration considering a linear response, U_c, (Lima e Silva, 2000), the uncertainties of tension, current and area of measurement. Tension and current were measured with a Goldstar digital multimeter with resolution of 0.01 V for the tension and 0.001 A for the current. The area was measured with a caliper with an uncertainty of 5 x 10^{-05} m.

$$U_{H.T.} = \left(U_c^2 + U_I^2 + U_V^2 + U_A^2\right)^{1/2} = 1.98\% \tag{21}$$

The numerical uncertainty is estimated taking into account the discrepancy previously presented (in the subsection Comparison between semi-finite and finite models) and the maximum difference between the temperature calculated by the trapezoid rule and the temperature calculated analytically (Lima e Silva, Duarte and Guimarães, 1998). This difference is 0.152°C, so the maximum uncertainty was estimated as:

$$U_{Num} = 0.47\% \tag{22}$$

Substituting Eqs. (18)-(22) in Eq. (17), the uncertainty for the objective function is:

$$U_{Obj} = 2.74\% \tag{23}$$

An analysis of propagation errors shows that the uncertainty in the original data propagates in a conservative way, and the total uncertainty of the thermal effusivity was found to be:

$$U_b = U_{Obj} = 2.74\% \tag{24}$$

In this work there are inherent bias errors due to the limitations of theoretical model and the uncertainty in the experiment values. The samples were considered homogeneous and heat flux unidirectional. In addition, the thermal property was considered temperature independent. It can be observed that the uncertainty value estimated for the thermal property is a qualitative value and it is in agreement with the values found in the literature. This value of U_b can be used as a reference value.

Conclusions

This work presented a non-destructive method for thermal characterization of a conductive system. It allows an *in situ* measurement, which is important for engineering operations. The implementation of the system requires the sensors to measure the heat flux and temperature only on the top surface of the material. The thermal contact resistance can be more troublesome for *in situ* measurements due to the irregularities on the surface. To reduce this effect, a thermal grease of high thermal conductivity can be used. The method presented good results to estimate the thermal effusivity of three different polymers using experimental data. These materials have low thermal conductivity and they can be assumed a semi-infinite medium. Differently from many authors who used the frequency domain, the thermal effusivity here was estimated in time domain. There are several advantages of using time domain, as for example, it is easier to estimate temperature dependent thermophysical properties than it is in the frequency domain.

There is no restriction to use this technique for materials of thermal conductivity higher than 2 W/m.K. Nevertheless, to use this technique for these materials, it is necessary that the sample present large thickness and the experiment time be short. This procedure must be used to respect the hypothesis of a semi-infinite medium.

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