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THE COEFFICIENT OF CONVECTIVE HEAT TRANSFER DETERMINATION IN RUBBER BLENDS

Ružiak, I., Koštial P., Kopal, I., Mokryšová M., Kučerová J., Mošková, Z.
[1]The faculty of industrial technologies, the institute of materials and technological research
I. Krasku 491/30, 02001 Púchov
The Slovak Republic

ABSTRACT
We deal with the coefficient of the heat transfer determination of a distinguished rubber blend in this paper. We measured the specific heat and the thermal conductivity of the distinguished rubber blend with the EDPS and flash method. The differences between these two methods do not exceed 5 percent. The measurement errors of both methods do not exceed 5 percent. The coefficient of the heat transfer was obtained from the iteration of the cooling curve of a temperature.
Key words: relaxation time, coefficient of convective heat transfer, Biot number

1. INTRODUCTION

Many heat transfer applications involve processes which change with time. The examples of such applications include the cooling and heating of materials. The cooling process is described by Newton law of cooling. The theoretical background to the cooling and heating processes can be found in [1].
The extended dynamic plane source method (EDPS method) is often used as a standard contact method for the determination of the thermophysical properties of low conductive materials such as rubber blends. The theoretical background to the EDPS method can be found in [2].
On the other hand, the laser flash method is used as a standard contact-less method for the determination of thermophysical properties for homogenous materials. Authors deal with the determination of the thermophysical properties of metals by the flash method in the work [3]
In iteration processes it is very important to know intervals where searched parameters should be situated. This is so called parameter estimation and it is described for the DPS method in [4].
Authors deal with the coefficients of a sensitivity analysis in the EDPS method in the work [5].
In this paper we deal with the coefficient of the convective heat transfer determination for rubber blends. We measured the thermophysical properties of distinguished rubber blends with the extended dynamic plane source method and the flash method. The measurement errors of both methods do not exceed 5 percent. Obtained thermophysical properties from the EDPS method were then used for computing Biot number and the coefficient of the convective heat transfer of the distinguished rubber blend.

2. THEORETICAL BACKGROUND

The heat transfer coefficient depends on the velocity of the surrounding fluid, physical properties of the surrounding, geometry of the body. The value of coefficient of convective heat transfer *h,* described later, is the amount of the heat which passes through the unit area of a medium or system in a unit time when the temperature difference between the boundaries of the system is one degree. The coefficient of the convective heat transfer can be calculated from the following equation

$$\frac{dQ}{dt} = h.A.dT \tag{1}$$

where: *dQ*- heat income to the sample
dt – time
h – coefficient of convective heat transfer
A – characteristic surface of a sample
dT – temperature difference between temperature in time dt and temperature in the beginning of the cooling process

The characteristic surface *A* of sample is s total area where the heat transfer occurs. For a rectangular sample with the width *a,* length *b* and thickness *L,* that is much lower than the width and length, A can be described by the equation

$$A = 2.a.b \tag{2}$$

The Biot number is also important in the transient heat transfer. When this number is small (less than 0.100) then the lumped system analysis can be assumed. The physical meaning of the Biot number can be explained by the ratio of the internal thermal resistance to the external thermal resistance. It is given by the following equation:

$$Bi = \frac{h.V}{A.\lambda} \tag{3}$$

where: *h* – coefficient of the convective heat transfer
λ - thermal conductivity of the sample
V - volume of the sample
A - characteristic area of the sample

Basic working hypothesis is based on the estimation of cooling function in the form

$$\frac{T - T_\infty}{T_0 - T_\infty} = e^{-\frac{t}{\tau}} \tag{4}$$

where: T – experimental temperature function
T_∞ - ambient temperature
T_0 - temperature in the beginning of the cooling process
τ – thermal time constant

The coefficient of the convective heat transfer then can be computed from the equation

$$h = \frac{\rho.a.b.c_P.L}{\tau.2.a.b} = \frac{\rho.c_P.L}{2.\tau} \tag{5}$$

3. RESULTS AND DISCUSSION

The thermophysical properties of blend A were measured by the flash and EDPS method. In the figure 1 is shown the scheme of an apparatus for the EDPS method.

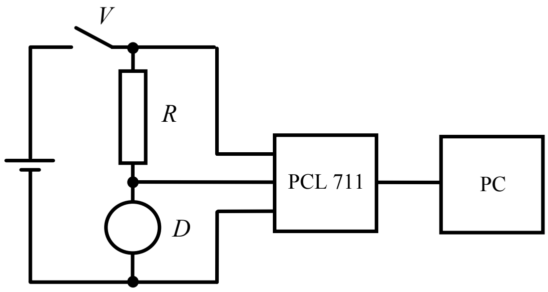

Figure 1. The scheme of the contact measuring apparatus

The thermophysical properties of the distinguished rubber blend, obtained from the contact and contact – less method, are listed in table 1.

Table 1: Thermophysical properties of rubber by the EDPS and flash method

Method	$\alpha.10^7[m^2.s^{-1}]$	$c_P[J.kg^{-1}.K^{-1}]$	$\lambda[W.m^{-1}.K^{-1}]$
EDPS	1.668 ± 0.043	1460.4 ± 49.42	0.297 ± 0.003
Flash	1.756 ± 0.075	1383.2 ± 41.99	0.297 ± 0.015

In the figure 2 is shown the experimental cooling curve for distinguished rubber as the blue curve and model as the red curve.

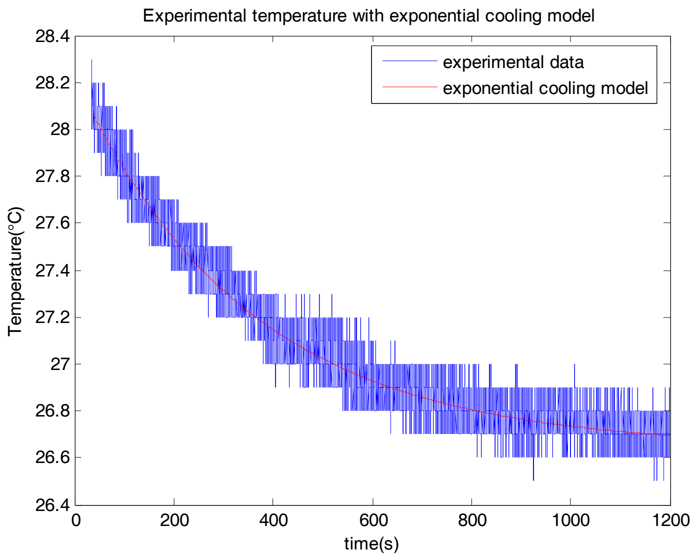

Figure 2. Experimental cooling curve with model

In our measurements we heated up the sample, with width 0.0964 m, length 0.1174 m and thickness 0.002025 m, from distance 0.2 m by light pulse / power 1500 W/ of different lengths from 0.2 seconds to 0.7 seconds. We found from obtained measurements that experimental data had the highest ratio of a signal to the noise for an impulse length of 0.4 seconds. Thermophysical properties haven´t been influenced by the length of an impulse. We did the final measurements for the impulse length 0.4 seconds and for the distance of 0.2 m.

We evaluated physical values of interest from the measured decrease of temperature (see Figure 2). We did 5 measurements and because these measurements had the high value of correlation coefficient close to 0.95 we used the averaging of these 5 signals to obtain one signal with a higher ratio of signal to noise.

Then we found the coefficient of the sensitivity analysis to establish the time intervals where all three characteristic parameters of the cooling process are linearly independent. From sensitivity coefficients analysis we found that *maximal temperature difference* ΔT_{max} should be found near the beginning of the cooling curve, *thermal time constant* τ in time where the following equation $T = T(t = 0s) - 0.38(T(t = 0s) - T_{\infty})$ is satisfied and the temperature of steady – state T_{∞} near the end of the cooling curve.

Then we fitted the obtained average signal into the theoretical function given by (4).

The characteristic parameters of the cooling process are listed in the table 2, also with 95% coincidence intervals obtained from an average signal.

Table 2: Characteristic parameters of the cooling process

ΔT_{max}(°C)	95% CI(ΔT_{max})	τ(s)	95% CI(τ)	T_{∞} (°C)	95% CI(T_{∞})
1.5807	(1.579,1.583)	250.83	(349.6,352)	26.6435	(26.640,26.647)

The *h* value and Biot number, obtained from equations (5) and (3), are 7,2002 W/m^2.K and 0,0245 respectively. The time constant for copper was found to be 204,7 s.

4. CONCLUSIONS

From the presented results of thermophysical properties of rubber blends there is one which can conclude that the flash method and the EDPS method are proper methods for the determination of thermophysical properties.

From the presented values of the maximal temperature difference, thermal time, constant and steady – state temperature and their coincidence intervals there is one which can conclude that the experimental data follow very well proposed exponential decay. It is necessary to underline the fact that Biot number is much lower than 0,1, which is the critical value of Biot number when the exponential cooling model could be used.

The computed value of a convective heat transfer is close to 7 $W.m^{-2}.K^{-1}$. Table values give interval from 5 to 15 $W.m^{-2}.K^{-1}$. Our data can be therefore considered as good fitted. From the measurements of the different length of impulse we obtained that this coefficient is always close to 7 $W.m^{-2}.K^{-1}$. The theory of the exponential cooling model says that the coefficient of convective heat transfer is not the function of a material and impulse length. Our measurements also confirmed this fact.

5. REFERENCES

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