STUDY OF THERMAL DIFFUSIVITY IN HEAT-INSULATING MATERIALS

PAVLA ŠTEFKOVÁ, OLDŘICH ZMEŠKAL

Institute of Physical and Applied Chemistry, Faculty of Chemistry, Brno University of Technology, Purkyňova 118, 61200 Brno, Czech Republic, email: stefkova@fch.vutbr.cz

Introduction

The building industry is using modern materials that are usually extremely porous to improve the thermal insulation properties. The performance of these materials depends on their thermophysical properties. This paper discusses the heat transport properties in glass wool fibers measured by pulse transient method and deals with the use of new data evaluation method[1]. The method results from generalized relations that were designed for study of physical properties of fractal structures[2]. As it is shown these relations are in a good agreement with the equations used for the description of time responses of temperature for the pulse input of supplied heat[3, 4, 5]. Thermal parameters (specific heat, thermal diffusivity and thermal conductivity) calculated are corresponding for both methods.

Theory

The dependence of fractal structures' (characterized by the fractal dimension D in E-dimension space) temperature on the distance from heat source h_T and on the time t was determined [1] using the theory of the space-time fractal field [2]

$$T = \frac{Q}{c_p \rho (4\pi a t)^{(E-D)/2}} \cdot \exp\left(-\frac{h^2}{4at}\right), \tag{1}$$

where Q is the total heat transferred to the body from the heat source with the thermal conductivity $\lambda = c_p \rho a$. This relation[3, 4, 5] is applicable for fractal dimensions D = 0, 1, 2 and topological dimension E = 3, see Fig. 1.

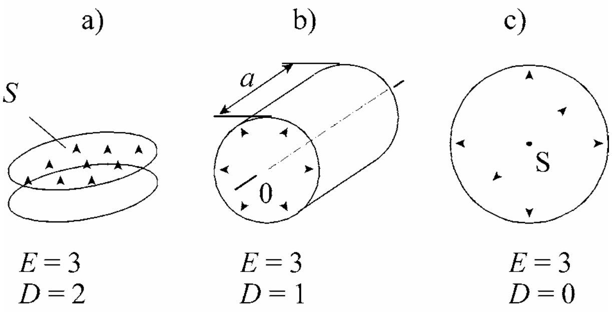


Fig. 1 Heat flow geometry for a) plane-parallel, b) cylindrical and c) spherical coordinates Euclidean space.

From this equation the thermal diffusivity at the maximal time can be determined

$$a = \frac{h^2}{2t_{\mathrm{m}} f_{\mathrm{a}}} = \frac{h^2}{2(E-D)t_{\mathrm{m}}}, \tag{2}$$

where f_a is a coefficient that characterizes the deformation of the thermal field[5]. This coefficient is equal to one for the ideal plane source (E = 3, D = 2). The maximum temperature of the response for Dirac thermal pulse is obtained by introducing of the thermal diffusivity (2) in the term (1)

$$T_{\mathrm{m}} = \frac{Q}{c_{\mathrm{p}}\rho} \exp\left(\frac{D-E}{2}\right) \cdot \left(\frac{E-D}{2\pi h^2}\right)^{(E-D)/2}. \tag{3}$$

It is possible to definite the coefficient f_a (fractal dimension D respectively) for every point of the experimental dependence

$$f_a = E - D = \frac{2\ln(T_{\mathrm{m}}/T)}{\ln(t/t_{\mathrm{m}}) + (t_{\mathrm{m}}/t - 1)}, \quad f_a = E - D = \frac{2\ln(T_{\mathrm{m}}/T)}{\ln(t/t_{\mathrm{m}}) + (t/t_{\mathrm{m}} - 1)} \text{ respectively.} \tag{4}$$

The relations on the left side are used for the temperature increase; the relations on the right side are used for the temperature decrease. The value of the coefficient f_a could be also affected by the geometry of sample[5] or by the finite pulse width[6], too. When the value f_a is known it is feasible to determine the parameters of the studied thermal system.

Experimental

The Thermophysical Transient Tester 1.02 was used for measuring of the responses to the pulse heat. It was developed at the Institute of Physics, Slovak Academy of Science[6].

Thermal responses from Slovak Academy were used for the data evaluation. The measured sample was round shaped with diameter R = 0,03 m. Its density was ρ = 77,9 kg.m^{-3} for its thickness h = 0,0075 mm, the thermal conductivity was λ = 0,0254 W.m^{-2}.K^{-1}.

Results

The Fig. 2 represents the typical time responses of temperature for the pulse of input power. The coefficient f_a of the fractal heat source for every point of the experimental dependence was calculated using the Eq. (4). The fractal heat source characterizes the distribution of the temperature in the specimen in specific time. From the Fig. 3 it is evident that for very short time there is the value of the fractal dimension $D \approx 2$ and therefore, the plane heat source is formed. The value of the fractal dimension decreases with increasing time value since the heat disperses into the space. From the time $\tau_1 \approx 16$ s (the intersection of tangents of the curves) the fractal dimension is getting settled to the value $D \approx 0{,}15$. The spatial distribution of the temperature in the sample does not change yet in this area. It is possible to determine the coefficient of the heat source $f_{a0} = 1$ and the diffusivity of the specimen $a \approx 4.679 \cdot 10^{-7}\,\mathrm{m^2 s^{-1}}$ from the extrapolated value of the fractal dimension to the time t = 0 s. This value is identical to value determined by the Institute of Physic, Slovak Academy of Sciences, Bratislava.

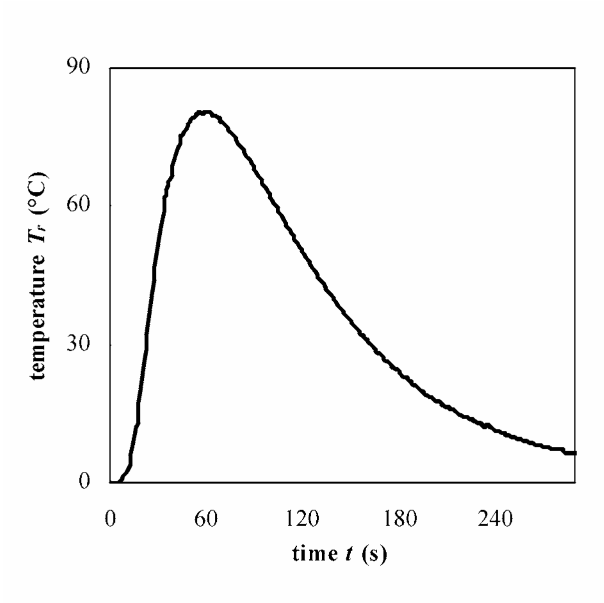
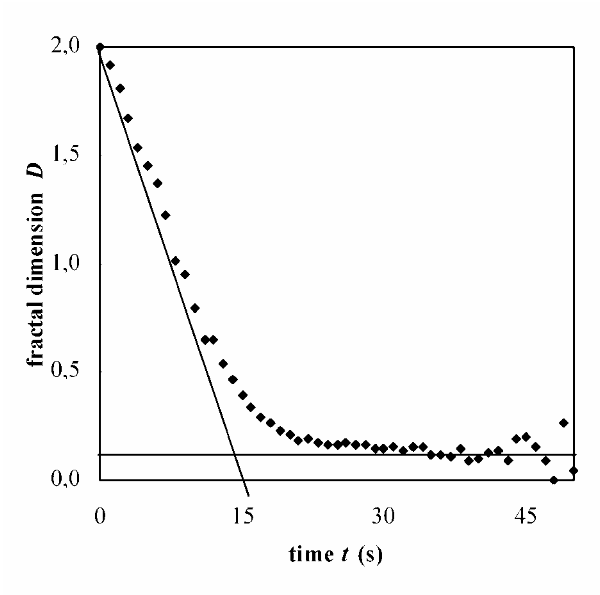


Fig. 2 Thermal response of the sample measured by the pulse transient method.

From the descending characteristic we can again determine, by using (4) for each point of experimental dependence of measured temperature on time, coefficient f_a, fractal dimension D of the fractal source "*of cold*" presented by specimen surface. From Fig. 3b it is evident that there are not any cold spots over the surface of specimen for time intervals close to the maximum. With rising time the value of fractal dimension of decreasing temperature is smaller again until the value $D \approx 2$. This is a fractal dimension of the specimen surface.



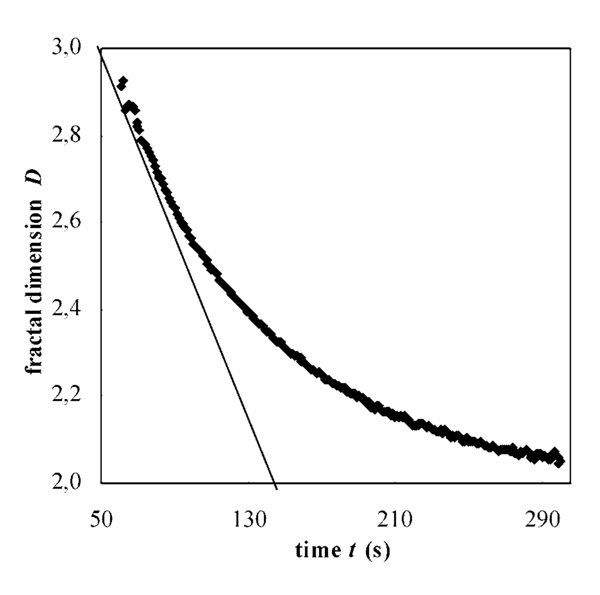


Fig. 3 Fractal dimension of the heat distribution in the specimen from a) increased and from b) decreased part of characteristics.

Conclusion

In this article, the results of thermal responses to the pulse of supplied heat evaluations are discussed. To interpret the outcomes, the simplified heat conductivity model is used[1]. The model is based on expectations[3]. Results show the image of heat distribution in the specimen, in various time intervals after the heat supply from the source. These evaluations could be used for more accurate determination of the thermal parameters of studied matters.

References

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