DETERMINATION OF THE THERMOPHYSICAL CHARACTERISTICS OF FREE-FLOWING MATERIALS AND THICK LAYERS OF VARIOUS SUBSTANCES

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Results are presented from the determination of the thermophysical characteristics for various mixtures of pigments and fillers. The investigations were carried out by the method of a single temperature time interval. A description of this method is presented in this article.

The thermophysical characteristics of powders are strong functions of bulk density. To prevent the nonuniformity of the density distribution through the volume of the powder from distorting the values determined for the thermophysical characteristics, the layer of the free-flowing material to be tested must be made sufficiently thick. However, with a very thick layer—on direct application of the method of two temperature-time intervals [1]—the experiment becomes excessively long, thus making it necessary to enlarge [lengthen] the heat receiver, to improve the thermal insulation of the sides, etc. It is therefore expedient to devise a procedure for observing the powders so as to make it possible (with a very thick layer) to limit the duration of the experiment to the measurement of only a single time interval $\Delta\tau$.

Table 1

The Function $\varepsilon = f(p)$ for the Interval from $N_1 = 0.95\ N_0$ to $N_2 = 0.90\ N_0$

ε	p	ε	p	ε	p	ε	p
0.32	2.00	0.72	3.83	1.12	4.80	1.74	5.67
0.34	2.14	0.74	3.89	1.14	4.84	1.78	5.71
0.36	2.27	0.76	3.95	1.16	4.88	1.82	5.75
0.38	2.40	0.78	4.01	1.18	4.92	1.86	5.79
0.40	2.52	0.80	4.07	1.20	4.96	1.90	5.83
0.42	2.63	0.82	4.13	1.22	4.99	1.94	5.86
0.44	2.73	0.84	4.18	1.24	5.02	1.98	5.90
0.46	2.82	0.86	4.23	1.26	5.05	2.02	5.94
0.48	2.92	0.88	4.28	1.28	5.08	2.06	5.97
0.50	3.02	0.90	4.33	1.30	5.11	2.10	6.01
0.52	3.11	0.92	4.38	1.34	5.17	2.14	6.04
0.54	3.20	0.94	4.43	1.38	5.23	2.18	6.07
0.56	3.28	0.96	4.48	1.42	5.29	2.22	6.10
0.58	3.35	0.98	4.53	1.46	5.35	2.26	6.13
0.60	3.42	1.00	4.57	1.50	5.40	2.30	6.16
0.62	3.49	1.02	4.61	1.54	5.44	2.34	6.19
0.64	3.56	1.04	4.65	1.58	5.49	2.38	6.22
0.66	3.63	1.06	4.69	1.62	5.54	2.42	6.24
0.68	3.70	1.08	4.73	1.66	5.59	2.46	6.27
0.70	3.77	1.10	4.76	1.70	5.63	2.50	6.30

The determination of the thermal diffusivity and of the thermal conductivity will be carried out separately in this case.

Experiment I. Determination of the thermal diffusivity of the powders. If the two media A and B (see figure) consist of the identical test material [free-flowing], the quantity $\varepsilon = \lambda\sqrt{a_B}/\sqrt{a}\,\lambda_B$ will be equal to unity, regardless of the values chosen for N_1/N_0, N_2/N_0, and N_3N_0, i.e., regardless of which of the working tables from [2] we choose for the values of the parameters p and ε. Since the values of the parameters p and ε in the working tables are interrelated, i.e., $\varepsilon = f(p)$, the value of the parameter $\varepsilon = 1$ in a given working table corresponds to a fully defined value of $p = p_0$. The function $\varepsilon = f(p)$ is determined by choosing only a single interval from N_1/N_0 to N_2/N_0 and is entirely independent of the second interval.

Table 1 gives the function $\varepsilon = f(p)$ for the interval from $N_1 = 0.95\ N_0$ to $N_2 = 0.90\ N_0$.

Having measured the time interval $\Delta\tau$ corresponding to the difference $N_1 - N_2 = \Delta N$, we find the value for the coefficient of thermal diffusivity from the formula $a = h^2/4p_0\Delta\tau$.

Experiment II. Determination of the thermal conductivity of the powders. If we take the free-flowing test material, as before, as the heat receiver B, and if for the medium A we take a plate with known characteristics a_A, λ_A, and h_A, by experimentally measuring the time interval $\Delta\tau'$ corresponding to the difference $\Delta N = N_1 - N_2$, we will have

$$a_A = \frac{h_A^2}{4p'\,\Delta\tau'}.$$

Since the quantities a_A, h_A, and $\Delta\tau'$ are known, we find

$$p' = \frac{h_A^2}{4a_A\,\Delta\tau'}.$$

Knowing the parameter p' and using the table for the functions $\varepsilon = f(p)$, we find the value of ε' which corresponds to the value of p'. Then

$$b = b_A/\varepsilon' \text{ and } \lambda = b\sqrt{a},$$

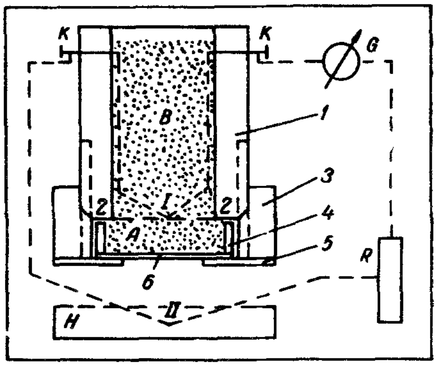
where the value of a is taken from the first experiment.

In determining the thermophysical characteristics of the given free-flowing material, we also have to measure the density of the material. In this case, the determined values of the coefficients a and λ will correspond to the determined density of the powder being tested.

If we know the density, we can calculate the corresponding value of the heat capacity $c = \lambda/a\rho$.

To determine the thermophysical characteristics of thick layers of monolithic materials, we also have to carry out two experiments. However, the sequence of the observations and calculations will be different from the study of powders.

Experiment 1. The item being tested is the heat receiver B which is a solid cylinder with excellent thermal insulation at the sides. If the test specimens are made in the form of circular plates each of whose



Scheme of the laboratory installation for determination of the thermal properties by the method of two-temperature intervals: H0 heater made in form of the multijet sprayer fed with water from a circulating thermostat; 1) hollow cylinder, made of thermal insulating material; 2) thins steel needle or tensed string with thermocouple junction I fastened to it. Needle is rigidly connected to cylinder base; 3) sectional cuvette screwed on cylinder 1; 4) measuring cylinder for setting thickness of the powder under study; 5) metal ring rigidly fastened to cuvette 3; 6) thin copper plate pressed to ring 5 protrusion with cylinder 4 when cuvette 3 is screwed to cylinder 1.

Table 2

Results from the Determination of Thermophysical Characteristics for Free-flowing Pigments and Fillers

Designation of powder and its basic composition	$a \cdot 10^8$, m^2/sec	λ, W/m · deg	b, $(W \cdot sec^{1/2})/(m^2 \cdot deg)$	c, J/(kg · deg)	ρ, kg/m^3
Titanium white TiO_2	8.9	0.068	228	713	1073
Barite $BaSO_4$	14.7	0.155	406	397	2655
Zinc powder Zn	19.2	0.215	491	360	3133
Aluminum powder Al	47.7	0.256	371	1210	438
Zinc white ZnO	19.1	0.090	206	470	1000
Lithopone $ZnS + BaSO_4$	11.0	0.082	248	486	1525
Chrome yellow $Pb \cdot CrO_4$	8.3	0.056	194	482	1400
Petroleum carbon black (carbon 94%)	26.9	0.066	128	678	364
Talc $4SiO_2 \cdot 3MgO \cdot H_2O$	16.4	0.105	259	658	1024
Mica $K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$	13.3	0.077	211	965	598
Microdiatomite SiO_2	24.1	0.048	976	860	231

Table 3

Results from the Determination of the Thermophysical Characteristics of Powdered Polyvinylbutyral (PVB) and of its Mixtures with Various Fillers

Designation of powder and percentage content of mixture	$a \cdot 10^8$ m²/sec	λ, W/(m · deg)	b, (W · sec$^{1/2}$)/(m² · deg)	c, J/(kg · deg)	ρ', kg/m³
PVB (100%)	14.9	0.058	150	1300	303
PVB (74.6%) + barite (25.4%)	13.0	0.072	200	1170	482
PVB (65.0%) + zinc powder (35.0%)	13.3	0.068	187	1005	506
PVB (83.5%) + aluminum powder (16.5%)	15.6	0.092	233	1415	414

thicknesses is inadequate for the size of the heat receiver, two or three specimens can be connected to each other at their ends, these ends having been lubricated with castor oil.

Any free-flowing material with a given layer thickness h_1 and with known thermophysical characteristics a_1 and λ_1 is taken as the medium A. A free-flowing substance is chosen because it is better able than other materials to ensure good thermal contact between the media A and B in these experiments.

Having measured the $\Delta\tau$ corresponding to the chosen $\Delta N = N_1 - N_2$, we will have $a_1 = h_1^2/4p\Delta\tau$. Since the quantities a_1, h_1, and $\Delta\tau$ are known, we find

$$p = \frac{h_1^2}{4a_1\,\Delta\tau}.$$

Knowing the parameter p, from the table we find the $\varepsilon = f(p)$ corresponding to the value of the parameter ε

Experiment 2. The medium A of thickness h serves as the monolithic test specimen. The heat receiver B in this experiment is the same free-flowing substance which was used in the first experiment as the medium A.

In this case $\varepsilon' = 1/\varepsilon$. Using the table for $\varepsilon = f(p)$, we find the corresponding value of p'.

Having experimentally measured $\Delta\tau'$ corresponding to the difference $\Delta N = N_1 - N_2$, we find

$$a = \frac{h^2}{4p'\,\Delta\tau'};$$

$$\lambda = b_1\varepsilon'\sqrt{a} = \frac{\lambda_1}{\sqrt{a_1}}\varepsilon'\sqrt{a}.$$

The component parts for the laboratory installation used to determine the thermophysical characteristics of the free-flowing substances and the thick layers of the various materials are shown in the figure.

To prevent the penetration of water from the heater into the test powder, a paraffin-soaked paper layer can be used to cover the protrusion of ring 5.

We note that in the second experiment, both to study the powders and to investigate the monolithic specimens, measuring cylinder 4 and copper plate 6 are not necessary, since plate A and the monolithic test specimen are waterproof and their thicknesses are well known. Cuvette 3 in the second experiment is screwed onto cylinder 1 until joint I is tightly fixed to plate A or to the test specimen.

The detailed methods were used to determine the thermophysical characteristics of various mixtures of pigments and fillers. The investigations were carried out both on powders and on monolithic specimens.

The measurement results are presented in Tables 2–4.

Table 4

Results from the Determination of the Thermophysical Characteristics of Monolithic Specimens of Polyvinylbutyral (PVB) and of its Mixtures with Various fillers*

Designation of the monolithic specimen and the percentage content of the mixture	$a \cdot 10^8$, m²/sec	λ, W/(m · deg)	b, (W · sec$^{1/2}$)/(m² · deg)
PVB (100%)	13.9	0.200	535
PVB (75.6%) + titanium white (24.4%)	16.9	0.258	630
PVB (74.6%) + barite (25.4%)	15.8	0.252	635
PVB (65%) + zinc powder (35%)	15.3	0.252	645
PVB (83.5%) + aluminum powder (16.5%)	49.2	0.805	115

*The monolithic specimens were made by extrusion of polyvinylbutyral powder with various fillers at a pressure of 50 atm and at a temperature of 150° C.

NOTATION

$\Delta\tau$ is the time of light-indicator motion in the galvanometer between given scale divisions; a is the thermal diffusivity; λ is the thermal conductivity; b and b_B are the thermal activities of the material studied and of the heat receiver, respectively; c is the specific heat capacity; ρ is the density of substance; h is the thickness of the material under study; ε and p are the parameters from working the tables [2].

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