ANALYSIS OF EXPERIMENTAL DATA ON THE HEAT CONDUCTIVITY OF SOLID POROUS SYSTEMS

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Inzhenerno-Fizicheskii Zhurnel, Vol. 9, No. 4, pp. 517–519, 1965

Theoretically calculated and experimentally measured values of the effective heat conductivity of a large group of structural and industrial disperse materials are compared.

It is desirable to correlate published data on the heat conductivity of solid porous systems. We shall write down a relationship between the effective heat conductivity of the system λ and the heat conductivity of the skeleton λ_1, the heat conductivity of the inclusions λ_2, and the porosity p in the form

$$\lambda/\lambda_1 = f(p, \lambda_2/\lambda_1). \quad (1)$$

The basic difficult in constructing Eq. (1) from experimental data is that most authors do not give explicitly all the parameters entering into this functional relationship. Usually, the effective heat conductivity, the designation of the material (sometimes extremely complex), and the porosity or weight by volume are reported. Therefore the parameters entering into (1) had to be determined indirectly and sometimes estimated.

The relationship (1) for certain porous building materials is plotted in Fig. 1, the experimental data of B. N. Kaufman [1] being principally employed.

From a certain group of materials (for example, foam concretes) the material with the greatest density γ was selected. For this material the literature gives the density, the mean number n of pores per 1 cm^2 of surface, the mean pore diameter D, and the effective heat conductivity λ.

The porosity was determined as the ratio of the volume V_2 occupied by pores to the volume V of the material. For this a rectangular parallelepiped was cut from the material with base area 1 cm^2 and height equal to D. Then

$$V_2 = nD^3\pi/6,\ V = D\cdot 1,\ p = V_2/V = 0.524\,nD^2.$$

The specific weight of the basic material d was determined from the formula

$$d = \gamma/(1-p).$$

The heat conductivity of the basic material was determined from the formula [1]

$$\lambda_1 = 0.0935\sqrt{d}\cdot 2.28^d + 0.025. \quad (2)$$

Here it was assumed that the basic material itself had a microporous structure.

The porosity of the remaining materials of the group was determined from the formula

$$p = 1 - \gamma/d.$$

The heat conductivity of the gas in the pores λ_2 is made up of molecular λ_{2m} and radiative λ_{2r} components ($\lambda_2 = \lambda_{2m} + \lambda_{2r}$). The radiative component at a gas (air) temperature T = 300° K and pore diameter D ≈ 1 mm may be roughly estimated from the formula [1]

$$\lambda_{2r} = 2\varepsilon^2\, 5.67\cdot 10^{-8} T^3 D,$$

where ε is the emmissivity of the pore walls ($\varepsilon \approx 0.9$). Calculations give $\lambda_{2r} \approx 0.003$.

The molecular component of the heat conductivity for air $\lambda_{2m} = 0.03$, i.e., $\lambda_2 \approx 0.035$ W/m·deg. The possible range of variation is $\nu = \lambda_2/\lambda_1 = 0.10$–$0.18$.

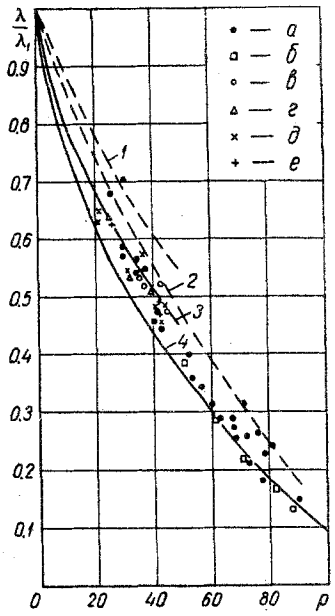

Fig. 1. Relationship $\lambda/\lambda_1 = f(p, \nu)$ for industrial materials at $\nu = 0.18$ (1, 3) and 0.10 (2, 4): a) foam concrete; b) cellular gypsum; c) foam diatomaceous brick; d) gas anhydride; e) foam gypsum: f) foam anhydride.

In this manner relationship (1) was constructed for foam concrete, gypsum, foam anhydride, gas concrete, gas anhydride, and foam diatomaceous brick. For cellular gypsum it was assumed that the basic material is cast gypsum with specific weight 97×10^2 N/m^3 and heat conductivity 0.37 W/m·deg [2].

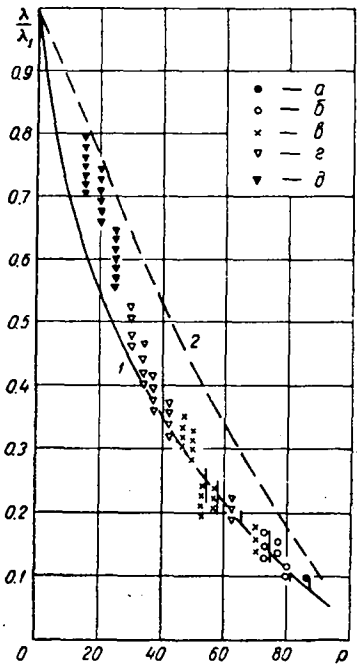

Fig. 2. Relationship $\lambda/\lambda_1 = f(p, \nu)$ for industrial materials at $\nu \approx 0.03$: a) foam concrete; b) pumice concrete block; c) tripoline and slag block; d) slag concrete, expanded-slag concrete; e) concrete with crushed stone, common brick, and silica brick aggregate (length of the column of symbols characterizes the possible error in determining the parameter λ/λ_1): 1 and 2) theoretical curves according to (1) for models with interconnecting and closed pores.

In Fig. 1 the continuous broken curves were constructed theoretically from the results of [3], the continuous curves for $\nu = 0.10$ and 0.18 corresponding to a model with interconnecting pores and the broken curves for the same values ν to a model with closed pores.

Moreover, the effective heat conductivity of many other materials was also reduced to relationship (1) (Fig. 2). The experimental data were taken from [4]; for this group of materials the authors give the porosity, but no information on the on the heat conductivity of the basic materials; therefore, the latter were determined approximately.

Comparison of relationships (1), derived analytically and on the basis of experimental results, permitted the following conclusions to be drawn:

1. The theoretical relationship (1) satisfactorily conforms with the experimental results of different authors, by far the best correlation being given by the model system with interconnecting pores. Apparently, a significant number of pores in the materials examined are in fact interconnecting.

2. It is possible to recommend the formulas derived theoretically in [3] for practical calculations of the effective heat conductivity of solid disperse systems. When it is not known whether the inclusions (pores) are interconnecting or not, it is necessary to construct relationships (1) for two model systems and to take intermediate results.

3. A considerable number of empirical formulas have been derived without any physical basis for the form of the functional relationship and some take an extremely odd shape (for example, formula (2)). Therefore in experimental investigations of the effective heat conductivity of solid disperse systems it is desirable to analyze the experimental data on the basis of relationship (1), since it has a sound physical justification.

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13 October 1964

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