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ANALYSIS AND TRENDS IN THE DEVELOPMENT OF MODELS FOR STUDYING THERMAL PHYSICAL PROPERTIES OF SOLID AND DISPERSE SUBSTANCES

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Abstract

The paper studies the thermal physical properties of solid disperse, powder and granular materials, and also reveals that the thermal physical properties of various materials are of different nature, mainly the thermal physical properties of metallic and nonmetallic materials are sharply determined by the nature of their detection, which indicates the reliability of the mathematical model that describes the basic thermal physical parameters that are structural geometric parameters of solid disperse, powder and granular materials and as a result they are classified on their thermal physical properties. Also the choice of the method for calculating the basic properties of solid disperse, powder and granular materials that exist up to now and on the basis of the chosen method, the possibilities of compiling mathematical models are established, the main issues of numerical modeling, calculation methods and its advantages and disadvantages are created, the possibilities of solving the determination and analysis of basic thermal physical properties of materials using modern mathematical models and calculation methods.

Key words: *granular, porosity, hard and bulk materials, thermal conductivity, heat flow, specific heat capacity, temperature absorption, temperature jump, mathematical model.*

Thermal property of materials represents a physical property of all existing natural substances and is characterized by such features as thermal conductivity, heat transfer, temperature transfer and volumetric expansion ratio. Thermal conductivity represents main property of the studied materials and is described as follows. Thermal conductivity is the process by which particles interact with each other directly at different temperatures and thus dissipate heat, i.e., the molecular transfer of heat energy.

Thermal exchange and thermal conductivity for various materials indeed do vary, particularly for metal and non-metallic materials, the above thermal physical properties vary substantially. Meanwhile, it is impossible to study thermal physical properties for a unified group of non-metallic materials. Therefore, these types of materials are usually studied in several subclasses, and their thermal physical properties are dependent on their molecular structure and geometric positions. The present paper is aimed at studying thermal physical properties of nonmetallic materials, as a function of their classification.

While classifying nonmetallic materials as per thermal properties we focus our attention primarily on the widely applied materials, namely powder and disperse porous matters, which are substantially used in engineering and engineering practice. The basic structure of these materials consist of particles and porous spaces between them, which are usually filled with air or moisture. Such materials are commonly found in nature, but virtually do not have any technical value. Indeed, the thermal properties of spray and powder materials of a class of substance no more than 0.1 μm in size are of great importance in assessing fog and smog formation. When the substances are relatively large in size, i.e., in the range of 0.1-1.0 microns, proper knowledge of their thermal properties are of great interest for heat engineering, builders, electrical engineers, dryers, glassworkers, power plants, railroad workers, food industry, soil scientists, water management professionals.

In this view herewith we are going to consider the most important types of nonmetallic

materials, which are grouped by the nature of the material, their geometric properties or method of their study:

1. Hard porous materials (bonded). This type of materials are classified as building-protective materials that represent wide area of application, rigid in structure and therefore require a special methodological approach to the study their thermal properties. This type of materials include marble, albaster tiles, bricks of various quality, lime, concrete, granite, celluloids.
2. Disperse materials (granuls). Substances used for the protection represent such materials as melamine, ash, slag, clay, sand, fine coke, magnetic powder, sawdust and powder plaster. Food, clay, and soil may also be included in this category.
3. Fiber materials. The study of this type of material differs from that of disperse materials. When it comes to the structure of fibrous materials, one can imagine longitudinal and cross heat conduction properties of such substances. These types of materials include sugar cane, asbestos, cotton, and silk.
4. Ground-soil, ore-mining materials. A special approach to the study of the thermal physical properties of these substances is required, as they should be sampled and any experiments on them are to be carried out *in situ*, in natural conditions, under the influence of sunlight, and without disturbing the structure of materials.
5. Fire-resistant class of materials. Different types of ceramic metal oxides and carbine porcelain are unique in that their structure is resistant to high temperatures. Therefore, in the study of their thermal physical properties, temperature is of greater importance (especially high temperatures). This makes it difficult to study the physical properties of heat while studying these materials.

In view of the above mentioned, a number of scientific reports and investigations related to the distribution of heat in matter and materials have been made over recently. We can also summarize the research done on non-metallic solid and fracture materials .

Mathematical models are used to study the relationship between solid and disperse materials and thermal conductivity in their pores. These models were created in the early 20th century and still remain relevant today. Tentative studies on general conductivity of disperse and multilayered objects was allegedly first done by Maxwell. Maxwell was the first to propose a model of electrical conductivity of objects. His hypothesis is pertinent only to small porous substances that are made up of whole isotropic masses, composed of cubed dial, dot balls. Most of the theory of thermal conductivity has been studied based on Maxwell's theory, which is based on the permeability of particles in substances.

In 1912, for the first time, Aiken developed a λ - formula for calculating the average efficiency of air-conjugation for spherical concrete by theoretical analysis of heat transfer calculations [1].

$$\lambda = \frac{\lambda_{\text{т}}\,(1-v_{\text{в}})}{1+\frac{v_{\text{в}}}{2}}, \qquad (1)$$

where $\lambda_{\text{т}}$ – *thermal conductivity of the solid phase material,*

$v_{\text{в}} = f(\varepsilon)$ – *volume of added air content;*

ε – *porosity.*

In 1919, Burger investigated how the form of particles (cylindrical and elliptic) impact λ - thermal conductivity of the planar surface. Later, the thermal conductivity of fissile and porous materials has been studied by Ollendorff (1931), Bruggeman (1935), Ribo (1937), Battcher (1945), Polder and Van Santen (1946).

The formula developed by Aiken is not so convenient for disperse materials, but the

following formula is still widely used:

$$\lambda = \lambda_{т}\left[1 + v_{т}/(1 - v_{т}^{1/3})\right], \quad (2)$$

where $v_{т}$ *is volume of solid body in unit of volume*

If the material contains cracks and breaks in addition to pores, it is necessary to correct the above equation. To do this, the initial formulas would be convenient for us and we get the following formula based on (1) and (2):

$$\lambda = a\lambda_{(1)} + b\lambda_{(2)}, \quad (3)$$

where $\lambda_{(1)}$, $\lambda_{(2)}$ – *(1) and (2) are thermal conductivity obtained by applying formulas;*

a and b are coefficients dependent on the size of pores and cracks.

These coefficients vary according to different studies and are not similar.

In the determination of the thermal conductivity of disperse products, an additional heat flux through the adjacent particles is also taken into account. But for cakes there is a "temperature jump" feature, which was first discovered by Smoluchowski.

As a result of research conducted by A. Misnar, the formula (3) is recommended for the calculation of thermal conductivity of powdered substances [2].

In these recommendations, the values of *a* and *b* may vary, for example, the porosity coefficient for dual-atomic powder products containing air, hydrogen, carbon dioxide and methane is 0.71, and the coefficient of air for dual-atom sandy products is 0.72. The pore coefficient for compressed dust is 0.77. Therefore, the values of the coefficients *a* and *b* should be chosen in the range 0.3 and 0.7. It should be noted that these values are suitable for powdered materials where the concentrated particles are arbitrarily located and the thermal conductivity is low.

Appropriately close results of calculations of the thermal conductivity of the grain for porous products are given in the mathematical models of G.N (G.N. Dulnev [3], V.Z. Bogomolov [4], M.G. Kaganer [5], Kuni and Smith).

By analyzing the known models, we can assume that the thermal conductivity of a heterogeneous material is a function of the phase pores of substances in the solid and gas phases.

$$\lambda = f(\varepsilon, \lambda_{т}, \lambda_{г}).$$

This function depends on many factors, namely the material dispersity, the size of the pores, their contact surfaces, the height of inequality, and so on.

The heat capacity and density of solid and disperse materials are additive units and the following formula is used for their determination.

$$c = (1 - \varepsilon)(c_{т} + \varepsilon c_{г}); \quad \rho = \rho_{т}(1 - \varepsilon),$$

where *c is relative heat capacity;*

ρ – *density;*

$c_{т}$– *specific heat capacity of solid phase;*

$c_{г}$ – *relative heat capacity of gas phase.*

The following formula was determined by A.P. Sorokin to determine the temperature permeability in porous structures [6]:

$$a(\mathrm{T}, \varepsilon) = a_0 f_{т}(\mathrm{T}) f_{\varepsilon}(\varepsilon), \quad (4)$$

where a_0 – *temperature permeability corresponding to some initial temperature;*

$f_{т}(\mathrm{T})$ – *function of material solid phase, temperature dependence of temperature permeability;*

$f_\varepsilon(\varepsilon) = 1$ – *porosity function.*

As can be seen from A.P. Sorokin's formula (4), the pores of the materials under consideration virtually do not affect the temperature permeability of the material, despite the dependence on λ, ρ, c.

By analyzing the existing models, one can assume that a universal model describing the relationship between thermal conductivity and porosity has not yet been revised. When selecting models and calculating them, it is recommended taking into account the structure of the heterogeneous materials, the physical and chemical properties of solid and gas phases, the size of the pores, and some other characteristics and external factors.

Most physical models based on the above mathematical models provide for measurument of physical properties of materials, including temperature conductivity or thermal conductivity, which provide transfer of heat through the materials studied that are existent heat and cooling units.

Analyzing the experimental resulsts one can conclude that measuring solid and disperse substances in isolated environment, such as sealed and protected chambers, heaters and modifiers for powder and disperse materials is convenient, as they provide for limiting the phase filled with the material under study. Nevertheless, as mentioned above, there are enough disadvantages and some of the parameters have significant errors due to inability to calculate them [7].

Based on the conclusions drawn from the above discussions, one can point out that while choosing computational methods, in our opinion, one must revise only high-precision and properly selected mathematical models. In other cases, one can assume that performing an experiment with high number of errors due to the influence of several characteristics and external factors might be convenient.

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