TEMPERATURE ON A SPHERICAL SURFACE WITH INTERNAL HEAT LIBERATION AND JET STREAMLINE FLOW

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The reliable operation of equipment with a purged dense layer is determined to a significant extent by the strength of the solid particles, which have a spherical shape in many cases. However, the thermal stresses which arise in the course of operation can exceed the tensile strength of the particle material and lead to fracture of the latter. In addition an abrupt nonuniformity of the temperatures over the surface of the spheres can result in nonuniform wear of them. The temperature distribution over the surface of the particles depends on their geometrical and thermophysical characteristics (diameter and shell thickness, thermal conductivity of the shell material), the heat liberation power, the geometrical characteristics of the cassettes (shape and dimensions of the openings in the walls of the distributing and collecting collectors, the method of packing the particles in a cassette, and the number of kinds of particles along the path of motion of the coolant), and the parameters of external heat exchange. The results of experimental investigations on the appearance of an influence of the enumerated parameters on the nonuniformity of temperatures in shells of rod fuel elements with longitudinal streamline flow by a liquid metal coolant are generalized in [1]. Shells made out of materials with thermal conductivity λ_m = 17-380 W/(m·°K) were used in the experiments.

At present metal alloys and nonmetallic materials with lower thermal conductivity are finding application for the manufacture of shells. In addition their thermal conductivity is lowered [2] as a result of thermal aging of the materials.

In this connection an investigation of the effect of the thermal conductivity of the shell material on nonuniformity of the temperatures in it is of interest for possibly a larger range of variation of λ_m.

The effect of the geometrical characteristics, the thermal conductivity of the shell material, and the heat liberation power on nonuniformity of the temperatures in the shell is most simply investigated with a single sphere. The need for such investigations is still caused by the fact that jet streamline flow around a single sphere in the initial section of the jet is poorly studied, although it is practically identical to the interaction of a particle of the first category with a jet of coolant from an opening in the wall of the distributing collector.

The experimental setup included a measuring calorimeter and an air supply system. The spherical calorimeter (Fig. 1) consisted of a shell 1 with outer diameter D_c = 50 mm and thickness 5 mm comprised of two hemispheres joined by a tight fitting. Six Chromel—Copel thermocouples 2 with wire diameter 0.2 mm pressed on the generatrix of the shell with an angular spacing of 30° are led out to the shell surface from inside. The calorimeter shells were made out of Teflon-4 (λ = 0.25 W/(m·°K)), 12Kh18N9T steel (λ = 13 W/(m·°K)), steel-45 (λ = 50 W/(m·°K)), and brass (λ = 102 W/(m·°K)). A spherical core 3 made out of fireproof clay with an electric spiral 4 uniformly wound onto its surface was placed in the shell. A thin insulation layer is placed on top of the spiral. The uniform winding of the spiral provided a constant density of the thermal flux on the outer shell surface. A metal tube with outer diameter 6 mm, through which the thermocouple and heater leads were routed, served as the support 5. In order to decrease the heat transfer through the support, the latter was connected to the calorimeter through a thermally insulated sleeve 6. The calorimeter could be rotated about its axis with the help of the support and a coordinate device, which provided for determination of the temperature field over its entire surface. The investigations were performed with axisymmetric jet streamline flow in the initial section of

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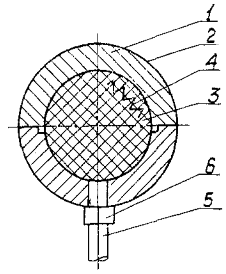

Fig. 1

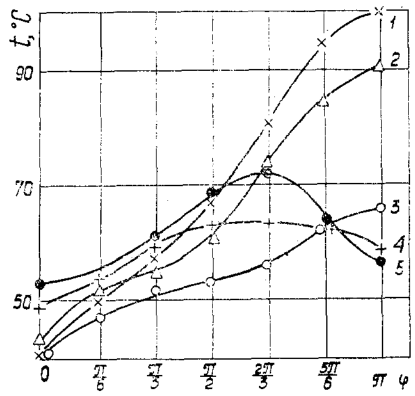

Fig. 2

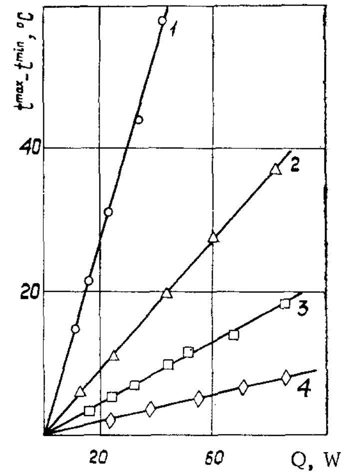

Fig. 3

the jet with variable parameters. An air jet flowed out of openings with diameter D_0 = 50, 40, 25, 15, and 10 mm. Air was supplied to the opening through a damper chamber having a series of equalizing grids, which permitted obtaining a rather uniform velocity field at the exit from the opening. The distance from the plane of the opening to the calorimeter was 0-1 D_c.

The Reynolds numbers were calculated from the average gas velocity at the exit from an opening and the calorimeter diameter. The range of Reynolds numbers in the experiments was 10^4-$3 \cdot 10^5$. The experiments were performed under steady heat exchange conditions. No effect of distance from the opening plane to the calorimeter on the distribution of the temperature fields on its surface has been detected in the investigated range of Reynolds numbers for all the opening diameters. The nature of the temperature distribution on the surface of a sphere does not depend on the value of the Reynolds number in the investigated region. This is in agreement with the conclusions of [3] concerning the fact that the self-similarity region for jet streamline flow occurs at Re $\approx 2 \cdot 10^4$.

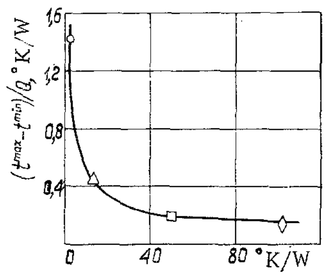

Fig. 4

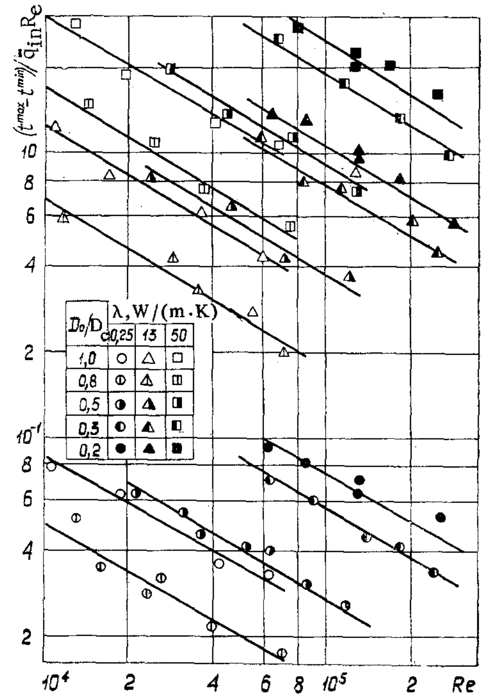

Fig. 5

The temperature distribution on the surface of a Teflon sphere for Re = $6.2 \cdot 10^4$ and a heat liberation power Q = 31.5 W/(m·°K) for different values of D_o/D_C = 0.2, 0.3, 0.5, 0.8, and 1.0 (curves 1-5, respectively) is presented in Fig. 2, in which φ is the angle figured from leading critical point of the calorimeter. The nature of the temperature distribution on the surfaces of the remaining shells used in the experiments was similar to that cited.

The dependence of the maximum temperature nonuniformity on the surfaces of shells made out of different materials (λ = 0.25, 13, 50, and 102 W/(m·°K) — curves 1-4, respectively) on the heat liberation power Q is presented in Fig. 3 for constant conditions of external heat exchange Re = $1.26 \cdot 10^5$ and D_o/D_C = 0.2. They show that the maximum temperature nonuniformity on the surfaces of spheres is a linear function of the heat liberation power.

The dependence of the maximum temperature nonuniformity on the surfaces of spheres relative to the corresponding heat liberation power on the thermal conductivity of the shell material is presented in Fig. 4. As is evident, the dependence has a clearly nonlinear nature. In [1] a dependence of this kind for rod fuel elements with a ratio of the inner shell diameter to the outer of less than 0.8 and a ratio of the thermal conductivity of the shell material and the coolant of more than 0.05 is assumed to be approximately linear.

An approximate dependence for the determination of an additional temperature difference of relatively average differential in the shell of a spherical fuel element for the case of six contacts of the calorimeter with its neighbors is given in [4] with a reference to the investigations of Lamb performed using a spherical electrocalorimeter with a shell made out of 1Kh18N9T steel. It follows from analysis of this dependence that the temperature nonuniformity on the surface of a spherical calorimeter is a nonlinear (hyperbolic) function of the thermal conductivity of the shell material. However, this dependence is of a special nature, and the absence of the value of the heat liberation power in it remains obscure.

The dependences of the maximum temperature nonuniformity on the surfaces of shells on the Re number are presented in Fig. 5 for different values of D_0/D_C. The results obtained can be generalized by the expression

$$(t^{max}-t^{min})\lambda_m/(\bar{q}_{in} R_e) = 25.8(\lambda_m/\lambda_t)^{0.66}[1-2.34D_0/D_c + 1.52(D_0/D_c)^2]\mathrm{Re}^{-0.59}$$

with a maximum error of 15%. Here $\bar{q}_{in}$ is the average density of the thermal flux on the inner shell surface in W/m², R_e is the external radius of the shell in m, and λ_t is the thermal conductivity of the gas in W/(m·°K).

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INFLUENCE OF THE TYPE OF THERMODYNAMIC APPROXIMATION ON THE DESCRIPTION OF THE DYNAMIC COMPRESSIBILITY OF MULTICOMPONENT MEDIA

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A large class of soils can be treated as multicomponent mixtures. Accordingly, in the analysis of strong dynamic effects acting on them it is necessary to inquire into the nature of the thermodynamic interaction of the components. Considerable difficulties are met in the attempt to solve this problem insofar as one must work with nonequilibrium thermodynamic models. In the solution of many practical problems this fact can inject unwarranted complexities into the description of the state of the medium. The simplest approximations in the solution of this problem are the equilibrium and completely nonequilibrium approximations. They can be regarded as limiting approximations. The actual interaction of the components will produce parameters occupying an intermediate domain of thermodynamic states. In the present study we consider the degree of disparity between the limiting approximations in shock compressions and isentropic stress relief and we investigate the conditions under which they yield either close or sharply different mechanical parameters of the state of the medium. The solution of these problems will provide a basis for considering the application of a particular thermodynamic approximation to various practical problems involving multicomponent soils.

1. Equations of State and Fundamental Assumptions

The equations of state proposed in [1-4] for granite, water, salt, and air can be used to describe the thermodynamic properties of water-impregnated porous soils with a silicate and salt base. We consider the equilibrium and completely nonequilibrium approximations for these classes of multicomponent media. It is well known that the equilibrium approximation postulates equality of the pressures and temperatures in all components of the medium. In the nonequilibrium approximation only equality of the pressures is postulated. In the comparative analysis of these approximations, therefore, it is meaningful to compare only the "mechanical parameters" of the mixture, i.e., the pressure and specific volume or the

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