Novel Heat Transfer Mechanisms Governing the Thermal Conductivity of Porous Solid Materials and Actual Problems in the Database Development

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The thermal conductivity and thermal diffusivity values of refractory oxide ceramic materials with porosities 5 to 98 % vary in a complicated manner with temperature, T, and gas pressure, p. These variations cannot be explained on the basis of known classical heat transfer mechanisms in porous materials, such as heat conduction in solid and gas phases, radiation, and gas convection within the pores. This paper reviews these and novel mechanisms and processes affecting heat transfer in ceramic materials that have been recently investigated, in order to explain and rationalize the p- and T-dependences of oxide ceramics in the ranges 500 K < T < 2500 K, 10^{-2} Pa < p < $2 \cdot 10^{7}$ Pa. Two main groups of mechanisms are considered:

1. Heterogeneous heat and mass transfer processes occurring in pores existing at grain boundaries and in cracks; in particular, surface segregation and diffusion of impurities on pore surfaces and transport of gases produced from chemical reactions, evaporation, and sublimation.
2. Microstructural changes due to nonuniform thermal expansion of particles and grains. These changes are caused by a mismatch between the thermal expansion coefficients of different material phases and the anisotropic thermal expansion of crystals.

We discuss the predominant factors, which, together with temperature and gas pressure, affect the thermal conductivities of several commonly used ceramic materials. These factors include porosity, geometrical parameters of pores, cracks, and grain boundaries. A physico-mathematical model for the calculation of the thermal conductivities of composite porous materials is described and used to explain and correlate the extensive experimental data collected for this quantity in wide ranges of gas pressures and material temperatures. The model incorporates all relevant heat transfer mechanisms and physico-chemical processes occurring within ceramics, and allows us to explain the complicated pressure and temperature dependences of the material thermal conductivity.

The actual problems concerning the development of a database for thermal physical properties of solid materials (refractory, building, and insulation materials; glasses) are outlined.