

Thermal Conductivity and Diffusivity of Porous Materials: Abnormal Dependences on Temperature and Gas Pressure and Development of Novel Heat Transfer Mechanisms

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Dense and insulating ceramics materials, refractories, and composites, are used in different environmental conditions: in vacuum and high gas pressure furnaces, vacuum metallurgy, vapor deposition apparatus, aero-space applications, etc. These applications require understanding and prognoses of protective materials' thermal conductivity, k , and diffusivity, a , in a wide range of different gas composition and pressure and temperature range. We analyze a wide range of experimental data measured by steady state and transient methods in the temperature range 500 K-2400 K and gas pressure 10^{-3} Pa- 10^8 Pa. Thermal conductivity and thermal diffusivity of refractory oxide ceramic materials with porosities 5-98 % vary in a complicated manner with temperature, T , and gas pressure, p . The most important "abnormal" effects are the following:

- Strong gas pressure dependence of k and a of most ceramic materials at low temperatures.
- Gas pressure dependences of k and a of ceramics collected at high temperatures differ markedly from the comparable data collected for low temperatures. Sometimes the values increase with decreasing gas pressure.
- Temperature dependence of k of many ceramic materials at low gas pressure is qualitatively different from that observed at atmospheric gas pressure. For example, increasing or non-monotonic dependence on temperature instead decrease which is predicted by classical thermal conductivity theory

These data were impossible to explain on the basis of classical models of porous structure and heat transfer mechanisms in porous ceramics, such as heat conduction in solid and gas phases, radiation and gas convection within the pores. This paper reviews new heat transfer mechanisms and processes, determining apparent thermal conductivity in ceramics and insulation materials, which were discovered and investigated during recent decades.

Two main groups of novel heat transfer 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, 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 mismatch between the thermal expansion coefficients of different material phases, and anisotropic thermal expansion of crystals.