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Textural parameters influencing the radiative properties of a semitransparent porous media

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ABSTRACT

In the field of thermal radiation, a current key challenge is to understand the role played by the texture of semitransparent heterogeneous materials on their thermal radiative properties. This paper is restricted to the case of any porous materials endowed with spherical pores and for which their mean pore size is greater than the incident wavelength. In this work, an algorithm had been developed to elaborate porous silica glass with prescribed textural properties. The design of virtual pore's geometries was based on the textural investigation of a real porous glass, beforehand characterized by synchrotron x-ray μ-tomography. Then a Monte Carlo Ray Tracing code is carried out to predict the thermal radiative properties of the numerical samples. In this work, the solid phase of each sample is composed of silica of high chemical purity for which the optical functions are known. Lastly, for the spectral range where the numerical glasses are transparent, the roles played by both the porosity and the volumetric surface on the scattering behavior are discussed.

1. Introduction

The fundamental understanding of the relation between the texture of a porous material and its thermal radiative properties still remains an open topic of research. Here, the term texture [1] is used to describe both the spatial arrangement of the scatterers i.e. pores, cracks, struts, fibres, grains, and inclusions in their host solid matrix and their respective size distributions. A significant advance in this domain will constitute a noticeable breakthrough, for the design of porous materials with prescribed radiative properties. In turns, one can expect to control the amount of energy radiated by a system operating at high temperature (heat exchanger, thermal barrier coating, and thermal shield for spacecraft) by pertinently acting on the textural parameters associated to the porous materials involved in its designs. As a first step to deal with this tricky problem, this work is focused on the study of porous semitransparent materials constituted of polydisperse and disconnected pores with a spherical shape. Pores with more complex shapes (ellipsoidal, cylindrical, polyhedral…) are beyond of the scope of this work.

A brief review of the literature concerning porous semitransparent materials with spherical pores indicates that their radiative properties have been computed using the Mie scattering theory. According to the pore volume fraction and the pore size distribution, different approaches were applied. For translucide ceramics [2–4] with a low pore volume fraction (<1%) their normal spectral transmittances were described with a Beer-Lambert type equation in which the extinction scattering is given by the application of the Mie scattering theory in the case of the independent scattering [5–7]. For transparent porous compounds [8–11] with an higher porosity (>1%) the radiative properties (directional hemispherical spectral reflectance and transmittance) are given according to relations that were obtained by solving of the radiative transfer equation with various methods, namely the discrete ordinates method [6,11], the two-flux approximation for the radiation transfer in homogenous isotropic media [9,12], and another one based on three-flux solution of the radiative transfer equation [8]. In all these relations the scattering, absorption and extinction coefficients are computed from the use of the Mie scattering theory. Note that some efforts have been done to model the radiative properties for the spectral range where the host matrix of the porous material is absorbing. In this case, authors used an extended version of the Mie scattering theory in absorbing media [13].

On the other hand, numerical approaches aiming to calculate the radiative properties and based on Monte Carlo ray tracing method operating within a 3D image of the studied porous material have also been implemented. Some studies are based on 3D realistic off lattice reconstructed porous media. This reconstruction method requires the knowledge of two-dimensional statistical

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