PREDICTION OF THERMAL RADIATIVE PROPERTIES IN POROUS MEDIA: A MONTE-CARLO RAY TRACING METHOD

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Knowledge of the thermal radiative properties of materials involved in industrial systems is crucial for dealing with energy balance. The evolution of computer performances opens today new perspectives in the development of predictive code aiming to accurately compute the radiative properties of a given industrial material from its 3D numerical image. In the other hand, predictive approaches appear insightful when experimental measurements cannot be easily performed (high pressure, high temperature, corrosive atmosphere, irradiative exposure…). In this work, a numerical tool has been implemented to reproduce the normal spectral emittance of porous media that can be measured by infrared emittance spectroscopy (300→3000 K). The code takes into account the chemical composition and the 3D numerical image of the heated sample. In particular, x-ray μ-tomography is used to provide such images. Then, from the analysis of the sample texture, a Monte Carlo ray tracing scheme is applied for the retrieval of the radiative properties. In this work, we discuss of this procedure and its use for the characterization of aluminium foam (ERG Al 20).

THREE-DIMENSIONAL NUMERICAL SAMPLE

The numerical simulation aims to reproduce both the normal hemispherical spectral reflectance and transmittance that can be experimentally obtained with an integrating sphere inserted in Bruker IFS 113 v. In order to take full advantage of the correspondence between the experimental and numerical approach, the sample size in the numerical simulation must be similar to the one required for experiment. In our work, acquisition of the 3D image is performed by x-ray μ-tomography (ID19, ESRF Grenoble, France). The resolution is 88.9 μm and sample size is 40×40×15 mm. Scanning Electron Microscopy (SEM) is also done to check the struts and pores shapes at lowest scale. For the 3D image (Fig.1), a free software iMorph is applied to visualize the air/solid interface [1]. For this purpose, a marching cube algorithm generates a triangular mesh with which stochastic rays can interact.

THE TRANSPORT RULES AT THE LOCAL SCALE

A set of rules must be decided when tracking the propagation of rays within the porous medium. The selection procedure was based on a thorough analysis of the sample texture that is achievable within iMorph. It shows that for struts and pores and according to spectral range of interest [2-25 μm], the Mie parameter is greater than 1. Furthermore the porosity is found to be 92 %. Therefore, geometric optics approximation can be used with confidence. Moreover, SEM imaging shows the rough surface of the struts that cannot be revealed with the tomographic experiment since roughness is smaller than its resolution. At last, Energy Dispersive x-ray spectroscopy indicates that the foam is only composed of aluminium. Then, at the local scale the complex refractive index of aluminium will be used to deal with the law of the geometric optics [2].

SIMULATION PROCEDURE

The Monte-Carlo algorithm has been implemented within the iMorph program previously used for the morphological analysis and the reconstruction of the numerical sample. The algorithm is now described.

The first task is to generate rays in a parallel and collimated infrared light beam of variable diameter and normally directed toward the sample. Each ray carries the same intensity before impinging the sample. Next, the first interaction with the medium interface is evaluated with an accelerating procedure. The strut being optically thick, only reflection is stochastically treated at the interface. The ray propagation is allowed within the sample volume until the ray is absorbed at the local scale or exited by the sample faces. The whole procedure is described in more details in Ref. [3]. This numerical method allows the computation of the normal hemispherical spectral reflectance and transmittance. The local thermal equilibrium being supposed, the normal spectral emittance can be deduced by application of the Kirchhoff's law.

RESULTS

Figure 3 shows the computed normal hemispherical spectral reflectance and the experimental one at T = 300 K by considering specular behaviour of the rays at each impinged triangle. As for the experimental spectra acquired on aluminium foam (ERG Al 20) with a lower thickness (12 mm) the computed spectra has a plate shape. The simulation allows the recording of each ray position and properties during its propagation. As such, Figure 4 reports the energy maps of a lateral exiting face. It shows that the propagation occurs on 12 mm even if the tomographied foam has thickness of 15 mm. So it means that now experimental and calculated normal hemispherical spectra can be compared for an active thickness of 12 mm. As proposed by Loretz [4] a weighted law mixing specular and lambertian rays behaviour can be introduced. In other word, at the local scale, the light scattering can be dictated by a virtual smooth opaque surface as defined by the Marching Cube algorithm or at the extreme case by an opaque rough surface as viewed by SEM imaging. In our case the application of a lambertian model of reflection gives good results (see Fig. 3). The rough structure identified by SEM plays a decisive role on the local scattering behaviour and thus acts as an additive optical mechanism reinforcing those directed by the solid skeleton of the foam.

CONCLUSION

A Monte Carlo Ray Tracing algorithm has been successfully implemented in the iMorph code that had been beforehand developed for viewing and quantifying porous cellular material. In particular the effect the struts roughness has been evidenced. Future works will help us to retrieve the radiative parameters required to solve the RTE. For this purpose, both absorption and scattering mean free path as the angular repartition of the exhausted rays will be calculated.

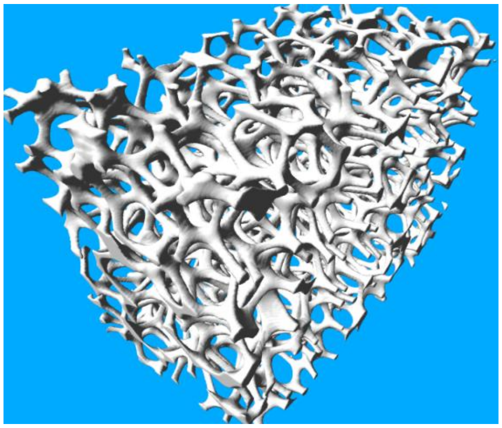

Figure 1: 3D view of the foam (ERG AL20).

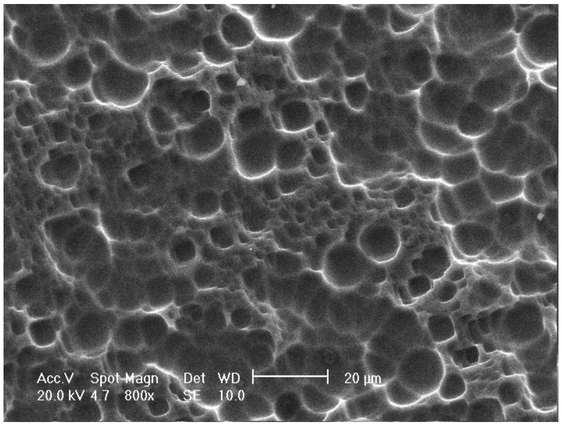

Figure 2: SEM image of a strut (Philips XL 40) .

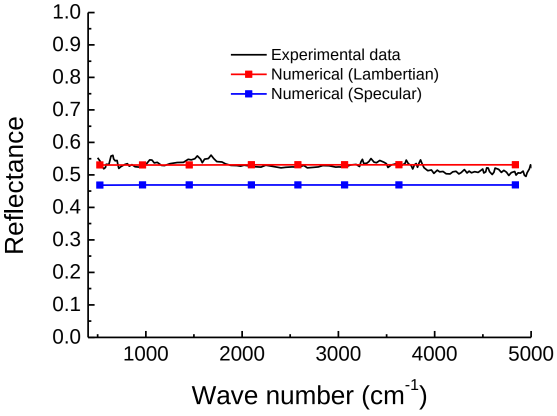

Figure 3: Normal hemispherical spectral reflectance evaluated with two models of reflection.

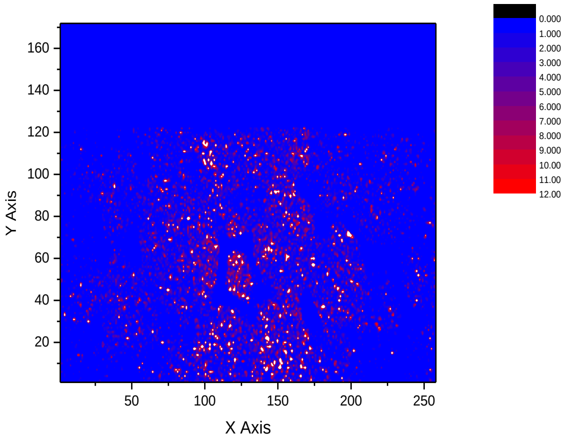

Figure 4: Energy map on a lateral face of the sample for specular reflection model.

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