Proceedings of CHT-15
ICHMT International Symposium on Advances in Computational Heat Transfer

May 25-29, 2015, Rutgers University, Piscataway, USA

CHT-15-119

NUMERICAL PREDICTIONS OF THE EFFECTIVE THERMAL CONDUCTIVITY FOR MULTIPHASE POROUS BUILDING MATERIALS

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ABSTRACT This article provides a full numerical tool for modeling and prediction of effective thermal conductivity of multiphase porous building materials. Scale of the pores in building materials can be categorized as macro and meso pores and the connection between them is quite significant to predict the effective thermal conductivity. A new numerical random generation macro-meso pores (RGMMP) method, in contrast to traditional models, which is based on geometrical and morphological information acquired from measurements or experimental calculations, is proposed here. This method not only illustrates the stochastic macro-meso pores distribution characteristics of porous building materials but also can aptly serve to calculate the heat diffusion through multiphase building materials. Lattice Boltzmann method along with proposed structure generating tool RGMMP, characterized with the energy conservation and appropriate boundary conditions at numerous interfaces in the complex system, is validated with some theoretical solutions for simpler cases as well as with existing experimental data. Then it is applied for modeling and prediction of effective diffusion coefficient of wide range of porous (multiphase) building materials. The comparison of present model and different theoretical models with the experimental results shows that the proposed model agrees much better with the experimental data than the traditional theoretical models. More validation of the present model for other building materials is needed. The present model is useful for the prediction of effective thermal conductivity which is an important parameter for thermal performance analysis of multiphase porous building envelopes.

Keywords: Lattice Boltzmann method, RGMMP, Effective thermal conductivity, Building materials

To determine the effective thermal conductivity of multiphase porous building materials, consider two dimensional pure conductive heat transfer problem with both conductive and isolating phase, with negligible heat transfer caused by phase change, convection and radiation.

Governing Equations The governing equations for heat transfer in such multiphase (e.g., fluid and solid) systems, without heat source, can be written as

$$\left(\rho c_p\right)_s \left(\frac{\partial T}{\partial t}\right) = \lambda_s \nabla^2 T \tag{1}$$

$$\left(\rho c_p\right)_f \left(\frac{\partial T}{\partial t}\right) = \lambda_f \nabla^2 T \tag{2}$$

Lattice Boltzmann Solver The lattice Boltzmann method (LBM) is inherently a mesoscopic approach and because of its essential kinetic nature, it is particularly used for solving the fluid flow problems with multiple inter-particle interactions and the complex geometry boundary conditions i.e. multi-component or multiphase flow in porous media. The lattice Boltzmann method, with spatially varying relaxation time, for calculation of effective thermal conductivity of typical building materials is adopted here. For D2Q9 model, the expression for dimensionless relaxation time can be written as

$$\tau_f = \frac{3}{2}\frac{\lambda_f}{(\rho c_p)_f c^2 \Delta t} + 0.5, \qquad \tau_s = \frac{3}{2}\frac{\lambda_s}{(\rho c_p)_s c^2 \Delta t} + 0.5 \tag{3}$$

Reconstruction of Porous Structures A new algorithm RGMMP (random generation of macro-meso pores) based on macro meso pores connection, in order to get microstructure closer to real porous building materials, is proposed here. Figure 1 shows the schematic illustration of reproduced 2D porous media using present RGMMP method.

Results Discussion The lattice Boltzmann method with present RGMMP method has been used for calculation of effective diffusivity of some typical multiphase porous building materials. In order to check the accuracy of the present numerical model, in case of chosen building materials, the computed values of effective thermal conductivities are compared with those acquired from various theoretical models as well as experimental data. The comparison between the results obtained through experimental data, various theoretical solutions and present predictions is shown in Table .1.

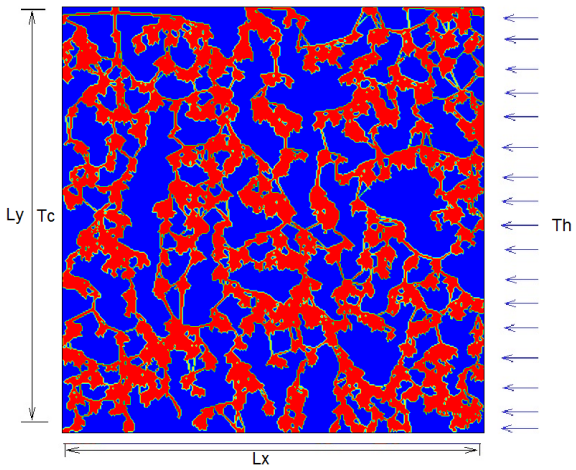

Figure 1. Schematic of the generated porous structure with RGMMP.

The computed values of effective thermal conductivity that vary ±10 % from those estimated by experimental data are bolded It can be seen that the value obtained by present numerical model lies within ±10% deviation from experimental values whereas all the theoretical show more than 10% percentage deviation from the experimental data. Hence it is proved that present model is rigorous, general and robust. More validation of this model for other building materials is needed. As far as the present case is concerned, this model is useful for prediction of effective thermal conductivity of different building materials which is very important parameter for the thermal performance analysis of complex structured building envelops.

Table 1
Comparison of Measured Data, Present Calculations and Existing Theoretical Solutions

Material	P	S	H	BB	ME1	ME2	EMT	A	WM	$\lambda_{Present}$	λ_{Exp}
Cement mortar	2.65	0.11	1.38	0.54	2.38	0.26	2.26	1.12	0.08	**1.736**	1.9
Sandstone concrete	3.76	0.15	1.95	0.75	3.47	0.37	3.38	1.88	0.06	**2.262**	2.21
Limestone concrete	2.74	0.16	1.45	0.65	2.54	0.38	2.49	1.51	0.06	**1.914**	2.03