Effective thermal properties of nanoaggregates in porous media

Nikolaos Karagiannakis, Christos Stiapis, Eugene Skouras and Vasilis Burganos

October 26, 2019

Effective thermal properties of nanoaggregates in porous media

N. P. Karagiannakis[1,2,*], C. S. Stiapis[1,2], E. D. Skouras[1,3] and V. N Burganos [1]
[1]*FORTH/ICE-HT, Institute of Chemical Engineering Sciences, Patras, Greece*
[2]*University of Patras, Department of Chemical Engineering, Patras, Greece*
[3] *University of the Peloponnese, Department of Mechanical Engineering, Patras, Greece*

*Contact: nick.karag@chemeng.upatras,gr

Abstract— **The effective thermal properties of nanoaggregates in porous media are calculated. The level-set percolation method is used to represent porous media realizations. Particle aggregates are constructed with the Diffusion Limited Aggregation (DLA) method and the application of a ballistic technique. The effective thermal properties of the systems are calculated using meshless methods.**

I. Introduction

Research of transport phenomena in porous media is enjoying increasing interest due to the wide range of their relevance to contemporary technology, such as electronics cooling, heat pipes, packed beds, heat exchangers, biological and tissue engineering, drug delivery, thermal insulation engineering, nuclear waste repository, spreading of chemical waste, enhanced recovery of petroleum reservoirs, and grain storage. Special attention is placed to the study of the structure of porous media and its effect on the macroscopic performance of the material.

Nanofluids are developed by the addition of nanoparticles (10–50 nm) to traditional fluids. They have showed the potential to improve heat transfer properties in a wide range of applications, such as industrial cooling, nuclear reactors, transportation industry, micro-electromechanical systems and biomedical applications. Many of the studies published in the literature are related to heat transfer enhancement using nanofluids both experimentally and theoretically.

In this work, a method for digitized pore structure reconstruction is presented. Particle aggregates are constructed with the Diffusion Limited Aggregation (DLA) method, and the implementation of a ballistic technique. A method to represent particle aggregates in the interior of porous media is developed, and the effective thermal properties of the resulting systems are calculated using meshless techniques.

II. Porous media reconstruction

The level-set percolation method is used to produce porous media realizations from random topographies. The pore space realization is obtained by applying a fixed level threshold to a generated hypersurface that is associated with a random topology. The desired hypersurface is generated by convolving a gaussian kernel with a realization of a random field. In our approach the desired topologies were obtained by the superposition of two different hypersurfaces resulted from fixed level threshold of two different convolutions of two different gaussian filters with the same random field [1].

III. Simulation of aggregate formation

For the representation of the aggregates, the well-known DLA (Diffusion Limited Aggregation) and the ballistic method are used. The appropriate phenomena for the formation of fractal structures are described by the DLA model. In case of mean free path smaller than the size of the aggregate, the morphological characteristics of the clusters are quite similar. In contrast, when the mean free path is larger than the aggregate size, the ballistic model is used (BA), and the resulting aggregates are denser than those of the DLA model [2].

IV. Particle aggregates in pore structures

Once the pore structure is constructed, particle aggregates are placed within the pores. A Gaussian distribution is assumed for the number of particles per aggregate. The volume fraction of the particles and their radius are determined. The aggregates are placed randomly in the pore structure, subject to the restriction that the particles lie in the interior of the pores, having no contact with the solid walls. The process continues until the desired volume fraction is achieved.

V. Results

The heat transport equation is solved in the resulting systems, using the MPLG method [3]. The normalized thermal conductivity dependence of the volume fraction of the particles is presented in Table 1. The thermal conductivity is normalized with the conductivity of the base fluid. The conductivity ratio of the particles to that of the base fluid ($k_{r,p}$) is set to 500 and results are presented for two different conductivity ratios of the solid phase to that of the base fluid ($k_{r,s}$). The porosity of the medium is 0.13.

TABLE 1
EFFECTIVE THERMAL CONDUCTIVITY

Volume fraction	**Effective thermal conductivity**	
	$\boldsymbol{k_{r,s} = 5}$	$\boldsymbol{k_{r,s} = 0.2}$
0	4.287	0.262
0.02	4.385	0.272
0.03	4.455	0.277
0.05	4.562	0.286

An enhancement of 5% is observed in the case where the conductivity of the solid phase is higher than that of the base fluid, whereas an enhancement of 10% is observed in the case where the conductivity of the solid phase is lower than that of the base fluid.

ACKNOWLEDGMENT

Financial support was provided by the Hellenic Foundation for Research and Innovation, PhD scholarships 2017 (HFRI, N. Karagiannakis) and by the Institute of Chemical Engineering Sciences, Foundation for Research and Technology, Hellas (FORTH/ICE-HT).

REFERENCES

[1] J. D. Hyman & C. L Winter. Stochastic generation of explicit pore structures by thresholding Gaussian random fields. *J. of Comp. Physics* 277, 16-31 (2014)

[2] C. M. Sorensen. The Mobility of Fractal Aggregates: A Review, *Aerosol Sci. and Tech.*, 45:7, (2011)765-779

[3] N. Karagiannakis, G.C. Bourantas, A.N. Kalarakis, E.D. Skouras, V.N. Burganos, Transient Thermal Conduction with Variable Conductivity using the Meshless Local Petrov-Galerkin Method, *Appl. Math. Comp.*, 272(2016)676-686