FUNDAMENTALS OF GEOMETRICAL AND PHYSICAL CONCEPT OF PORE SPACE TORTUOSITY

M. Cieszko,

Institute of Mechanics and Applied Computer Science,
Kazimierz Wielki University, Bydgoszcz, Poland

e-mail: cieszko@ukw.edu.pl

Abstract

Parameter of the pore tortuosity together with the volume porosity and permeability form a set of basic parameters characterizing macroscopic pore space structure of permeable porous materials. This parameter plays important role in all transport processes taking place in porous materials. This concerns among others the flow of fluids, electrical current, and also diffusion and heat conduction. The importance of general description of the pore space structure is determined by the fact that engineering of transport processes in porous media is directly related with engineering of pore structure. In spite of the fundamental character of the tortuosity parameter and great number of publications devoted to its definition, analysis of the physical and geometrical meaning and the methods of determination (e.g. [1-3]), there is still no commonly accepted general definition of this macroscopic notion and its relation with microscopic pore structure. This problem becomes even more complicated in materials with anisotropic pore space structure.

The aim of the paper is to present the general solution of the problem of macroscopic description of the anisotropic pore space structure, which allows precise and consistent formulation of definitions of macroscopic parameters of pore space structure: pore tortuosity and surface porosity, and also their natural introduction into macroscopic description of processes occurring in porous materials. The general character of these definitions is also a necessary condition for formulation of general representation of these parameters by quantities characterizing microscopic pore structure.

Considerations have been based on the model assumptions presented in papers [4] and [5]. It was assumed that at the macroscopic point of view interconnected pores in permeable porous materials form anisotropic space the structure of which is determined by its metric and this space is modelled as Minkowski metric space. Such approach to this problem raises a number of consequences: a) modelling of the pore space structure is a primary problem in comparison to the modelling of processes occurring in the pore space; b) parameters of the pore space structure are defined by the metric of the space; c) pore structure parameters codetermine the course of each process occurring in the pore space and are independent of them.

Application of the concept of Minkowski metric space as a model of anisotropic pore space enables precise and consistent definition of macroscopic measures of distance, surface and volume in this space, and as a consequence, also definition of macroscopic parameters of pore space structure: pore tortuosity and surface porosity, directly related to these measures. It was shown that these parameters and their tensor characteristics are directly defined by the metric tensor of the pore space. This means that character of these parameters is purely geometrical.

Definitions of the pore structure parameters formulated based on the concept of Minkowski metric space are also the basis for precise determination of their relation with quantities characterising microscopic pore structure. General form of such relation for surface porosity and pore tortuosity have been obtained requiring the full representation of macroscopic density of fluid kinetic energy in the potential flow, by microscopic velocity field.

It was shown that such approach is directly related with the variational problem of minimization of scalar field inhomogeneity defined in the pore region the measure of which is the integral of square of gradient of this scalar field, called Dirichlet integral or Dirichlet energy. Euler equation for this problem takes form of the Laplace equation that is the basic equation describing various types of potential transport. This equation do not contain any material characteristics, and due to the pure geometrical character of the variational problem, its solutions are contingent also upon geometry of the region on which it is defined. In the case of potential flow of fluid, the variational problem means minimization of kinetic energy of fluid in the considered pore region.

The obtained microscopic representations of the macroscopic parameters of pore tortuosity and surface porosity have been applied for determination of these parameters in the exemplary pore space structures of simple pore space geometry. This allows one to demonstrate the influence of microscopic parameters of pore geometry on the pore tortuosity and surface porosity.

References

[1] Carman P., *Fluid Flow through Granular Beds*, Trans. Inst. Chem. Engng, 15, 150-166, 1937.
[2] Lorentz P. B., *Tortuosity in Porous Media*, Nature, 189, 386-387, 1961.
[3] Clennel M., *Tortuosity: A Guide through the Maze,* in Developments in Petrophysics, eds Lovell M.A. & Harvey P.K., Geological Society London Special Publication No 122: 299-344, 1997.
[4] Cieszko M., *Fluid Mechanics in Anisotropic Pore Space of Permeable Materials. Application of Minkowski Metric Space* (in polish), Wyd. Uniwersytetu Kazimierza Wielkiego, Bydgoszcz 2001.
[5] Cieszko M., *Description of Anisotropic Pore Space Structure of Permeable Materials Based on Minkowski Metric Space*, Archives of Mechanics, 61, 6 (425-444), 2009.