COMMUNICATIONS IN COMPUTATIONAL PHYSICS
Vol. 6, No. 2, pp. 354-366

Commun. Comput. Phys.
August 2009

Numerical Study on the Tortuosity of Porous Media via Lattice Boltzmann Method

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Received 11 April 2008; Accepted (in revised version) 23 October 2008

Communicated by Sauro Succi

Available online 15 December 2008

Abstract. In this paper, we simulate the pressure driven fluid flow at the pore scale level through 2-D porous media,which is composed of different curved channels via the lattice Boltzmann method. With this direct simulation, the relation between the tortuosity and the permeability is examined. The numerical results are in good agreement with the existing theory.

AMS subject classifications: 76S05, 80M25

Key words: Tortuosity, lattice Boltzmann, porous media, pore scale.

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1 Introduction

Fluid flow through porous media is a common phenomenon in science and engineering. Thus, the prediction of the permeability, as the main transport property in porous media, is a long-standing problem of great practical importance. Existing experiment results and theoretical works [1–5] show that the permeability of various porous materials is determined by their structure parameters such as porosity, specific surface area, tortuosity etc. Among the existing theories, the Kozeny-Carman equation may be the most famous one, which can be expressed as:

$$k=\frac{\epsilon^3}{k_0 T^2 S^2}, \tag{1.1}$$

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where k is the permeability, k_0 is the shape factor, ϵ is the porosity and S is the specific surface area (i.e., the pore surface area per unit volume of porous material) and T is the tortuosity, defined as follows:

$$T = \frac{L_e}{L}, \tag{1.2}$$

where L_e is the length of real flow path and L is the length of sample of the porous material. According to Eq. (1.1), the square of tortuosity is inversely proportional to the permeability if ϵ^3/k_0S^2 is fixed. However, this relation is always assumed to be applicable for various porous materials although it is only analytically derived from rather simple inclined straight channel model [15–17]. To our knowledge, few works is available to test this relation in more complex cases via experiments or numerical simulations.

In recent decades, with the development of computer and numerical algorithms, numerical studies for fluid flow in porous media with extremely complex structures is possible. The lattice Boltzmann (LB) method, which appeared recently for simulating fluid flow has widely used in understanding the transport process in porous media at the pore scale level [6–8,11,12,15,18–26] due to its advantages such as easily dealing with complex boundaries over other simulation methods as finite volume method. However, few literature is available to study the relation between the tortuosity and the permeability using LB methods yet. In this work, we will focus on this topic by simulating the fluid flow at the pore scale level in some 2D porous media composed of different curved capillary channels via the lattice Boltzmann method.

Our paper is organized as follows: in Section 2 three test cases for 2D porous media are presented in order to test the relation between the permeability and the tortuosity; in Section 3 the LB model used in this paper is briefly introduced; in Section 4 the relation between the tortuosity and the permeability is examined and the numerical results obtained are compared with the Kozeny-Carman equation. Finally in Section 5 some conclusions are presented.

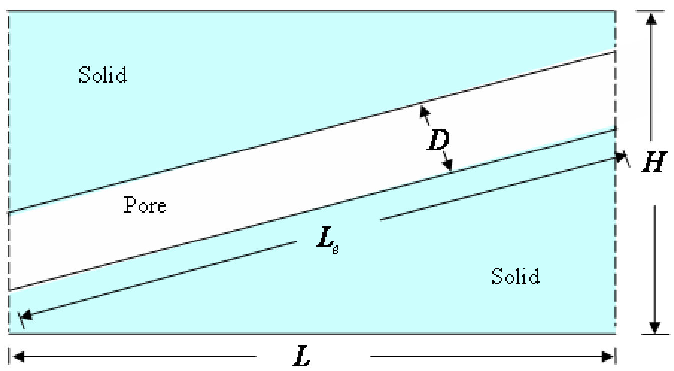

Figure 1: The Layout of a capillary model with inclined straight channel, i.e., Case I.