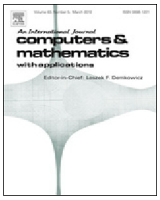
Contents lists available at ScienceDirect

Computers and Mathematics with Applications

journal homepage: www.elsevier.com/locate/camwa



Computational time and domain size analysis of porous media flows using the lattice Boltzmann method

Mayken Espinoza-Andaluz [a,b,*], Martin Andersson [a], Bengt Sundén [a]

[a] *Department of Energy Sciences, Lund University, PO Box 118, 22100 Lund, Sweden*

[b] *Escuela Superior Politécnica del Litoral, ESPOL, PO Box 09-01-5863, Guayaquil, Ecuador*

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Computational time
Domain size
Porous media
Lattice Boltzmann method
Porosity
Hydraulic tortuosity

ABSTRACT

The purpose of this study is to investigate the computational time required to describe the fluid flow behavior through a porous medium and its relation to the corresponding domain size. The fluid flow behavior is recovered using the lattice Boltzmann method (LBM). The selected methodology has been applied because of its feasibility for mimicking the fluid flow behavior in complex geometries and moving boundaries. In this study, three different porosities are selected to calculate, for several sizes domain, the required computational time to reach the steady state. Two different cases are implemented: (1) increasing the transversal area, but keeping the layer thickness as a constant, and (2) increasing the total volume of the pore domain by increasing all the dimensions of the volume equally. The porous media are digitally generated by placing the solid obstacles randomly, but uniformly distributed in the whole domain. Several relationships relating the computational time, domain size and porosity are proposed. Additionally, an expression that relates the hydraulic tortuosity to the porosity is proposed.

1. Introduction

The study of fluid flow through porous media is of particular interest in several fields of science such as geological or energy sciences. In geological sciences, various porous media properties are influenced by the physical characteristics found in soils or reservoirs [1,2]. On the other hand, in energy sciences, more specifically fuel cells, several microstructural parameters depend on the behavior of the fluid through the porous layers involved in the energy conversion [3–6]. Among the fundamental variables to be analyzed in porous media, the porosity and hydraulic tortuosity can be mentioned; which affect several transport phenomena that occur through the porous media, especially in the diffusion process. Considering the first mentioned application, the porosity of the soils has values in the range of 0.40–0.68 [7,8], whereas for the applications in fuel cells, the porosities are in the range of 0.30–0.90 [3,4]. In Fig. 1, the structures found in porous media related to soils and fuel cell electrodes are presented. Void space is required for fluid flow through the material. Although the morphological structure is similar for both cases, the pore size and particle size can differ in the order of hundreds of microns.

To obtain a detailed description of certain characteristics of the porous media, a microscale analysis is required. Considering the microstructural shapes of the porous media an accurate description of the fluid flow can be obtained. However, experimental measurements of certain variables at microscale are not easy tasks, and therefore; computational approaches appear as suitable tools to predict the fluid behavior through porous media. When complex geometries have

---

[*] Corresponding author at: Escuela Superior Politécnica del Litoral, ESPOL, PO Box 09-01-5863, Guayaquil, Ecuador.
E-mail addresses: mayken.espinoza_andaluz@energy.lth.se, masespin@espol.edu.ec (M. Espinoza-Andaluz).

http://dx.doi.org/10.1016/j.camwa.2016.12.001

Please cite this article in press as: M. Espinoza-Andaluz, et al., Computational time and domain size analysis of porous media flows using the lattice Boltzmann method, Computers and Mathematics with Applications (2016), http://dx.doi.org/10.1016/j.camwa.2016.12.001

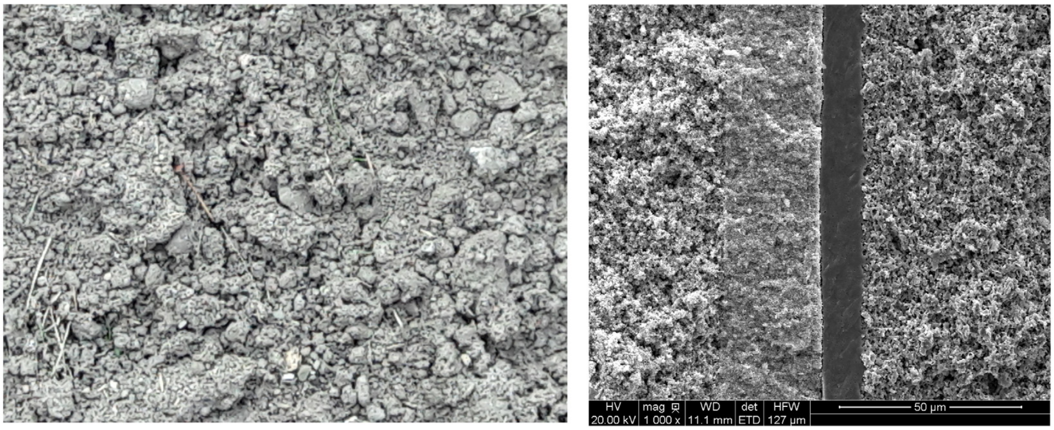


Fig. 1. Porous media found in different scenarios. Left side presents the porous media in soils, whereas the right side presents the pore microstructures in a fuel cell anode.

to be analyzed, the Lattice Boltzmann method (LBM) has proven to be an effective tool to describe several transport phenomena [9,10]. During the modeling process, the required computational time is one of the most important variables to be taken into account to optimize the computational resources. Although there are some attempts to provide a prediction of the computational time required to solve benchmark problems such as fluid flow in a channel or lid-driven cavity flow [11], relationships predicting the required computational time for full solution in porous media have not been proposed yet.

The purpose of this study is to propose expressions to relate the computational time and the domain size of the analyzed domain to predict when the fluid flow through the porous media has reached steady state. The porous media is digitally created and the domain size is increased in two different ways: in the first case the thickness of the porous domain is kept constant and in the second case the volume is increased considering all dimensions. The porous media generation is explained in more detail within Section 2. For both cases, considering the porosity found in soils and fuel cells, three different porosity values are studied, i.e., 0.5, 0.6 and 0.7. Relationships between the required computational time and domain size are proposed. Additionally, for the first case, the hydraulic tortuosity is computed and tortuosity–porosity relationships are proposed.

The rest of the paper is divided as follows: Section 2 is devoted to the variables analyzed, porous media generation, LBM and boundary conditions implemented. Section 3 is mainly dedicated to the obtained results and discussions, fluid flow distribution, porosity and hydraulic tortuosity computation and relationships proposed. Finally, in Section 4, the conclusions of the present study are presented.

2. Methodology

The methodology for solving the fluid flow behavior through the porous media is LBM. However, before the LBM application, the variables included in the study have to be defined and the generation of the porous media is explained.

2.1. Variables computed

As mentioned in Section 1, there are several variables to be analyzed in porous media. This study is focused on porosity, hydraulic tortuosity, computational time and domain size. In this sub-section, definitions and the process for their computations are given.

Porosity: For a given volume, the ratio between the void space and the total volume is known as the porosity of the medium. The void space allows the flow of the fluid through the porous media. The porosity is a dimensionless quantity, varying from 0 to 1 and can often be expressed as a percentage. The porosity is computed as follows:

$$\varepsilon = \frac{Void\ space}{Total\ Volume}. \tag{1}$$

Although the porosity is an important variable, there are some other variables to be considered during the analysis, such as particle size, pore size [12], particle size distribution, etc. The authors will address the mentioned variables in a further study.

Hydraulic tortuosity: The complexity of the medium is represented by the hydraulic tortuosity, which has a real impact on the diffusion parameters in transport processes in porous media [13]. Similar to the porosity, the hydraulic tortuosity is a dimensionless quantity, but is always greater than unity. If there are no solid particles in the domain, the tortuosity is equal to unity. Hydraulic tortuosity is defined as the ratio between the actual length path followed by the fluid through the

Please cite this article in press as: M. Espinoza-Andaluz, et al., Computational time and domain size analysis of porous media flows using the lattice Boltzmann method, Computers and Mathematics with Applications (2016), http://dx.doi.org/10.1016/j.camwa.2016.12.001