Commun. Comput. Phys.
doi: 10.4208/cicp.OA-2016-0236

Vol. **23**, No. 4, pp. 932-950
April 2018

Modelling Particle Capture Efficiency with Lattice Boltzmann Method

Jianhua Fan[1,*], Franck Lominé[1] and Mustapha Hellou[1]

[1] *INSA de Rennes, LGCGM, EA3913, F-35708, Rennes, France.*

Received 6 December 2016; Accepted (in revised version) 31 March 2017

Abstract. The transport and deposition of particles over a fixed obstacle set in a fluid flow is investigated numerically. A two-dimensional model, based on lattice Boltzmann (LB) method and discrete element (DE) method, is used to simulate particle deposition. The corresponding method is two-way coupling in the sense that particle motion affects the fluid flow and reciprocally. The particle capture efficiency, as a function of particle size and Stokes number, is investigated using one-way (effect of the particle on the fluid is not considered) and two-way coupling respectively. The numerical simulations presented in this work are useful to understand the transport and deposition of particles and to predict the single fiber collection efficiency. The effect of obstruction shape on single fiber collection efficiency is investigated with LB-DE methods. Results show that the influence of particle on the flow field cannot be neglected for particles with large size. Numerical results for circular fiber collection efficiency are in good agreement with theoretical prediction and existing correlations. Enhanced collection efficiency is achieved by changing the fiber shape.

AMS subject classifications: 74F10, 74S30, 76S05, 76T25

Key words: Fibrous filter, capture efficiency, two-way coupling, lattice Boltzmann method, discrete element method.

1 Introduction

The knowledge of particle behavior during their transport and deposition, on various obstacles placed in a fluid flow, is fundamental in many environmental and industrial applications such as transport in porous media, air purification, biological engineering and chemical processes. In early studies, many researches employed theoretical analyses [1], numerical simulations [2, 3] and experimental measurements [4] to examine particle deposition over different obstacles such as cylinders, spheres and disks [5]. Lee and

*Corresponding author. *Email addresses:* Jianhua.Fan@insa-rennes.fr (J. Fan), Franck.Lomine@insa-rennes.fr (F. Lominé), Mustapha.Hellou@insa-rennes.fr (M. Hellou)

Liu [6] considered a theoretical approach, based on Kuwabara's flow field [7], to predict the filtration of aerosol particles where diffusion and interception are dominant. Brandon and Aggarwal [8] numerically studied particle deposition on a square prism and investigated the effects of Stokes and Reynolds number on particle trajectory and deposition. Schweers et al. [9] determined experimentally the single fiber collection efficiency where the configuration of neighboring fibers was considered.

The particle deposition on the fiber is caused by simultaneous action of several mechanisms, which include Brownian diffusion, interception and inertial impaction. Brownian diffusion occurs when particle size is generally smaller than 0.1 μm [10]. The capture efficiency corresponding to Brownian diffusion is related to Peclet number, $Pe=UD_f/D$, where D and D_f are Brownian diffusion coefficient and fiber diameter respectively, U is fluid velocity. Interception happens when the distance between the center of a particle and the surface of a fiber is less than the particle radius, even if particle remains on the original streamline [11]. Particle size is generally larger than 0.1 μm for interception mechanism [10]. Interception efficiency depends on intercept coefficient R, $R=d_p/D_f$, where d_p is the particle diameter. Inertial impaction takes place when a particle is unable to adjust to the abrupt changes in original streamline near a fiber. This mechanism can be observed for particle size larger than 1 μm [12]. Inertial impaction is governed by the dimensionless parameter Stokes number, $St=\rho_p d_p^2 U/(18\mu D_f)$, where ρ_p is the particle density, μ is the fluid viscosity. This mechanism plays an important role for capture efficiency which is easily observed for large particles (≥ 10 μm) with large St number.

The velocity and position of solid particle rely evidently on the fluid velocity field. Thus, it is essential to acquire an accurate velocity field for particle trajectory analysis which is appropriately described by the Lagrangian approach. Conventional CFD model, based on the incompressible Navier-Stokes equation, combined with Lagrangian approach are usually used to simulate the fluid-solid flow within porous media such as filters. For dilute suspensions, the solid particle is viewed as mass point without volume (point-like approach), therefore the trajectory and velocity of the particle are calculated from the equation of the motion using Lagrangian approach by consideration of the different external forces such as drag force and Brownian force [10]. It is reasonable to neglect the effect of particle on the fluid flow when the particle-laden flow are dilute enough, the error caused by this assumption is believed to be limited since the results in the validation are acceptable [13]. Based on these information, obviously, point-like approach estimates roughly the actual displacement of particle within a time step. However, particle with large size ($d_p \geq 10$ μm) injected in fluid channel can change and affect significantly the flow field. In this case the volume of the particle and its influence on the flow field should be considered.

For particle-laden flow, the conventional numerical methods as finite element and finite volume methods need to adopt moving mesh to insure a high-resolution near the deposit when considering the particle motion. It leads to increase the computational cost. Lattice Boltzmann Method (LBM), as an efficient alternative for modelling particle-laden flow, demonstrates significant advantages due to easily implementing dynamic and com-