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A realistic approach for modeling permeability of fibrous media: 3-D imaging coupled with CFD simulation

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Abstract

Determining permeability of fibrous media is of great importance to many industries. While there are several 2-D and 3-D analytical models developed for predicting the permeability of fibrous disordered media, there are not many numerical works that compare the predictions of these *models* with that of *real* media. In this work, we present a series of numerical simulations performed on the microstructure of a real fibrous media. An efficient procedure is presented for reconstructing 3-D images from the 2-D images of the real fibrous media and processing them for the purpose of performing fluid flow simulation. Digital volumetric imaging (DVI) of a typical hydroentangled fibrous fabric is obtained, as an example, and its permeability is computed. These results are compared with those obtained from the analytical equations given in the literature. In particular, it was found that permeability of a typical hydroentangled material can be closely predicted by the layered anisotropic models.

Keywords: Permeability; Fibrous porous media; CFD; Digital volumetric imaging

1. Introduction

Nonwovens are assemblies of fibers bonded together in the form of sheets, webs, or bats. Nonwoven fibrous materials stem from the family of porous media. One of the most attractive characteristics of nonwoven materials is that they can form stable structures even at very low solid volume fractions (SVFs). Having low SVF allows a porous media to attain a high permeability which is an essential requirement for the porous media used in many applications. Highly permeable nonwovens have been utilized in absorbency products, filtration, composites micro-devices and microbiology-related applications amongst many others. Realistic modeling of fluid flow through fibrous materials, is, therefore, essentially important for determining the accuracy of existing theories and/or developing new predictive tools.

For slow flow through porous media, permeability is related to pressure drop across the media through the famous law of Darcy:

$$V = \frac{k}{\mu}\frac{\Delta p}{\Delta x}, \tag{1}$$

where V is superficial velocity, μ is fluid viscosity, k is permeability, $\frac{\Delta p}{\Delta x}$ is the applied pressure drop per unit thickness. Permeability, as given in Eq. (1), is a material property depending strongly on the material's microstructure. Microstructure of fibrous materials, in general, can be considered to fall into three major categories: aligned structures, where axis of the cylindrical fibers are oriented either perpendicular or parallel to the flow direction (see, for instance, Chen and Papathanasiou, 2006, 2007), layered structures, where axes of cylindrical fibers lie randomly in the plane perpendicular to fluid flow (see, for instance, Wang et al., 2006; Maze et al., 2007; Zobel et al., 2007), and random structures, where fibers axes can be randomly arranged in any spatial direction (Tomadakis and Robertson, 2005; Li and Park, 1999). In Section 4.2, we use these models to predict the permeability of a hydroentangled fabric.

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