# Two-Scale Modeling Approach to Predict Permeability of Fibrous Media

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**ABSTRACT**

We previously demonstrated how one can develop a 3-D geometry to model the fibrous microstructure of a nonwoven fiberweb and use it to simulate its permeability at fiber level [1-6]. Developing 3-D models of most nonwoven fabrics (bonded fiberwebs), however, is cumbersome, as in the case of hydroentangled fabrics, for instance. In such cases, microscopic techniques are often used to generate 3-D images of the media's microstructures. Nevertheless, whether the microstructure is modeled or obtained from 3-D imaging, extensive computational resources are required to use them in fluid flow simulations [7]. To circumvent this problem, a two-scale modeling approach is proposed here that allows us to simulate the entire thickness of a commercial fabric/filter on a personal computer. In particular, the microscale permeability of a hydroentangled nonwoven is computed using 3-D reconstructed microstructures obtained from Digital Volumetric Imaging (DVI). The resulting microstructural permeability tensors are then used in a macroscale porous model to simulate the flow through the material's thickness and the calculation of its overall permeability.

**INTRODUCTION**

Nonwoven fabrics have been utilized in absorbency products, air and liquid filter, and composite materials among many others. Modeling fluid flow through fibrous media helps to develop a better understanding of behavior of these materials under operating condition. It is, therefore, not surprising that during the past decades, there have been many pioneering works aimed at understanding the parameters that influence the permeability of fibrous materials. Flow through 3-D models consisting of arrays of rods randomly oriented in all directions, were first solved by Spielman and Goren [8] via analytical techniques. Jackson and James [9] proposed new expressions for the 3-D structures made up of straight fibers. Most recently, further investigations on 3-D fibrous structures were undertaken by Clague et al. [10], Wang et al. [1] and Zoble et al. [3] who investigated the permeability of viscous flow through disordered fibrous microstructures.

An alternative approach to obtain microstructure permeability of fibrous media is serial sectioning-imaging [11]. The 2-D images obtained from sectioning can be used to virtually reconstruct the original 3-D microstructure [11]. Along with the above sectioning technique, X-ray-computed micro-tomography has also been developed and widely used in studying porous materials in general. Only a few works, however, are dedicated to fibrous materials [12-17]. In our previous work, an integrated approach using automated serial sectioning technique Digital Volumetric Imaging (DVI) and finite volume method were reported to predict the permeability of nonwoven fabrics [7]. In this paper, we couple our previous study with a dual-scale modeling to extend the range of its predictions to macroscales.

**DIGITAL VOLUMETRIC IMAGING**

Digital Volumetric Imaging (Micro-science Group Inc.), is a block-face fluorescence imaging technique [18]. In this technique, the material, embedded in a polymeric resin, is repeatedly sectioned and imaged. These 2-D cross-sectional images are then combined to construct a 3-D image. The resolution of images obtained from DVI ranges from 0.48 to $4.48\,\mu m/\,pixel$, with a field of view ranging from 0.45 to 4.4 $mm$ [18].

For the current study, a hydroentangled nonwoven fabric made of nylon fibers with mean fiber diameters