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Simulating Liquid Flow through Virtual Glass Fiber Mats

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Abstract The focus of this paper is on simulating the in-plane and through-plane penetration of liquid water in virtual non-wovens. We consider a series of unsteady state two-phase (air–water) simulations performed in two-dimensional geometries obtained from a simulated three-dimensional glass fiber mat. The simulation planes are the cross-sectional planes in the horizontal and vertical directions. Simulations revealed that liquid penetration and spread depend strongly on the fiber orientation distribution as well as on the hydrophilic properties of the fibers. Our results are in good qualitative agreement with the available experimental data.

Key words unsaturated flow, virtual fibrous media, in-plane spreading

Liquid flow through unsaturated fibrous material has a variety of applications in different industries. Liquid distribution in fibrous structures has been experimentally studied for decades [1]. Accurate quantitative prediction of the liquid penetration, however, is not easy. This is because of the presence of a large number of parameters influencing the liquid transport in such structures. These parameters include but are not limited to porosity, anisotropy, and non-uniformity of the media as well as fiber surface properties. Moreover, liquid viscosity, density, and surface tension (even if they remain unchanged during the penetration) as well as injection conditions can play a significant role in the distribution pattern and time scale. For instance, the spread and penetration pattern of a droplet in a given non-woven sheet can completely change depending on its size or impingement velocity. Numerical simulations are attractive tools as they allow one to change a single fluid or structural property (e.g., liquid surface tension or fiber orientation) without altering any other properties (e.g., liquid density or fiber diameter). Obviously, the same is not always possible in an experimental approach.

Generally, unsaturated liquid flow in porous material has been numerically studied via network modeling approaches [1]. In network modeling, the porous structure is discretized into a series of cells and channels for which separate mass and momentum equations were solved. Network modeling is based on an oversimplified assumption that a porous media can be considered as a series of cylindrical channels connected to spherical reservoirs. Nevertheless, network modeling has shown great success in predicting the overall behavior of unsaturated porous material [1]. Amongst many others, the successful network modeling of Thompson [2] shows a promising future for fibrous structures. He developed a 3-D fibrous structure based on a random Voronoi diagram. He could emulate the spread of a 0.5-mm liquid droplet into his dry fiber network. However, Thompson's fibrous structures, being random, semi-ordered, or heterogeneous, were not constructed based on parameters of a real non-woven mat. On a parallel track, Zhong and Xing [3] and Zhong et al. [4] simulated spontaneous and under-pressure liquid penetration through fibrous media using Ising's model combined with the Monte Carlo technique. Their work, however, was in two dimensions and their fibrous structures were random.

Liquid penetration into a sheet of non-woven fabric is intrinsically a 3-D problem. However, under certain conditions it is possible to break this problem into an "in-plane" and a "through-plane" penetration. A 3-D liquid spread can be considered an "in-plane" distribution if the liquid pro-

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