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Wicking as partially-saturated flow of a liquid in thin swelling porous media

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Unsaturated flow through thin layers of porous media are encountered in many industrial applications, including the liquid-absorbing hygiene products such as wipes, paper towels, and diapers [1-4]. These consumer products demand specific absorbent properties with storage of liquid playing a significant role. Understanding fluid flow and deformation processes in thin swelling porous media is critical for the development and design of these products.

We use an averaging approach [5-17] for modeling a system consisting of multiple layers of thin, absorbing swelling porous media as the layer-wise 2D interacting continua, to rigorously derive a 2D averaged macroscopic mass-balance model for each layer and to develop the required constitutive relationships for a system of thin porous layers made of one liquid (water) and two deformable solid phases (fiber and hydrogel). The developed model consists of a set of partial differential equations that keep track the time dependent behavior of variables such as piezometric head, saturation, porosity, and layer thickness, as the liquid moves throughout the multi-layered porous medium. Hence, this model can be used to describe the absorbency process [18], to predict and understand the flow and storage of a liquid in conjunction with the deformation of layers in multilayered thin porous media that is absorbing the liquid, and swelling during deformation. This model will enormously improve the computational speeds, allowing one to develop a fast and reasonably accurate simulation of the unsaturated flow.

The numerical simulations are carried out with the flow parameters and geometries for a few representative cases such as wicking into dry horizontal and inclined porous plates. The simulation predictions, which predict detailed 2-D flow fields, are found to be in good agreement with the experimental and 3D computational results.

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