

Review Article

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Review on Modeling the Spontaneous Imbibition in Porous Wicks Made of Natural Fibers



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Abstract

The modeling of spontaneous imbibitions of a liquid into porous wicks which are made from natural fibers has been investigated in the current research. There has been numerous numbers of mathematical models to predict the wicking properties. The application of all the models depends on some factors such as the microstructure of the wick, porosity, wicking liquid and etc. Lucas-Washburn equation is one of the initial and old wicking models to predict the height of liquid front as a function of time. Darcy's law as an applicable model is based on the movement of the liquid in the wick with a sharp front. However, the sharp-front model is unable to explain region of partial saturation. Richard's equation covers this drawback and predicts the absorbed liquid-mass into the wick as function of time. In this research we overview the application of theses famous theoretical models and their applicability.

Introduction

Recently porous wicks has been confronted a surge in its application in several important and useful industries and commercial applications from a simple example, its application in lightening torches [1] and air refreshers and scent dispensers, to an advanced examples of using porous wicks in propellant management devices (PMD) in rockets [2,3] and their usage in heat exchanger and solar panels applications [4-9]. Hence, modeling spontaneous imbibitions which is called the wicking process is so important in term of predicting the height of liquid front and other properties.

Discussion

During the wicking process of a fluid into a porous medium, as the imbibitions under capillary pressure [10-12], depending on many factors such as pore structure and the wicking fluid properties, we may confront with different type of liquid-front such as: Sharp front, Semi-Sharp front and diffusive front. Depending on the type of the liquid front, there have been many theoretical models to investigate this wicking phenomenon. The oldest method, porous wicks are modeled as a bundle of parallel capillary tubes which are aligned along the direction of the flow. Initially it was investigated by Lucas-Washburn [13] and later continued by other researchers who have added and completed that equation based on other assumptions [14-24]. In Lucas Washburn equation, they neglected the effect of the inertia and gravity effects and used the momentum balance equation to

derive an analytical solution to predict the height of liquid front as a function of time and they presented their equation as

$$h = \sqrt{\frac{\sigma R_e \cos \left(\theta_d\right)}{2\mu} t}$$
 [1]

Where σ and μ are surface tension and viscosity of the wicking fluid and Re defined as the effective capillary radius. Based on the main assumption on which the Washburn equation is based, it is incapable of modeling 2D or 3D flows as the flow happens just in one direction. In addition, there are some fitting parameters such as hydraulic radius needed to be provided for the Washburn equation [25] and the actual microstructure of a porous medium is not made from a bundle of capillary tubes. These like mentioned drawbacks limit the application of the Washburn equation.

As a recent method to model wicking of liquids into porous wicks is based on using Darcy's law [26-28]. He developed his theoretical model based on his investigation on the relationship between flow-rate and the pressure gradient through a hydraulic resistance term. Darcy's model was built on the assumption that a clearly-identifiable liquid front progress during the wicking process and behind this sharp front all pores are filled by the wicking liquid the hat part of the wick is considered as a wet wick. There have been many efforts to develop the Darcy's law-

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based models for predicting and modeling liquid absorption in porous wicks [28-32]. In contrast with Washburn equation, Darcy's law allows researchers to model and predict the two and three -dimensional and, more importantly, it do not need any fitting parameter for hydraulic radius or capillary diameter.

As it was mentioned formerly, one of the liquid-front types during the wicking process in porous wicks is diffusive front which happens due to some in homogeneity in microstructure of the wick. This type of front occurs specially when a wick is made of natural fibers and there are some fiber clustering which lead to a diffusive front. Darcy's law is unable to explain this type of front and there is no sharp and clearly identifiable front and we are dealing with partial saturation which is due to fiber clustering. Richard [29] proposed his model for modeling unsaturated flows in porous media. Richards' equation is a highly non-linear elliptic equation that predicts the diffusive saturation field throughout a porous medium as a function of time. Richard's equation as a useful tool to predict partial saturation has been solved numerically and analytically using various numerical schemes such as the finite difference method, the finite element method, and the boundary element method for different cases of porous wicks [30-38].

Conclusion

Depending the type of liquid-front during the wicking process in porous wicks, the wicking properties can be obtained and modeled on using different type of mathematical models. Darcy's law is most applicable and useful model for all wicking process with a sharp front and it covers the drawback of the Washburn equation. Although it is unable to do the predictions for partial saturation case which happens due to in homogeneity. In those cases of partial saturation, Richard's equation is able to determine the saturation level at any point of the wick during the wicking process.

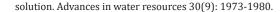
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