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Modeling and Simulation of Moisture Transmission through Fibrous Structures Part II: Liquid Water Transmission

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Abstract

Liquid flow through fibrous materials is important in a diverse range of applications. The prediction of flow through fibrous materials is influenced by a variety of factors and has been recognized as a favorite topic of research in recent years. Capillary flow through fibrous materials takes place by two subsequent processes, known as wetting and wicking. Wetting of the material is the initial process, followed by wicking or flow through its capillaries. In high temperature and high humidity conditions, wicking through a textile fabric plays a very important role in maintaining the thermo-physiological comfort of the wearer by transferring the sweat from the skin to the outside surface of clothing. Prediction of the moisture transmission properties of fibrous materials is useful to characterize clothing comfort and it helps in designing textile fabrics with specific requirements. A variety of mathematical models have been proposed in order to understand the liquid flow characteristics of textile fabrics. Flow through capillary tubes and flow through porous structures have been the two main approaches taken by researchers in order to model the capillary flow through fibrous structures. This paper reviews the relevant research in the area of liquid moisture transmission through fibrous materials, followed by experimental verification of some predictions using some of the developed equations. This experimental verification was undertaken by the authors.

Keywords: Wetting; Wicking; Flow Behavior; Modeling

1 Introduction

The behavior of liquids within porous structures has been intensively studied, both theoretically and experimentally, for many years and this is due to the important applications of these phe-

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nomena in a number of technical fields. The transport of liquids through a fibrous assembly, such as a yarn or a fabric, is caused by external forces or by capillary forces. Liquid flow through textiles is caused by fibre-liquid molecular attraction at the surface of the fibre, which is mainly determined by the surface tension and the effective capillary pore distribution and pathways [1].

Several research works have been conducted in order to characterize fabrics relatively to their liquid spreading properties and to understand the effect of fabric construction parameters on these properties. Marmur and Cohen [2] characterized porous media by analysing the kinetics of capillary penetration. Ichikawa and Satoda [3] described the interface dynamics of the capillary flow.

Wakeham and Spicer [4] showed that a good correlation existed between permeability and the inter-fibre and intra-fibre voids of a tightly woven fabric. The density and geometry of fabric pores, which can be varied according to woven fabric structure, have a significant influence on the liquid flow pattern, both in interstices and downstream [5, 6].

It has been reported that the most important mechanism of fabric wicking is the motion of a liquid in the void spaces between the fibres in a yarn [7]. According to the laws of capillarity, the larger pores between yarns contribute less to the long-range motion of a liquid. It has also been concluded by Minor and Schwartz [8] that, yarn intersections act as new reservoirs and feed all branches equally. The rate of movement of a liquid is governed by the fibre arrangement in the yarns which determines capillary size and continuity [9]. The liquid moisture transmission behaviour of a textile material is measured by several methods, namely horizontal or in-plane wicking, trans-planar or transverse wicking and vertical wicking [10, 11]. The effect of different textile parameters, such as yarn twist, fibre cross-sectional shape and fibre and yarn linear density on the in-plane and vertical wicking behaviour of fabrics has been experimentally studied by Das et al. [12, 13]. Along with the characterisation methods, the prediction tools are of utmost importance for clothing engineering design, as they can be used to predict the behaviour of different textile structures before they are actually manufactured and tested. A number of mathematical models have been proposed to simulate the liquid transfer characteristics of textile fabrics.

2 Liquid Transmission through Fibrous Structures

The processes involved in liquid transmission through fibrous structures are wetting and wicking. Wetting is the ability of a liquid to maintain contact with a solid surface and it results from intermolecular interactions when the two are brought together. The degree of wetting or wettability is determined by the balance between adhesive and cohesive forces. Wetting is the initial process involved in liquid spreading. In this process the fibre-air interface is replaced with the fibre-liquid interface. The forces in equilibrium at the solid-liquid boundary are commonly described by the Young-Dupre equation given below [14]:

$$\gamma_{SV} - \gamma_{SL} = \gamma_{LV} \cos\theta \tag{1}$$

where:

γ_{SV} = Surface tension between the solid and vapour interface

γ_{SL} = Surface tension between the solid and liquid interface

γ_{LV} = Surface tension between the liquid and vapour interface