Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 200 (2017) 349–356

Procedia Engineering

www.elsevier.com/locate/procedia

3rd International Conference on Natural Fibers: Advanced Materials for a Greener World, ICNF 2017, 21-23 June 2017, Braga, Portugal

Characterisation and prognosis of the capillary rise of fluids in textile structures, exemplified by wicking of sunflower oil into cotton nonwovens

Tobias Maschler[a]*, Hermann Finckh[a], Thomas Stegmaier[a], Meike Tilebein[a], and Götz T. Gresser[a]

[a] *German Institutes of Textile and Fiber Research, 73770 Denkendorf, Germany*

Abstract

Although there are several methods for describing the absorption behaviour of textile structures, there is no such one yet for identifying the material and fluid parameters that are necessary for simulating the dynamics of the capillary rise of fluids in textile structures.

This contribution describes a parameter identification method for a general model for wicking in capillary systems composed of a porous material and a liquid. The resulting characterisation enables modelling and optimising wicking of fluids in textile structures – not only from a static point of view, but as well from a dynamic one. With such acquired knowledge, it is possible to optimise e.g. the wicking effect or liquid absorption volume in absorber structures by modifying the product's composition, its construction, and surface finish. The contribution describes the underlying model from a physical-mathematical point of view and shows sample characterisations for vertical and horizontal wicking of sunflower oil in hydro-entangled cotton nonwovens.

Peer-review under responsibility of the scientific committee of the 3rd International Conference on Natural Fibers: Advanced Materials for a Greener World.

Keywords: wicking; capillary rise; nonwovens; liquid absorption; cotton; hydro-entangled nonwovens; sunflower oil; simplex downhill

* Corresponding author. Tel.: +49 711 9340-431; Fax: +49 711 9340-415, E-mail address: tobias.maschler@ditf.de.

1877-7058 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the scientific committee of the 3rd International Conference on Natural Fibers: Advanced Materials for a Greener World
10.1016/j.proeng.2017.07.049

1. Introduction

The ongoing trend towards digitalisation in engineering and product development requires new characterisation methods describing product properties in a simulation-ready manner. This paper presents a parameter identification approach for simulating wicking into textile structures in both vertical and horizontal direction. The transferability of results obtained from vertical wicking to horizontal wicking is validated.

Nomenclature

t	continuous time since first contact of material and liquid	[s]
t_i	i_{th} point in time since first contact of material and liquid with $i \in [0; 1; \dots; n]$ and $t_0 = 0$. There is no need for equidistant points in time, here.	[s]
α	inclination angle of the capillary structure to the liquid surface	[e.g. in °]
(t)	flow front position in capillary direction, time variant	[m]
(t_i)	*simulated* flow front position at t_i in the capillary	[m]
$l_i\,(t_i)$	*measured* flow front position at t_i in the capillary	[m]
r_i	residual at point in time t_i between simulated and measured flow front position with $r_i = l(t_i) - l_i\,(t_i)$	[m]
$h(t)$	vertical liquid rise with $h(t) = \sin(\alpha) \cdot l(t)$	[m]
v	capillary speed constant	[m/s]
h_{max}	max. vertical capillary rise/ liquid level	[m]
l_{max}	max. liquid rise in capillary tube direction with $h_{max} = \sin(\alpha) \cdot l_{max}$	[m]
l_{im}	immersion depth of the capillary structure	[m]
l_u	effective immersion depth	[m]
γ	surface tension of the liquid [	N/m=J/m²=kg/s²]
$\cos(\theta)$	contact angle between the liquid and the capillary	[e.g. in °]
ρ	density of the liquid	[kg/m³]
g	local gravitational acceleration	[m/s²]
r	radius of the capillary tube	[m]
η	dynamic viscosity of the liquid	[Pa s=N s/m²]

2. Theoretical Foundations

Models for capillary suction in cylindrical tubes are well known since about 100 years; see e.g. [1-3]. There are quite some models for wicking in special textile structures (e.g. yarns [3], filter media [4], woven [5] and knitted fabrics [6]), as well as general models for capillary suction in porous media (see e.g. [7-9]). These specialised models do refer in general to specific products, whose material properties are known in a sufficiently detailed manner. Unfortunately, this is rarely the case in operational practice. Existing wicking models based on the Washburn equation do not take the gravitational force into account. Hence, there is a need for a method that identifies the suction properties of capillary systems composed of a liquid and porous material in a simulation-capable manner. Especially for nonwovens, there are quite some material property and behaviour characterisation methods that describe the capillary effect: DIN53924:1997-03 [10] and DIN 9073-6:2003 [11] describe a method for characterising wicking in a system constituted by a liquid and a textile fabric. A major drawback of this method is that the capillary rise is only described as absolute rise levels at given time points; neither is the maximum rise level or the rise speed identi-