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Wicking behavior of fabrics described by simultaneous acquiring the images of the wet region and monitoring the liquid weight

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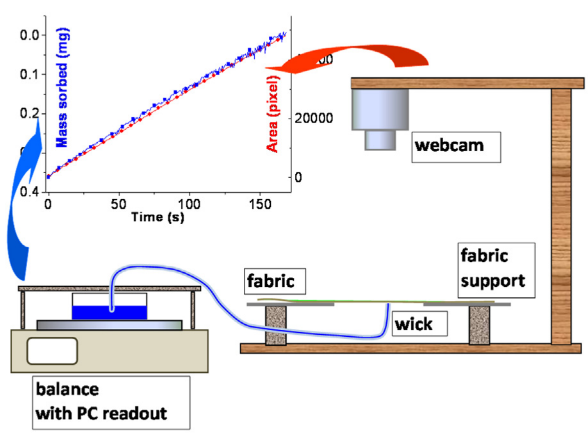
HIGHLIGHTS

- Setup for radial spreading from a reservoir onto a horizontal fabric sample.
- Images are collected simultaneously with monitoring the weight decrease.
- Recording with simple webcam gives advantages in processing.
- Programs are adapted to inhomogeneous and anisotropic structure of textiles.
- The data allow an easy comparison of different textile behavior.

GRAPHICAL ABSTRACT



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ABSTRACT

An experimental study on the radial spreading of the liquid from a virtually infinite reservoir onto a horizontal fabric sample was performed using a simple setup which is presented in two variants: One variant (the simplest) collects the images of the wet spot during the radial outward wicking and the other variant collects the images simultaneously with the monitoring of the weight decrease of the liquid reservoir. We notice that recording with a webcam gives advantages in the subsequent data processing. Afterward, the resulting image series were processed with routines developed in LabVIEW to determine the area of the wet spot. The programs are better adapted to the inhomogeneous and anisotropic structure specific to textiles than the existent edge-finding algorithms. The time dependence of the wet area provides information about the wicking kinetics and further, by modeling the data, to the possible mechanism. The experiments were performed using solutions of red (rhodamin 6B) or blue (brilliant blue E133) dyes in linen and polyester samples differing besides the chemical structure in the roughness of their surfaces as well. The data allow an easy comparison between the textile behavior. Determination of the mass loss of the test liquid might be useful especially for the colored fabrics. The infinite reservoir case is compared with that of the finite reservoir.

1. Introduction

Wicking is a well-known phenomenon of spontaneous liquid flow in a porous substrate, driven by the capillary forces. Since these

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forces are in turn related to the wetting, wicking is a result of natural wetting in a capillary system. The physical basis of wetting and wicking are thus the molecular interactions within a solid or a liquid or across the interface between liquid and solid. Much research has been done on the wetting of solid surfaces (see comprehensive reviews e.g. [1,2]), which cover topics ranging from contact angle, contact line, liquid/solid adhesion, to wetting transition and spreading dynamics.

Wicking and wetting are also common phenomena in the processing and use of textile materials, when water or other liquids come into contact with them and move through the fibrous structures. They are of the highest interest in evaluating comfort and performance of clothing fabrics, hygiene products, etc. Accordingly, extensive research has been carried out in this field to find the characteristics and testing methods, to model and simulate the phenomena [3]. The wetting of fibrous materials is a complex process: The liquid interacts with a medium of tortuous surface, instead of a simple smooth solid one. The imbibition of the liquid into the interior of the fibers might cause changes to the structure and properties of the fibrous materials.

Laboratory test methods for measuring wicking in textiles have already been reviewed (e.g. [4]): These include strip-, plate-, spot- and siphon tests. For example, a strip of a fabric [5–8] is suspended vertically with its lower end immersed in a reservoir of liquid. The height reached by the liquid through the fabric above the liquid surface level in the reservoir is measured either after a certain period of time, or recorded continuously by image analysis/data acquiring techniques. Most of the methods to investigate the wicking can be grouped into two types: gravimetric and optical methods. By gravimetric methods, either the sample is continuously weighed after its contact with the test liquid [9] or the weight decrease of the liquid reservoir is monitored [10]. These methods can only be used for those textiles, which are wetted by the test liquid. In addition, corrections have to be made for the evaporation of the liquid from the wet area of the sample. Optical methods take photographs or movies of the evolution of a limited amount of liquid [11,12] (a drop deposited upon the sample) or of a wetting spot on the textile sample held horizontally (fed from a reservoir with liquid). The liquid is applied in a fixed position on the sample surface by a capillary connected to the reservoir, usually on the face oriented downward [13]. The image of the upper face is acquired with a digital camera, which can be triggered at certain time intervals (time-lapse mode). A movie might also be obtained by choosing the frame frequency in the range of the camera capabilities. Processing of the obtained digital images was realized in several works either by using commercial programs (e.g. Photoshop, Corel Draw [14]) or by especially developed programs [13,15,16]. Other techniques detect the change of some other physical properties (as temperature [17], electrical conductivity [18] etc) of the fabric in order to put in evidence the advancement of the wet front.

Combining two methods to follow up the wicking phenomena onto textile materials has also been performed (see Ref. [13,14] or the more recent ones [19–21]); moreover, the equivalence of height-time and weight-time investigations has been discussed as well [22].

In the present work, we combined two investigation methods less used together, one optical, the other, gravimetric. Thus, a simple experimental setup was realized to obtain the images of the wet spot on the fabric as a function of time using a webcam to take images of the wicking process in the AVI format film. The wicking front propagates outwards in the horizontal plane (a circular or elliptic-like wicking front): Thus, the dynamics is not significantly affected by gravity. This setup was coupled with a second one which simultaneously measures mass of sorbed test liquid. We have then developed a suitable algorithm in an user-friendly program for the analysis of the time dependence of the images, which associates

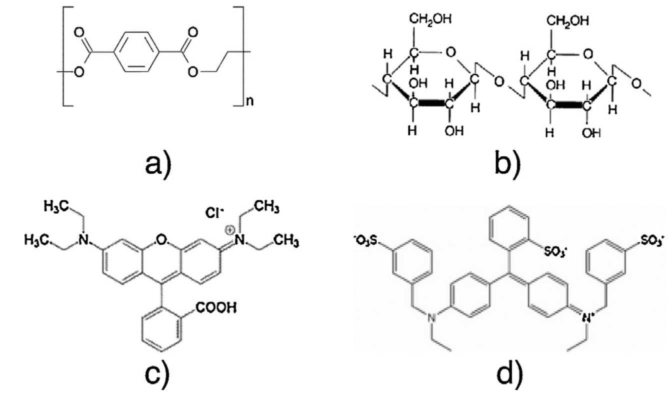

Fig. 1. Structure of the fibers and of the dyes used in the investigations: (a) polyester (polyethylene terephtalate); (b) linen (cellulose); (c) rhodamin 6B; (d) brilliant blue E133.

each movie frame to the corresponding value of the mass of the liquid contained in the wet region.

Our wicking experiments the devices and the programs are tested using textile materials with different surface roughness, void sizes distribution, and chemical nature (linen and polyester) of the fibers.

2. Method

2.1. Materials

The textile samples were a polyester fabric and a cellulosic one, the chemical structure of these fibers is given in Fig. 1. The main characteristics of the fabrics are shown in Table 1.

The optical images of the fabric samples (Table 1) were obtained to assess the mesh size by direct visualization with an optical microscope at diffuse or indirect illumination as described previously [23]. The scale appearing in these images allows an easy comparison of the size of the "pore" system of the samples.

To measure the spreading rate of the wet spot, a fabric piece of ca. $10 \times 10\,cm^2$ was mounted on a lab made frame (called fabric support) which was fixed so that the tension on all edges was equal and the fabric left flat, but stretch-free.

To make more visible the wicked part of the fabric, we have colored the water with organic dyes as brilliant blue (E133) or rhodamin 6B (R6B) (see the chemical structure of the dyes in Fig. 1), their color being chosen to contrast the hue of the studied fabric.

2.2. Experimental setups

The setup built for acquiring the images of the wet spot spreading and simultaneously for measuring the mass of the absorbed liquid is sketched in Fig. 2. The part that acquires the images (also noted Part A) consists of a commercial USB color webcam (to produce movies in AVI format) and a wick supplying the liquid to the fabric sample. The liquid lost from the reservoir is (ab) sorbed by the fabric. Images captured were transferred and stored on the computer. The wick contacted the fabric on the bottom edge; it was thus invisible on the captured images, making their computer processing easier.

Two types of wick were used. One type was a short glass tube of 2 mm inner diameter filled with (cigarette) filter, with the inferior extremity immersed in the liquid and the superior end contacting the fabric sample. The second type of wick was used a segment cut from a hypodermic needle inserted into one extremity of a flexible and chemically resistant Tygon tube. The other end of the tube was immersed into the liquid reservoir. Sessile drops of 5 μl coming