EXPERIMENTAL STUDY OF CAPILLARY RISE IN FABRICS USING AN ELECTRICAL RESISTANCE TECHNIQUE

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Abstract:

An electrical method has been used to study capillary rise in fabrics. This method is based on the measure of the electrical resistance and leads to the determination of time-space water content evolution. The obtained results allowed us to deduce the capillary pressure curve of the fabrics and the flow velocity.

Keywords:

Textile fabrics; wetting; Electrical resistance; liquid mass, liquid distribution

Introduction

Textiles fabrics generally have a complex structure comprised of two different direction yarns: weft and warp. This structure gives presence to pores of different shapes and sizes, which add to the complexity of the phenomenon.

Extensive research has been published in the literature on the diverse aspects of liquid-fiber contacts, both theoretically and experimentally in order to characterize any liquid rise of spin finishes, dyeing, etc... and optimize the various processes related to liquid-fiber contact [7, 12, 21] To date, most models used to describe the kinetics of liquid penetration into textiles fabrics treat the system as a composite of cylindrical capillary and assume the Washburn equation to be applicable [1, 5, 16-19, 24, 25].

Various techniques and methods are used to study experimentally the liquid penetration into fabrics. The first technique used [6, 13, 14] consists of observing and measuring the capillary flow in textile structure by using a colored liquid. A. Perwuelz et al [18] developed another method based on the analysis of CCD images taken during the capillary rise of colored liquid in a yarn's structure. The results obtained by image analysis technique depend on the resolution, the quality of images and the light source. Furthermore, the kinetics of water can be more important than those of dye and the diffusion coefficient found by this method presents the value of the diffusion coefficient of the dye, and not that of the liquid. Moreover, the addition of the dye changes the surface tension of the liquid and modifies its velocity [8]. Y. Hsieh et al [9, 10], Pezron [20], Bayramli et al [2-4] in their studies used a balance to measure the impregnation liquid mass variation in the solid structure. This method is unable to determine the equilibrium height and the quantity of liquid absorbed by the textile at different heights. The last method consists of measuring water transport along textile fibers by an electrical capacitance technique [11, 23]. This technique consists of constructing an apparatus with a specially designed electrical amplifier circuit and condenser electrodes, between which sample fibers are set. This method is unable to determine the liquid content at different heights, and permits only a global view of the evolution of liquid transport.

The method we present in this article is based on the measure of the electrical resistance coefficient developed so as to be used to determine the height attained by the liquid and the quantity of liquid absorbed without the addition of dye. Moreover, it permits us to have an idea about the spatial

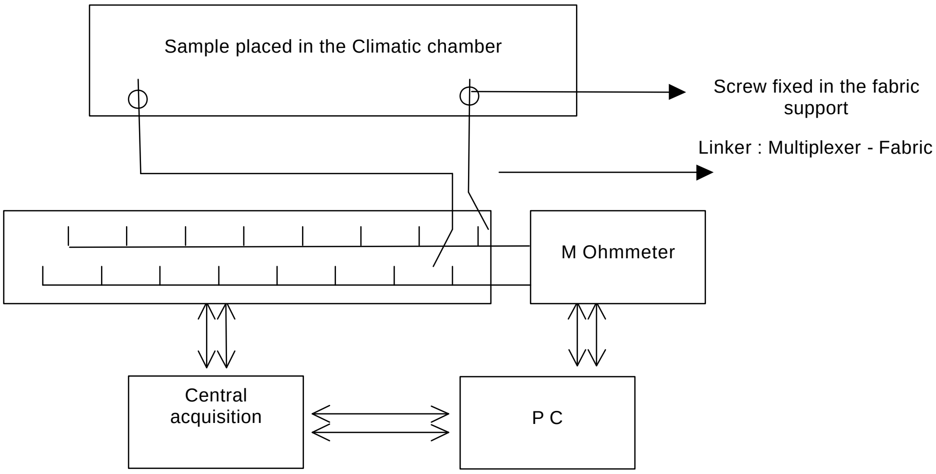

Figure 1. Experimental system.

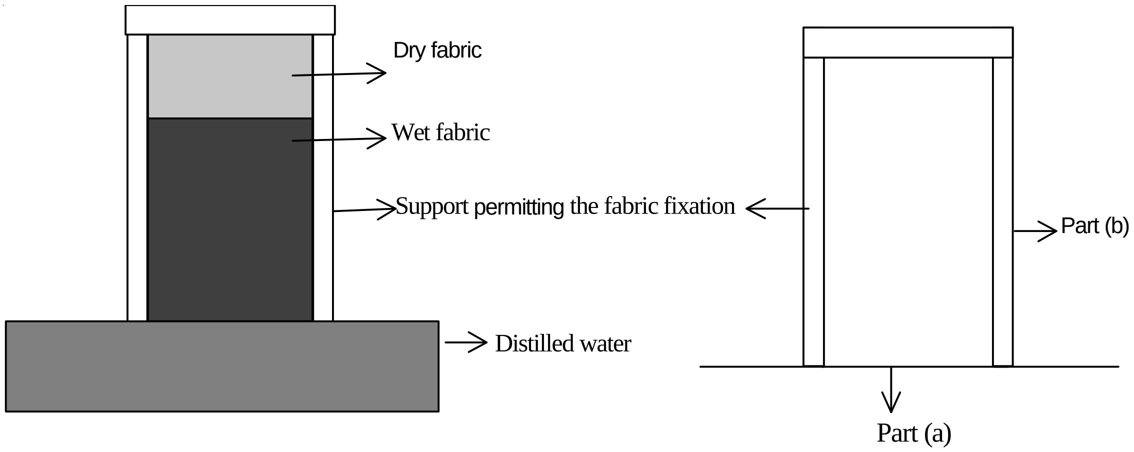

Figure 2-a. Device assuring the vertical suspension of the textile fabric.

distribution of the liquid content in the fabric surface and determine the mass of liquid absorbed.

Experimental system and methods

The experimental system (Figure 1) is composed of a high resistance meter “M ohmmeter” used to make ultra-high resistance measurements during the capillary flow in textile fabrics. The second element of the experimental system is a multiplexer, which permits us to make some successive measurements by opening and closing switches in the system. Also, a computer serves to control the entire experimental device. The computer is equipped with a software program permitting to command at the same time the M ohmmeter and the acquirement central.

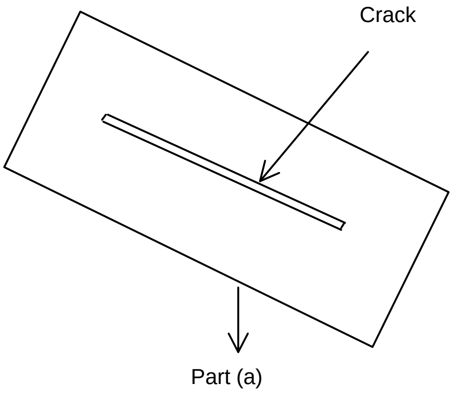

Figure 2-b. Part (a) of the fixation fabric support.

The chosen fabric, object of the study, initially dry, is maintained vertically and partially immersed in a bath containing distilled water (Figure 2-a).

The support permitting the fixation of the cloth is in plexi-glass. It is composed of two parts (a) and (b) (Figure 2-a). In part (a), there is a crack permitting the contact of fabric with water (Figure 2-b).

Electrodes are placed, every 1 cm, all along the fabric length. They are attached to a screw fixed in the plexi-glass. The electrode is relied to the fabric measured point by a metallic yarn (Figure 2-c).

The fabric sample has a dimension of 15 cm x 10 cm. After being placed in a climatic chamber at the temperature of 20°C, humidity of 65% and set in contact with the liquid, the fabric is alimented by a tension of 1V. The software program developed (Visual Basic) permits us to coordinate the measures rhythm. Thus, the electrical resistance measured is recorded in real time.

The liquid height in fabric is deduced at different instants experimentally from the variation of the electrical resistance value given by the software program. Then the liquid content is deduced using the curve presenting the relation between the electrical resistances of textile fabric with the liquid content, as shown in Figure 5.

Sample Materials

In this work, we used fabrics obtained from cotton and viscose fiber which have, respectively, twill, plain and satin structure. The number of weft yarns per centimeter is 26. To guarantee the best wetting of the fabric, a desizing treatment was conducted. The liquid used is distilled water.

Results and Discussion

The experiment consisted in the measurement of the resistance value at 8 points (every 1cm) of the fabric as shown in figure 2-c. In the beginning, the fabric is dry. The electrical resistance is equal to $7x10^{10}\Omega$. Thereafter the electrical

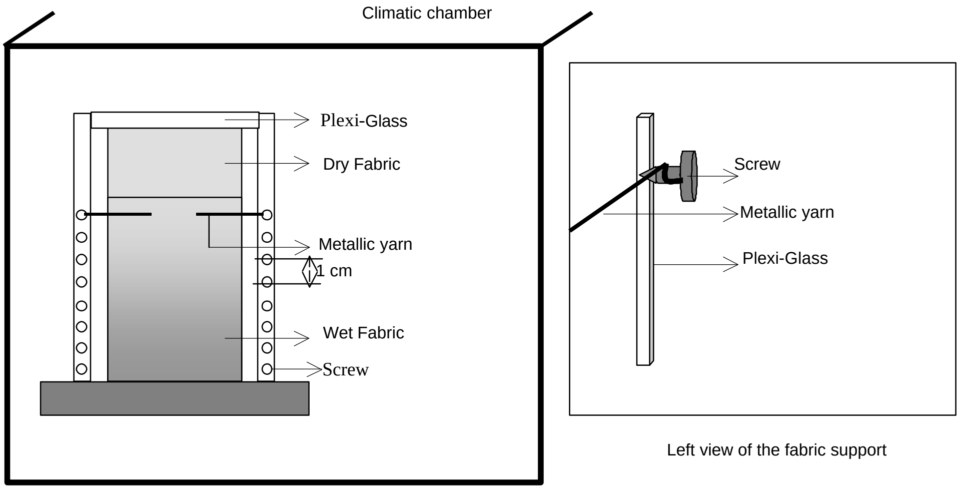

Figure 2-c. Elements assuring the link of M ohmmeter to fabric.

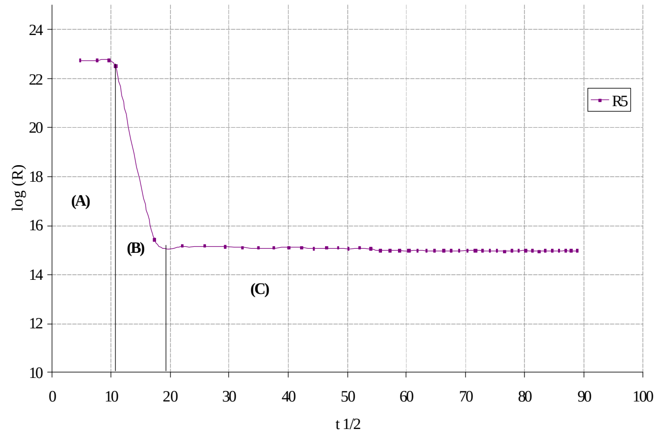

Figure 3. Evolution of electrical resistance with time in fabric, at the height of 5cm.

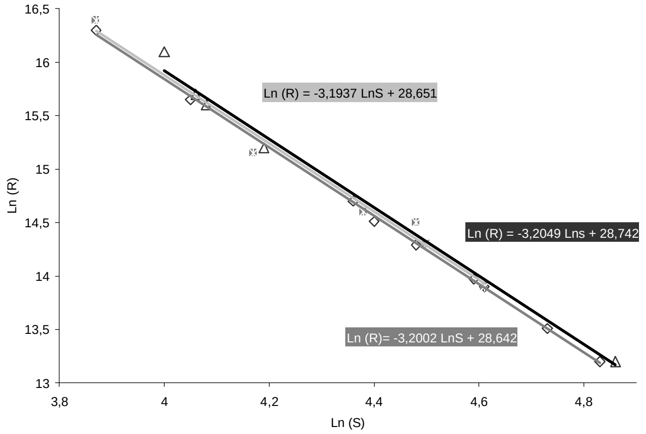

Figure 5. Evolution of fabric electrical resistance with liquid content at Hr = 65% and T = 20°C

resistance decreases with the quantity of liquid absorbed by the fabric (Figure 3).

The analysis of the curve permits us to pick out three regions A, B and C (Figure 3).

- Region A: at time t<121s, the electrical resistance of the fabric at the height of 5cm is constant and equal to $7\cdot10^{10}\Omega$. This value is high and corresponds to dry fabric.
- Region B: for 121<t<360, the electrical resistance of the fabric decreases. The front of the liquid attains the height of 5 cm and the fabric is partially wet at this position.
- Region C: from time t≈360", the electrical resistance becomes constant and reaches $10^7\Omega$. This is a state of low resistance practically corresponding to equilibrium in liquid content.

Figure 4. shows the evolution of the electrical resistance of the fabrics in contact with distilled water at different fabric hieghts (from 1 cm to 8cm).

In order to deduce the liquid content distribution inside the fabric during vertical capillary rise, we established a relation between the liquid quantity absorbed and the electrical

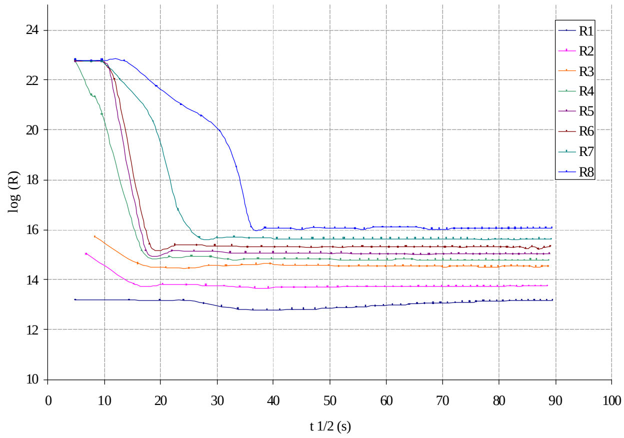

Figure 4. Evolution of electrical resistance value with time in fabric, Ri is the electrical resistance at the height of i cm.

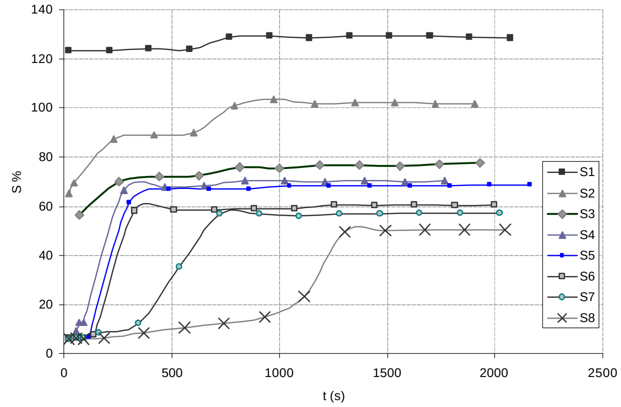

Figure 6. Evolution of the water content in the cotton-viscose twill fabric.

resistance value. This requires making some wet fabric portion at different water content. We determined the electrical resistance and the liquid mass content in this fabric portion ($M_e = M_h - M_s$) using an electronic balance. Figure 5 shows two different curves presenting the evolution of electrical resistance values with the liquid content S% in plain, twill and satin cotton-viscose fabrics.

$$S\% = \frac{M_h - M_s}{M_s} x100 \qquad (1)$$

where M_h is wet fabric mass and Ms is dry fabric mass.

According to the experimental results, R depends only on liquid content and not on the fabric's geometrical structure. As shown in Figure 5, the electrical resistance evolution with the water content is given by the equation:

$$LnR = B + A\,LnS \qquad (2)$$

In our case: A ≈ -3,199 and B ≈ 28,6.

This form of equation is founded by Stamm [22] and by Kochade [15] in the case of wood.

In Figure 6, we see that every curve of Si (1<i<8) presents the three regions (A, B and C), as defined previously and the liquid front become less steep with the height. This can be explained by the decrease of liquid velocity with increasing height, under the gravitational effect.

From the experimental results presented in Figure 6, we concluded also that the rise in liquid quantity in fabric decreases with height. The distribution of the liquid is not homogeneous. This is explained by the complexity of the fabric structure and the heterogeneity of pore size and shape.

Determination of the capillary pressure

A capillary pressure (moisture potential) curve requires the measurement of the equilibrium pressures at various saturations of a porous medium (the fabric in our case) during a displacement process.

The fabric is unsaturated, containing air and water. At the hydrostatic equilibrium, we have:

$$\frac{dp_a}{dh} = r_a g \qquad (3)$$

$$\frac{dp_l}{dh} = r_l g \qquad (4)$$

r_a and r_l are the air and the water density and g is the gravitational constant.

From these equations (3 and 4), we can deduce that:

$$\frac{d}{dh}(P_a - P_l) = (r_a - r_l)g \qquad (5)$$

The capillary pressure Pc=Pa-Pl is than deduced by integrating equation (5):

$$Pc(h) = \int_0^h (r_l - r_a)g\,dh + Pc(0) \qquad (6)$$

At the height of h=0cm the fabric is saturated and the capillary pressure is Pc(0) = 0.

The variation with height can be neglected. Thus the capillary pressure distribution can be expressed by:

$$Pc(h) = (r_l - r_a)gh \qquad (7)$$

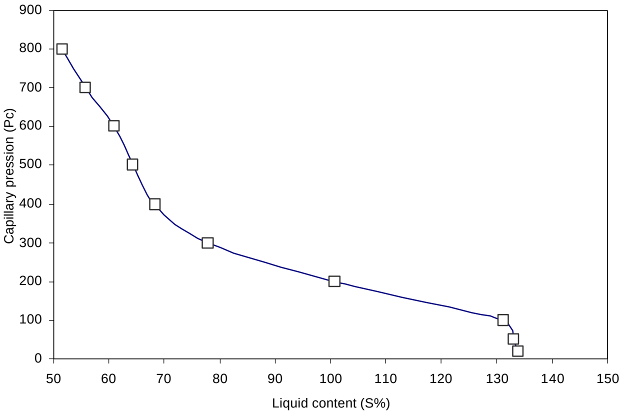

Figure 7. Capillary pressure versus liquid content in cotton – viscose twill fabric.

Knowing the water distribution in the fabric, we can present capillary pressure versus liquid content (Figure 7). This is necessary to determine the flow velocity using the generalized Darcy law.

As shown in Figure 7, the capillary pressure decreases with the liquid content in the fabric. In the textile fabric which is maintained vertically, the water flow and absorbency in a fibrous material depend on the height. The better water wettability, transport and the gravitational effect contribute to the significantly higher water retention properties at the height of 1cm, which is more than two times that at the height of 8cm. All this explains clearly the evolution and the curve allure of the capillary pressure.

Conclusions

In this study, an experimental method has been developed for studying water transport behavior in fabrics. This technique is based on the measure of the electrical resistance and leads to the determination of time-space water content evolution. The obtained results permit us to deduce the capillary pressure in fabrics versus liquid content.
Also, the electrical measurements give us an idea about the condition of the fabric part (dry or wet) and enables us to detect the height attained by the distilled water in the fabric. The new method leads to the local description of the capillary rise of liquid along the surface of the fabric: in the warp and the weft directions.

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