Investigation on moisture transport through polyester/cotton fabrics

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The wettability characteristics of different cotton, polyester and multi-layered cotton/polyester fabrics have been studied to manage human perspiration well. The vertical capillary action behavior of these fabrics has been compared by measuring the capillary height as a function of time. Wicking coefficients in multi-layered fabrics are found to be much better than in other fabrics of 100% cotton. The yarn and the bonding weave between the two layers are very important for the capillary rise.

Keywords: Capillary action, Fabric construction, Moisture transport, Multi-layered fabric, Polyester/cotton fabric, Wicking

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1 Introduction

Hospital bed sheets are commonly produced from mixture of cotton and PET fibres. These sheets become uncomfortable in humid days when cotton fibres become saturated with moisture, producing uncomfortable sensation which may cause frictional festers on patient's skin. In some other application also, the problem of moisture transport through fabrics is crucial, e.g. sports garments, which are commonly multi-layered fabric. Following two techniques have been used to solve the above problem:

- Inner layer of sports garments was made with special PET fibres (e.g. Coolmax, which has a special shape that enhances the capillary action) to keep a dry contact surface between the human body and the garment.
- Outer layer of sports garments was selected to transport the sweat away from the internal one to transfer it to the atmosphere.

To apply the above techniques to bed sheets, several multi-layered fabrics were produced to have a good management of human sweat, considering the following aspects:

- Hydrophobic layer (upper one)—This layer must have the capability to transfer the moisture out of contact surface while maintaining its hydrophobicity at the same time to keep a dry contact surface between patient body and bedsheet. But the migration of moisture stops when the other side is wet. So, to increase the moisture transfer, its chemical potential has to be decreased, e.g. making the external layer of cotton.
- Hydrophilic layer (lower one)—This allows obtaining an effective moisture management of human sweat.

The objective of this investigation is to study the wettability characteristics of cotton, polyester and cotton/polyester multi-layered fabrics.

2 Theoretical Consideration

2.1 Capillarity, Wetting and Wicking

Capillary action or capillarity can be defined as the macroscopic motion or flow of a liquid under the influence of its own surface and interfacial forces in narrow tubes, cracks and voids. The surface tension is based on the intermolecular forces of cohesion and adhesion. When the forces of adhesion between the liquid and the tube wall are greater than the forces of cohesion between the molecules of the liquid, then capillary motion occurs. Flow ceases when the pressure difference becomes zero. The primary driving forces responsible for the movement of moisture along the fabric are the forces of capillarity.

Wicking in fabrics may occur in a range of conditions and situations. Ghali et al.1 believes that “to define this range of conditions, researchers should attempt to distinguish between two phenomena,
namely wettability and wickability, related to liquid transport in fabrics”. According to Harnet and Mehta, ‘wickability is the ability to sustain capillary flow’, whereas wettability describes the initial behavior of a fabric, yarn, or fibre when brought into contact with water. The interaction of liquids with textile materials may involve several fundamental physical phenomena, such as wetting of fibre surface, transport of the liquid into assembly of fibres, adsorption on the fibre surface or diffusion of the liquid into the interior of the fibres.

Wetting is the displacement of solid-air interface with a solid-liquid interface. Spontaneous wetting is the migration of a liquid over a solid surface towards thermodynamic equilibrium. Forced wetting involves external hydrodynamics or mechanical forces to increase the solid-liquid interface beyond static equilibrium.

Wetting and wicking are not different processes. Wetting is a prerequisite for wicking. A liquid that does not wet fibres cannot wick into a fabric. When the fibres in assembly are wetted by a liquid, the resulting capillary forces drive the liquid into the capillaries created by the spaces between fibres in wicking process. In general, wicking takes place when a liquid travels along the surface of the fibre but is not absorbed into the fibre. This type of flow is governed by the properties of the liquid-solid surface interactions, and geometric configurations of the pores structure. The pores structure of a fibrous medium is complicated and difficult to quantify. Moreover, with hydrophilic fibres, the swelling of fibres influences the liquid flow.

2.2 Equation of Lucas-Washburn

The capillary flow in yarns and fabrics was studied in an extensive way. To describe theoretically the capillary flow in a fibrous assembly, it is usually considered as composed of a certain number of parallel capillaries. The theory of the liquid movement was developed independently by Lucas in 1918 and Washburn in 1921. The description of the aspiration of the liquid in fibrous material was reduced to wicking of a liquid in a linear pore which can be represented by a capillary. Lucas and Washburn established a traditional equation, describing the speed of a liquid which moves up or down in a capillary perpendicular to the free face of the liquid in the absence of a gravitational field.

In many common capillary systems which involve wicking in porous materials, the capillary pressure is much greater than the gravitational force in the earlier stage. So, the flow under capillary pressure can be modeled by the Lucas-Washburn equation, as shown below:

\[ h = \sqrt{\frac{r_c \gamma \cos \theta \cdot t}{2 \eta}} \equiv W_c t^{\frac{1}{2}} \quad \ldots \ (1) \]

which gives when complete wetting (\( \cos \theta = 1 \)):

\[ h^2 = \frac{r_c \gamma}{2 \eta} t \quad \ldots \ (2) \]

where \( h \) is the liquid front position or wicking length; \( \gamma \), the surface tension of the liquid-vapor interface; \( \eta \), the viscosity of the liquid; \( \theta \), the apparent contact angle of the moving front; \( r_c \), the effective hydraulic radius of the capillaries; \( W_c \), the wicking coefficient; and \( t \), the time.

The capillary rise \( h \) of the liquid in a porous media is proportional to the square root of time as long as the effect of gravity can be neglected. That is no more the case when the capillary rise becomes rather large. When the equilibrium between the capillary forces and the gravity is reached, the rise will cease.

Other following conditions postulated should also hold:

(i) Physical properties of the liquid and the solid remain constant throughout the system,
(ii) Driving forces are forces of capillarity,
(iii) Radius of the tube or the equivalent radius of the non-tubular system is substantially constant, and
(iv) Supply of liquid to the system remains adequate.

In spite of these limitations, the equation of Lucas-Washburn was employed successfully for the description of wicking.

The slope of the plot \( h \) versus \( t^{\frac{1}{2}} \) is called the wicking coefficient \( W_c \) (ref. 11), as shown below:

\[ W_c = \sqrt{\frac{r_c \gamma \cos \theta}{2 \eta}} \quad \ldots \ (3) \]

3 Materials and Methods

3.1 Fabric Construction

Double faced fabrics having 100% polyester (150 den, 48 filaments) warp yarns, and cotton or cotton/polyester weft yarns with different weaves
were used. Following two types of fabrics were selected:

(i) Simple fabric (satin 5, warp effect), and
(ii) Complex fabrics (two-layered weaves with a bonding weave).

The construction details of the complex fabrics are shown below:

**Tsh1 weave**

- Weft 2 (Cotton) → Connection weave satin 24 warp effect → Lower layer satin 5 warp effect
- Weft 1 (PET) → Higher layer of PET 100% satin 5 warp effect up → The weft yarn is on the warp yarn of PET 100% satin 5 warp effect

**Tsh2 weave**

- Weft 2 (Cotton) → Connection weave satin 24 warp effect → Lower layer satin 5 warp effect
- Weft 1 (PET) → Higher layer of PET 100% satin 5 warp effect → The weft yarn is on the warp yarn of PET 100% satin 5 warp effect

**Tsh3 weave**

- Weft 3 (Cotton) → Connection weave satin 20 warp effect → Lower layer twill 3 warp effect
- Weft 2 (PET) → Higher layer of PET → The weft yarn is on the warp yarn of PET
- Weft 1 (PET) → 100% satin 5 warp effect up → The weft yarn is on the warp yarn of PET 100% satin 5 warp effect

Two fabrics from each type were manufactured, by changing the weft yarn count and weft density. Another 100% cotton fabric was also tested. Table 1 shows the essential characteristics of the selected fabrics.

### 3.2 Wicking Measurement

All the fabrics were desized and washed in boiling water to eliminate the size products and oil added to polyester yarns before weaving. After drying and before measuring wetting characteristics, fabrics were stored for 72 h with a relative humidity (RH) of 65±6% and a temperature \( T \approx 20±2°C \). A different piece of fabric is used for each test. Two grips are placed on the two sides of the tested sample. The mass of the lower grip which maintains the sample under tension during the test is 11.13 g. It should be noted that a significant value of weight (of the lower grip) can affect the capillaries geometry.

The vertical wicking behavior of these 9 fabrics were compared by measuring the capillary height \( h \) as a function of time \( t \) in weft and warp directions.

### 4 Results and Discussion

In order to examine reproducibility of the vertical wicking, 8 repetitions of tests are performed on 8 samples of each fabric. The CV% is found to be less than 15, that is justified by the variability of the porous materials (fabrics) studied here.

The results are given graphically in Fig. 2 as \( h^2=f(t) \). Graphs seem to offer a reasonable linearity which shows that the rise is controlled by the equation of Lucas-Washburn. The coefficient of proportionality (wicking coefficient) is characteristic of the fabric. Table 2 compares wicking coefficient with other characteristics of fabrics. To obtain reproducible results, the textile hygrometric history must be under control. It is observed that the water content of the fabric influences this wicking coefficient. For instance, completely dry cotton does not absorb humidity rapidly.
<table>
<thead>
<tr>
<th>Fabric No.</th>
<th>Weave type</th>
<th>Count of weft yarns</th>
<th>Weft yarn properties</th>
<th>Torsion of weft yarns</th>
<th>Weft density (total)</th>
<th>Weft density (partial)</th>
<th>Weight of weft yarns</th>
<th>Warp density (10% PET except Fabric 9)</th>
<th>Distribution of warp yarns (polyester) in upper/ lower layer</th>
<th>Weight of warp yarns</th>
<th>Rate of cotton in weft yarns, %</th>
<th>Rate of cotton in fabric %</th>
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### Table 2—Experimental results

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<th>Weave type</th>
<th>Count of weft yarns</th>
<th>Properties of weft yarns</th>
<th>Torsion of weft yarns turns/m</th>
<th>Distribution of warp yarns (polyester) in upper/lower layer</th>
<th>Weight of warp yarns g/m²</th>
<th>Rate of cotton in weft yarns (%)</th>
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C—Warp sense, T—Weft sense, (+)—Cotton in weft yarns accelerates the capillary ascension, and (−)—Cotton (with high twisting rates) in weft yarns decelerates the capillary ascension.
4.1 Influence of Weave’s Structure

It is clear from Fig. 2 that the liquid rise in weft direction (cotton direction) is always faster than in warp direction. This phenomenon is caused by the wettability of scoured cotton. The capillary rise in Fabrics 6 and 7 is faster than in others. Wicking coefficients in multi-layered fabrics were much better than in others of 100% cotton (Fabric 9). It may be observed from Fig. 3 that the fastest capillary rise is not obtained in fabrics with 100% cotton weft yarns, but obtained in fabrics with 1/3 of cotton weft yarns and the remaining 2/3 of PET weft yarns. The interpretation of this phenomenon is that the cotton by itself absorbs water and swells. The absorbed water forms a kind of "gel" which makes it not available for further capillary rise. This result seems surprising but is due to the fact that we do not measure the volume of absorbed water but a kinetic of capillary rise.

The comparison of results among fabrics shows that the connecting weave has an influence on capillary rise. Fabrics (1) and (2) are without connecting weave and have the smallest wicking coefficient. When the density of connecting crossing is increased, wicking coefficient increases as in Fabrics (6) and (7).

4.2 Influence of Yarn’s Twisting

The results show that the ply yarns decrease the capillary rise as shown by the wicking coefficient on 3T, 4T and 5T. To interpret this result, some experiments were done with ply yarn. Two simple cotton yarns of 17 Nm count (560 t/m) were twisted at different rates. The results show that the capillary rise in yarns is very sensitive to twisting rates in ply yarns as shown in Fig. 4. When the twisting rate equals 2/3 of the simple yarn torsion, the wicking coefficient has a maximum value.

Fig. 2.—Vertical wicking in (a) weft and (b) warp directions

Fig. 3.—Influence of weave’s structure [(a) weft and (b) warp directions]
5 Conclusions

5.1 The measurements of capillary action on two-layered fabrics (polyester in one side and cotton in the other one) show that the water wets the two sides of the fabric, while it doesn’t wet a fabric of 100% polyester.

5.2 Two parameters, namely the yarn and the bonding weave between the two layers, are found to be important. When the two layers are linked, the capillary rise is exactly the same on both sides.

5.3 Humidity draining by textile depends on all parameters involving the capillaries geometry, i.e. the yarn structure (count number, torsion, simple/ply and classic/open end), and the fabric structure (weave type and bonding weave).

Industrial Importance: The physiological comfort of fabrics became one of the most important factors affecting the development of textile industry. The purpose of this work is the design and implementation of a bedsheet remaining dry from the side of sleeper by draining humidity on the other side.

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