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Study on the Wicking Property of Cotton Fabric

Abstract
In order to study the heat and moisture comfort, the wicking property of textiles has been used as an important and effective index. In this paper, the wicking behaviour of cotton fabric in the warp and weft directions was investigated in terms of the wicking height, rate of wicking, mass increment distribution per centimetre of the wicking height, and the durative wicking height after removal of the wicking liquid reservoir. The results showed that the wicking height square had a good correlation with the time in both the warp and weft directions. The wicking rate was higher in the weft direction than that in the warp, especially at the beginning of the wicking process. The mass increment of fabric per centimetre of the wicking height was inversely proportional to the wicking height; the mass of water absorbed in the fabric did not have a significant difference in the weft and warp directions.

Key words: *cotton fabric, rate of wicking, wicking behaviour, warp direction, weft direction.*

Introduction

It has been generally accepted that moisture transport in textiles is one of the critical factors affecting physiological comfort, especially for underwear and sportswear [1 - 3]. When people sweat, clothes absorb the moisture and transfer it outside owing to the concentration difference of liquid molecules and the pressure difference on both sides of the clothes. People would feel uncomfortable if the amount of sweat and perspiration is more than the absorption capacity of the clothes, or the clothes cannot transfer the moisture outside in a short time. Comfort afforded by textiles can be improved by understanding the liquid transport mechanism. In order to express the moisture transport in textiles, wicking, which is the spontaneous transport of a liquid driven into a porous system by a capillary force [4], has often been used.

According to the Lucas-Washburn equation [5, 6], which was used to describe the capillary behaviours in cylindrical tubes, the capillary penetration rate depends on the properties of the liquid such as surface tension, viscosity, density, and geometry of the capillary spaces. The Lucas-Washburn equation has been widely applied to evaluate the wicking behaviour in porous materials, yarns and fabrics [7 - 11]. Rajagopalan [12] reported that the motion of liquid in the void spaces between fibres in a yarn impacts the mechanism of fabric wicking critically. Much larger pores between yarns do not contribute much to the long-range motion of liquid based on the laws of capillarity. Minor [13] stated that yarn intersections act as new reservoirs and feed all branches equally. Hollies [14] declared that the rate of movement of liquid is governed by the fibre arrangement in yarns, which controls the capillary size and continuity. Saricam [15] also reported that the weft density, pore size and the arrangement of void spaces in fabric had a high impact on the wicking performance. Some theoretical works for analysing the wicking properties of textiles were focused on four forces, which are the capillary force, gravity, viscous drag, and inertia [8, 16]. But the wicking of liquid into fabrics is more complicated than that due to their nature and structure of, the difficulty of determining the effective radius of the capillary tube, and the effective contact angle [8]. In addition, the mass gradient of liquid in textiles allows the motion of liquid due to the moisture/liquid absorption of textiles.

Therefore in order to establish more detailed information about the wicking behaviour of fabrics, the wicking property of cotton fabric was studied in terms of the wicking height, wicking rate, wicking weight, and the durative wicking height after removal of the wicking liquid reservoir.

Experimental

The specifications of cotton fabric are given in ***Table 1***, and its surface morphology is shown in ***Figure 1***. Initially the cotton fabrics were placed in an incubator for 24 h at 80 °C, and then the temperature of the incubator was lowered to 20 °C for 24 h. After cooling, the dry relaxed cotton fabrics were used for testing. Samples were clapped vertically and then partially immersed in a liquid reservoir. The weights of fabrics before and after wicking were recorded and the wicking height measured in both the warp and weft directions. A sketch of the testing apparatus is shown in ***Figure 2***.

The sample size was 3 × 10 cm, the temperature of water 15 °C, and the im-

Table 1. *Specification of cotton fabric.*

Yarn diameter, mm	Surface mass, g/m^2	Thread density, number/10 cm		Thickness, mm
		Warp	Weft	
0.1027 ± 0.0067	108 ± 1	255 ± 5	551 ± 8	0.317 ± 0.01

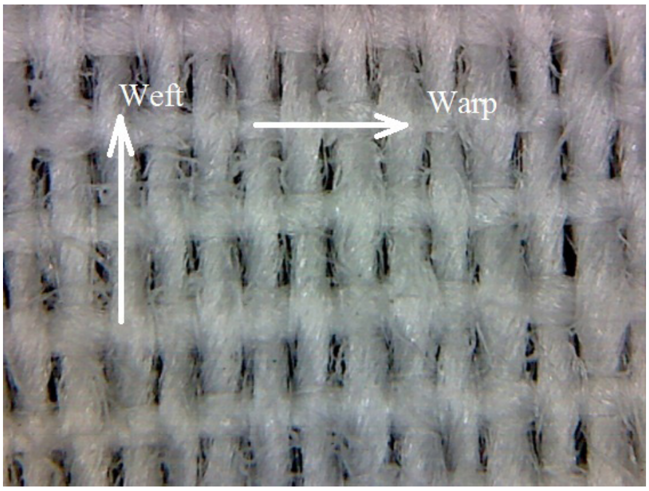

Figure 1. *Surface morphology of cotton fabric (185×).*

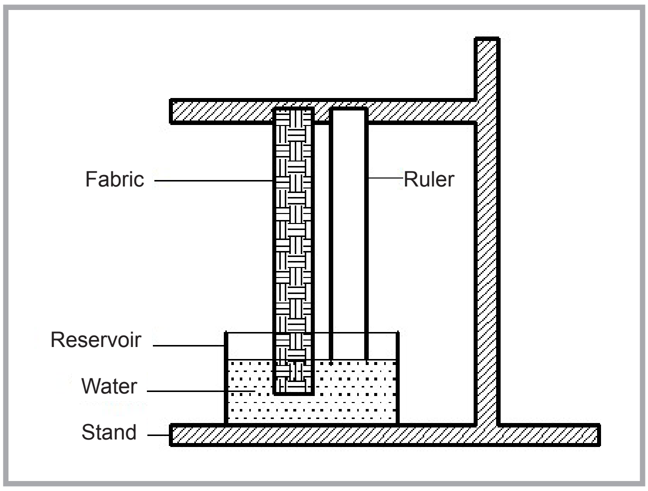

Figure 2. *Testing apparatus.*

mersion depth of the fabric in water was 0.5 cm. Measurement of the experimental data was carried out by the following two methods:

1) Measurement of the wicking height, weight of fabric before and after wicking, and time every 1 cm of the wicking height.
2) Fabric samples were removed from the distilled water when the wicking height reached 0.5, 1, 2 and 3 cm, respectively. And then the final durative wicking height was recorded.

Each group of samples were tested ten times and the average value calculated.

Results and discussions

The rate of saturated moisture adsorption of cotton fibre can reach 25% and the swelling rate of water absorption of cotton fibre can go up to 30% [17]. The pore dimensions in the fabric were 0.355 ± 0.0029 mm and 0.1251 ± 0.0062 mm.

Relationship between the wicking height and wicking time

According to Hagen-poiseuille's law, the expression for the rate of liquid capillary rise in porous media is,

$$\frac{dh}{dt}=\frac{R_D^2}{8\eta}\cdot\frac{\Delta P}{h} \qquad (1)$$

where, h is the height reached by the liquid at time t, R_D the mean hydrodynamic radius of pores, η the viscosity of the liquid, and Δp is the pressure difference. For vertical wicking with a gravitational effect, Δp can be calculated by [16],

$$\Delta P=\frac{2\gamma\cos\theta}{R_s}-\rho g h \qquad (2)$$

where, γ and ρ are the surface tension and density of the liquid, θ the advancing contact angle of the liquid on the solid, g the acceleration due to gravity, and R_S is the mean static radius of pores. Substituting ***Equation 2*** into ***Equation 1***, the vertical wicking equation becomes as follows,

$$\frac{dh}{dt}=\frac{R_D^2}{8\eta h}\cdot\left(\frac{2\gamma\cos\theta}{R_s}-\rho g h\right) \qquad (3)$$

In the early stages of the process, the hydrostatic pressure in ***Equation 2*** can be neglected and ***Equation 1*** yields by integration the Lucas-Washburn equation,

$$h^2=\frac{R_D^2\gamma\cos\theta}{R_s 2\eta}\cdot t \qquad (4)$$

or $$h^2=A\cdot t \qquad (5)$$

where is taken as a coefficient. Based on ***Equation 5***, the wicking height square is proportional to the time (see ***Figure 3***). Moreover the experimental results from this work demonstrated that the wicking height square had a positive and high correlation with time both in the warp and weft directions ($R^2_{\text{warp direction}}$ = 0.973, $R^2_{\text{weft direction}}$ = 0.993), indicating the Lucas-Washburn equation was suitable for evaluating the wicking property of

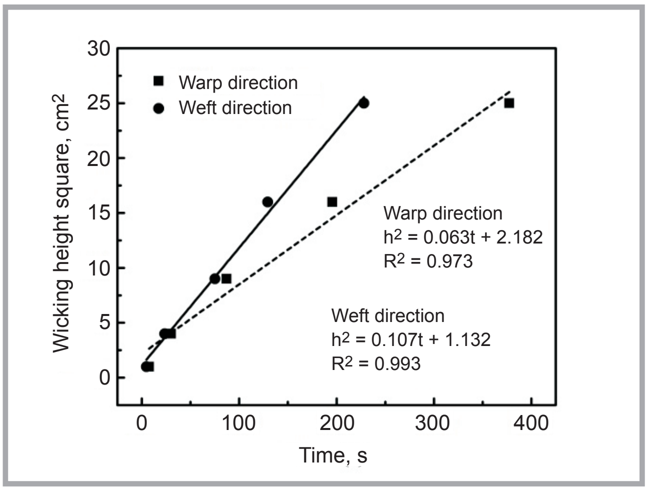

Figure 3. *Wicking height square vs. time in warp and weft directions.*

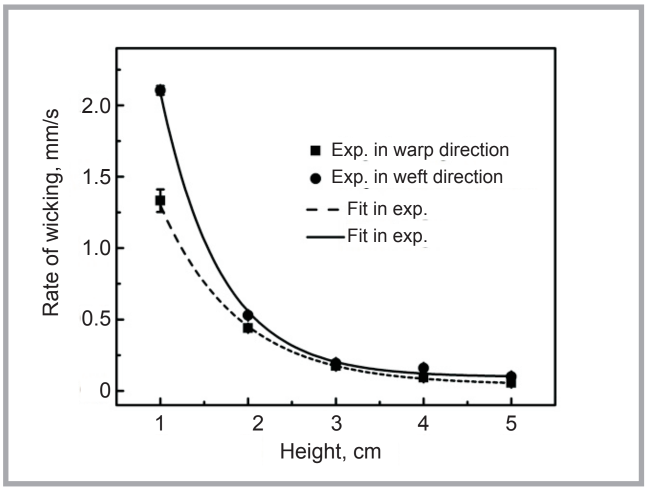

Figure 4. *Rate of wicking vs. height in warp and weft directions.*

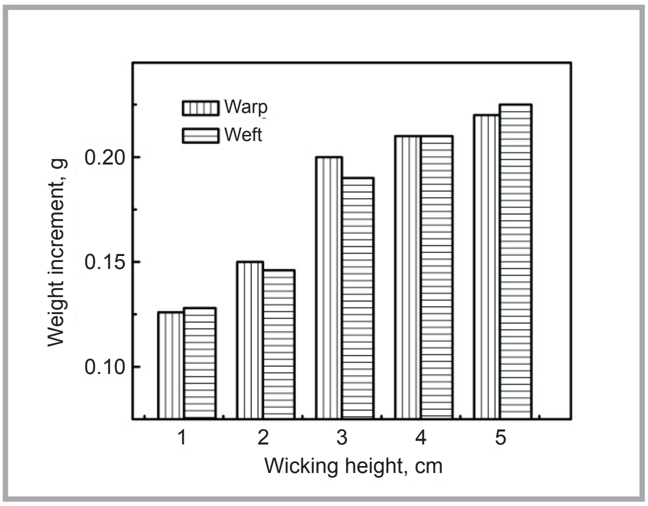

Figure 5. Weight increment vs. wicking height in warp and weft directions.

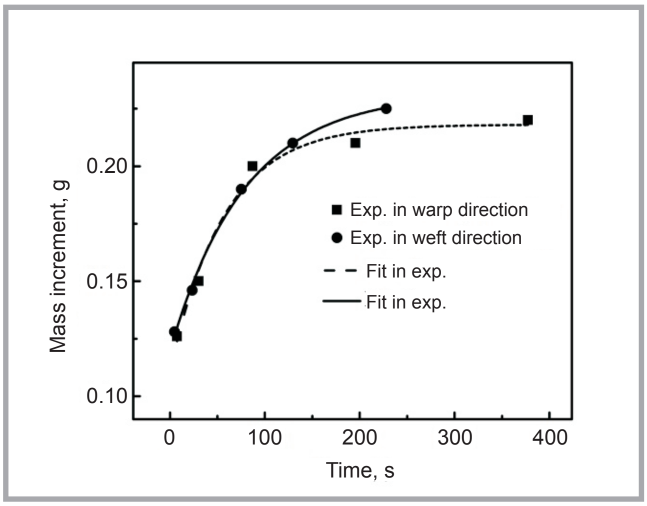

Figure 6. Mass increment vs. time in warp and weft directions.

fabrics due to the compact structure of woven fabric and the swelling property of cotton fibre.

But the rate of wicking in weft direction was a little faster compared to the warp direction, which may be due to the following reasons: (1) a higher number of yarns were in the weft direction in the fabric, and the yarns were responsible for the main portion of the wicking action in the fabrics [8, 14]. Therefore the capillary rise in the weft direction was more remarkable; (2) the spaces between weft yarns were smaller than those between warp yarns, which resulted in a smaller advancing contact angle of the liquid on the yarn, whereby the capillary rise in the weft direction was faster. Babu [18] also observed the same phenomenon in experiments and stated that the tension might be one reason.

Rate of wicking in different directions

Although the rate of wicking can be observed from Lucas-Washburn's equation, it is a general description of the whole wicking process. On the other hand, coefficient A (in ***Equation 5***) is not a constant. Therefore the whole wicking process was divided into small wicking height/time intervals in order to understand more detailed information about the wicking process.

The rate of wicking can be obtained by using equation, where v_w represents the speed of water rising in the fabric, s the wicking height, and t is the time. The wicking rates of cotton fabric in the warp and weft directions are shown in ***Figure 4***. The wicking rates at each 1 cm interval decreased with an increase in the height. The reason for this phenomenon might be due to the different liquid mass variation in each centimeter interval, which might be one more external force for driving water. The closer to the reservoir, the higher the liquid mass difference would be. Besides this, the wicking rate in the weft direction was higher than in the warp, especially at the beginning of the wicking process. The reasons could be as follows: (1) more fibres and yarns in the weft direction than in the warp, which led to more channels and a higher capillary force in the weft direction at the initial stage; (2) after water being absorbed by the fabric, the water would be spread to all yarns equally [13], and then the difference in the rate of wicking in both directions became smaller.

Mass of liquid absorbed increment vs. wicking height

The mass increment caused by absorbed water is also an important parameter for understanding the mechanism of wicking. Obviously the overall mass of water absorbed by the fabric increased with an increase in the wicking height in both the weft and warp directions, and the mass increment per centimeter interval decreased with an increase in the wicking height, which indicated that the mass increment gradient at each 1 cm interval became smaller. The reason may be due to the gravitational effect and the hygroscopicity of the fibre. Meanwhile the mass increments in the weft and warp directions had a small difference and alternate domination (***Figure 5***), which may be due to the yarn numbers and time effect. In the weft direction, the wicking was more effective; however, the time duration was shorter. Besides this, water in the fabric spread to all branches equally; therefore, the differences in mass increments between the warp and weft directions were smaller.

Mass increment of liquid absorbed vs. time

The rate of wicking in the weft direction was a little faster than in the warp, but the mass increment corresponding to time was almost the same in the first 2 minutes, which demonstrated the water absorption capacity of cotton fabric in the warp and weft directions did not have a significant difference (see ***Figure 6***).

Durative wicking height after removal of the wicking liquid reservoir

In order to investigate the impact of the hygroscopicity of fibres/yarns on the wicking property, the durative wicking height was established after removal of the wicking liquid reservoir. The durative wicking height was the difference between the final wicking height and the height after removal of the wicking liquid reservoir; the relative height increment HI_{Ri} is given by,

$$HI_{Ri} = H_{fi} - H_{wi} - Ha_{i-1} \qquad (6)$$

where, H_{fi} is the final wicking height after fabric removal from water at a I cm wicking height, H_{wi} the wicking height when the fabric was removed from water, and Ha_{i-1} represents the absolute wicking height after the removal of the fabric from water at a *(i-1)* cm wicking height.

The durative height increment was substantial when the reservoir was removed

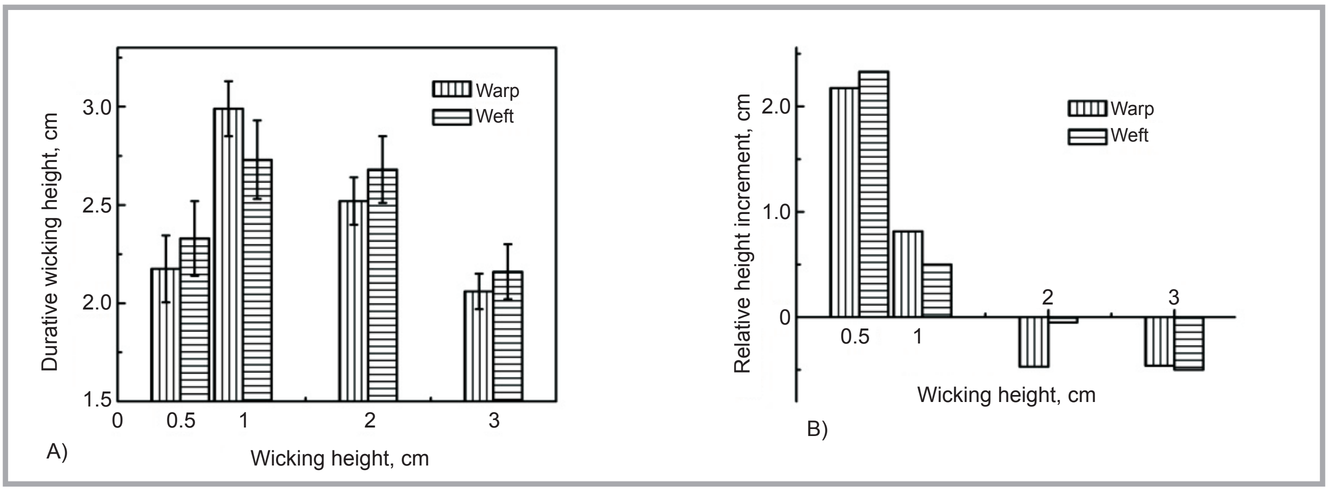

Figure 7. *Durative wicking height after removal of wicking liquid reservoir. A) absolute height increment, B) relative height increment.*

away from the fabric at a 1 cm wicking height, both in the warp and weft directions (***Figure 7.A***). It revealed that during the wicking process at 1cm, the amount of water absorption of the fabric was close to saturation. Moreover an interesting phenomenon was that the relative height increments were negative when the fabrics were removed from water at a 2 cm and 3 cm wicking height compared to that at a 1 cm wicking height. The reasons might be as follows: 1) the gravity effect- at higher wicking heights the influence of gravity is higher, thus lowering the absorption of water, 2) the mass of water at different height regions; the mass of water per centimetre was inversely proportional to the wicking height (***Figure 5***).

Conclusions

Some conclusions can be drawn in this work based on the experimental results: (1) The Lucas-Washburn equation was suitable for evaluating the wicking behaviour of woven cotton fabrics, and the wicking height square had a positive and good correlation with time in both the warp and weft directions; (2) the wicking rate in the weft direction was higher compared to the warp, especially at the beginning of the wicking process; (3) the increment in mass absorbed per centimeter of fabric was inversely proportional to the wicking height, (4) the mass of absorbed water in the fabrics did not have a significant difference in the weft and warp directions. More work on the liquid temperature, surrounding temperature and evaporation rate needs to be done in order to predict the wicking property of textiles. In the future, further investigations concerning the relationship between the product's hygroscopicity and the wicking effect should be carried out.

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