Measurement of Capillary Spaces of Woven Fabric by Wicking Determination of Water into Samples

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Abstract

A Technique based on electromagnetic field of wicked water used for measuring the distance of water rise in woven fabric samples as a function of time. Vertical wicking distance of water was obtained in weft direction of cotton fabric samples with different counts and densities of weft yarn. The effect of yarn count and density were studied in the wicking rise of water into fabric samples. By applying Washburn equation, the amount of geometrical constant factor; $K= (\gamma_{lv}\ r_e\ .Cos\theta/2\eta)=L^2/t$ was evaluated from experimental results where, L= the height of liquid rise, t=time, re= equal radius of capillary, γ_{lv}=the surface tension, η=the viscosity and θ=the contact angle of the liquid-surface. Using the specification of water solution diluted of Diavadin UN detergent, geometric structural factor of constant parameter of capillary spaces of fabric samples were evaluated.

Keywords: Capillary wicking; Structural factor; Woven; Cotton

1. Introduction:

Many processes in different industrial and household applications include wetting and transfer of solutions of chemical agents with water through the fiber assemblies in fabrics. The water wets the fiber surfaces and being transported through the inter-fiber spaces. The manner in which a liquid wicks through the pores depends on capillary forces[12].

In 1921, Washburn derived the time (t) dependence of the height rise of a liquid, L; into a capillary straight linear tube of radius r. The result of this derivation is based on the equality of both the capillary pressure and the pressure loss due to the internal friction (Hagen-Poiseuille equation).In a fibrous structure such as yarns and fabrics, liquids can wick into the inter-fiber spaces because of the capillary pressures [4,5].The law of hydrodynamic flow through the cylindrical capillaries, in the presence of gravitational acceleration, leads to the following differential equation [3,10].

$$dL/dt=(\gamma_{LV}.rCos(\theta)/4\eta.L)-(g\rho r^2/8\eta) \qquad (1)$$

θ is the contact angle of solid–liquid system with the parameters of the test liquid; surface tension γ_{LV}, viscosity η, and density ρ where g is the gravitational acceleration.

In the absence of gravity due to horizontal wicking of liquid into porous media equation 1 changes to equation 2. As one can see from equation 2, the distance of wicked liquid is predicted to be a square root of function of the time.

$$L^2(t) = (r.\gamma_{LV}\ Cos\theta/2\eta).t \qquad (2)$$

Theoritical equation 2 has been used for vertical wicking [2,4,5,13]due to the small effect of gravity of liquid wicked into the sample specially in the beginning of the measurements[2,9].The previous measurements of wicking were based on many methods such as visual observation of colored water penetration [2,4], electrical capacitance technique[8], the mass of liquid wicked in the capillary spaces [6,7,10], electrical resistance technique[2,5]. In this research , a technique based on the electromagnetic field of water[1,11] is considered to follow the time required for water to wick vertically into the fabric samples spontaneously. The theoretical behavior of wicking into the fabric sample due to equation 2 has been used for evaluation of geometrical structural factor of constant parameter of capillary spaces of fabric samples.

2. Experimental

2.1. Apparatus

Fig. 1 shows the principle of method for wicking measurement. An inductive sensor was used for signal detection. The signal is a 100KHZ sinusoidal wave that is near the sensor's resonance frequency to obtain the maximum sensitivity. A head of a magnetic record player was chosen as the inductive sensor. The smooth surface of the sensor is in contact with the fabric sample vertically held by a small weight in the measuring unit. The contact area of sensor with fabric sample is $2\times2\ mm^2$. While detecting water rise, the surface contact of the sensor with sample has no effect on physical structure of inter-fiber spaces in the fabric.

Two sensors have been employed for measurement. One of the sensors is in contact with the fabric sample and picks the main signal and the environmental noise up. The other sensor picks the environmental noise. So the effective signal is obtained by subtraction of the two sensor's outputs. The liquid vessel and the fabric sample are placed on a laboratory jack which can move vertically up and down by a DC motor[1].

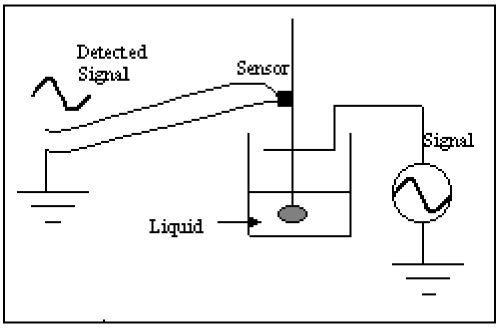


Fig. 1- The principle of the measurement method for water transport

Fig.2 shows the whole measurement system. The differential signal is obtained by the two sensors are sent to PC for processing and the appropriate control signal is sent from the PC to the DC motor. As the water moves up, the motor drives the vessel down and the dry section of the test sample faces the sensor . In this case the speed of the water transport into the fabric sample is equal to the speed of the water vessel (setup) in opposite direction. Labview and Visual C++ were used for the software part of the measurement system. An A/D and D/A ISA card was used to process the signals and drive the DC motor.

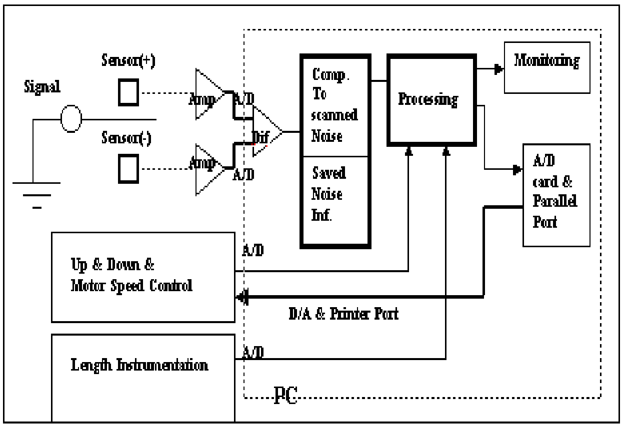


Fig. 2- Electrical circuit design of the apparatus

2.2. Materials and treatment condition

Plain woven fabric produced by Sulzer DS700 machine made in Switzerland. The samples made of different count and density of weft cotton yarns vertical wicking measurements. Weft yarn characteristics are shown in Table1. Warp yarns characteristics were same in all samples with pet filament 80 den, 800 tpm and density of 300 per meter. Cotton fibers were prepared from domestic cotton 3.3 dtex without further treatments. The fabric samples were washed with 2g/lit a commercial laundry detergent and a solution of 0.1% sodium bicarbonate at 50-55^{o}C for 30 min. The dimensions of fabric samples for wicking measurements were 5 mm wide and 30 cm length. The average of 5 tests were obtained in every individual sample for comparing the results. The liquid used for wicking measurement was single distilled water with an nonionic detergent (a commertial nonionic detergent,Diadavin EWN).
The surface tension of diluted water-detergent solution obtained 35mj/m^2 by plate method in room temperature while using the apparent viscosity of water in the literature which is approximated to 1 *mpas.s* due to neglected effects on water viscosity. All the wicking measurements were performed at room-condition of 28-30 ^{o}C and 38%-40% relative humidity.

Table 1- weft yarn characteristics of fabric samples

Yarn count Ne	Density of yarn in fabric /cm
10,,30	18.1
10,,30	20.8
10,,30	23.1

3. Result and discussions

3.1.Effect of weft yarn count on wicking rise of water

Experimental data of wicked water into fabric samples in figure 2(a,b,c) shows the effect of yarn count in plotted as L (distance of water) versus t(time). The results show that, wicking velocity slows down as the time passes for every individual sample. The curves have a sharp slope in the beginning and tend to a constant state in longer time.
It is observed that increasing of weft yarn count has increased the capillary rise of water in fabric samples. So the fabric samples which produced of 10 Ne yarn count have raised water upward wicking through their weft direction comparing with 30 Ne yarn count.

3.2. Effect of weft yarn density in wicking rise of water

The geometric configuration of porous medium is affected of weft yarn density in fabric samples which determine its water transport properties. Figure 3(a,b) shows that wicking of water rise changes with increasing the density of weft yarn in the fabric sample. The water height in fabric sample with lower yarn density 18.1/cm is faster than in 20.8 /cm and 23.1/cm. capillary spaces between yarns according to reduction of capillary radius between capillary spaces between fiber and yarns.

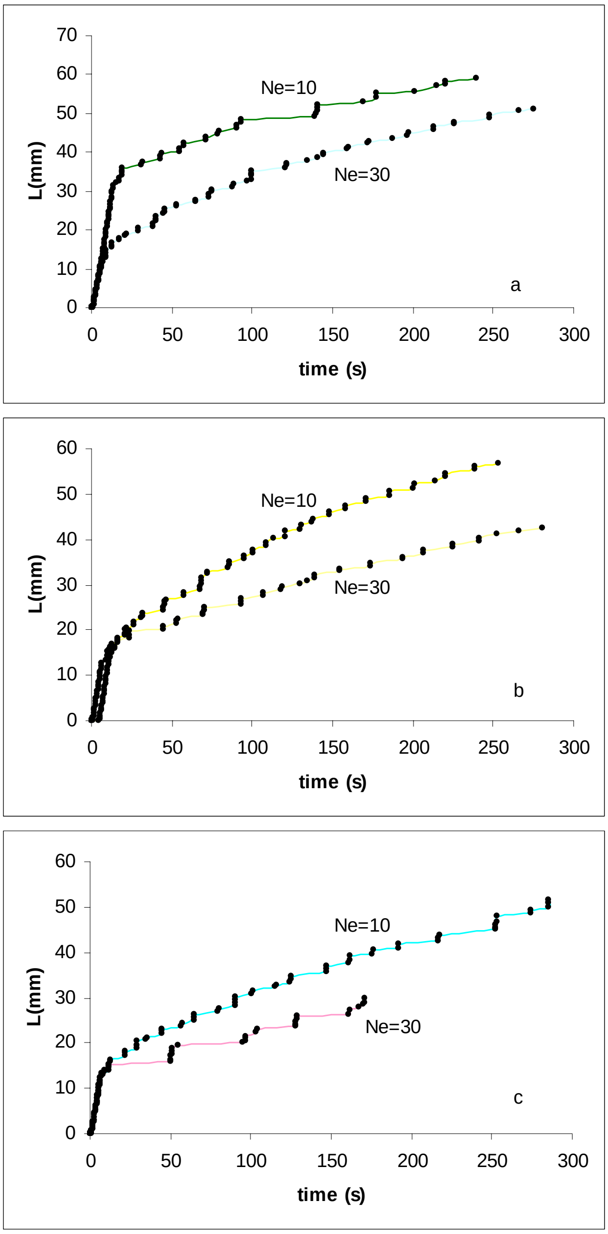
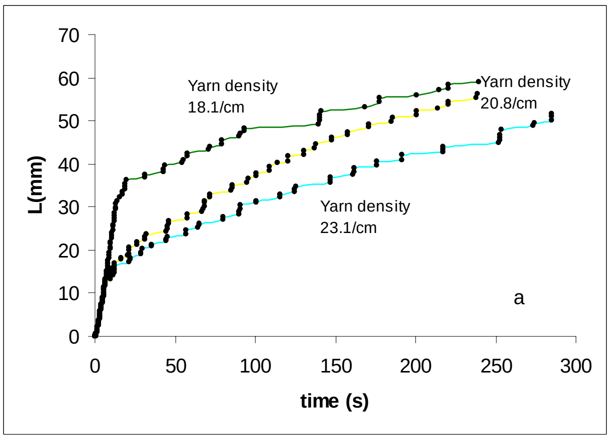


Fig.2- The effect of yarn count on wicking of water into the samples a:yarn density=18.1/cm, b:yarn density=20.8/cm, c:yarn density=23.1/cm



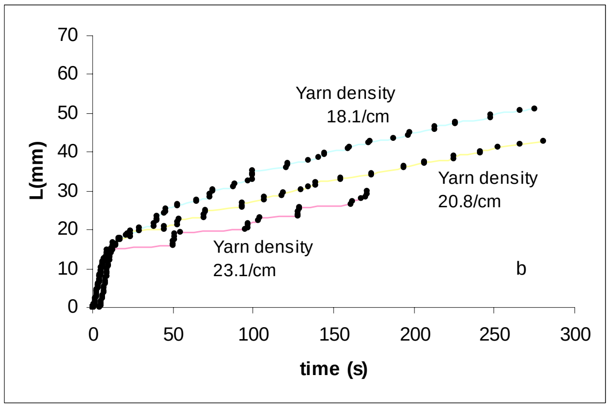


Fig.3 - The effect of warp yarn density /cm on wicking of water into fabric sample; a:,Ne=10, b:Ne=30

2. *Evaluation of capillary spaces of fabric samples*

The equivalent geometric factor is calculated by the average slope L^2/t from the experimental data of wicking of water into the samples. The amount of slope is equal to ($r.\gamma_{lv}$ $\cos\theta/2\eta$) according to theoretical equation 2. Using the value of surface tension and viscosity of water solution, the amount of $r\cos\theta$ as the geometrical structural factor of constant capillary spaces of fabric sample can be evaluated. The values of $r\cos\theta$ for individual samples are given in table 2. To be differentiated from the actual values of capillary radius and contact angle , r $\cos\theta$ is replaced by $r_e \cos\theta_e$, where r_e is the effective capillary radius and $\cos\theta_e$ is the overall valve of $\cos\theta$ in fabric sample.

Table 2-Averages of $r_e \cos\theta_e$ for individual fabric samples

Weft yarn characteristics	L^2/t	$r_e \cos\theta_e$(μm)
Ne=10, density=18.1/cm	20.722	1.184
Ne=30, density=18.1/cm	14.593	0.834
Ne=10, density=20.8/cm	18.849	1.077
Ne=30, density=20.8/cm	11.368	0.650
Ne=10, density=23.1/cm	12.580	0.719
Ne=30, density=23.1/cm	10.179	0.582

It can be assumed that r_e and $\cos\theta_e$ are constant for a water-fabric system and then the value of $r_e \cos\theta_e$ can be considered as a basic geometric structural parameter of the fabric-water system. It indicates that the radii of open channels which act as capillary tubes tend to decrease as a result of using finer yarns and increasing weft yarn density in the woven fabric sample.

Conclusion

A technique for determining the wicking behavior of water in fabrics has been developed. The inductive sensors in the device have the proper sensitivity for tracing the electromagnetic field of water wicked into the fabric samples.

The capillary spaces in porous media of fabric changes by increasing the count and density of weft yarn in the woven fabric which mainly affect in capillary wicking of water into the sample. The study shows that the wicking distance and penetration rate reduced by using finer count and higher density of weft yarn in the woven fabric sample.

It has been possible to study equivalent geometric factor of capillary spaces during wicking measurement of water into woven fabric samples. The radii of open channels in the woven fabric sample tend to decrease as a result of using finer yarns and increasing weft yarn density.

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