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Measuring In-Plane Liquid Spread in Fabric Using an Embedded Image Processing Technique

Abstract
A new technique based on the embedded image processing principle is described to measure the in-plane liquid spread in fabric as a function of time. The water spreading area recorded with a digital camera and the picture analysing process was automated by use of an image segmentation algorithm: background subtraction. Where commercial image analysing software fails due to the specific porous structure of textiles, the algorithm developed succeeds in calculating the wicking area automatically. The speed and accuracy of area calculation are also improved by using a 32bit embedded Digital Signal Processor. The in-plane spreading of an area for ring, compact yarn of different counts and different combinations of doubled yarn produced from ring, compact & ring/compact yarn was carried out. It was found that the yarn count and doubling combinations influence the liquid spread behaviour of the fabric significantly.

Key words: *comfort, liquid transport, wetting, spreading, in-plane wicking, image processing.*

Introduction

Recently the use of sportswear has been quite widespread due to the fact that many people are involved in sports. The heat generated in the body while doing sports leads to considerable sweating. The sweat rate is likely to vary with the many sports activities and individual.

In sportswear design, among the most influencing parameters of the fabric used, the rates of liquid spreading on the surfaces are of great importance. Their experimental measurement and theoretical prediction are therefore challenging in view of the varying conditions.

Transverse wicking is a unique phenomenon with respect to the water transfer behaviour of fabrics, since it has no directional effect. When the area spread is high, the evaporation of the fabric is also high. One of the advantages of these assessments is that with transverse wicking being multi-directional, it eliminates the directional effect, and the results are most valuable for developing sportswear.

The liquid wets the fibre surfaces and gets transported through the inter-fibre spaces. The manner in which a liquid wicks through the pores depends on capillary forces [1, 2]. A variety of techniques and methods are used to study experimentally liquid penetration into fabrics.

The idea of studying the spreading of drops on materials dates back to the 1950s when Gillespie [3] developed a method to measure the radius of drops on filter paper at fixed time intervals. The studies showed that the spreading process could be divided into two phases (***Figure 1***): phase I, where the liquid is still above the substrate, and phase II, where the drop is completely contained by the substrate. In the second phase the liquid wicks through the fabric horizontally under the influence of capillary forces.

Gillespie developed the following equation to describe the spreading process:

$$R_t^2\left[R_t^4 - R_0^4\right] = \frac{3\beta}{2}\left(\frac{3V}{2\pi h}\right)t$$

in which R_t denotes the radius of the stain at time t, R_0 the radius of the stain at time zero, V the volume of the liquid, and h the thickness of the substrate. The value of β is given by the term:

$$\beta = \frac{b q_s \gamma \cos\theta}{C_s^{\partial}\eta}$$

in which b is a constant characteristic of the substrate, q_s the permeability of the substrate, γ the surface tension of the liquid, η the viscosity of the liquid,

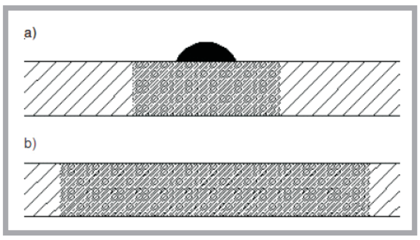

Figure 1. *Schematic illustration of the two phases of spreading; a) represents the first phase, where part of the drop is still above the substrate, b) represents the second phase, where all the drop is contained within the substrate.*

θ the advancing contact angle, and C_S the saturation concentration of the liquid in the substrate.

Unlike filter paper, textile fabrics are not isotropic, and hence the area formed by a liquid spreading on a textile fabric is seldom a perfect circle. It is therefore more meaningful to measure the area covered by the spreading liquid. Another difficulty with measuring the spreading of liquids on porous substrates is the speed with which the liquid front moves, in particular during the first phase.

Fichet et al. [4] developed another method based on the change in electrical resistance of the fabric with its water content. Here they used six concentric rings (sensors) of different sizes placed on both surfaces of the fabric. The distance between two consecutive rings is 5 mm, except the first one, which is at 1.5 mm from the centre. The results obtained by this method depend on how closely the concentric rings are placed and on the accuracy of the electrical resistance value.

Ramesh Babu et al. [5] developed another new multi-probe vertical wicking tester based on the change in electrical resistance of the fabric with its water content. Here they used 16 probes, 8 at the front and 8 at the back for measuring the wicking height. The results obtained by this method depend on the accuracy of the electrical resistance value.

Another instrument has been developed by IIT Delhi for measuring the in-plane wicking of fabrics. The instrument works on the siphonic principle, and the water uptake by the fabric sample with time is recorded. The fabric sample is placed on a horizontal base plate connected to a liquid reservoir by means of a siphon tube. The fabric is covered by a glass top plate so as to ensure intimate contact between the base plate and fabric [6].

A similar instrument has been developed by Adams et al. [7] to measure the in-plane flow of fluids in a fibrous network. They used an image analysis technique to obtain the shape and position of a radially advancing fluid front, which can define the directional permeabilities in the plane.

Kissa [8] measured the spreading area of a drop on textile fabric as a function of time. The area of a spreading liquid was photographed at uniform time intervals with an instant-picture camera. The area depicting the spreading liquid was cut out from the dried photograph and weighed.

Lee et al. [9] conducted horizontal wicking with a spectrophotometer in order to avoid using balances. They determined the liquid weight wicked into the fabric by measuring the difference in colour depth between wet fabric and dry fabric. Various researchers, *e.g.* Morent et al. [10] and Perwuelz et al. [11] have proposed image analysis instead of an analytical balance to determine the extent of horizontal wicking. In the study by Morent, the progression of the liquid front during wicking was recorded with a digital camera and an algorithm was used to calculate the area of the fabric wetted by fluid.

Petrulyte et al. [13 - 15] measured the dynamic water absorption of terry woven fabrics using an image analysis technique. They established the absorption speed of terry woven fabrics, the influence of pile height with respect to the liquid retention capacity and the impact of the macerating process on the absorption process.

However, in the present work, a technique based on the embedded image analysis technique using a 32 bit Digital Signal Processor was used to determine the water spreading area with respect to time. This technique helped us to make an in-depth study of the water spreading behaviour of the fabrics. Although many have studied moisture management in yarns and fabrics, very few have examined spreading, and no-one known to the authors has studied the water spreading behaviour of fabrics produced from different combinations of doubled yarns.

Material and methods

In this study, two sets of 14.76, 9.84, 7.38 tex yarn were spun on Ring and Elite Suessen compact spinning machines. These yarns were doubled in different single yarn combinations like ring/ring, compact/ring and compact/compact of the same count using a Jeetex (DRT) Doubling machine with the following parameters. Detailed parameters concerning fibres and yarns used in the experiiments are presented in ***Tables 1, 2*** and ***3***.

Table 1. *Details of fibre and yarn properties used to produce 3 yarns of different linear densities with both the ring and compact systems.*

No.	Fibre properties					Yarn properties		
	Fibre type	Fibre length, 2.5% Span length)	Strength, cN/tex	Mc value	UR%	Linear density of yarn in Tex	t.p.m.	Twist multiplier
1	100% cotton	29.10	22.5	3.5	47.0	14.76	1001	3.97
2		31.40	25.3	3.9	46.5	9.84	1243	4.08
3		33.23	29.2	4.2	47.2	7.38	1337	3.79

Table 2. *Details of doubled yarn properties used to produce different combinations of doubled yarn.*

Linear density of yarn, tex	Single yarn combination in doubling					
	Ring/Ring		Compact/Compact		Ring/Compact (Hybrid yarn)	
	t.p.m.	Traveller	t.p.m.	Traveller	t.p.m.	Traveller
9.84 × 2	959	2/0	959	2/0	959	2/0

Table 3. *Single and doubled yarn fabric construction details*

Yarn fabric construction details	Fabric sample no.	Linear density of yarns, tex	Type of yarn used in both warp and weft	Warp setting, dm^{-1}	Weft setting, dm^{-1}
Single	1	14.76	ring yarn	240	200
	2		compact yarn		
	3	9.84	ring yarn		
	4		compact yarn		
	5	7.38	ring yarn		
	6		compact yarn		
Doubled	7	9.84 x 2	ring/ring	260	240
	8		compact/compact		
	9		ring/compact		

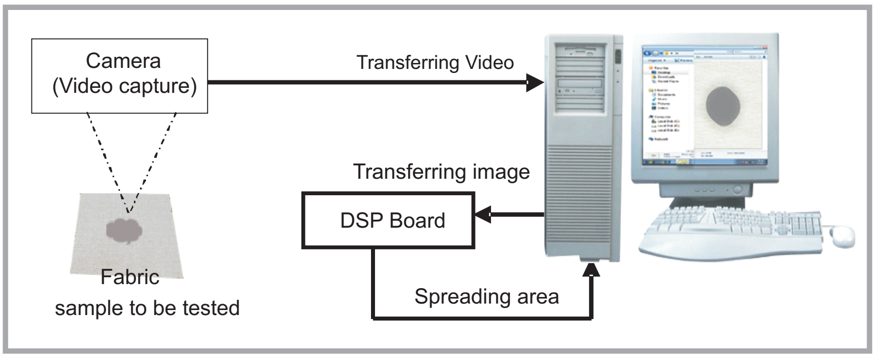

Figure 2. Experimental system.

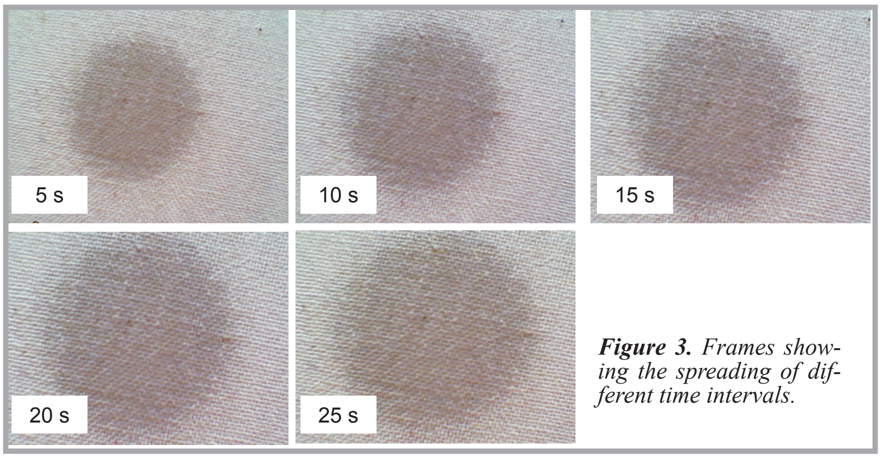

Figure 3. Frames showing the spreading of different time intervals.

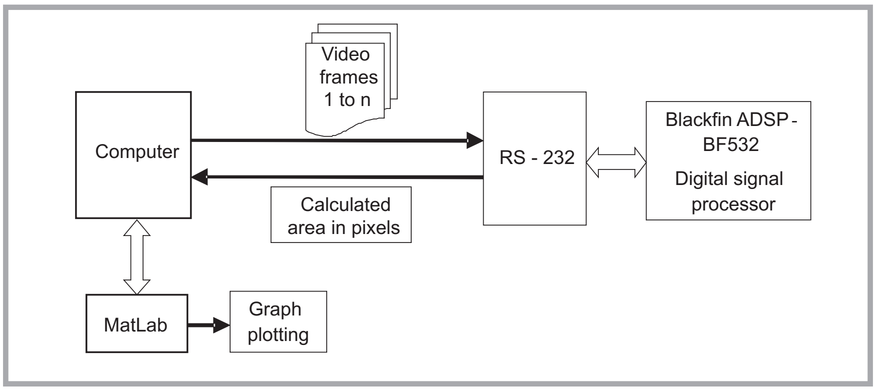

Figure 4. Image analysis system.

9 different plain woven cotton fabrics were produced on a Sulzer Ruti C Machine. The samples were made with varying counts and varying doubled yarn combinations. Two sets of fabrics were produced from ring and compact yarn of 14.76 tex linear density by maintaining the same warp and weft settings. A Similar procedure was followed for 9.84 tex and 7.38 tex.

Another sample of three sets of fabric were produced from 9.84 tex, 2 ply doubled yarn of different single yarn combinations like ring/ring, compact/compact, and ring/compact by maintaining the same warp and weft settings.

The fabrics were subjected to commercial scouring and bleaching processes. A sample of 10 cm was prepared and then placed in a climatic chamber at 27 °C and 65% RH.

10 tests were conducted for each sample of 9 different fabrics to compute the average value. Distilled water was used for the testing.

Experimental system

A high resolution optical 5-glass lens with the sharp and bright image quality of a 24-bit true colour digital camera of 13.1 megapixels was used to measure the dynamic movement of the liquid over the fabric surface. The camera had the facility of automatic brightness adjustment and colour compensation. The camera was mounted on a stand equipped with a C-mount and LED light, and connected to a personal computer via its USB port, as shown in ***Figure 2***. The camera is compatible with Image Analysis software, which was used to record the film and process the images.

For measurement of the spreading rate, a fabric sample of 10 cm diameter was mounted on an embroidery frame. The frame was fixed without any movement so that the tension on all edges was equal and the fabric stretch-free. A burette was placed 6mm above the surface of the fabric[12]. One drop of water was allowed to fall from the burette and the area spread

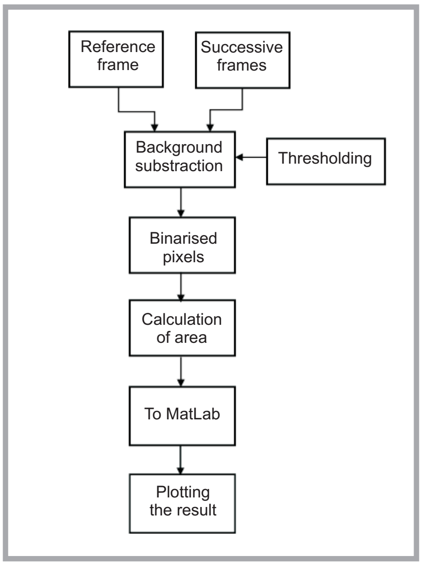

Figure 5. Spreading Area Calculation.

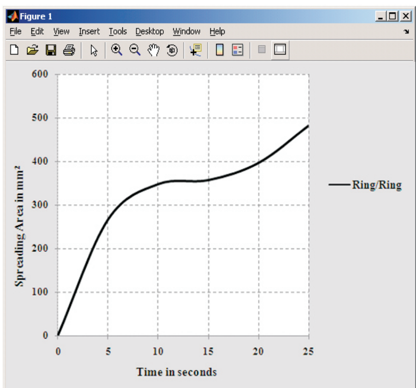

Figure 6. Sample MATLAB graph showing the Spreadability of 9.84 tex, 2ply doubled yarn produced from the ring-yarn/ring-yan combination.

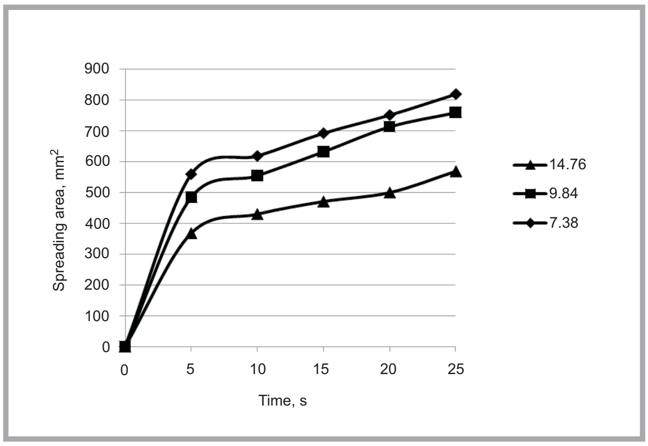

Figure 7. Spreading behaviour of ring yarn of different linear densities.

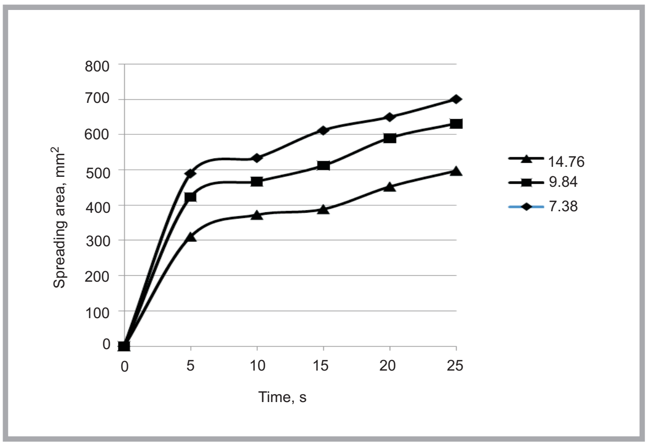

Figure 8. Spreading behaviour of compact yarn of different linear densities.

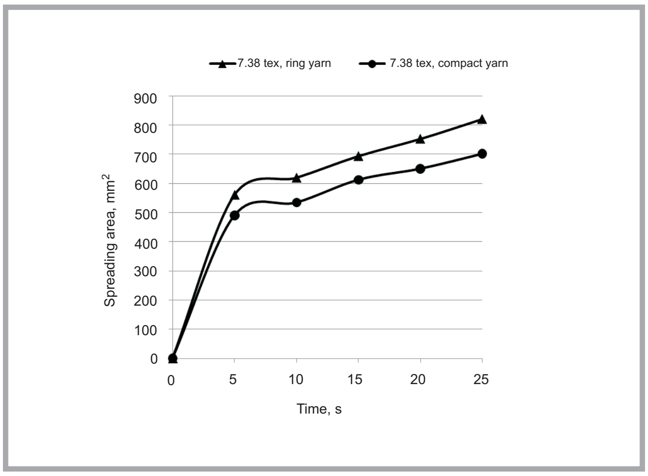

Figure 9. Spreading behaviour of ring and compact yarn of 7.38 tex linear density.

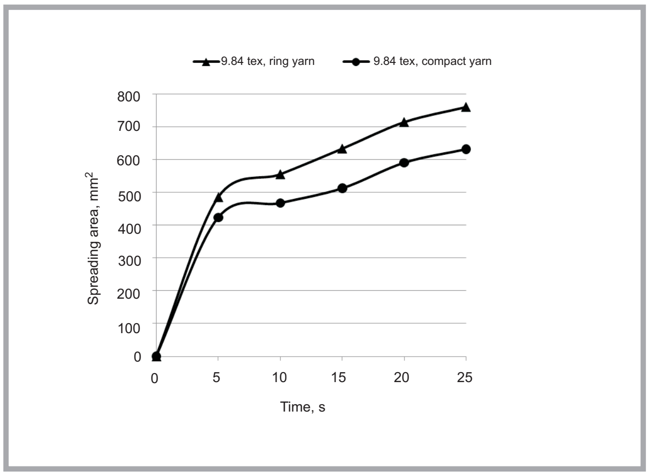

Figure 10. Spreading behaviour of ring and compact yarn of 9.84 tex linear density.

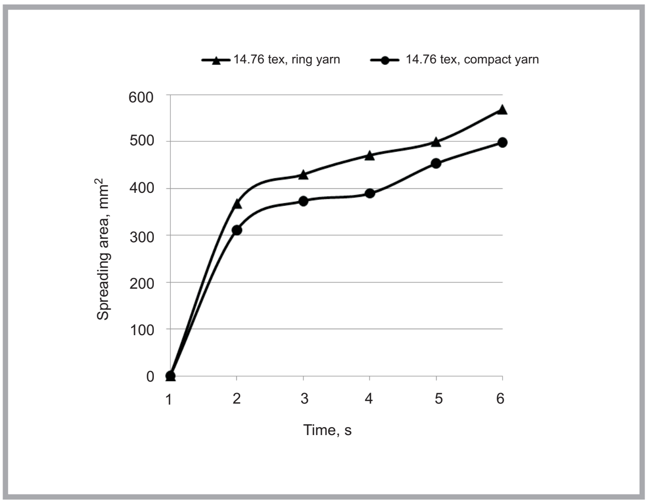

Figure 11. Spreading behaviour of ring and compact yarn of 14.76 tex linear density.

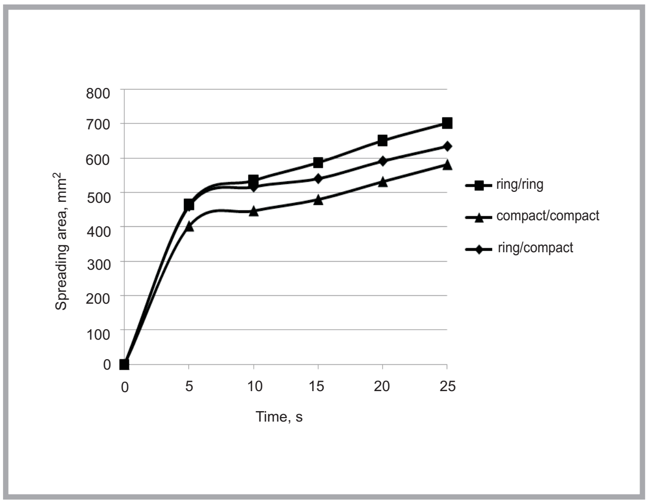

Figure 12. Spreading behaviour of 2 ply yarns of 9.84 tex linear density prepared from different combinations.

on the fabric was measured. Proper care was taken to avoid any vibration.

All the experiments were carried out in a conditioned room at a temperature of 22 °C and relative humidity of 65%.

The software was adjusted to record the number of frames per second. The software had the provision to change the interval time (seconds) of image capture. For each sample, the recording started approximately one second before the drop fell for the purpose of taking a reference frame, which was used to subtract from the remaining frames for calculating the area of spreading. The images in ***Figure 3*** demonstrate the spreading process on fabric.

Spreading area calculation

Using the image analysis system in ***Figure 4*** (see page 74), the videos captured were transferred and stored simultaneously on the computer. The videos stored were converted into individual frames using Mat lab coding. Individual frames were transferred into the embedded Blackfin ADSP-BF532 DSP kit through a RS-232 cable. Using the background subtraction algorithm in ***Figure 5*** (see page 74), the processor subtracted the reference frame from the successive frame, and the resulting output image was the difference image. The difference image is a binary image, obtained by thresholding. The area of spreading was calculated based on the number of white pixels for each successive frame.

The thresholding process may vary depending on the lighting conditions, hence there should be constant lighting conditions. The final areas calculated were sent back to the computer to plot a graph with the help of MATLAB software, ***Figure 6*** (see page 74).

Sample plotted graph obtained through MATLAB coding (***Figure 5*** see page 74).

Results and discussion

Figures 7 & ***8*** (see page 75) shows the spreading area of yarns of three different counts, while keeping the density of the fabric the same as a function of time (t). The results show that the spreading area increases as the time passes for every individual sample. The curve has sharp slopes at the beginning, becoming constant over a period of time. It is observed that the yarns of lower linear density show a higher spreading area of the liquid in the samples. Hence the fabric sample produced with yarn of 7.38 tex linear density shows the highest spreading area, followed by both ring and compact yarn of 9.84 and 14.76 tex linear density. This is due to the lower water retention capacity of yarn fabric of lower linear density. ***Figures 9, 10*** & ***11*** (see page 75) show the spreading area of ring yarn fabric produced from yarn of 7.38, 9.84 and 14.76 tex linear density, highlighting the higher spreading area compared to compact yarn fabrics of the same count, due to the higher packing density of compact yarn.

Figure 12 (see page 75) shows the spreading area of yarns of three different doubling combinations (ring/ring, compact/compact & ring/compact), keeping the linear density of yarns in the fabric the same as a function of time (t). The results show that the spreading area increases as the time passes for each individual sample. The curve has sharp slopes at the beginning, becoming constant over a period of time. It is observed that the doubled yarn produced from the ring/ring combination shows an increase in the spreading area of the liquid in the samples. This is because of the low packing density and greater air space of fibres in the yarn structure compared to compact yarn. Thus the fabric sample produced with ring/ring doubled yarn, followed by ring/compact yarn, shows the highest spreading area as compared to the compact/compact combination. Ring/compact doubled yarn lies between the ring/ring and compact/compact combination.

Conclusions

The spreading behaviour of fabrics produced from single, doubled yarns using various combinations of doubling was studied using a novel technique which involves an embedded image processing technique (background subtraction algorithm) using a Blackfin ADSP-BF532 Digital Signal Processor. This technique was found to have the advantages of greater accuracy, speed, reduction of manual error and storage of samples for future reference, as compared to the manual drop test method.

The spreading area is dependent on the linear density of yarns, type of doubling and type of yarns. Yarns of lower linear density show greater propensity to spread in comparison with those of higher linear density. Fabrics produced from a ring/compact combination lies in between the compact/compact and ring/ring combinations.

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References

1. D'Silva A P, Greenwood C, Anand SC, Holmes DH, Whatmough N. Concurrent determination of absorption and wickability of fabrics: A new test method. *J Text Inst* 2000; 91, 1(3): 383–396.
2. Washburn EW. The dynamic of capillary flow. *Phys Rev* 1921; 17: 273-283.
3. Gillespie T. The spreading of low vapour pressure liquids in paper, J. Colloid Sci. 1958; 13: 32-50.
4. Fichet D, Lesage F, Ventenat V, Latifi MA. Excerpt from the Proceedings of the COMSOL Multiphysics User's Conference. Paris 2005.
5. Ramesh Babu V, Koushik CV, Lakshmikantha CB, Subramaniam V. Influence of the Weave Factor on the Character of Fabric Wicking Measured by a Multiple Probe Vertical Wicking Tester. *FIBRES & TEXTILES in Eastern Europe* 2011; 19, 5(88): 60-63.
6. Chattopadhyay R, Chauhan A. Wicking behavior of compact and ring spun yarns and fabrics. In *One Day Seminar on Comfort in Textiles*, I I T Delhi, October 16 2004, p. 20-30.
7. Adams KL, Rebenfeld L. In-plane flow of fluids in Fabrics: Structure/flow characterization. *Text. Res. J.* 1987; 11: 647-654.
8. Kissa E. Capillary Sorption in Fibrous Assemblies. *J. Colloid Interface Sci.* 1981; 83(1): 265-272.
9. Lee J. H., Kim S. H., Lee K. J., Lim D. Y., Jeon H. Y.; 'Determining the absorption properties of split-type microfiber fabrics by measuring the change in color depth'. *Textile Res. J.* 2004; 74 (3): 271-278.
10. Morent R, De Geyter N, Leys C, Vansteenkiste E, De Bock J, Philips W. Measuring the wicking behavior of textiles by the combination of a horizontal wicking experiment and image processing. *Review of Scientific Instruments* 2006; 77: (9).
11. Perwuelz A, Mondon P, Caze C. Experimental study of capillary flow in yarn. *Text. Res. J.* 2000; 70(4): 333-339.
12. Saville BP, Physical testing of textiles. UK: Woodhead Publishing, 2002, pp. 223–235.
13. Petrulyte S, Baltakyte R. Liquid Sorption and Transport in Woven Structures. *FIBRES & TEXTILES in Eastern Europe* 2009; 17, 2(73): 39-45.
14. Petrulyte S, Nasleniene J. Investigation of the Liquid Retention Capacity of Terry Fabrics. *FIBRES & TEXTILES in Eastern Europe* 2010; 18, 5(82): 93-97.
15. Petrulyte S, Baltakyte R. Investigation into the Wetting Phenomenon of Terry Fabrics. *FIBRES & TEXTILES in Eastern Europe* 2008; 16, 4(69): 62-66.

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