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Moisture management behaviors of high wicking fabrics composed of profiled Fibres

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The effect of fibre cross-section shape, fibre content, yarn count, number of monofilaments, and loop density on moisture management properties of some knitted fabrics composed of profiled fibres has been investigated. The moisture management properties are assessed by moisture management tester in order to simulate the dynamic human body sweat transferring in different directions of clothing system. The indexes of the moisture management tester have been analyzed and interpreted regarding micro and macro equations of porosity, and horizontal and downward wicking. The results show that profiled cross-sectional fibres affect the moisture management and sweet transferring behaviors of functional knitted fabrics. Furthermore, accumulative one way transport capacity of fabrics is mainly dependent on both yarn (staples or filament) and fabric (loop density, knitting pattern and fabric thickness) structures.

Keywords: Coolmax/cotton blend, Moisture management, Profiled fibre, Single jersey fabric, Wicking

1 Introduction

The wetting and wicking behaviors affect the moisture and thermal comfort of clothing systems[1-4]. A clothing system with high wicking ability can move quickly perspiration from skin area and transfer it to top side of fabric, providing a good level of comfort to wearer due to evaporating cooling. The effect of fibre content[5], fibre cross-section[6,7], number of filament[8], fabric structure[9,10], spinning system[5] and the topogragraphy structure[6] on the wicking properties of textiles have been investigated by many researchers. Hasan *et al.*[6] investigated the effect of fibre cross-section shape on topography and wettability of some woven fabrics. They concluded that fabric with cruciform fibres has smaller cover factor and are more hydrophobic than those composed of fibers with round fibres. Kucukali *et al.*[5] investigated wicking properties of cotton-acrylic rotor-spun yarns and knitted fabrics and showed that the wicking abilities of yarns and fabrics increase with the increase in acrylic content in the blends as well as with the use of coarse yarns.

High wicking fabric composed of profiled fibre is designed to wick sweat away from the skin to improve physiological and thermal comfort to prevent heat strain injury[8]. Moisture may accumulate in microcilmate (skin/clothing interface) during the period of activity and produce clothing discomfort sensation[8]. Wickwire *et al.*[8] showed that the chest temperature of participant who wears the commercial wicking t-shirt was significantly lower than that of the participant wearing cotton t-shirt. Fangueiro *et al.*[11] analyzed the wicking behavior and drying capability of different plated knitted functional fabrics, produced using functional fibres and polypropylene or polyester. They showed that Viscose Outlast® provides the best wicking ability but its drying capability is low and Coolmax® shows a good wicking ability and the best drying capability. Onofrei *et al.*[9] studied the influence of knitted fabrics' structures on their thermal and moisture management properties. They reported that Outlast® fabrics are preferred candidates for warmer climate sportswear, particularly due to their lower thermal resistance, higher thermal conductivity and absorptivity, air and water vapour permeability, while for sportswear colder weather, Coolmax® based structures seem to be the best choice.

Moisture management is the behavior of moisture in different directions of fabric. The moisture management tester is able to measure dynamic liquid transfer in clothing materials. This device gives ten different indexes related to liquid transfer

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in different directions of fabric including top and bottom wetting time in second, top and bottom absorption rate in %/s, top and bottom wetted radius in mm, top and bottom spreading speed in mm/s, cumulative one way transport capacity and overall moisture management capacity[12,13].

In this study, to investigate the fibre, yarn and fabric structural parameters involved in production of high-wicking fabrics, moisture management properties (MMP), including wetting time, absorption rate, wetted radius, spreading speed, cumulative one way transport capacity and overall moisture management capacity for different weft knitted fabrics (single and double jersey) have been measured and interpreted. Samples with 3 different types of fibre complex, two numbers of filaments per yarn, and two fabric loop densities have been produced and their MMP results are compared. Furthermore, staple (coolmax and cotton) and filament yarn types are compared for studying the effect of fibre content percentage and yarn structure.

2 Materials and Methods

2.1 Materials

The yarn samples used in this study were Coolmax/cotton, 100% Coolmax staple fibre (linear density 30 NE), Coolplus multi microfilament (75 den/ 72 filaments, and 75 denier/48 filaments) with plus cross-section, and Coolplus multi microfilament (75 den/ 72 filaments, 75 den/48 filaments and 150 denier/ 72 filaments) with five-leaf cross-section (Fig. 1).

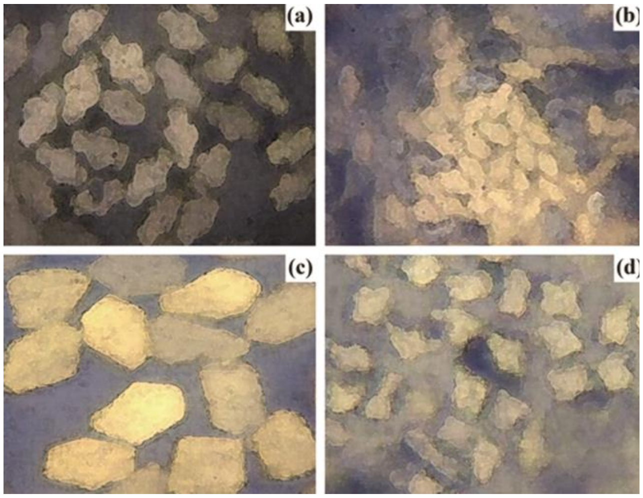

Fig. 1—Fibre cross-sections (a) 4 channels coolmax cross-section (100% Coolmax staple yarn), (b) 4 channels coolmax cross-section (50/50% Coolmax/cotton staple yarn), (c) 5-leafs cross-section of the monofilaments in Coolplus yarns and (d) plus cross-section of the monofilamentsin Coolplus yarn

Single jersey fabric samples were produced with two different loop densities. All fabric samples were produced on a circular weft knitting machine with the gauge 22 inch and relaxed in the standard condition.

2.2 Test Methods

2.2.1 Moisture Management Measurements

Moisture management tester consists of two series of sensors that are located on both top and bottom sides of fabric samples. After introducing 0.2 g synthetic sweating on top surface of the fabric, the change in electrical resistance of fabrics is recorded dynamically. With regards to the indexes, this device can categorize fabrics in view of moisture management properties in different categories[12]. Ocumulative one way transport capacity (OWTC) is the difference between the water content on the two surfaces of fabric, as shown by the following equation:

$$\mathrm{OWTC} = \frac{\int U_b - \int U_t}{T} \qquad \ldots (1)$$

where T is the testing time; U_b, the water content of the bottom surface of fabric; and U_t, the water content of top surface of fabric. Overall moisture management capacity (OMMC) is an index to indicate the overall ability of the fabric to manage the transport of moisture[13], as shown below:

$$\mathrm{OMMC} = C_1\mathrm{MAR_b} + C_2\mathrm{OWTC} + C_3\mathrm{SS_b} \qquad \ldots (2)$$

This index includes moisture absorption rate of bottom surface (MARb), OMMC, and spread speed of bottom side ($\mathrm{SS_b}$), indicating the overall ability of fabric moisture management. Here, C_1 and C_3 are 0.25 and C_2 is 0.5, respectively. From Eq. (2) it is obvious that OMMC is more affected by OWTC.

The sample was cleaned by the washing machine for removing oil and dust, then put in an ultrasonic cleaner for 5min and finally conditioned for 24 h. After ironing for removing wrinkles and extra water, 5 specimens were considered for test. The average value for each sample was recoded (Table 1). The statistical analysis of data obtained was performed on SPSS-16 software package.

3 Results and Discussion

3.1 Governing Equations

It has been proposed by many researchers that the speed of flow under capillary pressure in horizontal capillaries can be modeled by the Lucas-Washburn equation[14], as given below:

$$\frac{dl}{dt} = \frac{\gamma \cos\theta R}{4\eta l} \qquad \ldots (3)$$

Table 1—Moisture management indexes of produced samples

Sample number	Sample code[a]	WT[b], s		AR, %/s		MWR, mm		SS, mm/s		AOWT	OMMC
		Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom		
1	SS1,30Ne	2.27	2.25	35.78	38.88	30.00	30.00	8.30	8.23	2.42	0.38
2	SS2,30Ne	17.25	2.70	27.21	45.47	25.00	25.83	1.86	3.28	357.76	0.70
3	SS3,75D48F	2.02	2.06	35.48	37.64	30.00	30.00	9.21	9.11	26.41	0.41
4	SS3,75D72F	2.41	2.41	33.45	35.93	25.00	25.00	6.12	6.01	10.72	0.39
5	SS4,75D48F	2.48	2.48	34.25	36.90	22.50	23.75	5.65	5.75	12.14	0.39
6	SS4,75D72F	2.88	2.86	31.50	33.83	20.00	20.00	4.20	4.19	6.24	0.38
7	SS4,150D72F	2.31	2.34	34.98	37.85	28.75	27.50	7.54	7.40	23.91	0.41
8	SS4,150D144F	2.37	2.41	28.87	32.58	23.75	23.75	5.65	5.61	39.31	0.41
9	SL1,30Ne	2.30	2.37	33.74	36.42	30.00	30.00	7.89	7.72	6.38	0.39
10	SL2,30Ne	27.07	2.02	22.32	40.00	18.75	20.00	0.96	2.77	527.88	0.73
11	SL3,75D48F	2.46	2.48	33.66	36.32	22.50	22.50	5.54	5.53	24.05	0.40
12	SL3,75D72F	2.39	2.39	33.80	36.59	22.50	22.50	6.01	5.95	19.39	0.40
13	SL4,75D48F	2.32	2.32	34.09	36.26	27.50	27.50	7.53	7.52	9.63	0.39
14	SL4,75D72F	2.47	2.47	28.87	30.75	22.00	24.00	7.03	6.42	32.80	0.40
15	SL4,150D72F	2.48	2.53	34.05	35.90	24.17	23.33	6.09	5.97	25.90	0.41
16	SL4,150D144F	2.27	2.42	29.10	31.08	28.00	27.00	6.63	6.17	16.20	0.38
17	DS1,30Ne	13.55	8.32	26.83	64.77	15.71	15.71	1.22	1.55	593.44	0.70
18	DS2,30Ne	8.17	25.07	68.26	124.65	8.00	8.00	0.63	0.26	496.63	0.75

[a] First letter: S- single jersey and D double jersey.
Second letter: S small loop density and L- Large loop density.
First Number: 1- four channel coolmax, 2- coolmax/cotton, 3- pluss cross section and 4- five leaf cross section. The last part is the yarn count and number of filament.

[b] WT- Wetting time, AR- Absorption rate, SA- Spreading area, SS- Spreading area, OWTC- One way transport capacity, OMMC-Overall moisture management capacity.

where *l* is the liquid front position or wicking length (here it can be considered as max. wetted radius for *t*=120 as testing time); γ and η, the surface tension and viscosity of the liquid respectively; θ, the apparent contact angle of the moving front; *R*, the effective hydraulic radius of the capillaries (voids), this term in fibre networks means an equivalent radius of the capillary porous structure[14]; and *t*, the time. In moisture management tester the max wetted radius can be formulated by the following equation:

$$\mathrm{l}^2 = \frac{\mathrm{R}\gamma_{\mathrm{L}}\cos\theta}{2\eta}\mathrm{t} \qquad \dots (4)$$

The next part is the top to bottom side through-plane moisture transfer. The accumulative one way transport (AOWT) capacity can be explained by the volumetric flow in porous media according to Darcy low[14], as defined below:

$$\frac{\mathrm{dV}}{\mathrm{dt}} = \frac{\mathrm{Ak\rho g}}{\mathrm{L\eta}}\left[\Delta\left(\frac{\mathrm{P}}{\rho\mathrm{g}}\right)\right] \qquad \dots (5)$$

where d*V*/d*t* is the volumetric flow rate; *L*, the flow length; *A*, the flow area perpendicular to *L*; *P*, the pressure; and *k*, the permeability of the porous medium and in principle is only a function of the pore structure. Benltoufa *et al.*[15] in analyzing the textile fabric structure, observed two porosity scales, namely (i) macro pores having vacuums between yarns in the structure and (ii) micro pores having vacuums between fibres in the yarn. The porosity of the macro channels is determined as:

$$\varepsilon_{\mathrm{macro}} = 1\text{-}\frac{\pi\mathrm{d}^2\mathrm{lCW}}{2\mathrm{t}}$$

or

$$\varepsilon_{\mathrm{macro}} = 1\text{-}\frac{\pi\mathrm{d}^2\mathrm{lCW}}{\mathrm{d}} \qquad \dots (6)$$

where *t* is the sample thickness in cm (*t*=2*d*); *l*, the elementary loop length (cm); *d*, yarn diameter (cm); *C* the number of courses per cm; and *W*, the number of wales per cm. The porosity in the yarn is defined as:

$$\varepsilon_{micro} = 1 - \frac{4n_s d_{fiber}^2}{t^2}$$

or

$$\varepsilon_{micro} = 1 - \frac{n_s d_{fiber}^2}{d} \quad \ldots (7)$$

where n_s is the number of fibres. In micro scale, estimation of average distance (d) between fibres is:

$$d = \frac{t}{2}\sqrt{\frac{\pi}{2\sqrt{3}n_s}} \quad \ldots (8)$$

and the mean micro pores radius is determined as follows:

$$R_{mi} = \sqrt{\frac{t^2}{32n_s} - \frac{d_{fiber}^2}{8}} \quad \ldots (9)$$

The capillary kinetics of liquid in yarn is described by Washburn law for horizontal wicking according to Eqs (3) and (4) as shown below:

$$\frac{dl}{dt} = \frac{\left(\frac{R_{mi}}{\tau}\right)^2}{8\eta h}\left(\frac{2\gamma_L \cos\theta}{R_{mi}}\right) \quad \ldots (10)$$

$$l^2 = \frac{R_{mi}\gamma_L \cos\theta}{2\eta} t \quad \ldots (11)$$

where τ is the touristy, determined by using following equation:

$$\tau = \frac{L_{loop}W}{2} \quad \ldots (12)$$

The capillary rise between yarns (on fabric scale) can be regarded as equivalent to a flow between two distant parallel plates of capillary distance (e_{mac}). The macro vacuum volume is:

$$\text{Vaccum volume} = \frac{t}{CW} - \frac{\pi d_{yarn}^2 L_{loop}}{2} \quad \ldots (13)$$

And the equivalent distance between two plates is:

$$R_{mac} = \frac{1}{C} - \frac{\pi W d_{yarn}^2}{2t} L_{loop} \quad \ldots (14)$$

The capillary kinetics of liquid in macro channels according to Eqs (3) and (4) is respectively shown below:

$$\frac{dh}{dt} = \frac{\left(\frac{R_{mac}}{\tau}\right)^2}{12\eta h}\left(\frac{2\gamma_L \cos\theta}{R_{mac}}\right) \quad \ldots (15)$$

$$l^2 = \frac{R_{mac}\gamma_L \cos\theta}{2\eta} t \quad \ldots (16)$$

They also showed that the macro pores are responsible for the diffusion during short time and micro pores for long time diffusion. So, in fabric experiments, it initially the capillary diffusion is observed in the macro channels, and then it takes place in the micro channels.

3.2 Influence of Fibre Cross-section and Fibre Content

In filament yarns fabrics, wetting times (top and bottom), absorption rates (top and bottom), max wetted radiuses (top and bottom), spreading speed (top and bottom) and OMMC of fabrics with plus cross-section are found better than hole of 5 leaf cross-section samples, but the AOWT of 5 leaf cross-section shows better performance. Wetting is the starting step of wicking phenomenon. The cross-sections of fibre affect the cover factors and topography of surface and subsequently affect the wettability of surface[6].

When comparing similar structures produced from different raw materials, coolmax/cotton blended fabrics have the more wetting time (WT), accumulative one way transport capacity (AOWT), OMMC and smaller values for absorption rates (AR), maximum wetted radius (MWR) and spreading speeds (SS) in comparison with 100% coolmax staple fibre (Table 2).

The wetting and wicking behavior of fibrous materials is mainly determined by the liquid–solid interfacial dimensions as well as contact angle (cosine of contact angle) of fabric and liquid according to Washburn Eqs (2) and (3). The contact angle varies depending on the fibre type, i.e. cotton (86° for cotton-water interface) and polyester (76° polyester-water interface), which, in turn, causes differences between the moisture transferring behavior of the fabrics. Also, the greater variation in the diameter and cross-sectional shape of the cotton fibres in comparison to the polyester ones and also the changes in the geometry of the cotton fibres due to swelling might have led to different moisture managing behaviors in the Coolmax/cotton fabrics.

3.3 Effect of Numbers of Mono-filament

It has been reported that the most important mechanism of fabric wicking is the motion of liquid

Table 2—Effect of fibre content on MMP results of samples

Fibre content	WT, s		AR, %/s		MWR, mm		SS, mm/s		AOWT	OMMC
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom		
Coolmax	2.30	2.33	34.60	43.28	30.00	30.00	7.98	7.88	2.59	0.38
Coolmax/cotton	21.17	2.42	25.25	37.51	22.50	23.50	1.50	3.08	425.81	0.71

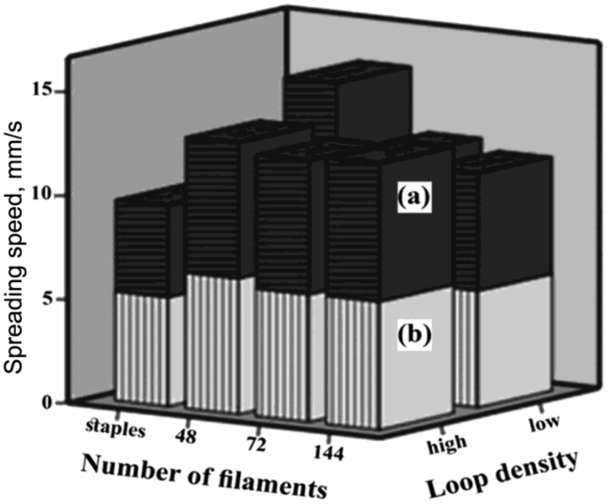

Fig. 2—Effect of loop density and number of monofilaments on (a) top and (b) bottom spreading speed (mm/s) of fabric samples

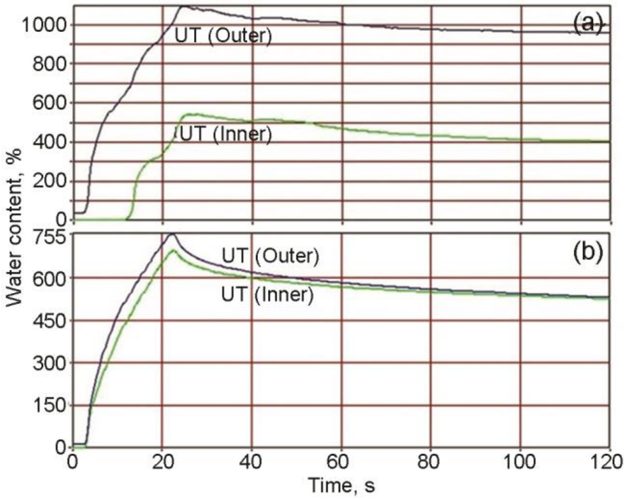

Fig. 3—Water content *vs*. time for typical fabrics produced with staple fibre (a) and filament fibre (b)

in the void spaces between the fibres in a yarn (intra-yarn)[15]. There is meaningful difference between moisture transferring indexes of samples produced with different number of monofilaments. With increasing the number of multi micro filaments from 48 to 75 and from 75 to 144, all the moisture management indexes except OWTC of samples are improved. However these differences get small with increasing loop density. Figure 2 shows the effect of loop density and number of monofilaments on top and bottom spreading speed of fabric samples.

It is due to the fact that with increasing the number of monofilament, the surface of produced fabric gets smoother and hence, wetting times are ascended and absorption rates are descended. It is clear From Eqs (8) and (9) that with increasing number of monofilament in yarn with constant diameters, distance between fibre (d) and mean micro pores radius (R_{mi}) decrease then spreading speed [Eq. (10)] and the maximum wetted radius [Eq. (11)] of samples decrease. On the other hand, synthetic fibre yarns with high number of monofilaments are compact, resulting in a low MMP.

It is also obvious from Eq. (7) that with increasing the number of monofilament and decreasing fibre diameter (ε_{micro}), permeability and volumetric flow in fabric increase according to Eq. (5), resulting in better performance of fabric with higher number of monofilaments in OWTC parameter.

3.4 Effect of Yarn Count

The results reveal that the wetting time, OWTC and OMMC of fabrics made of coarser yarns (150den) are comparatively better than those produced using finer yarns for the same cross-section and raw material [Samples 5-7 and Samples 13-15]. Other moisture management performances of coarser yarns are weaker than those of finer yarns (75 den). With increasing yarn diameter, the topography of fabric surface changes and the roughness of surface increases, leading to enhanced wetting time of fabric with coarser yarn.

As the Eqs (6), (13) and (14) show that the ε_{micro}, vacuum volume and equivalent distance (R_{mac}) of samples decrease with increasing the diameter of yarn, this subsequently increases the spreading speed [Eq.(15)] and maximum wetted radius [Eq.(16)].

A greater number of fibres in the cross-section of coarse yarns might lead to higher capillarity and continuity of capillaries formed by the fibres and thus the improved OWTC. Also, the higher value of OWTC of the fabrics from coarser yarns may be partly a result of their higher thickness values. This is because the fabric thickness can provide more space to accommodate water, which can lead to more water transferring, depending on the capillary space available as well as the capillary pressure present.

3.5 Effect of Spinning System

The trend of water content *vs*. time of samples made of filament yarns is more even with only one peak, whereas in staple ones the curve has more fluctuations (Fig. 3). In filament yarns, the monofilaments are more parallel to each other in comparison with short staple fibres in the spun yarns, and the movement of water in the filament yarns, and

Table 3—Effect of loop density on MMP of samples

Loop density	WT, s		AR, %/s		MWR, mm		SS, mm/s		AOWT	OMMC
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom		
Low	5.09	2.46	32.33	37.92	25.61	25.76	6.02	6.03	78.82	0.45
High	5.29	2.39	31.09	35.11	24.56	24.71	5. 81	6.01	79.73	0.43

the movement of water in the filament yarns is more even than staple yarns.

The samples made of spun yarns have some capillary pathway normal to plan w of fabrics due to the random orientation of staple fibre, which helps moisture transferring from top side to bottom side of fabric, leading the better performance in accumulative one way transport index and OMMC of staple samples. However, the top and bottom maximum wetted radius in staple fibre fabric have better performance due to the unique cross-section of coolmax fibres; statistical significant differences are not observed.

3.6 Effect of Fabric Structures

3.6.1 Loop Density

Table 3 shows that with increasing loop density all indexes except accumulation one way transport capacity (AOWT) is improved. The AOWT is related to the thickness of fabric; with increasing the loop density the thickness and capacity of water transport increase.

With increasing loop density touristy of stitch increases [Eq. (12)] and vacuum volume [Eq. (13)] and equivalent distance [Eq. (14)] decrease, thus yielding to decreasing spreading speeds [Eq. (15)] and max wetted radius [Eq. (16)] of samples with higher loop densities. These results are in accordance with other researchers findings[15, 16].

3.6.2 Effect of Knitting Pattern

The fabric with single jersey structures shows the highest wetting time, wetted radius and spreading speed but lowest absorption rate, accumulative one-way transport and subsequently lower OMMC than the double jersey structure.

As it has been explained in previous sections, with increasing the thickness of fabric (in double jersey) the AOWT and OMMC increase. It is obvious from Eqs (6) and (7) that with increasing thickness of fabric ε_{macro} and ε_{micro} of double jersey samples increase, and with regards to increasing k (porosity) in Eq.(5), it can be expected that volumetric flow (AOWT) of fabric increases. These results are in agreement with the work of Onofrei *et al.*[9]. They reported that the fabric with high bulk density and high thickness have worse in-plane wicking ability.

The visible detection of wicking for different samples shows that the movement of moisture in wale directions is significantly more than in course directions. This may have resulted by the fact that the free channels in the wale direction parallel to the loops make the capillary paths, and these paths improve the moisture transfer through samples.

With regards to the indexes, moisture management tester categorizes fabrics on the basis of their management properties[2]. The produced samples are categorized in three different types, namely moisture management fabric (Samples 2, 10,17,18), fast absorbing and quick drying fabric (Samples 1,3, 9,4,5,7,11,12,13,15) and slow absorbing and slow drying fabric (Samples 6,8, 14,16).

4 Conclusion

It is found that under the same condition, the moisture management properties of the fabric made by plus cross-section yarns is obviously better than those made by the 5-leaf cross-section yarns. This work has shown that accumulative one way transport capacity of fabrics is mainly dependent on yarn (staples or filament) and fabric (loop density, knitting pattern and fabric thickness) structures. Furthermore, the results show that the fabric composed of 100% polyester fibre has better MMP than those made of polyester/cotton fibres. With decreasing loop density all moisture management indexes except accumulation one way transport capacity get improved. The samples fabricated from yarn with less number of monofilaments have better moisture management performance than those with more numbers of monofilaments. Also it can be concluded that in a same cross-section, sample made of coarser yarn has lower MMP. Double jersey fabric showed the lowest indexes of moisture transmission rate and the highest indexes of AOWT and OMMC.

As it has been investigated in this research, the moisture management behavior of textile materials is so complicated and depends on lots of structural parameters. It is rational that the end-use and application of textile fabric should be considered for the selection of the fibre, yarn and fabric properties and structures to achieve appropriate moisture management properties and comfort.

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References

1 Bagherzadeh R, Gorji M, Latifi M, Payvandy P & Kong LX, *Fiber Polym*, 13 (2012) 529.

2 *M 290 MMT Instruction Manual version 4.0*, www.sdlatlas.com_(July 2010).

3 Gorji M, Bagherzade R & fashandi H, in *Electrospun nanofibers*, Edited by M Afshari (Elsevier, Chennai), 2016, 567.

4 Gorji M, JeddiAli A A, Gharehaghaji A A, *J Appl Polym Sci*, 125 (2012) 4135.

5 Kucukali M, Nergis B & Candan C, *Text Res J*, 81 (2011) 324.

6 Hasan M, Calvimontes A & Synytska A, *Text Res J*, 78 (2009) 996.

7 Wickwire J, Bishopb P A, Greenb J M, Richardsonb M T, Lomaxc R G, Casarub C, Curther-Smithb M & Dossb B, *Int J Ind Ergonom*, 37 (2007) 643.

8 Wang N, Zha A & Wang J, *Fiber Polym*, 9 (2008) 97.

9 Onofrei E, Rocha A M & Catarino A, *J Eng Fiber Fabric*, 6 (2011) 10.

10 Fan JT, Sarkar M K, Szeto Y C & Teo X M, *Mater Lett*, 61 (2007) 561.

11 Fangueiro R, Filgueiras A, Soutinho F & Meidi X, *Text Res J*, 80 (2010) 1522.

12 Hu J, Li Y, Yeung K, Wong A S W & Xu W, *Text Res J*, 75 (2005) 57.

13 *Liquid Moisture Management properties of Textile Fabric*, AATCC Test Method, 95(2009).

14 Simile B, *Critical evaluation of wicking in performance fabrics*, M.Sc thesis, Georgia Institute of Technology, Georgia, 2004.

15 Benltoufa S, Fayula F & Nasrallah B, *J Eng Fiber Fabric*, 3 (2008) 47.

16 Hes L, *Proc Int Text Conf*, Terrasse (2001).