Indian Journal of Fibre & Textile Research
Vol. 48, March 2023, pp. 91-98
DOI: 10.56042/ijftr.v48i1.59978

Moisture management properties and drying behaviour of knitted fabrics for inner layer applications

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Received 1 February 2022; revised received and accepted 24 June 2022

The present research work is focused on moisture management properties and drying behaviour of various knitted fabrics for inner layer application. Nineteen knitted samples have been prepared by changing the blend percentage of wool/acrylic, number of filaments in polypropylene yarn and structure of knitted fabric. Yarns of different blend ratio of wool/acrylic fibre are used to knit fabrics of different structure. Polypropylene yarns having different number of filaments are also used to knit samples of different structure. These fabrics are tested for moisture management properties and drying behaviour. Wetting time, absorption rate, spreading speed, wetting radius, accumulative one-way transport index (AOWTI), overall moisture management capacity (OMMC), drying time and drying rate of the fabrics have been studied. It is observed that the overall performance of polypropylene knitted fabric and cotton knitted fabric are better as compared to the wool/acrylic having same structural parameters. The OMMC index of polypropylene plain knit, pile knit and cotton knit fabric is found as 0.70, 0.60 and 0.75 respectively. The polypropylene and cotton knitted fabrics shows better results than others in terms of the parameters, like maximum wetting radius, AOWTI, etc. Polypropylene knitted pile structure fabric shows minimum drying time (0.228 h) and zero residual moisture after wash at 90 min under standard conditions. So, it is found that the higher wool content in fabrics gives better moisture management and drying behaviour. Polypropylene fabrics having high number of filaments in the constituent yarn show better moisture management and drying behaviour than the wool/acrylic fabrics. Moisture management and drying behaviour of pile fabrics are better than the plain and rib fabrics.

Keywords: Drying rate, Knitted structure, Moisture management property, Polypropylene filament, Sweat

1 Introduction

Clothing comfort refers to the human comfort feeling in different climatic conditions that are basically related to the balance of energy transfer between the human body and the atmosphere. Knitted fabrics are worn next to skin due to various advantages, such as high elasticity, comfort, conformity with the shape of the human body, ease of care and economical[1]. Functional knitted structure must have excellent moisture management properties and claimed to have quick wetting and drying rate, most efficient transmission of moisture from the human skin with excellent breathability. Moisture transfer through fabrics is a critical factor affecting physiological comfort especially in inner garment, sportswear and protective clothing[2,3]. When metabolism is very high, humans sweat and perspiration spread over the skin. Cloths should transfer quickly the sweat out side to provide comfort for the user[4,5]. Moisture management properties of the fabrics have great influence on comfort behavior of the human body which is balanced by perspiring both in liquid and vapour form. The fabrics to be worn should forward this sweat to the next successive layers or surrounding atmosphere in order to maintain the thermal balance of human body[6]. The effect of comfort depends on the fibre content, fibre cross-section, number of filament and fabric structure like knitted or woven[7-12].

The moisture management tester (MMT) is able to measure dynamic liquid transfer in fabric Fig. 1. This instrument gives ten different indexes related to liquid transfer in different directions of fabric and define the results in form of top and bottom wetting time in seconds, top & bottom absorption rate in %, top & bottom maximum wetted radius in mm, top & bottom spreading speed in mm/s, cumulative one way transport capacity and overall moisture management capacity [13-16].

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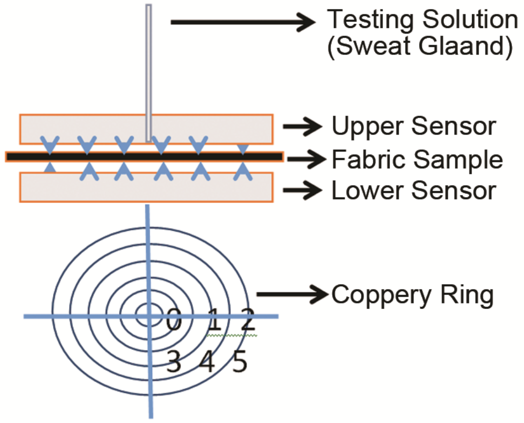

Fig. 1 — Sketch diagram of MMT sensor and sample mounting system

Drying behavior of textile materials governs the end use and life of the fabric. The inner layer fabric directly touches the skin and gets wet by absorbing sweat from the skin, thus making it dry. During the same time fabric also dries progressively with the help of human body temperature (37^{0}C), air etc. Drying rate is defined as the change in volume of a liquid evaporates from the fabrics per unit time and it depends upon the fabric construction, fibre content, garment construction, finishes and atmospheric condition in which the test is conducted, and the volume challenge of the liquid.[14]

Fangueiro *et. al*[17] studied the influence of functional fibres in the functional knitted structured fabrics on the physiological comfort of the sport garments. It was evaluated by estimating liquid transport and drying rate of the fabrics. The drying capability was evaluated by the drying rate tests at 22± 2^0 C and 65 ± 3% RH, in an oven at 33± 2^{0}C, in order to simulate the human body temperature. Raechel *et. al.*[18] designed and developed the machine set to determine the drying time of the appeal fabrics simulating both during and after wear of clothing system. The researchers also used polyester/wool knitted fabrics and studied the moisture transport and moisture management behavior[19]. Qing Chen *et. al.*[20] studied the moisture management and drying properties of weft knitted plating fabric using polyester /cotton, polypropylene/cotton, polypropylene/ polyester, and polyester/ polyester. They also studied variation in the number of filaments in polyester and polypropylene. They have found that the polypropylene shows better results than polyester and cotton. Increasing the number of filaments in yarn also improved the performance. All these studies show that the properties of 100% polypropylene fabrics in inner layer have not been studied so far. This research work shows the future need of study on the moisture management properties of the polypropylene fabrics. To the best of our knowledge the polypropylene filament yarn has never been used in the thermal undergarment for extreme cold weather clothing.

The main objective of this study is to analyze and evaluate the potential use of the polypropylene filament yarn in the thermal undergarment for extreme cold weather clothing. The moisture management properties and drying rate properties of knitted fabrics are studied.

2 Materials and Methods

2.1 Materials

Nineteen samples of knitted fabrics structures were prepared inV bed flat knitting machine bychanging the blend percentage of wool/acrylic, number of filaments in polypropylene yarn and structure of knitted fabric. Detailed construction parameters are given in Table 1.

2.2 Methods

2.2.1 Fabric Physical Parameters

The fabric samples were conditioned understandard atmospheric conditions (20 ± 2°C, 65 ± 2% RH) for 24 h. Knitted fabric's stitch densities were measured using counting glass according to ASTM D3775-03 & ASTM D-3887 standard. Yarn linear density and fabric weight per unit area were measured according the ASTM D 1059 standard. The thickness of fabrics was measured as per the ASTM D 1777-96(2002) standard test methods using Shirley thickness gauge at a pressure of 7 g/cm^2 with an accuracy of 0.01mm. An average value of ten readings was taken for each sample in case of each test and calculated standard error. The details of knitted fabrics are listed in Table 1.

2.2.2 Moisture Management Test

The moisture management tester (MMT) was used to measure dynamic liquid transfer in fabric. This instrument gives ten different indexes related to liquid transfer in different directions of fabric and define the results in the form of top and bottom wetting time in seconds, top & bottom absorption rate in %, top & bottom maximum wetted radius in mm, top & bottom spreading speed in mm/s, cumulative one way transport capacity and overall moisture management capacity[21]. Accumulative one-way transport index (AOWTI) is the difference in the cumulative moisture content between the two surfaces of fabric. The AOWTI is calculated as:

Table 1 — Basic constructional parameters of wool/acrylic and polypropylene knitted fabrics

Sample code	Structure of fabric	Composition of fabric (Wool:Acrylic)	No. of filament (PP)	Wales/ inch	Courses / inch	Arial density, g/m^2	Thickness, mm (Under pressure of 7g/cm^2)
			Wool : Acrylic Fabric				
WA1	Plain	30:70	--	14	17	161.58±0.42	1.23±0.021
WA2	Rib	30:70	--	17	27	438.04±0.47	1.93±0.016
WA3	Pile	30:70	--	13	24	467.34±0.49	3.21±0.030
WA4	Plain	50:50	--	13	16	162.52±0.47	1.24±0.020
WA5	Rib	50:50	--	15	26	409.35±0.47	1.94±0.022
WA6	Pile	50:50	--	14	27	452.41±0.43	3.39±0.044
WA7	Plain	70:30	--	13	16	163.9±0.50	1.25±0.017
WA8	Rib	70:30	--	17	26	408.69±0.31	2.04±0.026
WA9	Pile	70:30	--	14	25	458.04±0.43	3.42±0.025
			Polypropylene fabric				
P1	Plain	--	24	16	22	181.01±0.38	1.21±0.023
P2	Rib	--	24	16	28	344.99±0.37	1.54±0.016
P3	Pile	--	24	17	28	351.81±0.30	2.43±0.030
P4	Plain	--	48	15	23	239.41±0.36	1.31±0.023
P5	Rib	--	48	15	28	445.688±0.26	1.82±0.025
P6	Pile	--	48	15	28	345.94±0.35	2.36±0.031
P7	Plain	--	66	16	24	202.51±0.39	1.11±0.028
P8	Rib	--	66	14	25	377.02±0.44	1.58±0.025
P9	Pile	--	66	14	24	348.70±0.43	2.21±0.035
C	Plain	-	Cotton	26	35	126.78±0.30	0.41±0.003

$$\text{AOWTI} = \frac{\int U_b - \int U_t}{T} \qquad \text{...(1)}$$

where U_t is the water content *vs*. time on the fabric top surface (generally the surface in contact with the human skin); U_b, the water content *vs*. time on the fabric bottom surface (generally the surface exposed to the environment); and T, the total testing time. Because of reflecting liquid transport ability of fabric, AOWTI is an important parameter[22].

Overall moisture management capacity (OMMC) is an index to indicate the overall ability of the fabric to manage the transport of liquid moisture, which includes three aspects of performance, namely moisture absorption rate of the bottom side, one-way liquid transport ability and maximum spreading speed of the bottom side[22]. The OMMC is calculated using the following the relationship:

$$\text{OMMC} = \text{C}_1 \times \text{AR}_\text{b} + \text{C}_2 \times \text{AOWTI} + \text{C}_3\text{SS}_\text{b} \quad \text{... (2)}$$

where C_1, C_2, and C_3 are the weights of the indexes of the absorption rate (AR_b), the accumulative one-way transport index (AOWTI) and the spreading speed (SS_b) respectively. Here, C_1 = 0.25, C_2 = 0.5 and C_3 = 0.25, and they can adjust with respect to end-of-use purposes. The values of the coefficients used here are determined. In a humid environment, the evaporation of liquid water is relatively slow, and one-way transport of liquid sweat is very important for keeping the skin dry, so that AOWTI is more significant than AR (absorption rate) and SS (spreading speed)[22,23].

2.2.3 Drying Time and Drying Rate Test

The drying time and drying rate (skin model) were tested by a RF4008HP Drying rate tester (heated – plate method, REFOND Equipment Co. China) as per standard AATCCRA63 (201-2012). The drying time is the difference of the end time and start time[24]. Drying time and drying rate can be calculated using the following equations:

Drying time (h) = End time – Start time …(3)

Drying time is the time it takes for a specified amount of liquid to evaporate from fabrics under controlled testing condition.

$$\text{Drying rate } \left({}^{ml}\!/_{h}\right) = \frac{\text{Volume of water applied in the test (mL)}}{\text{Drying time (h)}} \qquad \text{…(4)}$$

Drying rate is the change in volume per unit time a liquid evaporates from fabric.

2.2.4 Rate of Drying of Fabrics (Vertical Line Drying)

The fabric samples werefully immersed in water for 5 min and than hanged after removal of extra water from samples with the help of paper towel; when there was no water dropping, the weight of wet samples (M_i) was recorded. Fabrics weights were measured using the condition of the test wind velocity 8 - 13 km/h, UV index 7 - 10 and humidity 32 - 50 %. After every 15 interval, the weight of fabric (M_t) was taken. The drying rate was calculated using the Eq. (5) and expressed in gram of water loss per unit area per minute. Sample size was 20 × 20 cm. The drying behaviors of knitted fabrics were analyzed to define drying time. Equation (5) is given below:

$$\text{Drying rate}\left(\frac{g/m^2}{min}\right) = \frac{\text{Mi}-\text{Mt}}{txA} \qquad \ldots(5)$$

The water holding capacity of the fabric samples depends upon how the fabric is supported vertically and the mechanical treatment given to remove water. For easy drainage in vertical position, the water holding capacity of small samples is more closely correlated with fabrics thickness than with fabric weight. The samples WA1, P7, P9 and C dried completely at 90 min. That is the reason why, rate of drying of these samples is zero (0)

3 Results and Discussion

The prepared samples have been tested for moisture management properties, drying rate and rate of drying. The findings are discussed hereunder.

3.1 Moisture Management Properties of Fabrics

3.1.1 Wetting Time

The wetting time (top & bottom) of wool/acrylic samples is shown in Table 2. It is clearly visible that the wetting time increases with increase in wool percentage. Wool fibre is naturally water repellent due to overlapping scales (cuticles) on the outer side of the wool fibre[24]. This is the main cause of increase in wetting time (top & bottom) with increase in wool content in the knitted fabric. Increasing trend in the wetting time (top & bottom) is observed as the knitted structure changes from plain to rib and from rib to pile. Pile fabric is more bulky than rib and rib fabric is more bulky than plain. The continuity of the fabric surface also reduces as the structure changes from plain to rib and rib to pile. These structural changes prevent the liquid moisture to wet the surface and promote it to be transferred into fabric structure. For wool/acrylic knitted fabric, wetting time (bottom) is found to be higher than the wetting time (top), which indicates that the top surface of the fabric wets faster

Table 2 — Moisture management test of the wool/acrylic knitted, cotton & polypropylene fabric

Sample code	Wetting time (Top) s	Wetting time (Bottom) s	Absorption rate (Top) %/s	Absorption rate (Bottom) %/s	Max wetted radius (Top) mm	Max wetted radius (Bottom) mm	Spreading speed (Top) mm/s	Spreading speed (Bottom) mm/s	AOWTI %	OMMC
Wool/acrylic & cotton										
WA-1	2.53	4.78	4.53	68.34	20	20	4.12	4.73	182.82	0.67
WA-4	3.50	4.98	34.33	43.68	15	20	4.10	5.21	212.83	0.64
WA-7	7.69	6.56	65.40	7.13	5	5	0.63	0.73	412.38	0.50
WA-2	1.22	10.88	60.59	66.13	5	5	0.36	0.45	239.52	0.45
WA-5	7.69	57.38	94.37	124.27	5	5	0.63	0.87	240.27	0.45
WA-8	8.06	86.25	134.04	168.16	5	5	0.61	0.78	342.31	0.25
WA-3	7.69	64.41	48.06	63.36	5	5	0.63	0.77	73.00	0.14
WA-6	7.88	71.53	80.32	100.50	5	5	0.62	0.70	132.17	0.25
WA-9	12.84	79.19	161.10	241.05	5	5	0.38	0.43	168.39	0.34
Cotton	120	9.94	0.0	152.23	0	5	0.0	0.49	1042.316	0.75
Polypropylene fabric										
P1	3.28	3.84	42.21	36.18	20	20	3.57	3.53	320.09	0.695
P4	5.34	4.78	26.2	38.03	15	15	3.25	2.36	155.37	0.419
P7	3.19	3.65	47.34	49.97	25	25	4.64	4.24	4.23	0.421
P2	4.69	5.44	28.12	30.92	15	15	2.54	2.31	285.13	0.54
P5	13.03	6.66	5.9	13.45	0.0	10	0.0	1.41	91.25	0.201
P8	4.5	4.69	24.53	32.5	20	20	3.01	2.75	71.32	0.344
P3	120	6.94	0.0	20.95	0.0	10	0.0	2.14	412.28	0.626
P6	120	4.59	0.0	24.55	0.0	10	0.0	1.94	237.4	0.438
P9	5.63	4.31	32.55	44.86	15	20	2.78	3.14	198.51	0.551

than the bottom surface. It shows that the wearer may feel little uncomfortable with this kind of inner garments.

The wetting time (top & bottom) of polypropylene samples is shown in Table 2. It is clearly visible that wetting time reduces with increase in the number of filaments in the yarn, while keeping the structure same. Increasing the number of filaments in the yarn increases the number of capillaries which helps quick transfer of liquid moisture. Increasing trend of wetting time is observed as the knitted structure changes from plain to rib and from rib to pile. Pile fabric is more bulky than rib and rib fabric is more bulky than plain. The continuity of the fabric surface also reduces as the structure changes from plain to rib and rib to pile. These structural changes prevent the liquid moisture to wet the surface and promote it to be transferred into fabric structure. For polypropylene plain knitted fabric, wetting time (bottom) is found to be higher than the wetting time (top). For polypropylene rib knitted fabric, wetting time (bottom) is found to be almost same as the wetting time (top). For polypropylene pile knitted fabric, wetting time (bottom) is found to be lower than the wetting time (top). This trend in wetting time indicates that changing the fabric structure from plain to rib and from rib to pile, the tendency of wetting bottom fabrics surface is increasing which indicates that the knitted fabric with pile structure will give better comfort to the wearer.

3.1.2 Maximum Absorption Rate

The maximum absorption rate (top & bottom) of wool/acrylic samples are shown in Table 2. It is clearly observed that maximum absorption rate (top) increases with increase in wool percentage which is explained by the high moisture regain of wool fibre. The maximum absorption rate (bottom) also increases with increase in wool content except for the plain knitted fabric, which shows decrease. This behavior of plain knitted fabric indicates that the liquid moisture distribution on fabric top surface increases with increase in wool content. This may be attributed to the smooth fabric surface of plain knitted fabric. So, this kind of fabric is not good for inner garments. The differenceinbottom and top maximum absorption rateincreases as the structure changes from rib to pile, which indicates that the more and more amount of liquid moisture will be distributed on the bottom surface of fabric.

The maximum absorption rate (top & bottom) of polypropylene fabric samples are shown in Table 2. Since the sweat is not reached to the top surface of the fabric due to structure of the fabric, the reading are zero (0). Trend observed from the data shows that the polypropylene fabric having more number of filaments in constituent yarn and bulkier fabric structure will give better maximum absorption rate. Sample P9 is the most suitable fabric in which most of the liquid moisture is distributed on the bottom surface of the fabric. So, high openness, bulk, more capillary, more capillary contact points and high wool content are the key factors to improve the quality of fabric, and making it more comfortable by quickly absorbing liquid moisture from skin surface and transfer it to the outer surface of the fabric.

3.1.3 Maximum Wetting Radius

The maximum wetting radius (top & bottom) of wool/acrylic samples are shown in Table 2. For plain knitted fabric, maximum wetted radius reduces with increase in wool fibre content. Higher moisture regain of wool fibre does not allow liquid moisture to spread on the surface. Maximum wetted radius is found lower in the pile and rib fabrics than that in plain fabric. Low bulk of the latter fabric allows the liquid moisture to spread easily on the fabric surface. Fabrics with higher wetted radius exhibits better drying and consequently better moisture management property. Plain cotton, rib and pile knitted fabrics show similar top and bottom wetted radius for all blends.

The maximum wetting radius (top & bottom) of polypropylene samples are shown in Table 2. Maximum wetted radius for plain knitted polypropylene fabrics is higher than other two structures of the fabric. Increasing the number of filaments in the constituent yarn facilitates the moisture transfer and increases the maximum wetted radius. Fabrics with rib and pile structures show lower wetted radius because the moisture is distributed inside the fabric structure rather than on surface. Top and bottom wetted radius is almost same in all the fabrics, except in fabric having pile structure, in which bottom wetted radius is slightly higher. So, the fabric sample P9 gives the best moisture management property. The fabrics (P7, P8 & P9) prepared with more number of filaments in yarn show better moisture management property.

3.1.4 Spreading Speed

The spreading speed (top & bottom) of wool/acrylic samples are shown in Table 2. Spreading speed increases with increase in wool content. This may be explained by liquid moisture repelling behavior of wool fibre. Decreasing trend of spreading speed is observed as the structure changes from plain to rib and from rib to pile. Surface discontinuity and higher bulk of fabrics are responsible for this trend. Spreading speed of the bottom surface is slightly higher than that of top surface. This difference is increasing as the structure changes from plain to rib and from rib to pile.

The spreading speed (top & bottom) of polypropylene samples are shown in Table 2. Spreading speed trend of polypropylene samples is similar to that of the wool/acrylic samples. However, the values are much higher than the wool/acrylic samples. This shows that the polypropylene samples (P7, P8 & P9) have better moisture management properties.

3.1.5 Accumulative One –Way TransportIndex

The accumulative one –way transport index (AOWTI) of wool/acrylic samples is shown in Table 2. The accumulative one-way transport capacity is the difference in the cumulative moisture content between two surfaces of the fabric in the unit testing time. The water one-way transport index shows the capability for water transport from top surface of the fabric to bottom surface. The fabricsshow a good one-way transport property when the value of AOWTI is higher than 200, and an excellent AOWTI property when this index is higher than 400 [23].

AOWTI increases with theincrease in wool content and decreases as the fabric structure changes from plain to rib and from rib to pile. Moisture repellent nature of wool fibre and bulkiness of the structure is responsible for this behavior of the fabric. In case of polypropylene fabrics, AOWTI increases with increase in number of filaments in the constituent yarns. Not much difference in AOWTI is observed as the structure changes from plain to rib and from rib to pile. The negative effect of fabric bulkiness is covered up by the positive effect of increase in number of filaments in constituent yarn. Samples P7, P8, and P9 give better results than WA7, WA8, and WA9 samples.

3.1.6 Overall Moisture Management Capacity

Overall Moisture Management Capacity(OMMC) values for wool/acrylic and polypropylene fabric are given in Table 2. The OMMC is an index to represent the overall ability of the fabric to manage transport liquid moisture, which includes three aspects of performance, viz maximum absorption rate of bottom surface, spreading speed and AOWTI. Higher moisture management capacity indicates better overall moisture transport ability of the fabric. The OMMC grading of PP cotton fabrics is more than that of wool/ acrylic fabrics. The grading chart indicates that the OMMC value from 0.6 to 0.8 comes under the class of very good. It can be concluded that polypropylene fabrics (P7, P8 and P9) show fast absorbing and quick drying properties. The finger print analysis test results provided by MMT also show that OMMC grading for wool/acrylic is 'fair' overall, while the grading of cotton and PP fabrics is 'excellent'. The finger print figures are provided in Fig. 2

3.2 Drying Rate of Knitted Fabrics

3.2.1 Skin Model

The drying time and drying rate explain the ability of a wet fabric to become dry quickly at body temperature. Good drying ability of fabrics enhances the sweat evaporation and keeps the fabric dry and comfortable after excessive sweating. Table 3 clearly shows that the knitted structure and yarn

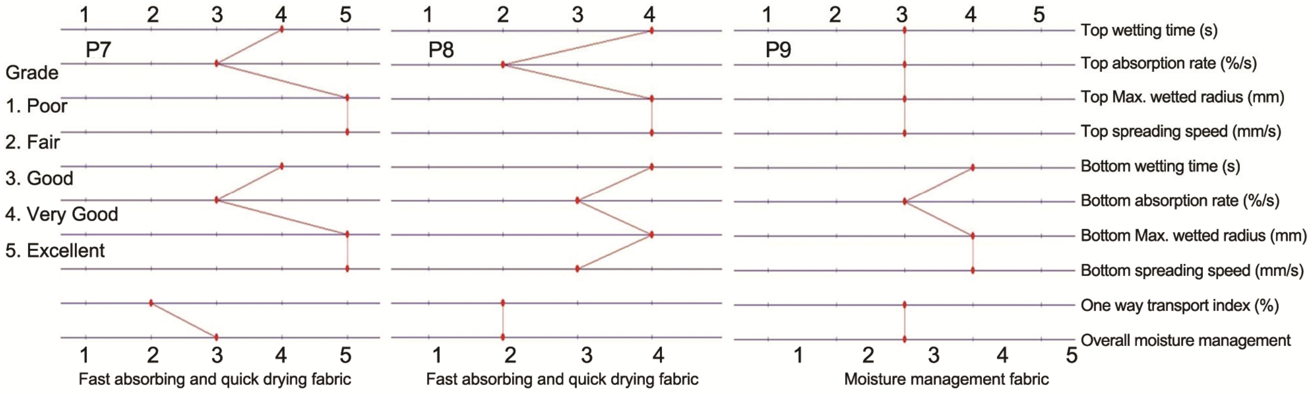

Fig. 2 — Fingerprint of MMT of PP fabric (P7) plain, (P8) riband (P9) pile knit

Table 3 — Evaporation characteristics of knitted fabric

Sample code	Drying properties (skin model)		Rate of drying g/m^2/min
	Drying time h	Drying rate mL/h	(Evaporation 90 min)
WA1	0.655	0.306	0
WA2	0.756	0.267	0.025
WA3	0.358	0.562	0.83
WA4	0.398	0.503	0.18
WA5	0.657	0.304	1.0
WA6	0.377	0.531	0.91
WA7	0.318	0.636	0.05
WA8	0.622	0.322	0.38
WA9	0.426	0.472	0.21
P1	0.274	0.735	0.03
P2	0.315	0.635	0.017
P3	0.250	0.809	0.65
P4	0.258	0.791	0.15
P5	0.309	0.651	0.756
P6	0.236	0.848	0.606
P7	0.247	0.7498	0
P8	0.299	0.6715	0.011
P9	0.228	0.8802	0
C	0.2636	0.7594	0

composition both have significant effects on the drying performance of knitted fabric samples. In both wool /acrylic and polypropylene fabrics, the drying time decreases as the structure changes from plain to rib and from rib to pile. Drying rate for both wool/acrylic and polypropylene fabrics increases as the structure changes from plain to rib and from rib to pile. Increasing the percentage of wool in the fabrics increases the quick drying ability of the fabrics. More number of filaments in the constituent yarns also helps in quick drying of the fabric. In pile and rib structure of the fabric, liquid moisture is evenly distributed in larger volume of the fabric, thus decreasing the concentration of the moisture in the structure this ultimately helps in easy vaporization of sweat molecules. This is the main reason of good drying behavior of pile and rib fabrics.

3.2.2 Vertical Line

Table 3 shows that the samples P9, P8, P7,P1, WA9, WA8, WA7 and WA1 have good drying property. Amount of residual moisture after 90 min in various samples are also shown Table3. In wool /acrylic and polypropylene fabrics, the drying behavior improves as the structure changes from plain to rib and from rib to pile. Increasing the percentage of wool in the fabrics increases the quick drying ability of the fabrics. More number of filaments in the constituent yarns also helps in quick drying of the fabric. In pile and rib structures of the fabric liquid moisture is evenly distributed in larger volume of the fabric, thus decreasing the concentration of the moisture in the structure which ultimately helps in easy vaporization of sweat molecules. This is the main reason of good drying behavior of pile and rib fabrics.

4 Conclusion

Results of the present study conclude that the higher wool content in fabrics gives better moisture management and drying behaviour. Polypropylene fabrics having high number of filaments in the constituent yarn show better moisture management and drying behaviour than the wool/acrylic fabrics. Moisture management and drying behaviour of pile fabrics are better than those of the plain and rib fabrics. Finger print of MMT also shows that the polypropylene samples are better than wool/acrylic samples. So, polypropylene fabrics knitted with yarn having high number of filaments and with pile knit structure are best suited for inner wear applications.

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