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The Influence of Yarn and Knit Structure on Comfort Properties of Sportswear Fabric

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ABSTRACT

The moisture management behavior of knitted activewear made of micro polyester, texturized polyester and polyester spandex blend; knitted in different structures - single jersey, rib and interlock was analyzed using multi-dimensional liquid transport properties and fabric structural parameters. In this research work, moisture management property is evaluated through dry rate performance, air permeability, water vapor permeability, vertical wicking height. The conclusions derived indicate the best performance from the plain single jersey knit structure manufactured using Micro Polyester. The moisture management properties are found to be directly correlated with dry rate performance, water vapor permeability and vertical wicking. These all properties are further associated with porosity of structure and micro channels available for water transportation, which is highest in case of micro polyester yarn and single jersey knit.

Keywords: Moisture management, dry rate performance, WVP, vertical wicking

1. INTRODUCTION

Clothing functions as a resistance to heat and moisture transfer between skin and environment [1-3]. However, a garment is more than just the textile layer. Textiles are fibrous porous media made up of textile fibers in different structural forms [4]. Dynamic comfort of the wearer is influenced by the process of moisture transport under transient humidity condition through clothing. Moisture may be transferred through fabric in two forms – in vapor and in liquid [5]. The controlled movement of water vapor and liquid (perspiration) from the surface of skin to atmosphere through the fabric is defined as moisture management [6]. The desirable characteristics for the functional sportswear are as most favorable heat and moisture regulation, quick moisture absorption and transport capacity, good air and water permeability, preventing the long term feeling of dampness, low water absorption by the layer next to skin, rapid drying of fabric and easy care, soft and pleasant touch [7]. It is not normally desirable to have damp clothing next to the skin, especially when stationary in extremely cold conditions, and so fibers such as polyester and polypropylene are chosen for their wicking properties. The insulation layer varies in thickness in its ability to trap still air in down, synthetic waddings, fleeces, fibrepile or other three- dimensional knitted and non-woven assemblies. Diffusion of water vapor is mainly dependent on the porosity of the fabric. The convection methods are important in transferring perspiration from the skin to the atmosphere in high air velocity [8]. Wetting and wicking are complex phenomena and are intrinsically linked with each other and this is particularly so when a fibrous assembly is involved such as a fabric. The parameters such as water absorption, liquid transportation, drying and water vapor permeability stands out in this context [9-10].

2. MATERIALS AND METHODS

2.1 Fiber and Yarn Characteristics

Three different filament yarns used in this study are prepared at Reliance India Limited. The polyester filaments are varied in fineness and surface texture. Yarn tex is kept constant 11.11 for equivalent fabric properties where number of constitute hexagonal polyester filaments is varied as per table 1. The settings while manufacturing sample yarns on ring frame are mentioned in table 2 and the quality parameters of manufactured yarn is mentioned in table 3.

Table 1: Characteristics of polyester sheath and elastane core yarn used

	Material	Fineness (tex)	No. of filaments in cross- section	Fineness of filament (TPF)
Micro Polyester Filaments Yarn	100% PES	11.11	144	0.0771
Texturized Polyester Filaments Yarn	100% PES	11.11	72	0.1543
Core Spun Filaments Yarns	96% PES 4% EL	11.11	72 (Sheath)/ (Core)	0.1543
*TPF- tex per filaments				

Table 2: Setting of the ring spinning frame (PES/ EL)

Filament per- tension (N)	0.16
Traveler (rpm)	15.000
Break draft	1/25
Total draft	33.68
Twist M^{-1}	530
Fineness of EL (tex)	3.33

Table 3: Yarn mechanical properties

	Breaking force (kgf)	Tenacity (kg/tex)	Elongation (%)	Unevenness (%)
Micro Polyester	0.6232	0.0231	13.85	12.92
Texturized Polyester Filament Yarn	0.6463	0.0243	14.70	13.86
Core Spun polyester Elastane Filament Yarn	0.5784	0.0197	16.82	11.13

2.2 Fabric Structure

Weft Knitted fabric samples are prepared on circular knitting machine with three different knit types – single jersey, rib and interlock. Various machine parameters set for knitting of different constructions are given in table 4 and the constant machine settings and at the same tension. The fabric details measured were: wales per inch (WPI), course per inch (CPI), linear density of yarn (denier), fabric mass per unit area (g/m2) and fabric thickness (mm). WPI and CPI were measured according to the ASTM D- 3887 Standard.

Table 4: Machine parameters for knitting

Parameters	Structures		
	Plain	Rib	Interlock
Number of feeders	36	24	24
Diameter (inch)	26	28	26
Machine gauge	18	18	18
Machine type	Weft circular knitting		

2.3 TEST METHODS

2.3.1 Testing Procedures

The knitted fabrics were conditioned in standard atmospheric RH (65+/-2%) and temperature (27+/-2ºC) for 24 hours before testing. The fabrics were tested first for their fabric particulars and index properties and then Moisture Management Properties.

2.3.2 Index Properties Testing

Fabric thickness, air permeability and porosity, pore diameter are the important index properties which directly influence the fabric moisture management properties.

2.3.2.1 Thickness

Thickness testing was carried out as per BS EN ISO 9073-2 using the electronic thickness tester at 0.25 KPa pressure. For each sample 30 readings were taken to get the result at 95% confidence level.

2.3.2.2 Air Permeability

The air permeability of a fabric is closely related to the construction characteristics of the yarns and fabrics in which large volumes are occupied by air. The air permeability of a fabric is a measure of how well it allows the passage of air through it and is defined as the volume of air passed in one second through 100 square.mm of the fabric at a pressure difference of 10 mm of water Air permeability was carried out as per ASTM D737 using FX 3300 air permeability tester. Testing was carried out in a circular test head of diameter 15.07 at test pressure of 98 Pa. The rate of air flow through the fabric was obtained in terms $cm^3/ cm^2/s$.

2.3.2.3 Porosity (%)

(ISO, 1996) Porosity value were calculated using the equation (1) given below

Porosity (%) = 100((1-M))/(h*p) ……… (1)

Where, M = fabric weight (g/m^2), h = fabric thickness (cm), p = fiber density (g/cm^3)

2.3.2.4 Capillary Flow Porometer

ASTM F-316-03 standard, the PMI capillary flow porometer, a fully automated through pore analysis machine, gives information on bubble point, pore size distribution, mean flow pore size. The capillary flow porometer allows you test samples under compression dry and wet condition.

2.3.3 Moisture management properties

2.3.3.1 Drying Rate Tester (DRT)

Dry rate testing was carried out using dry rate tester (figure 1), which evaluates the weight of water evaporated in given time from the fabric.

This device can be used independently to find a drying rate or in conjunction with the SDL Atlas Moisture Management Tester (MMT) in order to obtain a more complete understanding of the moisture management properties of a performance fabric.

<u>Procedure</u>: Sample size of 15 x 15 cm was used for the study, positioned horizontally on the balance. A measurement is taken in dry state and then 1 ml water was added on its surface and placed back on the balance. The software is initiated and sample is allowed to dry for required amount of time in the room conditions. The difference between initial and final weight gives the dry rate % of the fabric sample.

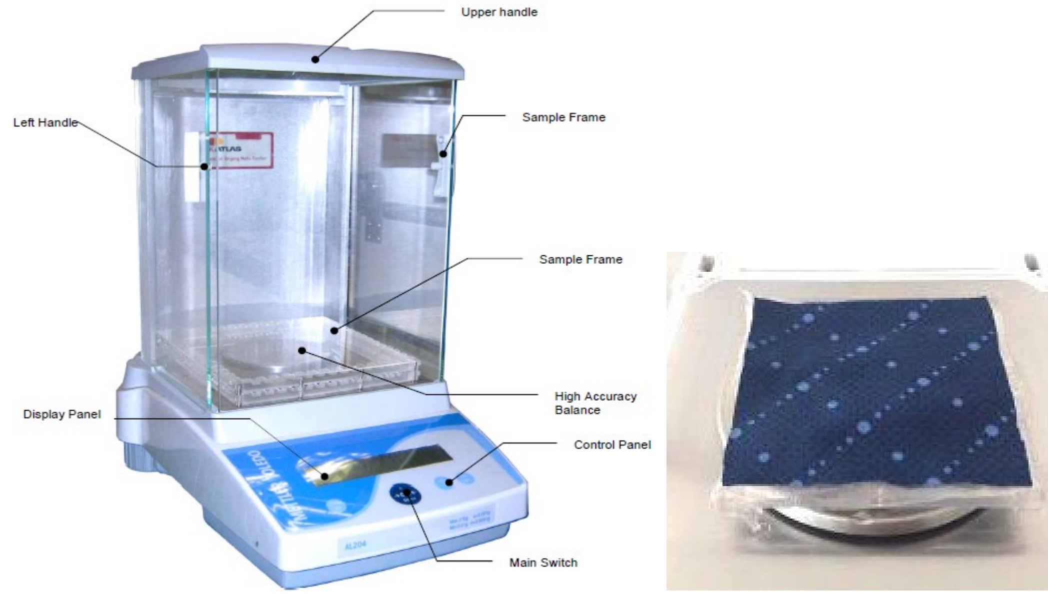


Figure 1: (left) Dry Rate Tester Equipment (right) Sample mounted on backing plate

2.3.3.2 Water Vapor Permeability Tester (WVP)

Water vapor permeability testing is carried out to determine the resistance of textiles and textile composites (particularly action wear fabrics) to water vapor penetration using testing standard BS 3424. This is carried out in the water vapor permeability tester which consists of 8 containers with water reservoirs, a standard permeable fabric cover, sample holder ring and precision drive system (figure 2). The water vapor permeability (WVP) of the fabric is calculated in $g/m^2/day$ is using the equation (i).

$$WVP = \frac{24\,M}{A_t} \quad g/m^2/day \quad \ldots.\ (i)$$

Where, M = Loss of water (g) through fabric,
A = Internal area of the fabric (m^2)
t = Time of testing (24 hours).

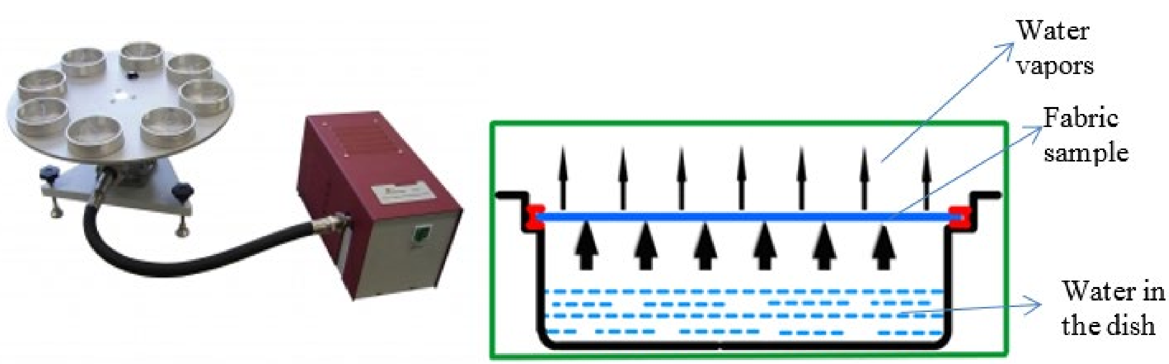
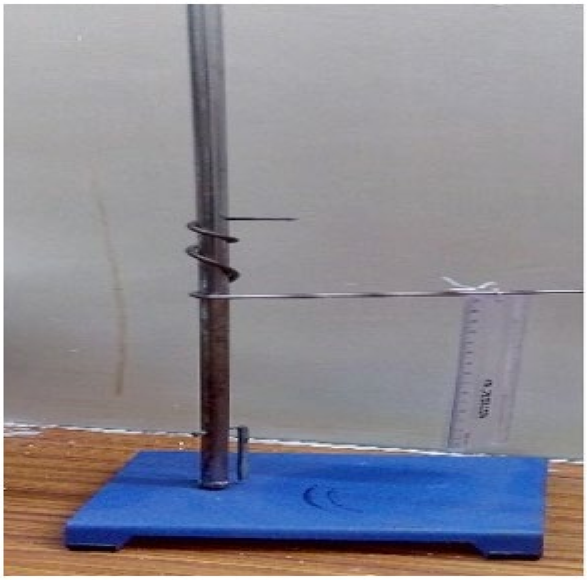


Figure 2: Water Vapor Permeability tester (left) Equipment and (right) Schematic diagram of procedure

2.3.3.3 Vertical Wicking Height

The vertical wicking test of the fabric was carried out according to standard DIN 53924 -strip test method through an apparatus developed in institute lab (figure 3) and the results were measured in terms of wicking height in centimeters'.

Procedure: In this test, a strip of fabric was suspended vertically with its lower edge in a reservoir of distilled water. The rate of rise of water through the leading edge was then monitored. To detect the position of the waterline, a dye was added to water. The measured height of rise in a given time was taken as a direct indication of the wick-ability of the test fabric. The sample size is 20 cm X 2.5 cm and the measurement is recorded 4 times after every 5 min i.e. at 5 min, 10 min, 15 min and 20 min in the wale's direction.



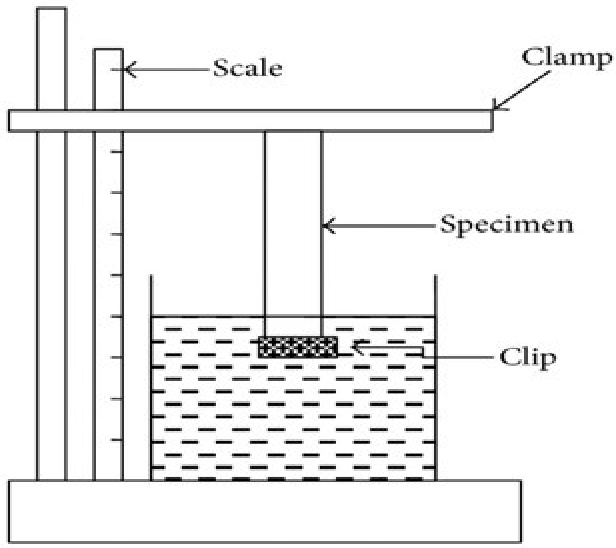


Figure 3: Vertical Wicking Tester (i) Apparatus (ii) Schematic of procedure

3. RESULTS AND DISCUSSION

3.1 Fabric Characterization

The fabric parameters and index properties are first recorded in table 5. The results of index properties are compared using line graphs in figure 4, 5, 6. The areal density of fabric samples is increasing with variation in fabric construction from plain to rib to interlock for all three types of fiber composition. When compared among the fabric composition, the fabric containing spandex fiber has a slightly more areal density which is obvious due to compactness in structure of fabric.

This trend of areal density (figure 4) also governs the decrease in porosity percentage. As the areal density increases, porosity in fabric decreases, thus there is less rate of flow of fabric from surface to inside of fabric capillaries. Therefore, the contact angle is more on the surface of fabric sample.

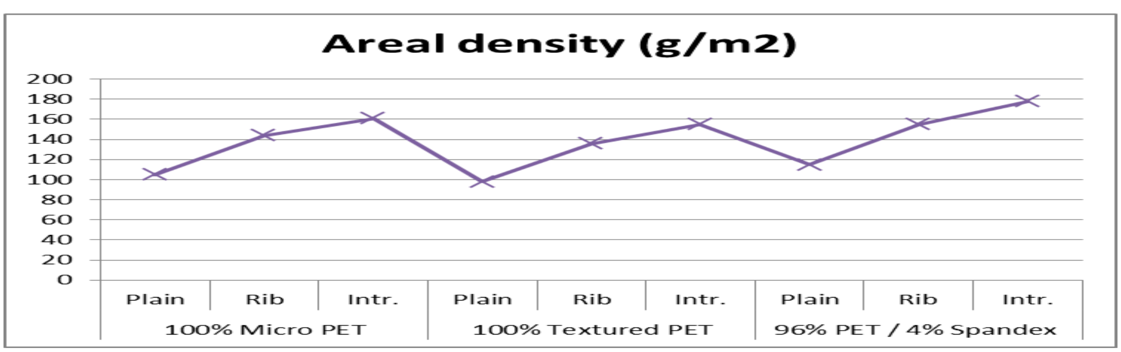


Figure 4: Comparison of Areal Density of Samples

Porosity of fabric also depends on the thickness of fabric. From (figure 5 & table 5) thickness of texturized polyester fabric is more than micro polyester and is highest in case of fabric containing spandex.

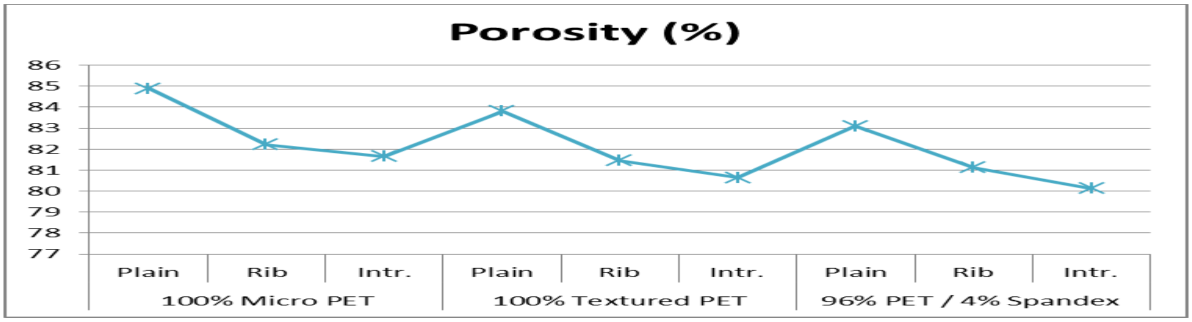


Figure 5: Comparison of Porosity of Samples

Air Permeability directly proportional to porosity also decreases when fabric structure is changed from single jersey to rib and then to interlock (figure 6). When compared in terms of fiber type, there is not a significant effect, but a tentative fall in air permeability is observed in case of fabric with spandex which may be due to its compactness.

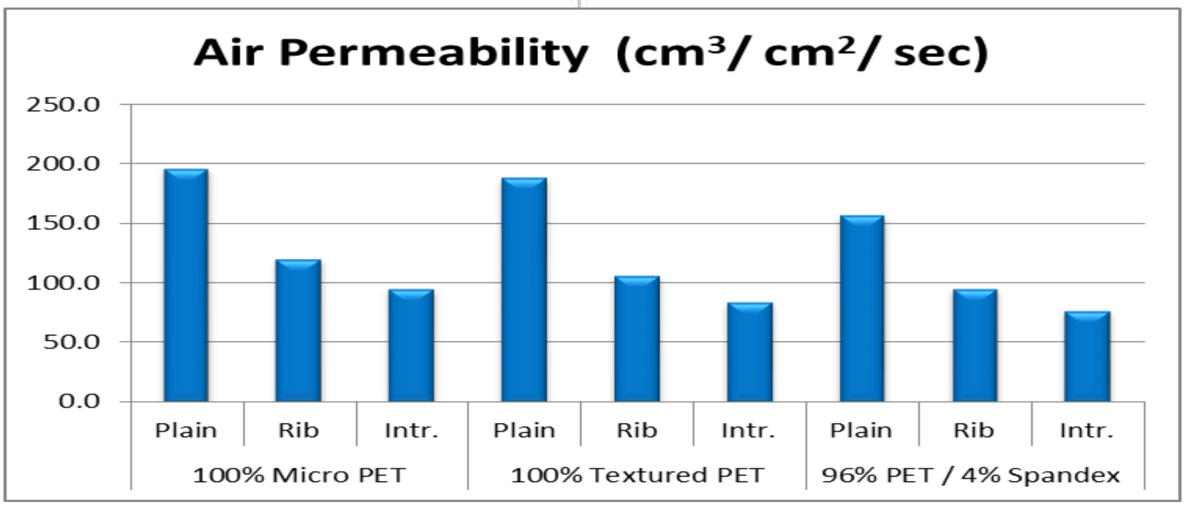


Figure 6: Comparison of Air Permeability for samples

The results obtained from dry rate performance, water vapor permeability and vertical wicking of various fabric samples are tabulated table 6. These results are statistically analyzed and contribution of each variable is calculated in table 7.

3.2 Drying Rate Testing (DRT) and Water Vapor Permeability (WVP)

According results in table 6, DRT and WVP values are uniformly decreasing when fabric structure is changed from Plain single jersey to rib and then interlock structure. Also, the contribution percentage from (figure 7) is higher for fabric structure (72.36%) than fiber content (23.78%) in case of DRT, while in case of WVP contribution percentage for fabric structure (47.66%) and fiber content (58.8%) are approximately close to each other. This analysis directs us towards the fact that both DRT and WVP are the important aspects of moisture management capability. These results also support the MMT results saying Plain single jersey structure to be the best among three in moisture management properties. This is due to the fact that thickness of fabric is less, porosity is high and the capillary channels formed are not obstructed at any stage. However, it will not be wrong to say that micro polyester has the maximum drying rate followed by texturized polyester, because of more capillary channels available in micro polyester than texturized polyester [11-13].

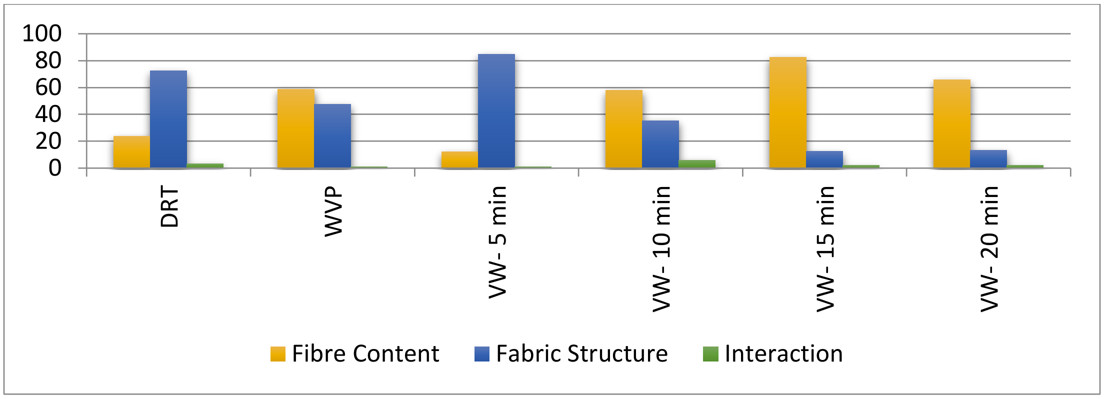


Figure 7: Contribution percentages of independent variables and their interaction on various moisture management properties

3.3 Vertical Wicking (VW)

The vertical wicking rate shows the rate of water transport through the fabric plane against gravity. It is believed that higher wicking rate might reduce skin wetness and so is associated with a dry feeling [14-15]. Also, higher the vertical wicking indicates higher spreading speed as moisture management properties. In this study the vertical wicking is checked at 4-time intervals 5 min, 10 min, 15 and 20 min. In which, values at 20 min does not significantly vary from the values at 15 min for any of the fabric samples (figure 8). Thus, this level can be ignored for further study of vertical wicking for similar sample group. Also, the contribution percentage of fabric structure is higher only till 5 min (84.64%), after that contribution percentage of fiber content is more than fabric structure viz. 10 min – 57.82%), 15 min – 82.54% and 20 min – 65.75%. The vertical wicking of Plain single jersey fabric is faster in each case. But as we move from micro polyester to texturized polyester, due to decrease in density of capillary channels, vertical wicking process is slower and water rise happens significantly faster after 10 min level [16-17].

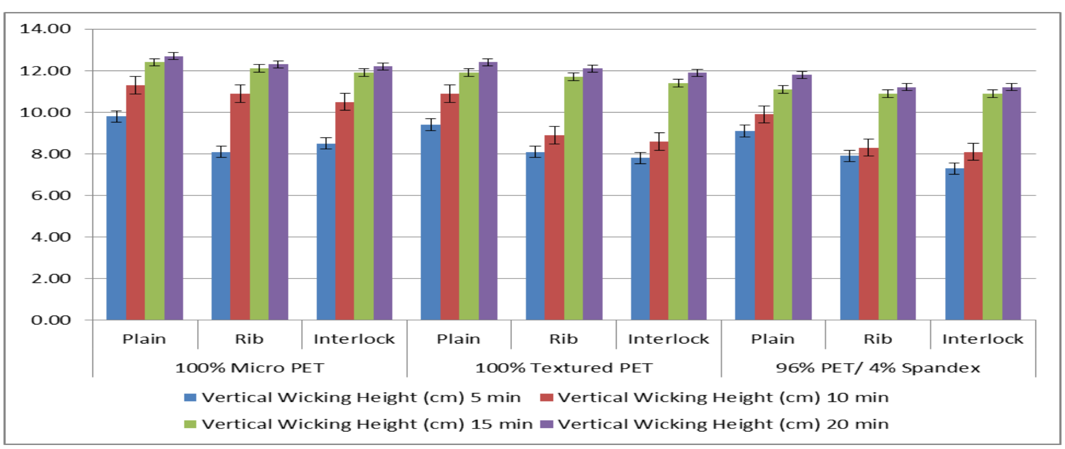


Figure 8: Vertical Wicking of all samples at 4 different time intervals

CONCLUSION

In this research work, the effect of independent variables - fiber content and fabric structure and their interaction is evaluated through Moisture management properties and supporting factors like DRT, WVP and Vertical wicking. All the parameters are significantly affected due to both of independent variables but little due to their interaction. The conclusions derived indicate the best performance from the plain single jersey knit structure manufactured using Micro Polyester. The moisture management properties are found to be directly correlated with dry rate performance, water vapor permeability and vertical wicking. These all properties are further associated with porosity of structure and micro channels available for water transportation, which is highest in case of micro polyester yarn and single jersey knit.

Table 5: Fabric parameters and Index Properties

Sample	**Micro PET**			**100% PET**			**PET / Spandex**		
Fabric structure	**Plain**	**Rib**	**Intr.**	**Plain**	**Rib**	**Intr.**	**Plain**	**Rib**	**Intr.**
Wpcm	20.08	21.26	22.54	13.78	16.57	21.41	21.26	20.08	26.86
Cpcm	20.08	20.47	25.98	24.80	24.50	25.67	21.26	27.56	37.01
Stitch density (loop/cm^2)	411.03	435.19	585.58	341.74	405.96	549.59	451.98	553.40	994.08
Areal density (g/m2)	105	144	161	98	136	155	115	155	178
Thickness (mm)	0.50	0.58	0.68	0.41	0.52	0.62	0.57	0.65	0.81
Loop length (cm)	0.39	0.31	0.26	0.39	0.32	0.26	0.39	0.32	0.26
Tightness factor ($Tex^{1/2}$/cm)	8.53	10.74	12.80	8.53	10.74	12.80	8.53	10.74	12.80
Contact angle, $^{\theta}$	65.12	76.54	89.32	67.34	79.32	94.56	71.82	84.24	109.20
Porosity (%)	84.89	82.22	81.65	83.81	81.45	80.65	83.09	81.12	80.13
Fabric density (g/cm^3)	0.21	0.24	0.23	0.23	0.23	0.24	0.21	0.23	0.21
Pore diameter (µm)	160	117	114	135	102	95	120	97	84

Table 6: Moisture management properties

Fabric		Plain	Rib	Interlock	Plain	Rib	Interlock	Plain	Rib	Interlock
Fabric Content		100% Micro PES			100% Texturized PES			96% PES/ 4% EL		
DRT		0.25 ± 0.01	0.22 ± 0.01	0.18 ± 0.01	0.22 ± 0.01	0.21 ± 0.01	0.18 ± 0.01	0.21 ± 0.01	0.19 ± 0.01	0.17 ± 0.01
	SD	**0.0033**	**0.0009**	**0.0011**	**0.0015**	**0.0016**	**0.0013**	**0.0008**	**0.0023**	**0.0006**
WVP		1472.9 ± 27.2	1309.12 ± 6.7	1179.29 ± 33.7	1374.11 ± 8.2	1255.6 ± 15.8	1084.3 ± 17.8	1151.5 ± 9.2	1068.04 ± 22.8	930.89 ± 6.77
	SD	**11.95**	**7.87**	**14.66**	**3.73**	**11.33**	**8.89**	**16.25**	**11.51**	**6.78**
Vertical Wicking Height (cm)	5 min	9.65 ± 0.25	8.22 ± 0.12	8.5 ± 0.1	9.5 ± 0.1	8.24 ± 0.14	7.73 ± 0.33	9.22 ± 0.12	7.8 ± 0.2	7.33 ± 0.23
	SD	**0.14**	**0.1**	**0.08**	**0.11**	**0.09**	**0.17**	**0.11**	**0.11**	**0.13**
	10 min	11.33 ± 0.13	10.82 ± 0.22	10.47 ± 0.17	10.8 ± 0.11	8.82 ± 0.22	8.53 ± 0.33	9.79 ± 0.19	8.28 ± 0.18	8.24 ± 0.14
	SD	**0.07**	**0.11**	**0.09**	**0.08**	**0.11**	**0.18**	**0.11**	**0.1**	**0.11**
	15 min	12.4 ± 0.1	12.25 ± 0.15	11.8 ± 0.21	11.84 ± 0.14	11.67 ± 0.17	11.48 ± 0.18	11.24 ± 0.1	10.84 ± 0.14	10.82 ± 0.22
	SD	**0.08**	**0.13**	**0.11**	**0.07**	**0.09**	**0.1**	**0.11**	**0.07**	**0.11**
	20 min	12.72 ± 0.92	12.34 ± 0.24	12.05 ± 0.25	12.32 ± 0.42	11.99 ± 0.19	12.1 ± 0.31	11.64 ± 0.2	11.12 ± 0.32	11.05 ± 0.25
	SD	**0.46**	**0.17**	**0.23**	**0.33**	**0.18**	**0.32**	**0.14**	**0.22**	**0.19**

Table 7: Results analysis from ANOVA – F Value and the contribution of independent variables

	F - Value from ANOVA			Contribution Percentage		
Parameters	**x**	**y**	**x.y**	**x**	**y**	**x.y**
DRT	1632.9	4968.2	116.5	23.78	72.36	3.39
WVP	3840.8	3603.6	42.2	58.8	47.66	1.12
VW- 5 min	199.6	1366.2	8.4	12.37	84.64	1.04
VW- 10 min	2293.9	1403.3	119.4	57.82	35.37	5.83
VW- 15 min	870	130.8	10.9	82.54	12.41	2.06
VW- 20 min	112.1	22.4	2.2	65.75	13.16	2.16

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