

## Study of the Effect Functional Finishes on Thermal Properties Sportswear Knit Garments

Ramratan Guru<sup>1</sup>, Awadhesh Kumar Choudhary<sup>2</sup>,  
<sup>1</sup>Research Scholar, <sup>2</sup>Associate Professor, Department of Textile Technology,  
<sup>1,2</sup>Dr. B R Ambedkar National Institute of Technology,  
Jalandhar, Punjab, India

### ABSTRACT

*The sportsperson mainly needs comfort cloth performance during sports activity. The sports and leisurewear exert barrier to the efficient transfer of excess body heat under working conditions and promote sweating, which may result in discomfort to the human body due to temperature change beyond  $37\pm 2^{\circ}\text{C}$ . To overcome this, an effective mechanism for transmission of perspiration and moisture from the skin into the atmosphere is required. Thermal performance of knitted fabrics depends on the thermal insulation needed for the wearer and is affected by the knitted structure and design layout of the wear. Thus, in this study, the thermophysiological competencies of fabrics were investigated after chemical treatments using different levels of concentration of four different finishes. The fabric structure used was weft knitting interlock in three types of fibers - micro polyester, texturized polyester and polyester elastane. The thermal comfort properties of fabric samples have been analyzed in this research work. Textile properties, such as thickness, porosity, air permeability, thermal conductivity and water-vapor transmission rate have been considered and correlated to the thermal and vapor resistance, permeability index and thermal effusivity to determine the overall comfort performance of sportswear fabrics. The overall results indicate towards the fact that thermal properties are directly proportional to thickness, compactness, permeability and in contact surface area of the fabric structure. To see the effect of Functional finishes on the thermal comfort properties of fabrics, the sportswear garments of the treated and untreated samples was measured and compared. It was found that the moisture management finishes did affect significantly the comfort performance of the fabrics. On the other hand, treated fabric samples conserved their strong antibacterial, soil release and ultraviolet finishes activities.*

*Keywords: Sportswear fabrics, thermal properties, functional finishes, laundry cycles*

---

### 1. INTRODUCTION

The clothing plays an important role in providing thermal protection for the human body and creates a comfortable thermal microclimate in that one can survive and live in the thermal environments in which our body cannot cope up alone.

Therefore, thermal functional design of clothing is critically important for human health and comfort, and in extreme cases, it can be a matter of life and death.

In dynamic sportswear, the execution of the sportswear is indistinguishable with its comfort qualities. The vital quality

conclusive factor that influences execution, proficiency and prosperity of sportswear is the wear comfort [1]. Thermal protection of clothing is essential function in most of the environmental conditions in various parts on the earth. The general clothing assemblies approximately covers around 90% of a human body. Therefore, the thermal transmission characteristics of clothing are extremely important, as our body responds to the external thermal environment through clothing. Any physical movement will create distinctive dimensions of the need to discharge unnecessary heat and keep up stable body temperature [2]. With the expanding necessity for pieces of clothing comfort, numerous examinations have concentrated on the comfort properties of fabrics [3]. Finishing of apparel and textile fabric is carried out to increase attractiveness and serviceability. In high active sports like tennis and soccer, heat stress is of great concern due to high level of metabolic heat generation which is in the range of 800 -1300W. This amount of heat can increase the body core temperature by 1.5 - 2°C. To control the core temperature of body, sweat generation takes place and heat of vaporization of water is used to give the cooling effect [4]. Sweat generation can go as high as 2.5L/h and hence the main functional requirement of high active sportswear is sweat absorbing, fast drying and cooling [5]. The first sensation, warm-cool feeling, and the structural roughness of the fabrics change according to fiber type and fabric structure; thus, a warmer feeling can be obtained when the interfacial contact between the skin and the fabric is small for rough fabric [6]. The basic properties for thermal comfort of the dressed body are heat obstruction, air permeability, wicking capacity and water vapor permeability [7]. Human body sweat in two structures, for example, numb (in vapor structure) and

reasonable sweat (in fluid-structure). To be in an agreeable express, the garments ought to enable the two kinds of perspirations to transmit from the skin to the external surface. The development thickness, and materials influence the heat exchange between the human body and nature. Notwithstanding that the encased still air and outside air development are the main considerations that influence heat exchange through the fabric [8]. The thermal comfort property of a dress framework amid dynamic conditions ought to be surveyed dependent on dampness vapor weight change inside the apparel. The surface temperature of the dress and heat loss from the body [9]. The articles of clothing ought to be able to discharge the dampness vapor held in the microclimate to the climate to lessen the soginess at the skin.

The considerable research work has been carried out to study functional finishes and knitted fabrics, but very little published work is available on the use of functional finishes and knitted fabrics for sportswear. Hence in this study, an attempt has been made to analyze the thermal comfort and water vapor permeability properties of functional finishes, laundry cycle performance and Interlock knitted structures made out of micro polyester, textured polyester and polyester- elastane blend fabrics. This study will be of vast help to the researchers who are analyzing the comfort characteristics of functional finishes and knitted fabrics for sportswear.

## 2. Materials and Methods

### 2.1. Fiber, yarn and fabric characteristics

Weft Knitted fabric samples are prepared on circular knitting machine with interlock fabrics using three different filament yarns with details mentioned in (tables 1, 2, 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, * PES- Polyester, *EL- Elastane				

**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 <sup>-1</sup>	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

All fabrics were knitted on Mayer & Cie Relanit circular knitting machine with 26 inches in diameter, gauge 18 and 24 feeders at 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/m<sup>2</sup>) and fabric thickness (mm). WPI and CPI were measured according to the ASTM D- 3887 Standard.

## 2.2. Chemical finishing

All three types of yarns are chemically processed to make the ready for dyeing (RFD fabrics). For this the scouring and bleaching process is carried out followed by application of four functional finishes mentioned in table 4. The method used for finish application is padding mangle with 100% wet pick up.

**Table 4. Functional finishes applied on fabrics.**

Functional Finishes (Producer – Dye Star)	Chemical characteristics	pH level	Ionic nature
Ecofinish AB 1000 antimicrobial finish	Quaternary ammonium compound	6	Cationic
Ecofinish UV 1000 ultra violet finish	Benzotriazole	6	Non-ionic
Evo Fin PSR soil release finish	Modified polyurethane	6-8	Non-ionic
Evo soft HDS moisture management finish	Hydrophilic silicone Softener	4-5	Non-ionic

### 2.2.1. Procedure to apply functional finishes

The three fabric samples are cut into four pieces each and conditioned in standard atmospheric conditions. Then the 12 fabrics of size 30 X 30 cm<sup>2</sup> are cut from the fabrics and are prepared for uniform application of finish as per below steps:

- a. The solutions of all four finishes prepared as per prescribed in TDS (Technical Detail Sheet) provided by the chemical manufacturer.
- b. The cut pieces are immersed in prepared solutions and 1% citric acid binder one by one for 5 min each.
- c. The padding mangle is switched on and set for a speed of 0.25 m/s and roller squeeze pressure of 98.0665 kPa. This pressure is enough spread out the solution evenly on fabric surface and remove excess amount.
- d. The fabric samples are then taken out of solution and passed through padding mangle. A 100% wet pick-up was maintained for all of the treatments.
- e. Then fabric is placed into an air-dry curing oven (which has already been set at 140°C temperature). This process is known as curing and carried out for proper fixing of finish on the surface of fabric sample. Curing is done for 2 min only.
- f. After curing, the fabric sample is immersed into a pre-prepared solution of 2 g/l sodium lauryl sulphate to remove unbound nanoparticles for 5 min.
- g. At last the fabric samples are rinsed with water to remove soap solution followed by air-drying. The fabric samples thus prepared are set for conditioning and testing.

### 2.3. Laundering

Clothing intended for repeated use must be able to be laundered. Thus, it is important to investigate any change in moisture management properties that may occur as a result of laundering. The investigation is carried out for 0 and 10 cycles to record changes occurring in moisture management property after wash.

The finished fabric samples are washed according to JIS-L 1089. This standard gives the most common method employed for home laundering using a neutral powder type detergent [10]. The durability of finishes has also been assessed along with moisture management capability for all fabrics. The laundering was carried out in home washing machine at room temperature i.e. 27°C and the total cycle time of washing and drying was 15 min.

### 2.2. Methods

#### 2.2.1. Testing procedures

The knitted fabrics were conditioned in standard atmospheric RH (65±2%) and temperature (27±2°C) for 24 hours before testing. The fabrics were tested first for their fabric particulars and index properties and then Thermal Properties.

#### 2.2.2. Index properties testing

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

##### 2.2.2.1. 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.

### 2.2.2.2. 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  $\text{cm}^3/\text{cm}^2/\text{s}$ .

### 2.2.2.3. Porosity (%)

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

$$\text{Porosity (\%)} = 100((1-M)/(h*p)) \quad (1)$$

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

### 2.2.2.4. 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

### 2.2.2.5. Thermal comfort properties

The instrument ‘‘Sweating Guarded Hotplate (SGHP)’’ measures the thermal properties of textile materials (according to ISO 11092 or ASTM F1868) under steady-state conditions (figure 1).

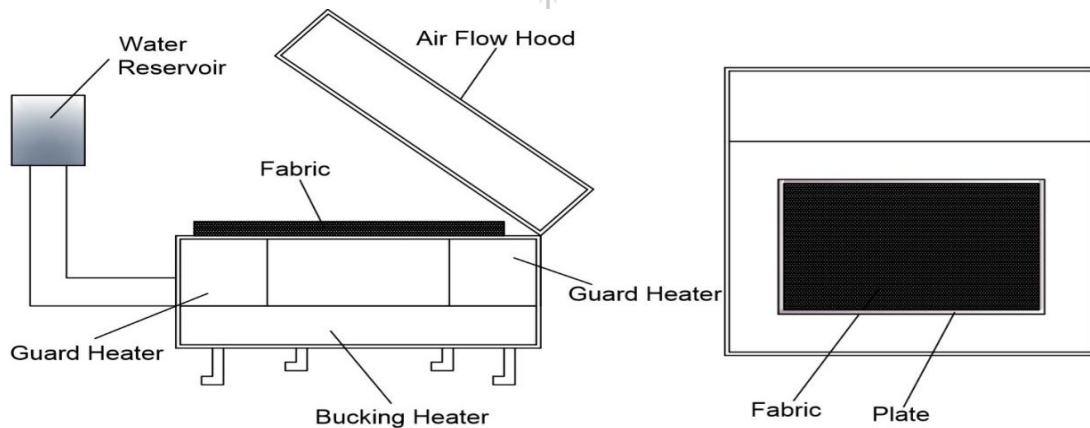


Figure 1. Sweating Guarded Hotplate Tester diagram of SGHP apparatus testing

#### 2.2.2.5.1. Thermal resistance ( $R_{ct}$ )

The thermal resistance of the fabric tests was conducted according to the ISO 11092 and ASTM F1868 test strategy utilizing a perspiring monitored hot plate (SGHP, SDL) under enduring state condition. The Sweating Guarded Hotplate (SGHP) described herein has been developed by Measurement Technology Northwest (MTNW), USA. This device was built to provide simple, fully automated testing in compliance. The velocity created

by the wind stream hood was set to  $1 \pm 0.05$  m/s. Each test in the fabric sample size 30x30 cm was used. For thermal resistance estimation, the example was mounted on the permeable plate, which was preheated to 350°C, while the temperature and RH at the test chamber were controlled at 200°C and 65%, separately. The fabric tests were anchored with adhesive tape keeping away from an air bubble in the test plate. The warmth motion produced by the radiator to keep up the test plate at a consistent

temperature was utilized in estimations for thermal resistance. After the framework achieved the steady-state, the Act of the fabric was determined from the equation (1).

$$R_{ct} = \frac{A(Tm - Ta)}{H - \Delta He} - R_{cto} \text{ (m}^2 \cdot \text{ }^\circ\text{C/w).} \quad (1)$$

where A is the range of the hot plate test unit (m<sup>2</sup>);

T<sub>m</sub> and T<sub>a</sub> are the measuring surface and ambient air temperatures of the plate (°C), respectively;

H is the electrical power supply to the plate maintained at (35 ± 0.1) °C (W);

ΔHe is the correction factor for dry testing (W);

R<sub>cto</sub> is the bare plate reading without any fabric sample (m<sup>2</sup> · °C/w) i.e. the thermal resistance of boundary air)

#### 2.2.2.5.2. Thermal conductivity (λ)

Thermal Conductivity is a property of materials that express the warmth transition (vitality per unit zone per unit time) that will move through the material if a specific temperature slope (temperature diverse per unit length) exists over the material. thermal resistance means that how well a material protects (dry warm opposition in a transient state and wet thermal resistance in the isothermal state) in view of the equation (2).

$$\lambda = T / R \text{ (m}^2\text{K} / \text{W)} \quad (2)$$

Where, R = Thermal resistance, T = Fabric thickness (meter), and λ = Thermal conductivity (W/mK).

#### 2.2.2.5.3. Thermal absorptivity (b)

As the target proportion of the warm-cool sentiment of fabrics, purported thermal absorptivity 'b' [Ws<sup>1/2</sup>/m<sup>2</sup>K] was presented by Hes. This parameter permits an evaluation of the character of the fabrics in the part of its 'cool warm' feeling. At the point when the human touch an article of clothing that has an unexpected temperature in comparison to the skin, warm trade happens between the hand and the fabric,

and the warm-cool inclination is the primary sensation. fabrics with a low estimation of warm absorptivity give a hotter inclination. The better inclination relies upon the client; for summer pieces of clothing, a cooler inclination is requested though in winter a hotter inclination is favored. It is based on the equation (3).

$$b = (\lambda \text{ PC})^{1/2} \text{ (Ws}^{1/2}\text{/m}^2\text{K)} \quad (3)$$

Where, λ = Thermal conductivity (W/mK), P = Fabric density (kg/m<sup>3</sup>), and C = Specific heat of fabric (J/kg K).

#### 2.2.2.5.4. Water vapor resistance (R<sub>et</sub>)

Water vapor resistance of the fabric samples was also tested in accordance with ISO 11092:1993 using the same sweating guarded hot plate (SGHP). The test example was in this manner set on the film and the warmth transition required to keep up a consistent temperature at the plate was estimated. Then Ret under the steady-state condition was calculated using equation (4).

$$R_{et} = \frac{A(Pm - Pa)}{H - \Delta He} - R_{eto} \text{ (m}^2 \cdot \text{ Pa/w)} \quad (4)$$

Where, A is the range of the hot plate test unit (m<sup>2</sup>);

P<sub>m</sub> is the partial water vapor pressure at the measuring surface of the measuring unit (Pa);

P<sub>a</sub> is the partial water vapor pressure of the air (Pa);

H is the electrical power supply to the plate maintained at 35± 0.10c (W); ΔHe is a correction factor for wet testing (W); and Ret<sub>o</sub> is the bare plate reading for the air layer with the membrane (m<sup>2</sup> · Pa /W), i.e. the water vapor resistance of the boundary air.

**2.2.2.5.5. Relative water vapor permeability ( $W_d$ )**

Water vapor permeability was estimated on Sweating guarded Hot plate Instrument working on similar at comparative skin show rule as given by the ISO 11092: 1993(E). Normal for material or composite relies upon water vapor resistance and temperature as per the equations (5).

$$W_d = \frac{1}{Ret \cdot \Phi T_m} \times 100 \quad (5)$$

Where  $\Phi T_m$  is the latent heat of vaporization of water at the temperature  $T_m$  of the measuring unit equals for example 0.672W-h/g at  $T_m = 35^\circ\text{C}$  and  $Ret$  is water vapour resistance

**2.2.2.5.6. Intrinsic water vapor permeability index ( $I_{mt}$ )**

Relation of thermal and water vapor resistances in accordance with equation (6).

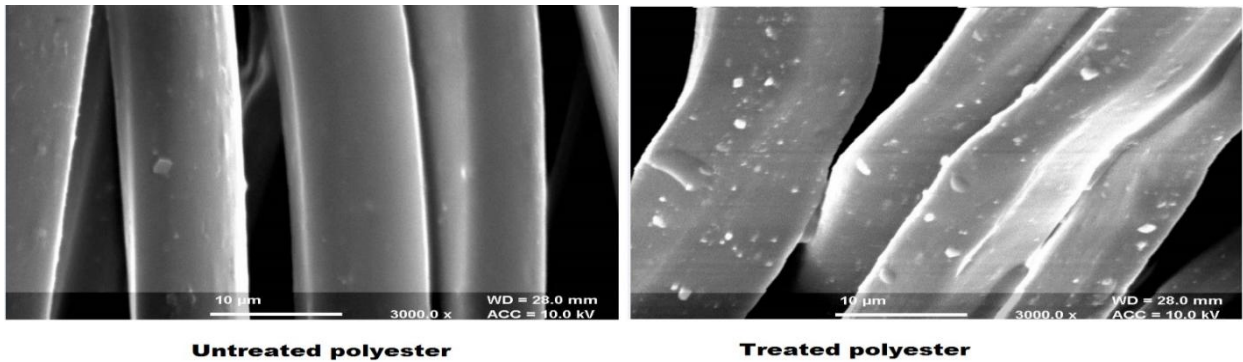
$$I_{mt} = S \cdot \frac{R_{ct}}{Ret} \quad (6)$$

Where  $S = \text{Constant } 60.6515 \text{ Pa}^\circ/\text{c}$ ;  $R_{ct}$ - Dry Thermal resistance and  $Ret$ - water vapor resistance.

$I_{mt}$  is dimensionless, and has values between 0 and 1. A value of 0 implies that the material is water vapor impermeable, that is, it has infinite water vapor resistance, and a material with a value of 1 has both the thermal resistance and water vapor resistance of an air layer of same thickness.

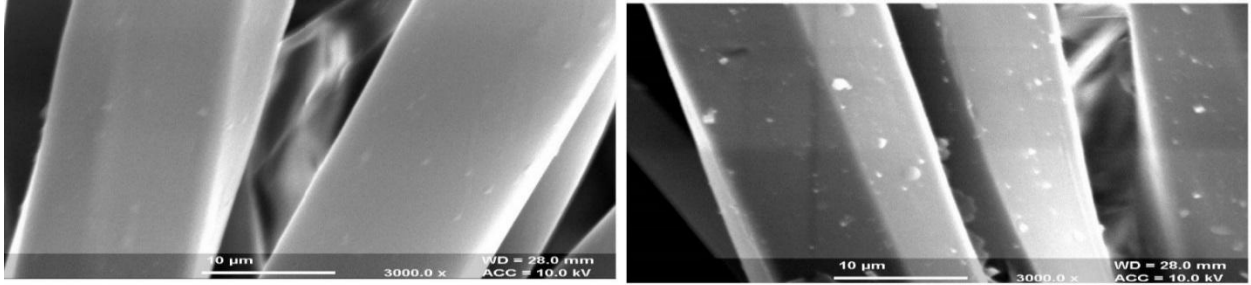
**2.2.2.6. Scanning electron microscope**

The surface of the coated fabrics was investigated using an SEM XL 30, Philips. According to SEM image confirm the impregnation of moisture management finish has used on the surface of the fabric. This can be also revealed from the SEM images of the moisture management finish shown as below figures (2-4). I have used coating on the textured polyester fibers with a particle size ranging 10 nm. The similar trend has also found for the micro-polyester and polyester - elastane blend.



**Figure 2. SEM images of untreated and treated texturized polyester Moisture management finishes.**

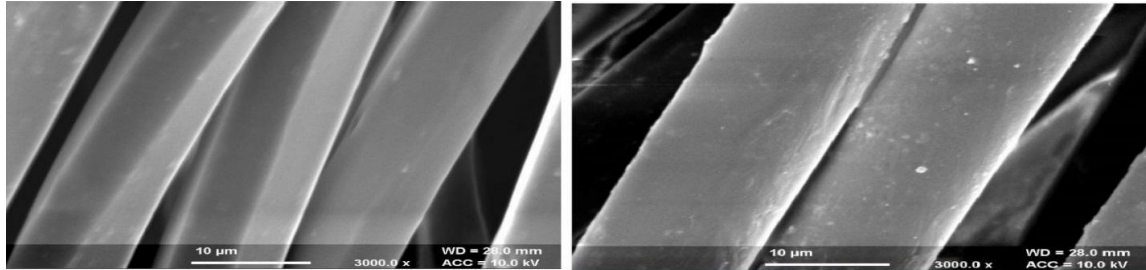




**Untreated Micro polyester**

**Treated Micro polyester**

**Figure 3. SEM images of untreated and treated Micro polyester Moisture management finishes.**



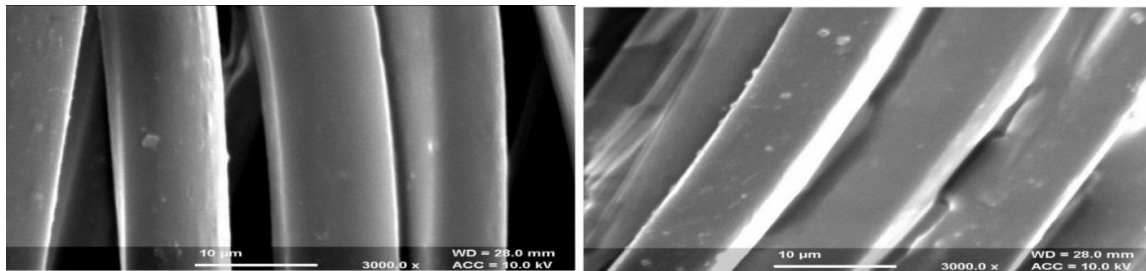
**Untreated polyester spandex blend**

**Treated polyester spandex blend**

**Figure 4. SEM images of untreated and treated polyester-elastane blend Moisture management finishes**

This can be also perceived from figures (5-7) in SEM images at the uniform coating of the antimicrobial finishes on the polyester fabrics surface with a particle size

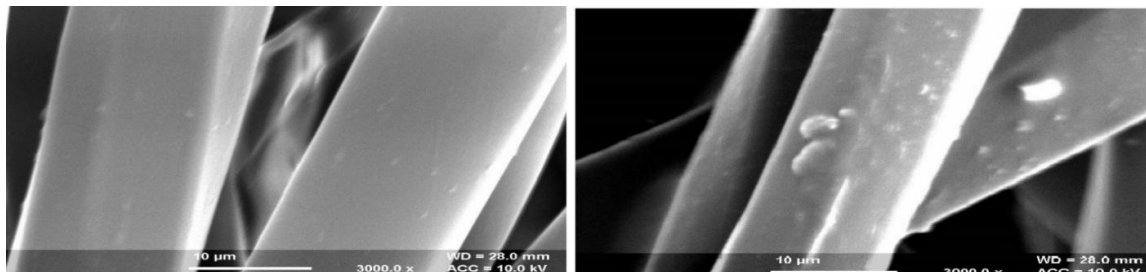
ranging 10 nm. The similar trend has also found for the micro polyester and polyester-spandex blend.



**Untreated polyester**

**Treated polyester**

**Figure 5. SEM images of untreated and treated polyester antimicrobial finish**

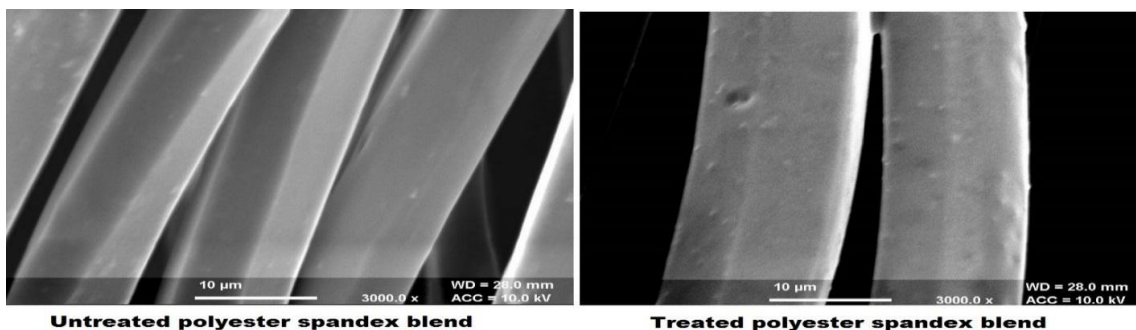


**Untreated Micro polyester**

**Treated Micro polyester**

**Figure 6. SEM images of untreated and treated Micro polyester antimicrobial finish**





**Figure 7. SEM images of untreated and treated polyester spandex blend antimicrobial finish**

The similar trend has been found uniformly coating SEM images on the fabric surface in ultraviolet and soil release finishes.

### FTIR (Fourier transform infrared spectroscopy)

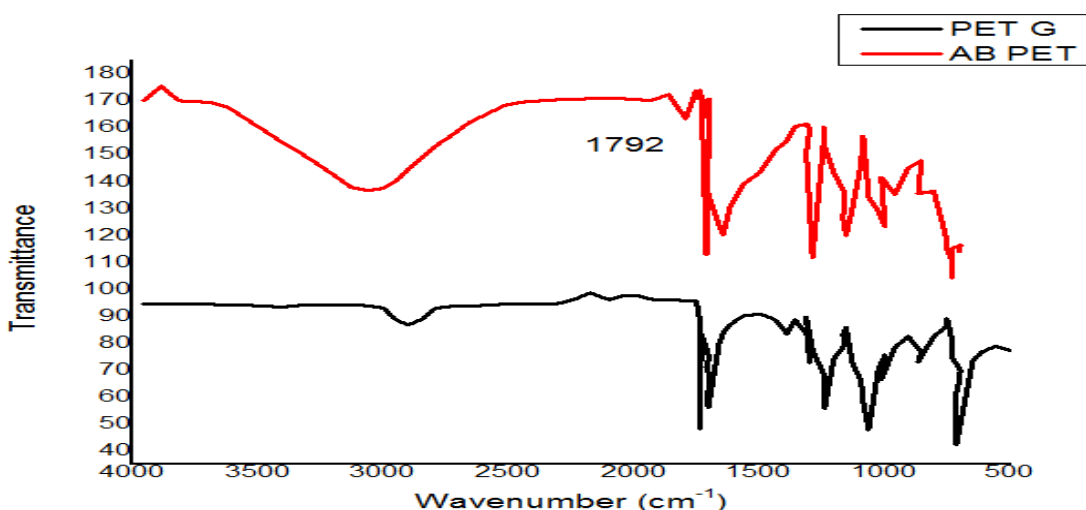
FTIR was recorded at a wave number range of 500 - 4000  $\text{cm}^{-1}$ . The characteristic peaks observed in FTIR graph could explain the presence of the functional group from applied finishes on the fabric surface.

### Antimicrobial finish

Figure 8, shows the FTIR spectra of all the polyester fabrics treated as well as untreated. To confirm the impregnation of finish on the polyester fabric, the fourier

transform infrared spectroscopy was recorded at a wave number range of 500 - 4000  $\text{cm}^{-1}$ . There were some characteristic peaks of the functional group which could explain the presence of antimicrobial finish on the polyester fabric. In the case of polyester knitted fabric, the ester (C=O) bond was observed at 1712  $\text{cm}^{-1}$ , while with treated polyester, N-H asymmetric vibration was observed at 3429  $\text{cm}^{-1}$ . This peak indicates the presence of antimicrobial finish on knitted polyester sample.

It is finally observed that the antimicrobial properties of polyester, micro polyester, blend of polyester-spandex fabrics got improved with the Quaternary ammonium compound antimicrobial finish.



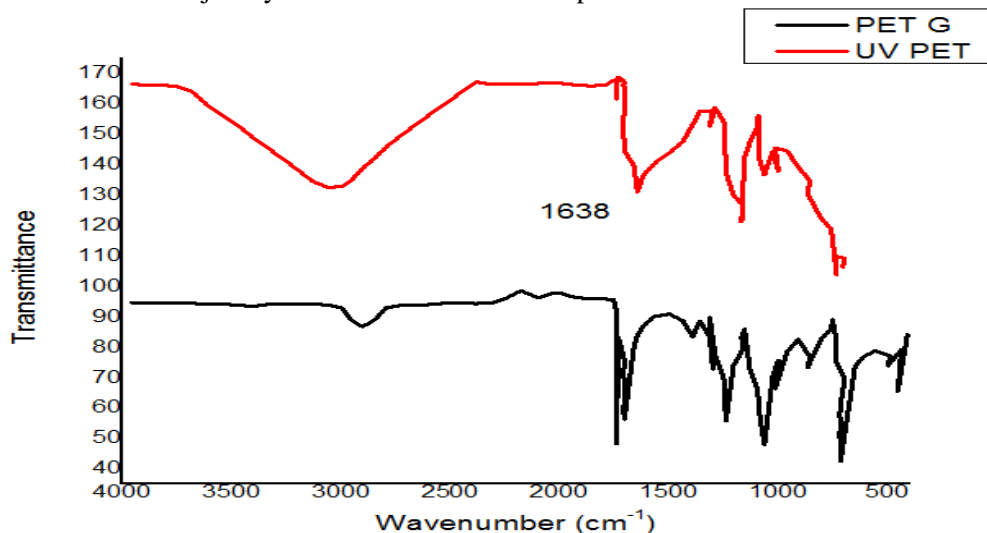
**Figure 8. FTIR spectrum of untreated and treated polyester knitted fabrics Antimicrobial finish.**

### Ultraviolet finish

Figure 9, shows a small peak at  $1638\text{ cm}^{-1}$  in FTIR test. This shows the presence of N-H bond vibration. N-H bonding vibration may also present but often their peak overlap with C=O stretching ( $1712\text{ cm}^{-1}$ ) so it is difficult to justify whether N-H

bonding vibration peak is there. This supported that Benzotriazole UV finish is present on the samples.

It is finally observed that the UV properties of polyester, micro polyester, blend of polyester-spandex fabrics got improved with the Benzotriazole UV finish.



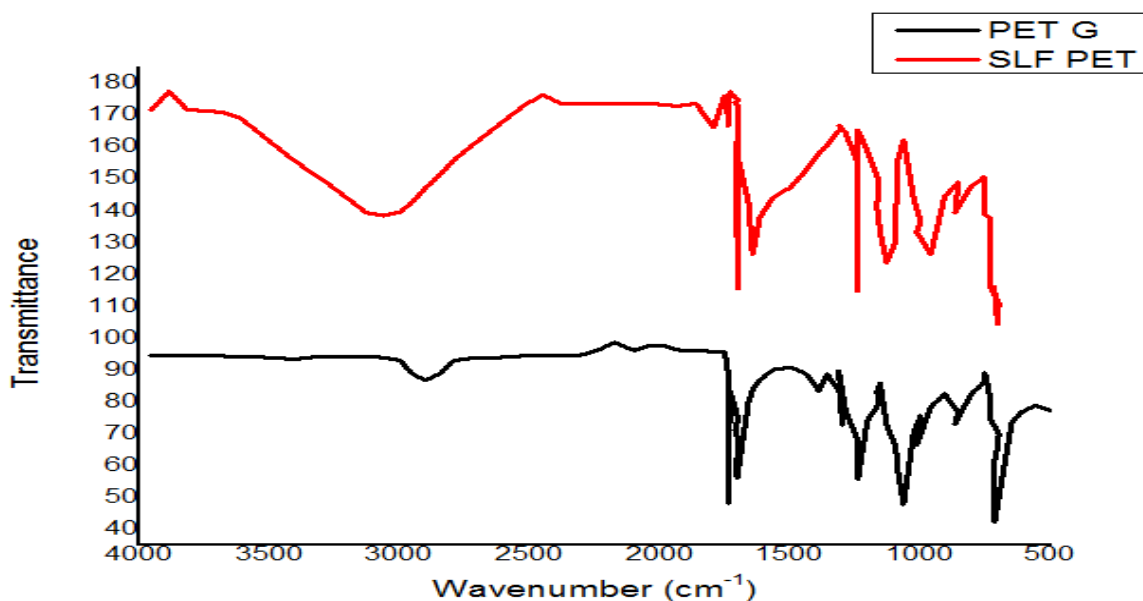
**Figure 9. FTIR spectrum of untreated and treated polyester knitted fabrics UV finish.**

### Soil release finish

From the figure 10, FTIR test result showed that the peak  $3360\text{ to }3380\text{ cm}^{-1}$  (N-H vibration) and  $3530\text{ to }3550\text{ cm}^{-1}$  (OH vibration). The peak of the  $1720\text{ to }1730\text{ cm}^{-1}$  (Urethane C = O vibration),  $1680\text{ to }1690\text{ cm}^{-1}$  (urea C=O vibration) and  $1600\text{ cm}^{-1}$  (aromatic  $\nu(\text{C}=\text{C})$  vibration) are also

significant and showed the presence of Polyurethane soil release finish on the fabrics.

It is finally observed that the soil release properties of polyester, micro polyester, blend of polyester-spandex fabrics got improved with the Modified Polyurethane soil release finish.



**Figure 10. FTIR spectrum of untreated and treated polyester knitted fabrics Soil release finish.**

**Moisture Management Finishes:**

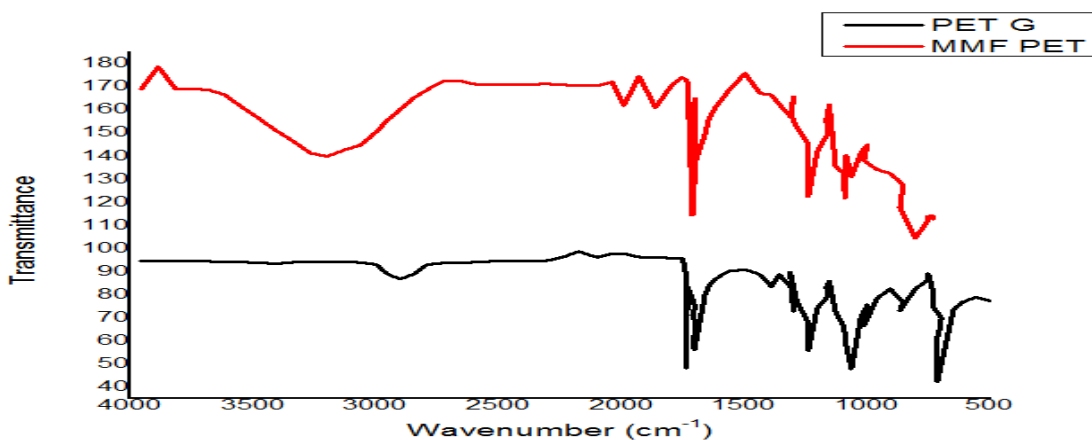
Shown in figure 11, FTIR spectra of all the polyester fabrics treated as well as untreated. There were some characteristic peaks of the functional group which could explain the presence of Moisture

A

T

M

Management finish on the polyester fabric. The peak  $1138\text{ cm}^{-1}$  given importance (Si-o-Si),  $1094\text{ cm}^{-1}$  C-O (stretch bond). This peak indicates the presence of Moisture Management finish on knitted polyester sample.



**Figure 11. FTIR spectrum of untreated and treated polyester knitted fabrics moisture management finish.**

#### 4. Results and Discussion

The fabric parameters and index properties recorded and evaluated in table 5 were used in analysis of thermal properties later. Also mean values of various thermal properties are tabulated here in table 6.

#### 4.1. Fabric parameters and index properties

The results of index properties are plotted in graph to abstract actual trend in figure 12. (a), (b) and (c). as observed:

**Table 5. Fabric parameters and index properties**

Fiber Type	Interlock Knitted Fabric	Fabric Parameters	Areal density (g/m <sup>2</sup> )	Thickness (mm)	Air permeability (cm <sup>3</sup> /cm <sup>2</sup> /sec)	Contact angle, $\theta$	Pore diameter ( $\mu\text{m}$ )
100% Micro PET		Without Finish	161	0.68	94.90	89.32	114
	MMF Finish	Before Wash	174	0.74	95.45	85.36	94.81
		After 10 Washes	170	0.72	95.85	85.09	93.09
	SR Finish	Before Wash	172	0.73	95.11	86.34	92.81
		After 10 Washes	168	0.71	95.23	86.01	92.11
	AM Finish	Before Wash	170	0.72	94.96	86.81	92.91
		After 10 Washes	167	0.70	95.06	86.53	92.23
	UV Finish	Before Wash	169	0.71	94.94	87.11	91.87
After 10 Washes		166	0.69	95.04	86.95	91.03	
100% Texturized PET		Without Finish	155	0.62	84.20	94.56	95.00
	MMF Finish	Before Wash	169	0.68	85.75	89.87	82.31
		After 10 Washes	166	0.66	85.97	89.26	81.08
	SR Finish	Before Wash	168	0.67	85.34	90.78	81.87
		After 10 Washes	165	0.65	85.49	90.16	80.13
	AM Finish	Before Wash	166	0.65	84.76	90.86	80.49
		After 10 Washes	163	0.63	84.87	90.41	79.89
	UV Finish	Before Wash	165	0.65	84.46	91.52	79.03
After 10 Washes		162	0.63	84.61	91.06	78.37	
96% PET / 4% Spandex		Without Finish	178	0.81	76.50	109.2	84.00
	MMF Finish	Before Wash	192	0.87	77.56	96.41	68.89
		After 10 Washes	189	0.85	77.79	96.03	67.09
	SR Finish	Before Wash	191	0.86	77.23	97.57	67.81
		After 10 Washes	188	0.84	77.34	97.07	66.19
AM Finish	Before Wash	188	0.85	76.85	97.83	66.83	

		After 10 Washes	185	0.83	76.93	97.39	65.37
UV Finish		Before Wash	186	0.85	76.85	98.29	65.08
		After 10 Washes	183	0.83	76.91	98.01	64.85

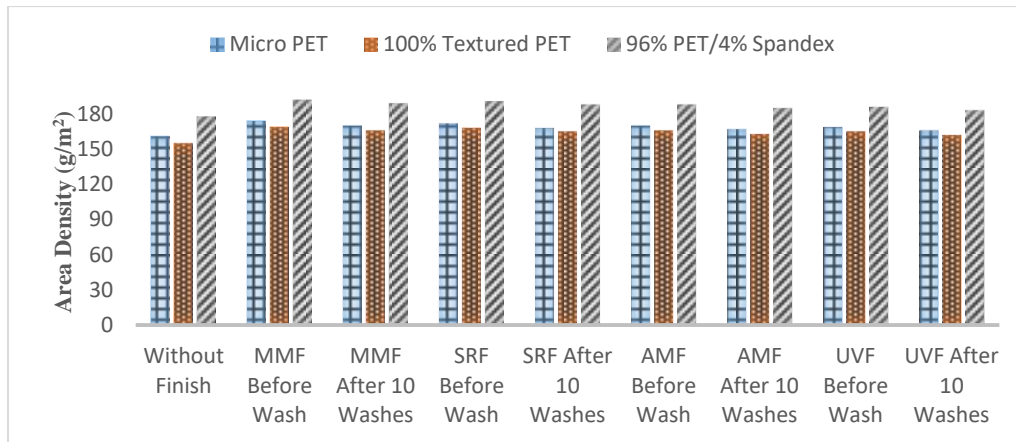


Figure 12. (a) Area density (g/m<sup>2</sup>) index properties of Interlock fabric after various finishes

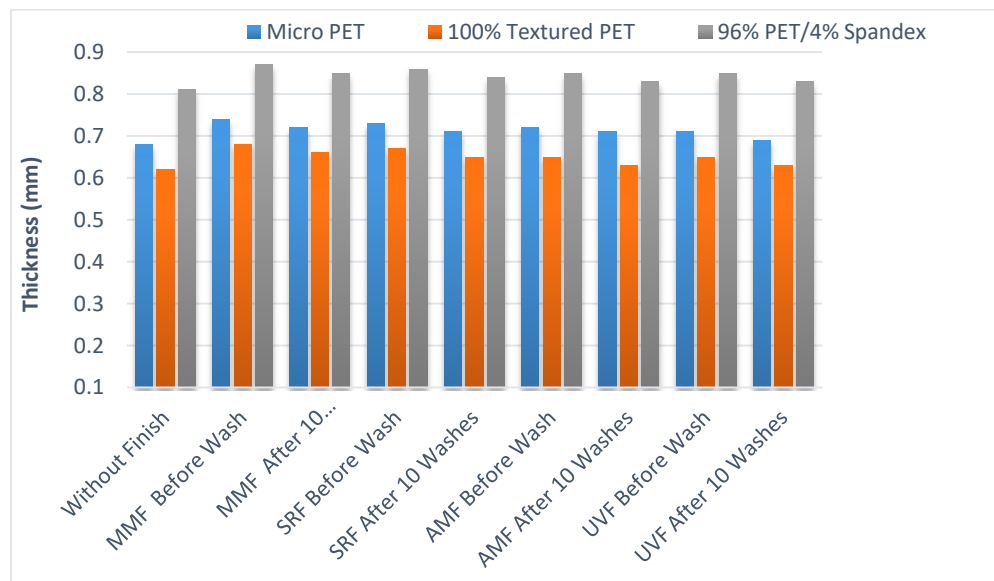
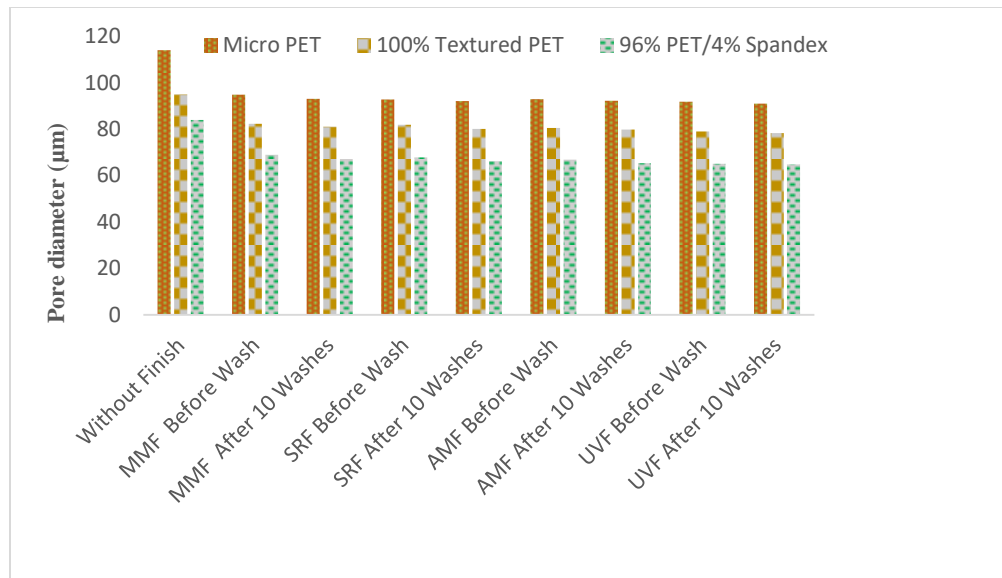


Figure 12. (b) Thickness (mm) index properties of Interlock fabric after various finishes



**Figure 12. (c) Pore diameter ( $\mu\text{m}$ ) index properties of Interlock fabric after various finishes**

### 5. Thermal properties

The thermal properties are evaluated on the basis of thermal resistance, thermal absorptivity, thermal conductivity, water vapor resistance, relative water vapor permeability and intrinsic water vapor permeability index. I have observed to this research work for the main role of the type of fiber, areal density, fiber thickness, pore diameter and finishing performance. This all results recorded in table 6. are statistically analyzed and the contribution of each variable is calculated in table 7.

In the antimicrobial finishes basically are used, when treated knitted fabric thereby increasing the fabric weight, enhancing the dimensional stability and formation of inter fiber and inter yarn bonds. the slight decrease in air permeability most probably is due to the restriction effect of the softener deposits in and/or onto the structure to the airflow. The decrease in heat transmittance of the softened fabrics reflects their ability to resist the transmission of heat. The enhancement in antibacterial functions of the soft-finished samples can be explained by the ability of the used softeners to modify the fabric surface to be more hydrophobic thereby reducing the effect of bacterial growth along with the possibility of

J  
T  
A  
T  
M  
disrupting the cell membrane of bacteria. The similar trend found ultraviolet finishes.

In case Moisture management finish basically is used, moisture management in polyester material could be enhanced appreciably, which could convert hydrophobic fibers into hydrophilic ones. Moisture management finish increases the moisture-holding power of the fibers. The main purpose of a Moisture management finish is to develop the ability of textiles to absorb humidity from the skin, transport it to their outer surface and release it into the surrounding air.

In case Moisture management finish when treated knitted fabric thereby increasing the fabric weight, enhancing the dimensional stability and formation of inter fiber and inter yarn bonds. The slight increase in air permeability. The slight increases in heat transmittance of the fabric. The similarly trend found soil release finishes.

According to results in table 6, thermal resistance ( $R_{ct}$ ) value for without finishes fabric is high compared to after finishes because this is the reason after finishes Increase area density and thickness as shown table 5. The effect of the fabric density on the thermal resistance of fabrics is shown in figure 12 (a). There was an

inverse relationship between fabric density and thermal resistance. Thus, if the fabric density increases, the thermal resistance will decrease. The reason is that the lower the fabric density, the higher the amount of air trapped in the voids in the fabric. The higher the thermal resistance value of the air compared to the textile fibers, the lower the total heat transfer in the fabric and the higher the thermal resistance.

Thermal conductivity ( $\lambda$ ) is an intrinsic property of a material that indicates its ability to conduct the heat. It is the flux of heat (energy per unit area per unit time) divided by the temperature gradient. In table 6, observed the highest thermal conductivity value has polyester 96% /elastane 4% blended knit fabrics. This is most probably due to elastane yarn composition. His supports previous studies, the amount of fiber in the unit area increases and the amount of air layer decreases as the weight increases. As is known, thermal conductivity values of fibers are higher than the thermal conductivity of entrapped air.

In the case of water vapor resistance (Ret) properties observed in from table 6, polyester/elastane fabric shows a maximum value, while micro-polyester fabric displays a minimum value. A lower value is desirable for better moisture transport and higher value indicates that the fabric is less breathable to vapor transmission. Micro polyester fabrics with low water vapor resistance values, it is easier for water vapor to pass through the fabric and into the environment, resulting in drier skin thereby improving comfort. Effect of moisture management finishes on water vapor resistance of micro polyester, textured

polyester, polyester/elastane blend fabrics have a significant effect.

The comparative analysis is carried for the contribution percentages in figure 13. The surface plots are developed from results for all six parameters of thermal properties as shown in figure 14.

### 5.1 Contribution of variables

Both the variables fiber type and fabric finish are contributing to the change in thermal properties (figure 13). According result have found good performance like water vapor resistance, relative water vapor permeability in micro polyester knit fabric. Other fiber polyester-elastane blend knit fabric higher thermal resistance value have observed because is most probably due to elastane yarn composition knit fabric. And other finishes are show minor significant effect on the thermal performance. I have observed table 6, to basically descending order show like soil release, antimicrobial and ultraviolet finishes significant effect have found.

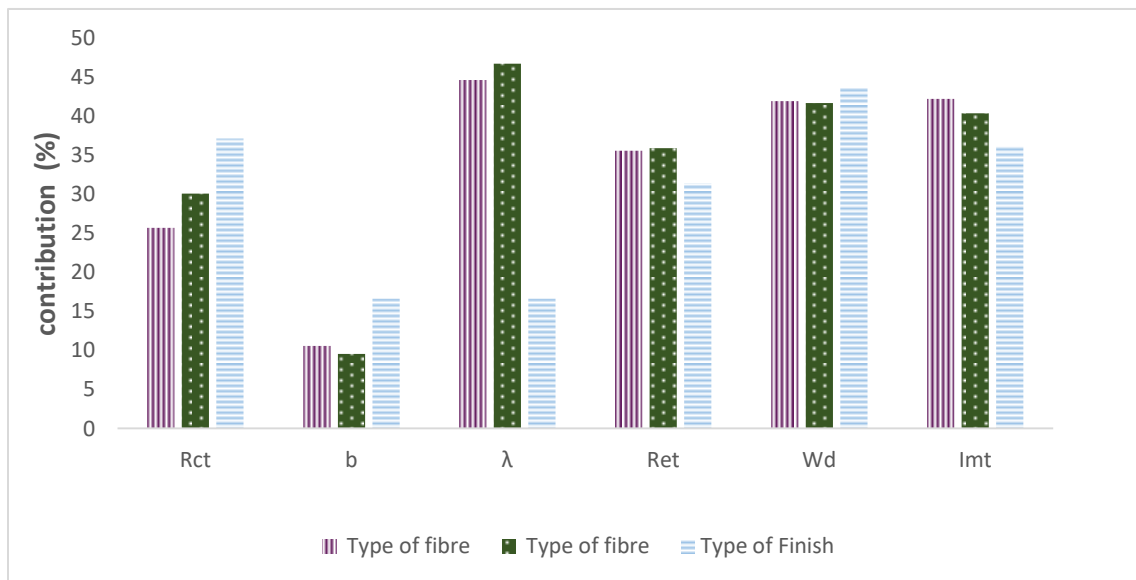
Finish type has more contribution in thermal resistance (37.14%) and thermal absorptivity (16.67%), while fiber type has more contribution in thermal conductivity (44.66%). Other properties are influenced almost equally by both variables. There is a significant contribution observed for the third variable i.e. contribution of finish type has increased after laundering of samples in case of thermal resistance as well as thermal absorptivity. It is also implied from the quadratic equations mentioned in table 7. As indicated in figure 14, all six parameters of thermal properties are plotted against change in yarn structure and fabric structure using the software STATISTICA 6.0.

J  
T  
A  
T  
M



**Table 7. Results analysis from ANOVA - F Value and the contribution of independent variables**

	Type of fiber				Type of Finish			
	After Finishing		After 10 Washes		After Finishing		After 10 Washes	
	F cal.	% Contr.	F cal.	% Contr.	F cal.	% Contr.	F cal.	% Contr.
<b>Rct</b>	16.72	25.71	27.73	30.11	15.53	37.14	26.24	43.33
<b>b</b>	4.306	10.6	4.323	9.551	10.07	16.67	10.29	34.16
$\lambda$	30.36	44.66	32.25	46.73	7.537	16.67	6.969	15.14
<b>Ret</b>	26.89	35.61	30.72	35.92	15.82	31.43	19.69	34.57
<b>Wd</b>	11.29	41.96	3042	41.69	766.2	43.72	2258	46.43
<b>Imt</b>	129	42.23	78.13	40.39	73.64	36.15	12.66	38.98



**Figure 13. Contribution percentages of independent variables on various thermal properties.**

**Table 8. Quadratic equations of thermal properties.**

Thermal Properties	Equation
$R_{ct} =$	$4.8789 - 0.1177 * x + 0.0214 * y + 0.0006 * x * x + 1.2838 * 10^{-5} * x * y - 0.0001 * y * y$
$b =$	$1.1544 * 10^5 - 1648.7014 * x - 603.005 * y + 7.9255 * x * x + 0.3392 * x * y + 2.7274 * y * y$
$\lambda =$	$104.5087 - 1.884 * x - 0.1634 * y + 0.0093 * x * x - 0.0001 * x * y + 0.0008 * y * y$
$R_{et} =$	$-1076.926 - 23.7182 * x + 43.2576 * y + 0.1332 * x * x - 0.0254 * x * y - 0.1955 * y * y$
$W_d =$	$54825.977 - 353.518 * x - 698.2038 * y + 0.6811 * x * x + 1.9795 * x * y + 2.3849 * y * y$
$I_{mt} =$	$279.3867 - 1.3467 * x - 4.0061 * y - 0.0005 * x * x + 0.0135 * x * y + 0.0126 * y * y$

- x be the Fiber type and y be the Finish Type

## 5.2 Thermal resistance

From figure 14. Interlock fabric sample treated with moisture management finish possesses the lowest thermal resistance among other finished and unfinished samples. This may be explained with the results observed for thickness in figure 12 (b). The thermal characteristics of fabrics are mainly dependant on the type of fiber and on the entrapped air within the fabric. Fabric thickness is a major factor affecting heat transfer [11-13]. The thickness value is highest for moisture management finishes. After moisture management finishes, thermal resistance is more for UV and AM finish but all finished samples have lesser thermal resistance than unfinished samples. When comparing within yarn structures for all finish types, the thermal resistance for texturized polyester is lesser than other two structures same as without finish sample.

## 5.3 Thermal absorptivity

A parameter to portray the warm-cool sentiment of fabrics, specifically, the warm absorptivity has been presented. The warm absorptivity is the parameter, portraying the dimension of heat stream, which goes between the human skin of unending warm limit and temperature and the reaching material fabric [6]. As observed in all three polyester fabrics, the interlock fabrics with the highest thermal absorptivity values, gave the coolest feeling at the beginning of skin contact. The analysis of variance showed that the differences between the thermal absorptivity values are significant ( $p=0.000$ ) for all three yarn structures with polyester spandex being at maximum. Further, the type of finish has significantly influenced the thermal absorptivity of fabric samples. The reverse of thermal resistance, moisture management finishes fabric possesses the highest thermal absorptivity. This is because of increased thickness and areal density of interlock fabric when treated with moisture management finishes.

The moisture management finishes are significant affect thermal absorptivity. Thermal absorptivity is less for other

finishes with UV possessing the least absorptivity. The laundering up to 10 washes cycles does not show a significant change in thermal absorptivity [14].

## 5.4 Thermal conductivity

As expected, there is an inverse relationship between thermal conductivity and thermal resistance, as observed  $\lambda$  thermal conductivity in figure 14. As discussed earlier, thermal resistance is highest for moisture management finishes fabric, thus thermal conductivity is least. And similarly, the trend of thermal conductivity of other finishes is inversely proportional to their trend for thermal resistance.

### 5.4.1 Water vapor resistance and permeability

As per figure 14, water vapor permeability is highest for moisture management finishes compare other finishes fabric sample. The analysis of variance indicates that the effect of the finish type on relative water vapor permeability is statistically significant. water vapor resistance (Ret) value is low for moisture management finishes compare other finishes fabric sample. this is better comfort performance of the moisture management finishes [15,16]. This is because the transportation of water vapor through a thicker fabric is difficult. Also, from table 5, water contact angle is least for moisture management finishes. There is not a significant effect seen with variation in yarn structure in our samples.

## CONCLUSIONS

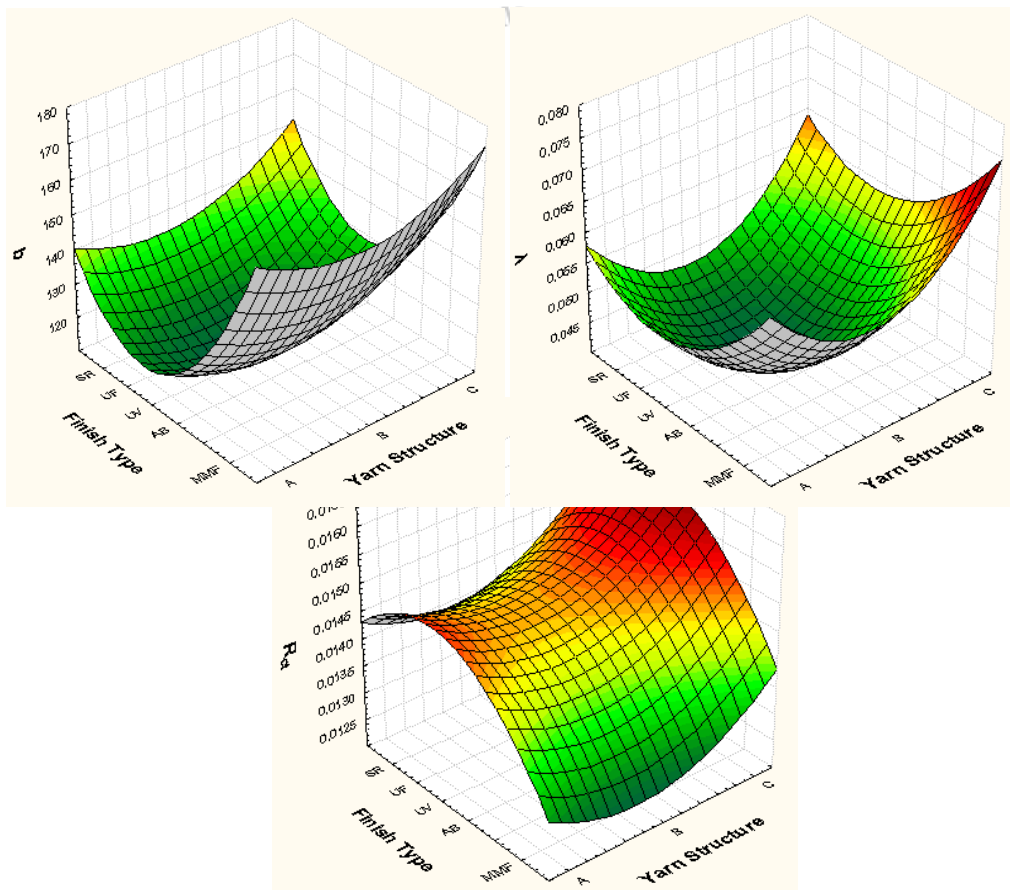
In this research work, the effect of independent variables fiber content and functional finish is evaluated through thermal properties and supporting factors like thickness of fabric, porosity, contact angle and functional of finishes. All the parameters are significantly affected due to both of independent variables. This research work mainly focuses to study the thermal comfort properties of three knitted fabrics with interlock structure made from different

yarn types which were subjected to a moisture management finish, soil release finish, antimicrobial finish and ultraviolet finishes. For this thermal resistance, thermal conductivity, thermal absorptivity, water vapor resistance, relative water vapor permeability and Intrinsic water vapor permeability index were investigated.

- The thermal comfort properties were compared between untreated and treated fabrics. Also, the effects of yarn types on thermal comfort properties were investigated. Moisture management finish treatment gives higher thermal conductivity and thermal absorptivity, lower thermal resistance and improved water vapor permeability fabrics. It has given better performance compared to soil-release finish, an antimicrobial finish and ultraviolet finish.
- After 10 washing cycle I have found all thermal and water vapor permeability better performance slight increase.

- Comparing the yarn types micro polyester fabrics and polyester and elastane fabrics gave higher thermal conductivity resulting in faster heat transfer. Micro polyester and textured polyester fabrics showed lower thermal resistance and higher vapor permeability enabling quicker evaporation of sweat. Polyester and elastane fabrics exhibited higher thermal absorptivity giving a cooler feeling.
- SEM images at the uniform coating of the textured polyester fabrics with a particle size ranging 10 nm. The similar trend is also found for the micro polyester and polyester elastane blend.
- The impregnation of finishes coating on polyester knitted fabrics was also confirmed by FTIR spectroscopy.
- Finally, it is concluded that functional finishing chemicals as found non-toxic can be useful for the sportswear knitted fabric finishing for improving its functional performance.

J  
T  
A  
T



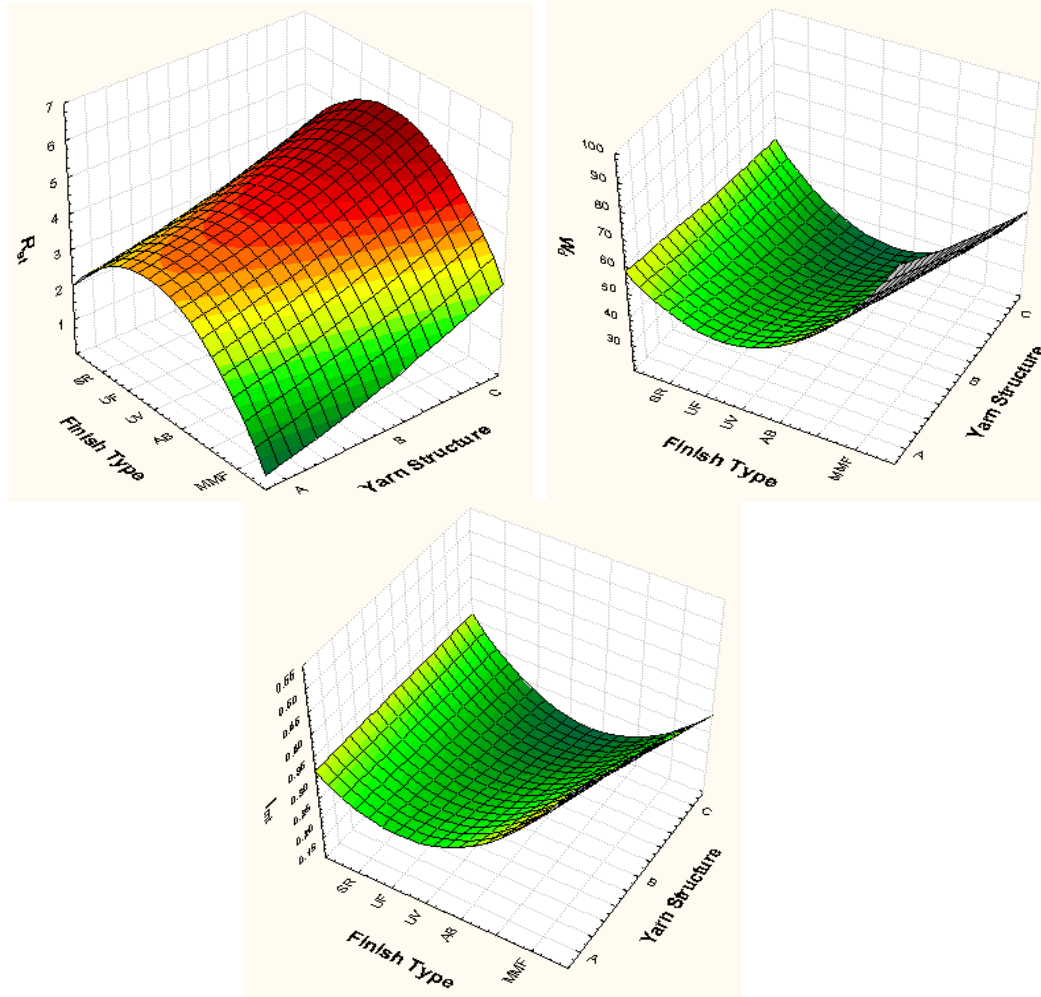


Figure 14. Surface plot representation of effect of variables on thermal properties.

\*  $R_{ct}$  – Thermal resistance,  $b$  – Thermal absorptivity,  $\lambda$  – Thermal conductivity,  $R_{et}$  – Water vapor resistance,  $W_d$  – Relative water vapor permeability and  $Imt$  – Intrinsic water vapor permeability index

\*\*A – 100% Micro PET, B – 100% Texturized PET and C – 96% PET 4% Spandex

#### References

1. Mounir Hassan, Khadijah Qashqary, Hany A Hassan, A shady M A, Influence of Sportswear Fabric Properties on the Health and Performance of Athletes. *Fibres text Eastern Europe*, 2012, Vol 4, pp. 82-88.
2. Esra Tastan O, Binnaz M, Thermophysiological comfort properties of different knitted fabrics used in cycling clothes. *Textile Research Journal*, 2015, Vol. 85, pp. 62-70.
3. A. Das, S.M. Ishtiaque, Comfort characteristics of fabrics containing twist-less and hollow fibrous assemblies in weft. *Journal Textile and Apparel Tech. Management*, 2004, Vol. 3, pp. 1-7.
4. J R. Brotherhood, Heat stress and strain in exercise and sport. *Journal of Science & Medicine in Sport*, 2008, Vol.11, pp. 6-19.

5. Bartels V T, Physiological comfort of sportswear, *Textiles in Sport*, edited by R Shishoo (Woodhead Publishing in Textiles, Cambridge, England) 2005, pp. 176-203.
6. PAC M J, Bueno M A, Renner M, Warm-cool feeling relative to tribological properties of fabrics. *Textile Research Journal*. 2001, Vol. 71, pp. 806- 812.
7. A Das, R Alagirusamy, P. K, Study of heat transfer through multilayer clothing assemblies: a theoretical prediction. *Autex Research Journal*, 2011, Vol. 11, pp. 54- 60.
8. D Brojeswari, A Das, V K Kothari, R Fanguero, M Araujo, Moisture transmission through textiles: Part I: Processes involved in moisture transmission and the factors at play. *Autex Research Journal*, 2007, Vol. 7, pp. 100- 110.
9. Gamze S, Nida O, Nigun O, Arzu Marmarali, Moisture management and thermal absorptivity properties of double-face knitted fabrics. *Textile Research Journal*, 2011, Vol. 81, pp.1320-1331.
10. Lee Sumin, D. Kimura, Keun H. L, J. C. Park, Ick S. K, The effect of laundering on the thermal and water transfer properties of mass-produced laminated Nanofiber web for use in wear. *Textile research Journal*, 2009, Vol. 0, pp. 1-7.
11. Biggi AB, Santos WLF, Rocha A, The effect of structural characteristics on thermal and moisture management properties of 3D fabrics designed for pressure relief applications. *Journal of Textile Science & Engineering*, 2018, Vol. 8, pp. 1-7.
12. Esra T O, Binnaz Meric K, Investigating thermophysiological comfort properties of polyester knitted fabrics. *Journal of Textile Engineering & Fashion Technology*, 2019, Vol. 5, pp. 50- 56.
13. T Suganthi, P Senthikumar, Comfort properties of double face knitted fabrics for tennis sportswear. *India Journal of Fiber & Textile Research*, 2018, Vol. 43, pp. 9-19.
14. Huang F L, Fujy, Cheng K B, Fabrication and functional properties of cooling, thermal insulation, and anti-UV polyester knitted fabrics. *Journal of Textile Engineering & Fashion Technology*, 2019, Vol. 5, pp. 64-67.
15. Ramratan, A. K. Choudhary. Review study of the moisture management finishes in knitted T-shirt activewear. *Asian Textile Journal*, 2019, Vol. 28, pp. 35-39.
16. M. Senthilkumar, M. B. Sampath, T. Ramachandran. Moisture management in an active sportswear techniques and evaluation-A review article. *Journal of the Institute of Engineers*, 2013, Vol. 93, pp. 61–68.

J  
T  
A  
T  
M