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# Effect of Blend Ratio on Thermal Properties of Blended Yarn Weft Knitted Fabrics

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**ABSTRACT:** Transmission properties such as air permeability, water vapor permeability, thermal insulation, thermal resistance and heat flux of a series of polyester/cotton blended yarn knitted fabrics were analysed in an effort to determine physical basis of clothing comfort. Also, for some polyester/cotton blends these transmission properties were predicted with the help of trend analysis. The physical characteristics of knitted fabrics such as thickness, areal density have been studied and their relationship with transmission properties were also analysed using two-way ANOVA. The experimental results show that the thermal conductivity, thermal resistance, air permeability and water vapor transmission rate are mainly dependent on thickness of fabric and not on the constituent blend ratio.

**KEYWORDS:** Air Permeability, Comfort, Heat Flow, Thermal Conductivity, Water Vapor Permeability

## I. INTRODUCTION

Consumers of textile and clothing products are becoming increasingly aware of the importance of the comfort. In addition to aesthetic properties, comfort is the one of the important properties which affects the choice of product. The term comfort is subjective concept which is recognized by the person experiencing it. This state of comfort can be achieved when the most complex interactions between a range of physiological, psychological and physical factors taken place in a satisfactory manner [1, 2]. Clothing comfort can be studied in historical, cultural and social contexts [3] and it can be treated as the physiology of a clothed person in a particular climatic environment.[4] The comfort provided by the clothing depends upon several factors and thermal comfort is one of them and blend ratio, fabric structure and clothing condition are some of the factors which govern thermal comfort. [2, 5, 6] Many factors are involved in thermal comfort; a large number of parameters are interrelated through the way in which fibers are packed into yarn and the fabric construction. N. Mao and S.J. Russell [7] studied the thermal insulation behavior of spacer fabrics and in their study, they found that the thermal properties of knitted fabrics depend on the fiber and fabric thickness. Similar study was carried out by B.V. Holcombe and B.N. Hoschke [8]. They analyzed thermal conductivity in the form of heat transfer through the textiles and found that the thermal conductivity depend on the physical parameters of the fabrics such as fabric thickness, areal density and air permeability.

Here the aim was to understand the physical basis of clothing comfort especially which are next to skin. Four factors are suggested as critical for thermal comfort of clothed body 1- effectiveness to stagnate the air; 2- thermal resistance; 3- vapor transmission properties and 4- liquid water transport. For this study a series of polyester/cotton blends are selected based on their reputed difference in comfort performance. These yarns are then further knitted and test were carried out under controlled atmospheric conditions to determine various thermal, water transport properties of fabrics and discussed how these parameters may have contributed to the recognized difference in comfort performance of polyester/ cotton blend fabrics.

## II. MATERIALS AND METHODS

### 2.1 Materials

100 % hosiery cotton, 100 % spun Polyester yarn and 2 blends of PC yarn with proportions of 20:80 and 35:65 respectively are used to knit a fabric. Care was taken that all the yarns to be used are nearly of same count i.e 30S or nearer to it.



2.2 Preparation of Fabric Samples

Double jersey interlock knitted fabrics were made from 100% cotton, 100% polyester and their blends. Above all yarns are knitted on a double jersey knitting machine and all machine parameters were kept constant for all samples. The details regarding machine parameters are listed in Table 1.

Table 1 - Machine Parameters of Knitting Machine

Machine Type	Double Jersey
Fabric Name	Interlock
Cylinder Diameter	30"
Gauge	24
Feeders	96
Stitch Length	3.3 mm

2.3 Enzymatic Scouring

The double jersey fabrics knitted from cotton, polyester and their blends were cut to the half of their length and this half-length of fabrics were processed on winch dyeing machine. The enzymatic scouring was done in the bath with material to liquor ration of 1:20 and enzyme concentration 20%. The fabric was loaded into the bath at 200C and then the bath was heated to 50-650C for 60 min. No bleaching was carried out. The scoured fabrics were rinsed at 800C for 10 min, twice at 600C for 10 min and cold washed at room temperature for 10 min.

2.4 Raw Material Testing

Yarn unevenness was measured on the Premier yarn Unevenness tester according to ASTM D1425 method. Yarn tenacity and breaking elongation were measured on a Premier Tensomax-7000 tester according to ASTM D2256 procedure. The results for the yarn properties are shown in Table 2.

Table 2 - Raw Material ( Yarn ) Properties

Test parameter	100 % cotton	PC 20:80	PC 35:65	100% Spun PET
Nominal count	30 Ne	30 Ne	30 Ne	172/48 d 32s Ne
Actual count	29.77	29.81	29.73	32
Count CV (%)	0.90	1.08	1.34	0.8
CSP	3022	3036	3067	3108
U%	9.77	9.86	9.77	9.6
Thin places/km	0.3	0.5	1	0.3
Thick places/km	20.8	20.8	45	19.7
Naps/km	35	37.8	110	33
Total imperf./km	56.11	59.6	156	53
Hairiness H	6.36	6.44	7.08	6.28
TPI/Tm	20.04/3.66	19.71/3.60	18.62/3.4	20.0/3.65
RKm	19.94	21.29	23.44	1.22 cN/dtex
Elongation (%)	5.16	6.53	7.90	16.34

2.5 Dimensional Properties of Fabric

The knitted fabrics made out of cotton, polyester and their blends were tested for their dimensional properties and results are listed in Table no.3

Table 3 - Dimensional Properties of Fabric

Sample	WPI	CPI	S.L. (cm)	TightnessFactor
Cotton	38*2	32*2	3.10	1.43
PC 20:80	38*2	32*2	3.00	1.45
PC 35:65	36*2	32*2	3.00	1.46
100 % PET	36*2	32*2	2.90	1.49



2.5.2 Structural Properties of Fabric

As stated above, the fabric properties of fabric for PC 50:50, PC 65:35 and PC 80:20 were predicted according to trend analysis.

2.5.2.1 Thickness (cm)

Thickness is the distance between two opposite surfaces of the fabric. Thickness of the knitted fabric made from cotton, polyester and their blends was measured with thickness tester as per ASTM D 1777. The average results of all readings are plotted in Table 4

2.5.2.2 Areal Density (g/m<sup>2</sup>)

Areal density is the weight per unit area of knitted fabric expressed in gm/m<sup>2</sup>. Areal density was measured with GSM cutter and then the samples were weighed on electronic balance as per ASTM D3776. The test results are given in Table 4.

Table 4 - Structural Properties Of Knitted Fabrics

Sample	Thickness (cm)	Areal Density (g/m <sup>2</sup> )
Cotton	0.86	203.96
PC 20:80	0.86	216.62
PC 35:65	0.80	212.56
PC 50:50	0.81	216.20
PC 65:35	0.80	218.76
PC 80:20	0.79	221.38
100% PET	0.78	224.00

2.5.3 Transmission Properties of Fabric

2.5.3.1 Air Permeability (cm<sup>3</sup>/cm<sup>2</sup>/sec)

Air permeability is important factor for comfort. It defines the rate of volume of air that can pass through unit area of knitted fabrics. In actual knit fabrics, pore is generally of a tetragonal shape & of varying cross-sectional area along its length. Air permeability test was carried out with TEXTTEST FX 300 machine as per IS 9237 standard. The test results of knitted fabrics made from cotton, polyester and their blends are given in Table 5. H. N. Yoon and A. Buckley [4] used an equation developed by Gooding relating air permeability with fabric structure and as given as follow-

$$\frac{Q}{\Delta p} = \frac{1}{8} \frac{\beta^2}{\mu NL} \dots\dots (3)$$

Where,

- Q – Air Flow Rate Per Unit Fabric Area
- L - Fabric Thickness
- N- Number Of Pores Per Unit Area
- Δ ρ – Pressure Drop Across The Fabrics
- M– Air Viscosity
- β – Fabric Porosity



2.5.3.2 Water Vapor Permeability (g/m<sup>2</sup>/24hr)

Water vapor permeability of clothing is an ability of clothing to transmit vapor from the body and it is given in terms of water vapor transmission rate (WVTR). WVTR is defined as ‘amount of water evaporated thorough unit area in a unit time when there is vapor pressure difference of 6.6 mm Hg’. WVTR is solely depending upon geometry of fabric and not on blend ratio and fiber physical property. [4]  
The water vapor transmission was tested on PERMETEST machine as per ASTM E 96-2005 B (water cup) method. The test results of knitted fabrics made from cotton, polyester and their blends are given in Table 5.

2.5.3.3 Thermal Conductivity (W/mK)

Thermal conductivity is an intrinsic property of a material that indicates fabrics ability to conduct heat. It is the flux of heat (energy per unit area per unit time) divided by temperature gradient. It is defined as- ‘the quantity of heat (Q) transmitted through thickness (L) in a direction normal to surface area (A) due to temperature difference (ΔT) under a steady state’ and is given as follow

Thermal conductivity = (Q\*L) / (A\*ΔT) ..... (4)

Thermal conductivity is has direct relationship with areal density of fabric. As fabric becomes heavier, the amount of fiber in the unit area increases hence, the factor governing thermal conductivity i.e. amount of air entrapped in the fabric, gets reduced. And, because of thermal conductivity of fibers is higher than that of still air, fabrics with higher areal density possesses higher thermal conductivity value. [9]

The thermal conductivity was tested on LASERCOMP FX 3314 THERMOCUBE tester as per ASTM D 1518-11a. The test results are given in Table 5.

2.5.3.4 Thermal Resistance (m<sup>2</sup>K/W)

Thermal resistance is a measure of the body’s ability to prevent heat flow flowing through it. Under a certain climatic condition, if the thermal resistance is small, heat energy will gradually reduced with the sense of coolness. Thermal resistance expresses the difference in temperature across a unit area of the fabric of a unit thickness. Thermal conductivity and thermal resistance are related as follow

$\lambda = h/r$  ..... (5)

- λ - Thermal conductivity
- r - Thermal resistance
- h - Thickness

The thermal resistance was tested on Lasercomp FX 3314 thermocube tester as per ASTM D 1518. The test results are given in Table 5.

2.5.3.5 Heat Flux / Intrinsic Thermal Resistance (Qmax) (W/m<sup>2</sup>K)

This property is an indication of feeling (warmth or coolness) when there is mechanical contact between human skin and fabric due to flow of heat from body to fabric which is at lower temperature than the skin. Qmax is an indication of maximum level of contact heat flow which is believed to reach peak value after 0.2 second after the contact is been established. This heat flow is assumed to be increase with increase in thermal conductivity i.e. further increase in areal density and thickness of fabric. The intrinsic thermal resistance was tested on Lasercomp FX 3314 THERMOCUBE tester as per ASTM D 1518-11a.





III. RESULTS AND DISCUSSION

3.1 Structural Properties

3.1 Transmission Properties of Fabric

Table 5 - Transmission Properties of Fabric

Sample	Air Permeability (cm <sup>3</sup> /cm <sup>2</sup> /Sec)	WVTR (g/m <sup>2</sup> /24hr)	Thermal Conductivity	Thermal Resistance (TOG) (m <sup>2</sup> K/W)	Heat Flux (W/m <sup>2</sup> K)
Cotton	125	726	0.55	0.3	31.4
PC 20:80	160	917	0.55	0.31	31.4
PC 35:65	141	892	0.56	0.3	34.9
PC 50:50	173.47	905.11	0.563	0.274	36.86
PC 65:35	184.27	931.556	0.567	0.264	36.6
PC 80:20	195.07	1000	0.571	0.254	40.35
100% PET	233	946	0.58	0.22	44.5

Table 6 - ANOVA Results for Transmission Properties of Fabrics

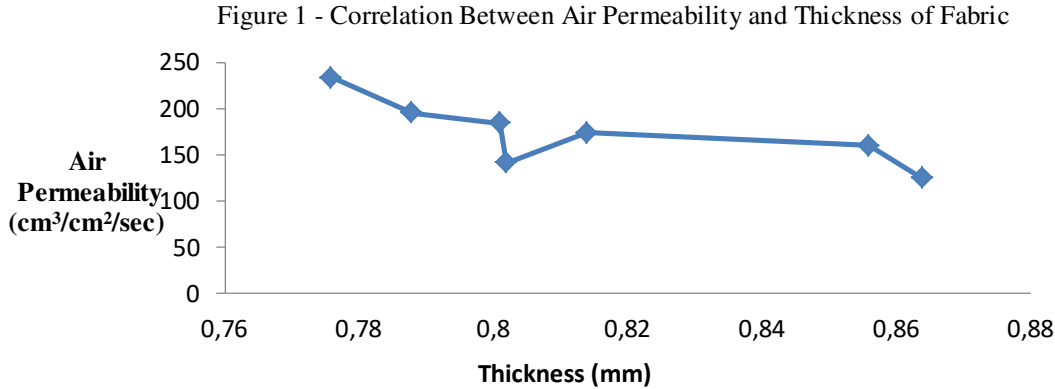
Air Permeability				
Source of Variation	F	P-value	F crit	Result
Sample	5283.032	4.42E-96	3.925834	S
Columns	492.7386	2.45E-64	2.685643	S
Interaction	190.9235	7.2E-44	2.685643	S
Water Vapor Transmission Rate				
Source of Variation	F	P-value	F crit	
Sample	0.235946	0.758261	9.591127	NS
Columns	3.444159	0.259318	5.636944	NS
Interaction	1.985562	0.984519	4.272822	NS
Thermal Conductivity				
Source of Variation	F	P-value	F crit	
Sample	0.059541	0.813364	5.317655	NS
Columns	3.372712	0.075116	4.066181	NS
Interaction	1.217329	0.364514	4.066181	NS
Thermal Resistance				
Source of Variation	F	P-value	F crit	
Sample	0.180804	0.68189	5.317655	NS
Columns	2.591723	0.12519	4.066181	NS
Interaction	1.122062	0.396037	4.066181	NS
Heat Flux				
Source of Variation	F	P-value	F crit	
Sample	7.524959	0.014435	4.493998	S
Columns	7.043661	0.003115	3.238872	S
Interaction	0.858292	0.482684	3.238872	NS

S – Significant Effect

NS – Not Significant Effect

3.2.1 Air Permeability (cm<sup>3</sup>/cm<sup>2</sup>/sec)

As per Gooding’s equation, the air can pass through the interstices of the yarn i.e through the pores available between two successive yarns. Protruding fibers from the surface of the yarn to the pores block this passage and resist the air to flow. This increases the air resistance which is reciprocal of air permeability. Gooding’s equation also shows inverse relationship between thickness of fabric (L) and air permeability. Test result shown in Table 6 shows that air permeability goes on increasing with increase in PET %. This is because, increase in PET fiber % reduces the thickness of fabric hence there will be less still air which is bad conductor of heat.



Hairiness of yarn is another cause for increase in air permeability with increase in PET fiber %. In comparison with 100 % cotton, 100 % polyester has much lower or negligible number of protruding fibers on surface and with incorporation of PET fiber in yarn the hairiness is assumed to be lower. However, in case of PC 20:80 yarn, the diameter gets increased due to improper blending and poor packing of fibers in yarn hence it shows higher air permeability than the PC 35:65 fabric, and with further increase in PET %, air permeability increases.

Due to relaxation treatment, the mechanical stress developed in knitted fabric during manufacturing gets removed and fabric gets shrink and become tight. This increases the stitches per inch (WPI & CPI) which is an indication of reduced air pore size, increased air resistance and reduced air permeability.

Two-way ANOVA shows that both the increase in PET fiber % in blend have significant effect on air permeability. [Table 7]

### 3.2.2 Water Vapor Permeability (g/m<sup>2</sup>/24hr)

100% cotton shows lower WVTR than the 100% PET and this transmission rate increases with increase in PET % in yarn. The values of WVTR for blends are assumed to be between the WVTR values for 100 % cotton and 100 % PET. In case of relaxation treatment too, the transmission rate is bound to come lower for a particular fabric sample and this can be attributed to higher values of GSM and thickness. The tests results for WVTR are simulated in Table no 6. However, no particular trend was observed which can give idea about the significant effect of blend ratio and relaxation treatment on WVTR.

Variation in WVTR observed with fiber composition is solely due to inter yarn pore size and thickness of knitted fabric which are governed by yarn diameter and blending irregularity i.e. further by fiber composition, fiber migration in blend and packing fraction of yarn. Relaxation treatment makes the fiber to shrink, hence stitches per inch increase and air pores reduced which increases resistance to water vapor to flow through the fabric so, WVTR reduces.

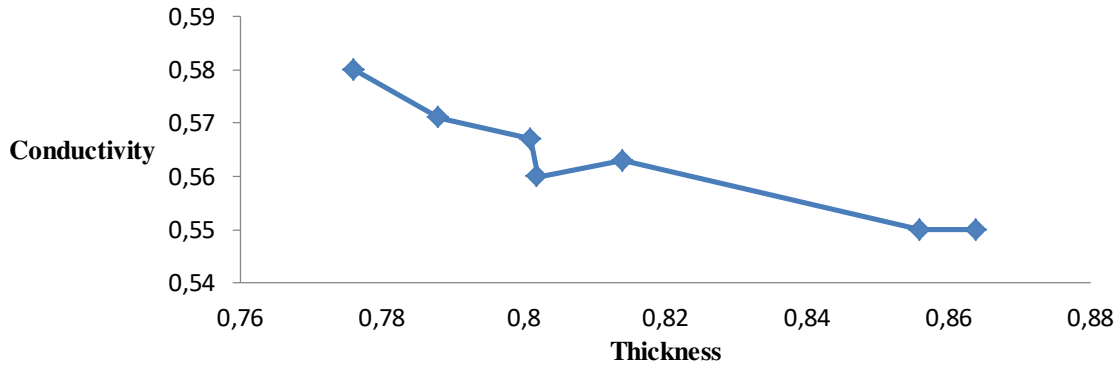
### 3.2.3 Thermal Conductivity (W/mK)

The relationship shown in equation (5) was found existing and thermal conductivity was found increasing with increase in PET fiber %. And after relaxation the value of thermal conductivity is found to reduce (except PC 20:80) with small amount due to reduction in air gaps. However no particular trend was observed and ANOVA [Table 6] also shows that effect of blend ratio and relaxation has non-significant effect on thermal conductivity of the fabric.

Thickness of fabric also play vital role in deciding thermal conductivity of fabric. Increase in synthetic fiber % reduces thickness of fabric hence amount of still air get reduced and thermal conductivity increases. [fig.2]



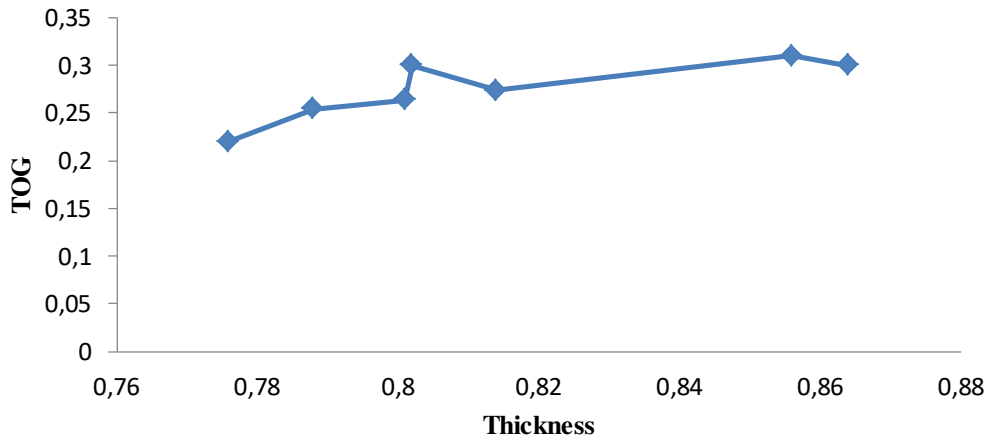
Figure 2 - Correlation Between Thermal Conductivity and Thickness of Fabric



3.2.4 Thermal Resistance (m2K/W)

Thermal resistance is a very important parameter from the point of view of thermal comfort and is depends on fabric structure. In general, inverse relationship exists between thermal conductivity and thermal resistance which shows that thermal resistance is mostly governed by thickness with the linear relationship. Higher the thickness more will be the air pores and as the still air in pore is a bad conductor of heat, thermal resistance increases and is shown in fig.3

Figure 3 - Correlation Between Thermal Resistance and Thickness Of Fabric



However, from the test results shown in Table 6, increase in thermal resistance value is observed after relaxation treatment (except for PC 20:80 fabric). This is because, after relaxation, fabric becomes tight and air pores in the fabric gets reduced which increases resistance to heat flow. However, no any particular trends have been found and ANOVA also shows that the thermal resistance is not significantly affected by blend % in yarn respectively. [Table 6]

3.2.5 Heat flux / Intrinsic Thermal Transmittance (Qmax) (W/m2K)

Heat flux or the intrinsic thermal transmittance follows the same path of shown by thermal conductivity. The test results shown in Table 5 and ANOVA [Table 6] show that with increase in PET fiber %, the heat flow through the fabric increases significantly while after relaxation heat flow decreases significantly due to reduction in amount of still air present in fabric. However, the combined effect of blend ratio and relaxation treatment does not show any significant effect on heat flow through the fabric.





#### IV. CONCLUSION

In this study, the heat transfer process through the interlock knitted double jersey fabrics made from cotton, polyester and their blends were studied. Transmission and structural properties for blends like PC 50:50, PC 35:65 and PC 80:20 was predicted using trend analysis

The transmission properties of fabric like thermal conductivity, thermal resistance, heat flux, air permeability and water vapor permeability are merely determined by structural properties of fabric like thickness and areal density. These properties show relatively small but distinct and effect of blend level. This difference is due to difference in packing fraction of cotton, polyester and their blends i.e further by migration of fibers in yarn. Hairiness might be another cause as these protruding fibers blocks the passage between inter yarn pores which reduced the heat flow through it.

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