

Thermal Comfort Properties of Knitted Fabrics in Dry and Wet States

Arvind Vashishtha¹, Dharendra Sharma²

Assistant Professor, MLV Textile and Engineering College, Bhilwara (Raj.), India

Associate Professor, MLV Textile and Engineering College, Bhilwara (Raj.), India

ABSTRACT: In recent years, there has been a growing emphasis on understanding the thermal properties of textiles due to their direct impact on clothing comfort. Achieving optimal comfort is closely linked to effectively managing moisture within textiles. Moisture management pertains to the controlled transport of water vapor and perspiration from the skin's surface to the surrounding atmosphere through the fabric. This research aims to explore the thermal comfort attributes of selected knitted fabrics, with a specific focus on analyzing the thermal behavior of moisture management finished (MMF) fabrics. The goal is to assess the suitability of these fabrics for diverse climatic conditions. The study involved knitted fabrics crafted from various yarn types, including micro-denier polyester filament, spun polyester, polyester/cotton blends, filament polyester, and 100% cotton.

Several thermal characteristics were evaluated for the MMF fabrics, such as thermal conductivity, thermal resistance, thermal absorptivity, relative water vapor permeability, and water vapor resistance. The results of these tests revealed that the nature of yarn used had a significant influence on the thermal properties once they were converted into fabrics. Notably, the MMF treatment had a marked impact on the thermal behavior of micro-denier polyester knitted fabrics, particularly in terms of thermal conductivity, thermal absorptivity, water vapor permeability, and water vapor resistance. Among the five fabric types, it was observed that micro-denier polyester fabrics facilitated faster heat transfer, accelerated sweat evaporation from the skin through the fabric, and offered a cooler initial sensation upon touch. These findings provide valuable insights into the relationship between fabric composition, moisture management, and thermal comfort, contributing to the development of textiles suitable for a range of environmental conditions.

KEYWORDS: Fabric comfort, Thermal conductivity, Thermal resistance, Water vapor permeability, Water vapor resistance, Moisture management finish

I. INTRODUCTION

The role of thermal protection in clothing is indispensable across various environmental conditions worldwide. Typically, clothing ensembles cover approximately 90% of the human body, making the thermal properties of clothing of paramount importance. This is because our bodies interact with the external thermal environment primarily through the medium of clothing.

The thermal behavior of textile fabrics is also profoundly influenced by the arrangement of fibers within yarns. The packing density of staple yarns exhibits considerable variation depending on how the fibers are structured. Regardless of the production techniques used, textile fabrics are inherently porous materials characterized by a solid matrix with interconnected voids. The thermal transmission characteristics of these fabrics primarily hinge on the porosity they exhibit. It is evident that parameters affecting fabric porosity also play a pivotal role in shaping their thermal behavior.

In terms of the geometric attributes of textile fabrics, fabric thickness emerges as the most influential factor in determining thermal behavior, accounting for over 90% of the observed phenomenon. This is attributed to the fact that an increase in fabric thickness directly impacts fabric porosity due to the corresponding expansion in volume.

Ibrahim et al. [1] stated that properties such as smoothness of the fabric surface, air permeability, heat transmittance, hydrophilicity, knit structure, and the presence of a bio-finish influence the comfort characteristics of the knitted fabric. According to Pac et al. [2] at a given temperature gradient, the heat flow increases with the thermal conductivity of the material. The more a material absorbs thermal energy, the more it acts as a thermal conductor, and the cooler it seems at the very first moment of contact with the human body.

Nida Oglakcioglu et al. [3,4] reported that the smooth surface structure of fabrics after mercerization provides a higher contact area. Also, fabrics made from filament yarns have a channeled fiber structure with a larger surface area.

Ukponmwan et al. [5] stated that fabric and foams filled with still air are better thermal insulators. But, if the void spaces are filled with water, which has higher thermal conductivity, the insulation value of the material decreases. Also, the total thermal resistance of the material is a function of the actual thickness of the material. According to Hes [6,7], after heavy activities or in hot weather, in order to maintain thermal balance the body begins to sweat and till that time the fabric touches wetted skin.

Shekar et al. [8] from their studies had observed the presence of moisture to an extent of 10–20% would cause a reduction in thermal resistance to an extent as high as 50%. Bankvall [9] indicated that the thermal conductivity of fabrics may be greater than a simple addition of the fiber thermal conductivity and the air in the fabric. This is due to the effect of interaction between the heat transfer in fibers and in the air, which becomes stronger as fabric density increases. Hes et al. [10] showed that when the fabrics are wet, the total relative cooling heat flow not only consists of the flow transferred through the fabrics but also of the flow caused by moisture evaporation from the fabric surface. Jintu Fan et al. [11] reported that the thermal comfort sensations during active sportswear are strongly related to the moisture vapor resistance and moisture accumulation within clothing. Indu shekar et al. [12] stated that the water vapor sorbed by substrate replaces the entrapped air in the interstices between fibers and yarns, and hence, it reduces the insulating effect of the material. According to Greyson [13] and Havenith [14], heat and water vapor resistance increases with the increment in material thickness and air entrapped in the fabric.

The aim of this research is to analyze thermal comfort characteristics of the MMF knitted fabrics made from the selected yarns such as micro-denier polyester, spun polyester, polyester/cotton, filament polyester, and cotton yarn, and to know the level of performance of micro-denier polyester knitted fabrics among the selected materials, in order to find out the suitability of optimized micro-denier polyester knitted fabric to be used in different climatic conditions.

II. MATERIALS AND METHODS

Five different types of yarns, namely micro-denier polyester (M1), spun polyester (M2), polyester/cotton blend yarn (M3), filament polyester (M4), and 100% cotton (M5), was used for the study. All the yarns were of the same count or denier (i.e.) spun polyester, polyester/cotton, and cotton were 35 s Ne count, whereas micro-denier polyester (containing 108 filaments) and filament polyester (containing 34 filaments) were of 150 denier average fineness. The selected yarns were knitted on the circular knitting machine of 28 gauge to produce five different fabrics of single jersey plain structure containing 2.9 mm stitch length.

Micro-denier polyester, spun polyester, and filament polyester fabric samples were first hot washed and then bleached. Cotton and polyester/cotton fabrics were first scoured and then bleached. All the five fabric samples were then coated with wetting agent (1 gpl) and acetic acid (0.2 gpl) for 15 minutes at 60°C–70°C temperature at material is to liquor ratio of 1:10. After this wetting process, the five varieties of fabrics were treated for MMF. That is, the fabric samples were treated with Ultraphil Hydrophilic Soluble Dispersion (30 gpl) and acetic acid (0.2 gpl). Ultraphil Hydrophilic Soluble Dispersion is a dispersion containing a chemical combination of hydrophilic polysiloxane and hydrophilic polyester. The fabric samples were treated in the finishing bath with pH value of 5.5 at 60–70°C temperature for 10 minutes. The fabric samples were then dried and cured at 150°C and subjected to relaxation for 48 hours.

III. TESTING METHODS

Thermal comfort characteristics such as thermal conductivity, dry thermal resistance, wet thermal resistance, thermal absorptivity, relative water vapor permeability, and water vapor resistance of the fabrics were measured. Alambeta instrument was used to measure thermal conductivity, fabric thickness, dry thermal resistance, and thermal absorptivity values. The specimen is kept between two plates provided in the instrument, one is hot and another is cold. A pressure of 200 pa is kept in the hot plate, while contacting the specimen. With the heat flux sensors, the flow of heat is measured, while hot plate touches the specimen. One observation time is 30–50 seconds.

Wet thermal resistance and water vapor resistance were measured using sweated guarded hot plate as given by ISO 11092:1993. This model measures the water vapor resistance of the fabric by measuring the evaporative heat loss in the steady state condition. In this method, water is supplied through holes in the guarded hot plate and distributed onto a wet membrane, which is placed on the hot plate to simulate sweating skin.

Relative water vapor permeability was measured on 'Permetest' instrument working on similar skin model principle as given by the ISO 11092. The temperature of the measuring head is maintained at room temperature for isothermal conditions. The heat supplied to maintain the temperature of the measuring head, from where the supplied water gets evaporated, is measured. The heat supplied to maintain a constant temperature with and without the fabric mounted on the plate is measured.

Thermal conductivity is a property of materials that expresses the heat flux (energy per unit area per unit time) that will flow through the material if a certain temperature gradient (temperature difference per unit length) exists over the material. Thermal resistance is an indication of how well a material insulates (dry thermal resistance in transient state and wet thermal resistance in isothermal state).

Table 1. Effect of material type and MMF treatment on thermal characteristics of the knitted fabrics (ANOVA statistical analysis)

Specification	Material effect (6.39)	Treatment effect (7.71)
Thickness	4.31	2.93
GSM	5.86	4.08
Coefficient of thermal conductivity	2.95	5.31
Thermal absorptivity	10.18*	14.80*
Dry thermal resistance (transient state)	2.29	3.23
Wet thermal resistance (isothermal state)	9.82*	2.96
Relative water vapor permeability	15.93*	4.36
Water vapor resistance	11.23*	1.80

MMF: moisture management finished, ANOVA: analysis of variance, GSM: grams per square meter.

*Significant effect.

IV. RESULTS AND DISCUSSION

The geometrical characteristics of five different knitted fabrics were measured and the average value of 10 samples is given in Table 2.

The wale and course density of the fabrics were increased after MMF applied. This area shrinkage due to finishing treatment affects the areal density (g/m^2) of the fabrics. Micro-denier polyester and filament polyester fabrics exhibit higher grams per square meter (GSM) and thickness than the other three fabrics. After MMF, there is an increase of 7% in GSM and 9% in thickness for both filament fabrics. Spun polyester and polyester/cotton show 6% and 9% increase in GSM, while the increase in thickness is 2% and 4%, respectively. Cotton exhibits a marginal 3% increase in GSM and 2% increase in thickness values. The application of MMF has reduced the loop length for all five fabrics thereby showing an increase of 8.5% in stitch density for all five selected fabrics.

The thermal comfort characteristics such as thermal conductivity, thermal resistance, thermal absorptivity, relative water vapor permeability, and water vapor resistance of five different knitted fabrics are given in Table 3. The MMF fabrics were compared with untreated fabrics and the effect on thermal behavior of the fabrics was also studied.

Table 2. Fabric geometrical characteristics

Material type	Wales cm	perCourses cm	Stitch density per(loops/cm ²)	Areal density (gms/m ²)	Loop length (mm)	Thickness (mm)
M1 UT	16.93	16.81	284.59	126	2.9	0.51
M1 T	17.85	17.71	316.12	135.5	2.7	0.56
M2 UT	16.53	14.96	247.28	106	2.9	0.44
M2 T	17.32	15.74	272.61	113	2.8	0.45
M3 UT	16.28	15.02	244.52	100	2.9	0.41
M3 T	17.13	15.56	266.54	110.5	2.8	0.43
M4 UT	16.91	16.53	279.52	121	2.9	0.5
M4 T	17.82	17.36	309.35	130.5	2.7	0.55
M5 UT	16.89	16.45	277.84	122	2.9	0.44
M5 T	17.66	17.28	305.16	126	2.8	0.45

UT: untreated fabric, T: moisture management finished fabric; micro-denier polyester (1), spun polyester (2), polyester/cotton blend yarn (3), filament polyester (4) and 100% cotton (5).

Table 3. Thermal comfort characteristics of untreated and MMF fabrics

Material type	Coefficient of thermal conductivity (W/m K)	Thermal absorptivity ($W_s^{1/2}/m^2 K$)	Dry thermal resistance (transient state; $m^2 K/W$)	Wet thermal resistance (isothermal state; [Rct]; $m^2 K/W$)	Relative water vapor permeability (%)	Water vapor resistance (Ret; Pa m^2/W)
M1 UT	0.039	101.9	0.0186	0.0119	72.48	2.59
M1 T	0.0423	113.8	0.0181	0.0110	74.06	2.07
M2 UT	0.035	77.02	0.0243	0.0244	64.28	3.26
M2 T	0.0357	84.54	0.0218	0.0206	65.2	2.49
M3 UT	0.035	78.10	0.0243	0.0260	65.06	3.31
M3 T	0.0358	96.42	0.0187	0.0191	69.28	2.53
M4 UT	0.035	91.60	0.0201	0.0143	68.82	2.54
M4 T	0.042	110	0.0199	0.0134	70.10	2.52
M5 UT	0.036	97.60	0.0209	0.0194	66.16	2.84
M5 T	0.0377	100.3	0.0200	0.0179	67.44	2.73

MMF: moisture management finished, UT: untreated fabric, T: moisture management finished fabric; micro- denier polyester (1), spun polyester (2), polyester/cotton blend yarn (3), filament polyester (4), and 100% cotton (5).

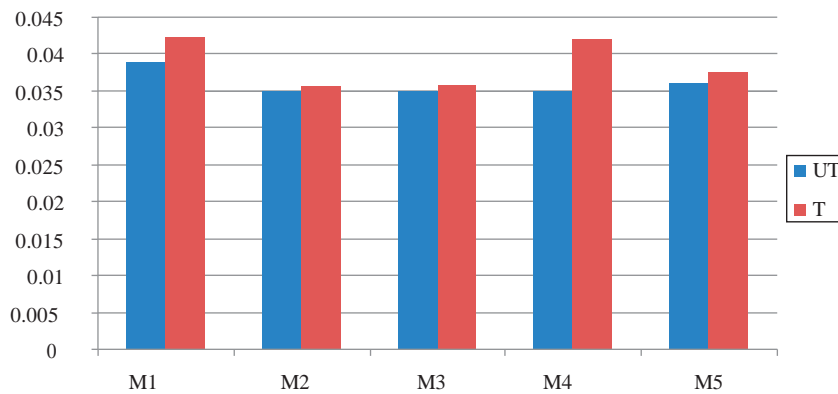


Figure 1. Thermal conductivity of untreated and moisture management finished (MMF) fabrics (X-axis = different type of knitted fabrics, Y-axis = coefficient of thermal conductivity, W/m K).

Thermal conductivity

Thermal conductivity is a phenomenon which indicates the capability of material to conduct heat from one point to another point. A look at Figure 1 shows that fabrics made of micro-denier polyester has a higher thermal conductivity than those of other fabrics.

The fabric knitted with micro-denier polyester filament yarns have higher thermal conductivity values than those knitted with spun yarns. On application of MMF there is an increase in values between 8% and 16% for filament yarn fabrics and only a marginal increase of 2–4% for spun yarn fabrics. This may be due to the larger surface area of the continuous filament yarns thereby giving a higher pickup [3]. Comparing the different fabrics it was seen that in fabrics made of filament yarns the air gaps are less because of higher fabric aerial density. As mentioned in the earlier literature [7], when fabric areal density increases the effect of interaction between the heat transfer in fibers and in the air becomes stronger thereby increasing thermal conductivity. Here, fabric areal density plays a vital role in obtaining higher thermal conductivity.

Spun polyester and polyester/cotton fabrics show lower values because of lower fabric areal density. This is due to more amount of entrapped air in these structures. Effect of MMF on thermal conductivity of the micro-denier polyester and filament polyester fabrics have significant effect at 95% confidence level.

Thermal absorptivity

Thermal absorptivity is a factor that indicates the ability of the material to regulate as per thermal condition. It allows assessment of the fabric’s character in the aspect of its cool–warm feeling. The parameters that are taken into account for computing thermal absorptivity are thermal conductivity, specific heat, and density.

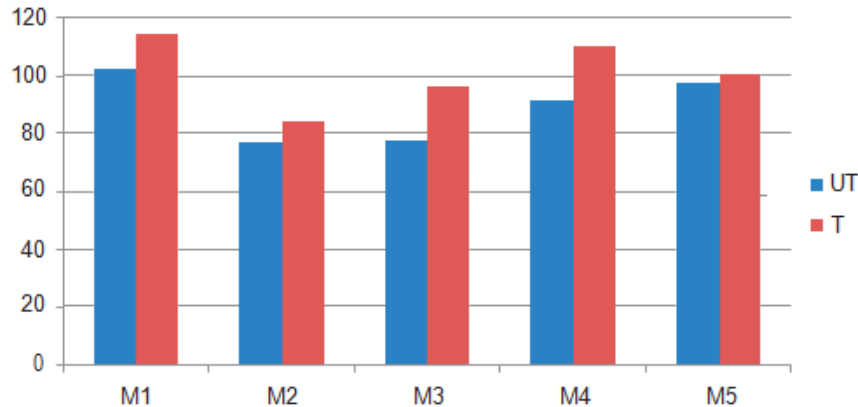


Figure 2. Thermal absorptivity of untreated and moisture management finished (MMF) fabrics (X-axis = different type of knitted fabrics, Y-axis = thermal absorptivity, Ws1/2/m2 K).

The results from Figure 2 show that knitted fabrics made of micro-denier polyester yarn has a higher thermal absorptivity, while spun polyester fabric has a lower value. Fabrics with a lower value of thermal absorptivity provide a ‘warm’ feeling, since they provide better thermal insulation and warmer feeling at initial touch. Fabrics having a higher value give a ‘cool’ feeling. On this basis, spun polyester and polyester/cotton give a ‘warm’ feeling than those of other fabrics. The fabrics after MMF show a higher value, which implies ‘cooler’ feeling at first contact.

Micro-denier polyester, filament polyester, and polyester/cotton fabrics show 12–18% increase in value after finish, while spun polyester and cotton fabric shows 7% and 3%, respectively. This situation can be explained by the higher contact area with the smooth surface structure of fabrics after MMF. The MMF gives a smooth and shiny feel to fabrics made from man-made fibers. Hence, thermal absorptivity values are higher in filament and polyester fabrics and only marginal in cellulose cotton fabrics. As mentioned in the literature [2] heat conduction transfer is higher in smoother surfaces and so they give cooler feeling. It is interesting to note that the trend noticed in untreated fabrics is maintained in finished fabrics as well. Effect of MMF on thermal absorptivity of the micro-denier polyester, filament polyester, and polyester/cotton fabrics have significant effect at 95% confidence level.

Dry thermal resistance

Thermal resistance is an important parameter, which is relevant to thermal insulation. It is directly proportional to thickness and inversely proportional to thermal conductivity. From Figure 3, spun polyester and polyester/cotton fabrics show higher values. Micro-denier polyester and filament polyester fabrics show a lower value.



Figure 3. Dry thermal resistance of untreated and moisture management finished (MMF) fabrics (X-axis = different type of knitted fabrics, Y-axis = dry thermal resistance, m² K/W).

On MMF treatment there is a 10–23% reduction in values for spun polyester and polyester/cotton and only a marginal reduction for other fabrics. Effect of MMF on dry thermal resistance of spun polyester and polyester/cotton fabrics have significant effect at 95% confidence level. The micro-denier polyester fabric has insignificant effect on MMF treatment.

Wet thermal resistance

From Figure 4, fabric sample of micro-denier polyester displays the minimum value. Spun polyester and polyester/cotton fabrics show two times higher value and cotton fabric show 1.6 times higher value than micro-denier polyester fabric. On MMF treatment there is uniform 8% decrease in values for micro-denier polyester, filament polyester, and cotton, while it is 20% for spun polyester and polyester/cotton. It is interesting to note that the trend noticed in dry thermal resistance values is maintained in wet thermal resistance also for spun polyester and polyester/cotton. This shows that the finish has a significant effect on wet thermal resistance.

Comparing dry and wet thermal resistance, it was found that thermal resistance values in wet state decreased by 25–36% for micro-denier polyester and filament polyester. For cotton, the reduction was 7–10%. As mentioned earlier [8,12], the water vapor sorbed by the fabric replaces the entrapped air in the interstices between fibers and yarns, and hence, reduce the insulation effect of the material. The extent of reduction falls in proportion to the amount of moisture, which is expected to vary with different fibers. Also, the presence of moisture to an extent of 10–20% would cause a reduction in thermal resistance to an extent as high as 50%.

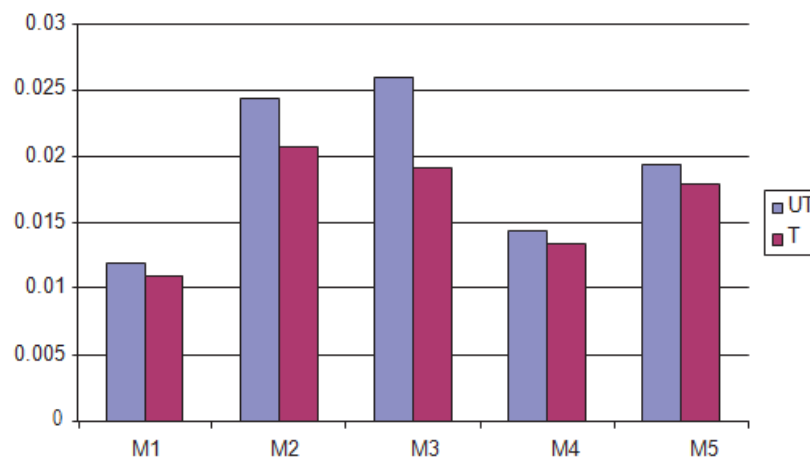


Figure 4. Wet thermal resistance of untreated and moisture management finished (MMF) fabrics (X-axis = different type of knitted fabrics, Y-axis = wet thermal resistance, m2 K/W).

It is interesting to note that the values for spun polyester and polyester/cotton fabrics more or less remain the same for dry and wet thermal resistance. This is due to the fact that polyester fibers absorb least water compared to other fibers, and hence, wetness does not alter their values. Effect of MMF on wet thermal resistance of spun polyester and polyester/cotton fabrics have significant effect at 95% confidence level. The micro-denier polyester fabric has insignificant effect on MMF, since the nature of material itself has lower dry and wet thermal resistance. As mentioned in literature [13], the structures with increasing thickness need not necessarily exhibit higher values since thermal resistance is found to be independent of the nature of fabric.

Relative water vapor permeability

Relative water vapor permeability is the rate of water vapor transmission through a material. From Figure 5, it is apparent that micro-denier polyester fabric has a higher water vapor permeability followed by filament polyester, while spun polyester fabrics exhibits lower value.

Micro-denier polyester fabric provides better water vapor permeability values because of larger surface area and channeled fiber structure. Channeled structures form a transport system that pulls moisture away from the skin to the outer layer of the fabric. Also, this is due to more number of filaments in the yarn cross section. The gap between the filaments inside the core of yarn is very less. Due to this, the rate of water vapor transfer through the fabric is more. Here, the nature of material affects the relative water vapor permeability significantly. With regards to spun yarn fabrics, cotton with higher moisture content show higher values than spun polyester and polyester/cotton fabrics.



Figure 5. Relative water vapor permeability of untreated and moisture management finished (MMF) fabrics (X-axis = different type of knitted fabrics, Y-axis = relative water vapor permeability, %).

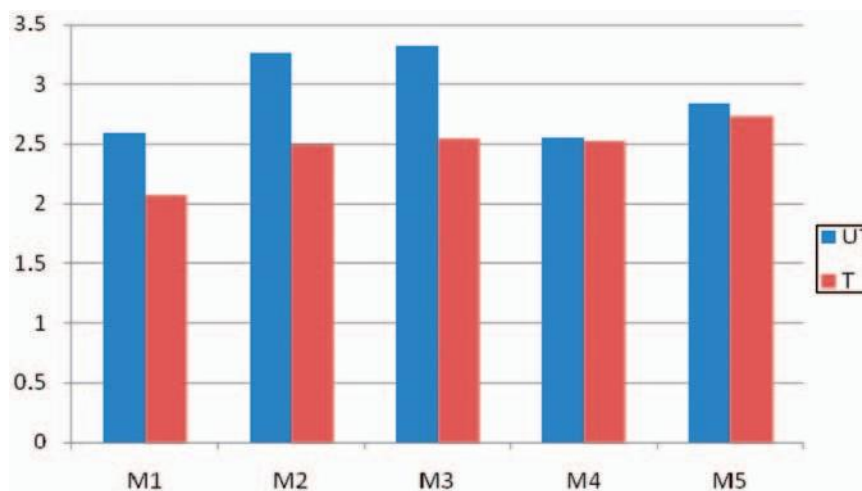


Figure 6. Water vapor resistance of untreated and moisture management finished (MMF) fabrics (X-axis = different type of knitted fabrics, Y-axis = water vapor resistance, Pa m²/W).

The MMF has improved water vapor permeability uniformly for all fabrics. Polyester/cotton shows 4% increase and all other fabrics exhibit 2% increase in values. Effect of MMF on relative water vapor permeability of polyester/cotton fabric has significant effect at 95% confidence level.

Water vapor resistance

From Figure 6, polyester/cotton fabric shows a maximum value, while micro-denier polyester fabric displays a minimum value. A lower value is desirable for better moisture transport and a higher value indicates that the fabric is less breathable to vapor transmission. The application of MMF has led to a drop in four cases.

It is interesting to note that micro-denier polyester shows a lower value thus maintaining the performance observed before finishing. As mentioned in literature [11], for 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 MMF on water vapor resistance of micro-denier polyester, spun polyester, polyester/cotton-blend fabrics has significant effect at 95% confidence level.

V. CONCLUSIONS

This research primarily focuses on the evaluation of thermal comfort characteristics, including thermal conductivity, thermal resistance, thermal absorptivity, relative water vapor permeability, and water vapor resistance, for five distinct

knitted fabrics treated with moisture management finishing (MMF). The objective is to assess the suitability of these fabrics for varying climatic conditions and compare the thermal comfort attributes between MMF-treated and untreated fabrics.

The MMF treatment consistently leads to higher thermal conductivity and thermal absorptivity, reduced wet thermal resistance, and enhanced water vapor permeability for all five fabrics. The analysis of thermal properties, such as thermal absorptivity, wet thermal resistance, relative water vapor permeability, and water vapor resistance, reveals substantial effects when considering MMF fabrics crafted from different yarns.

Among the various knitted fabrics, micro-denier polyester fabrics exhibit higher thermal conductivity, facilitating quicker heat transfer. Both micro-denier polyester and filament polyester fabrics demonstrate lower wet thermal resistance and increased vapor permeability, enabling faster sweat evaporation. Meanwhile, micro-denier polyester and cotton fabrics exhibit greater thermal absorptivity, resulting in a cooler sensation. Spun polyester and polyester/cotton fabrics provide superior thermal insulation and a warmer initial touch.

As a future avenue of exploration, these findings could inform the production of sportswear garments utilizing multilayer fabrics, warranting further investigation into their performance characteristics.

REFERENCES

1. Ibrahim NA, Khalifa TF, El-Hossamy MB and Tawfik TM. Effect of knit structure and finishing treatments on functional and comfort properties of cotton knitted fabrics. *Journal of Industrial Textiles* 2010; 40: 49.
2. Pac MJ, Bueno M and Renner M. Warm cool feeling relative to tribological properties of fabrics. *Textile Research Journal* 2001; 71(9): 806–812.
3. Nida Oglakcioglu and Arzu Marmarali. Thermal comfort properties of cotton knitted fabrics in dry and wet states. *TEKSTİLve KONFEKSIYON*, 2010; 213–217.
4. Oldrich Jirsak, Telem Gok Sadikoglu, Bulent Ozipek and Ning Pan. Thermo-insulating properties of perpendicular-laid versus cross-laid lofty non-woven fabrics. *Textile Research Journal* 2000; 70(2): 121.
5. Ukponmwan JO. The thermal insulation properties of the fabrics. *Textile Progress* 1993; (4): 1–54.
6. Hes L. An indirect method for the fast evaluation of surface moisture absorptiveness of shirt and underwear fabrics. *Vlakna a Textil* 2000; 7(2): 91–96.
7. Hes L. Optimisation of shirt fabrics – composition from the point of view of their appearance and thermal comfort. *International Journal of Clothing Science and Technology* 1999; 11(2/3): 105–115.
8. Shekar I, Kasturiya RN, Raj H and Nigam S. Influence of wool-synthetic fibre blends on thermal insulation. *Indian Journal of Fibre and Textile Research* 2001; 26: 287–295.
9. Bankvall C. Heat transfer in fibrous materials. *Journal of Testing and Evaluation* 1973; 1: 235–243.
10. Lubos Hes and Mario de Araujo. Simulation of the effect of air gaps between the skin and a wet fabric on resulting cooling flow. *Textile Research Journal* 2010; 80(14): 1488.
11. Jintu Fan and Humble WK Tsang. Effect of clothing thermal properties on the thermal comfort sensation during active sports. *Textile Research Journal* 2008; 78(2): 111.
12. Indu Shekar R, Kotresh TM, Subulakshmi MS, Vijayalakshmi SN and Krishna AS. Thermal resistance properties of paratrooper clothing. *Journal of Industrial Textiles* 2009; 39(2): 123–148.
13. Greyson M. *Encyclopaedia of composite materials and components*. New York, USA: Wiley & Sons, 1983.
14. Havenith G. The interaction of clothing and thermoregulation. *Exogenous Dermatology* 2002; 1(5): 221–230.
15. Thomas Hohberg. New approach to managing moisture in textiles. 20th IFVTCC Congress; 2005 August 7; Wiemer, Germany: Melliand International; 2005. pp. 118–120.
16. ‘Human Comfort and Health Requirement’, http://media.wiley.com/product_data/except/53/04716896/0471689653.pdf (accessed August 20, 2010).
17. Sampath MB and Ramachandran T. Development of moisture management finish on textile materials. *Non Woven & Technical Textiles* 2009; 2(2): 26–32.
18. Sampath MB and Senthilkumar M. Effect of moisture management finish on comfort characteristics of micro denier polyester knitted fabrics. *Journal of Industrial Textiles* 2009; 39(2): 163–173.
19. Sampath MB, Senthilkumar Mani and Nalankilli G. Effect of filament fineness on comfort characteristics of moisture management finished polyester knitted fabrics. *Journal of Industrial Textiles*, Published online 21 April 2011, DOI: 10.1177/ 1528083711400774.