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Study of Thermal Comfort Properties of Different Kinds of Polyester Knitted Fabrics

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Abstract
This research focused on the thermal comfort behaviour of polyester with respect to the type of yarn (spun, micro denier, continuous filament and hollow), linear density of the yarn (111 and 166 dtex), and the loop length of knitted fabric (0.25, 0.27 and 0.29 cm).The air permeability of continuous filament yarn fabric and micro denier yarn knitted fabrics was noted to be higher than that of spun yarn knitted fabrics. 111 dtex micro denier yarn fabric has the highest air permeability and 111 dtex spun yarn fabric the lowest air permeability value among all the other fabric samples. Comparatively, coarser spun yarn fabric has lower air permeability characteristics than finer microdenier fabric.The water permeability of the fabric shows a significant difference between the spun yarn, continuous filament yarn and Micro denier yarn knitted fabrics and between the linear density of the yarn. The water vapour permeability of spun yarn of 166 dtex single jersey fabric is higher, while the water vapour permeability of continuous filament yarn fabric of 166 dtex is lower. The thermal conductivity value is high for continuous filament polyester fabric of 100 D and low for microdenier polyester fabric of 166 dtex. Based on the statistical analysis, it is clearly shown that there are significant differences between the three different polyester yarn fabrics of two different denier of the same fabric. Furthermore, the count and different polyester yarn affect the comfort properties of single jersey fabrics.

Key words: *comfort, knitted fabrics, micro denier polyester, polyester, single jersey, thermal comfort.*

Introduction

Comfort is defined as a state where there are no driving desires to change the environment through action [1]. Clothing comfort is related to thermal comfort [2]. Apart from mechanical and dimensional properties, the comfort property is mostly required for a fabric. The movement of heat, air and moisture determines the total thermal comfort of clothing [3-4]. Heat transfer takes place by conduction combined with convection and radiation through the trapped air in the fabric. Mainly, the heat transfer depends on the thermal conduction with negligible convection and radiation losses. Combined heat conduction through air gaps and fibre content is the total heat transmitted through the fabric [5]. During activity, heat energy is produced and the body temperature increases. To decrease the temperature, the human body perspires a lot. This perspiration is transferred to the atmosphere, which reduces the body temperature and makes the body cool. This perspiration should happen in the garment, otherwise discomfort occurs. Clothing comfort is considered as one of the most important aspects, especially in textile products used for garments. It is a property that includes aesthetic, thermal, body movement and psychological comfort. Thermal comfort is defined as a pleasure sensation a person gets from the environment. It depends on the heat and mass transfer and relates to the water vapour permeability of the garment. The properties of the garment are to provide and sustain comfort in different environmental conditions, which includes insulation and water vapour permeability to be at a desired level, otherwise discomfort occurs.

Comfort is defined as a state where there are no driving desires to change the environment through action. Clothing comfort is related to thermal comfort. Apart from mechanical and dimensional properties, the comfort property is mostly required for fabric. The movement of heat, air and moisture determines the total thermal comfort of clothing. Heat takes place by conduction combined with convection and radiation through the trapped air in the fabric. Mainly the heat transfer depends on the thermal conduction with negligible convection and radiation losses. Combined heat conduction through air gaps and fibre content is the total heat transmitted through the fabric. The fabric requirement is not only based on dimensional and mechanical properties but the thermal comfort property is also required for the growth of textile technology. Hence, for a high degree of comfort, it is necessary to use special property fibres and blends. Majumdar et al. [6] reported that the range of fibre, yarn and fabric properties has a great influence on the thermal comfort properties of textile fabrics. The fibre type, spinning technology, linear density, twist and hairiness of yarn, as well as the thickness, cover factor, porosity and finish of fabric are certain factors that play a major role in regulating the comfort properties of fabrics. Cimilli et al. [7] reported that moisture also affects the thermal resistance of a fabric. Also, he found that along with the fibre type, the moisture regain and fabric thickness affect some of the comfort-related fabric properties. It is also suggested that different combinations of fibre blends are used for various end uses. His work proposed that an increase in moisture content from 0 to 75% of dry weight reduces thermal insulation. Achour et al. [8] observed that a blend of polyester fibres along with cotton fibre relatively improves many of the moisture management properties. It was also found that the spreading speed also increases with a polyester fibre blend. Ramakrishnan et al. [9] found that thermal conductivity is lower and thermal resistance higher for micro denier fibres.

The thermal comfort behaviour of fabrics is influenced by the type of fibre, structure of yarn, and structural behaviour of fabrics. As the comfort behaviour of fabric made from polyester fabric is significantly unsatisfactory, this research work aimed to improve the comfort behaviour of polyester fabric with respect to various parameters using a type of polyester yarn with two different linear densities and a type of knitted fabric structure with three different loop lengths.

Table 1. *Physical properties of continuous filament, spun, microdenier and hollow fibre polyester knitted fabric.*

S.No.	Sample	dtex	Loop length, cm	Fabric thickness, mm	Wales per cm	Coarse per cm	Mass per unit area, GSM
1	Continuous Filament Polyester (CF)	111	0.25	0.673	78.74	88.9	124.5
			0.27	0.664	73.66	81.28	115.2
			0.29	0.626	66.04	76.2	113.8
2		166	0.25	0.671	73.66	93.98	127.9
			0.27	0.634	71.12	88.9	118.7
			0.29	0.631	66.04	81.28	117.4
3	Spun Polyester (SPUN)	111	0.25	0.665	78.74	93.98	123.4
			0.27	0.632	68.58	88.9	120.1
			0.29	0.625	63.5	86.36	109.2
4		166	0.25	0.676	81.28	88.9	134.6
			0.27	0.657	73.66	83.82	130.3
			0.29	0.632	63.5	81.28	108.5
5	Micro Denier Polyester (MD)	111	0.25	0.642	83.82	86.36	125.4
			0.27	0.636	78.74	86.36	124.3
			0.29	0.631	76.2	91.44	123.8
6		166	0.25	0.675	78.74	73.66	124.6
			0.27	0.657	68.58	91.44	120.5
			0.29	0.632	63.5	88.9	118.5
7	Hollow Fibre Polyester (HF)	111	0.25	0.673	76.2	91.44	126.1
			0.27	0.664	68.58	88.9	123.2
			0.29	0.634	66.04	81.28	109.7
8		166	0.25	0.634	78.74	93.98	120.8
			0.27	0.626	76.2	88.9	114.6
			0.29	0.625	68.58	83.82	108.2

Materials and methods

Materials

Four different commercially available types of polyester yarn, namely continuous filament polyester yarn, spun polyester yarn, micro denier polyester yarn and hollow fibre polyester yarn of two different linear densities – 111 dtex and 166 dtex were obtained from different sources. Single jersey knitted fabrics were produced using a 21-feed circular knitting seamless machine, KNITMAC 24E gauge, 16 inch cylinder diameter, special attachment – positive storage feeder, at 27 rpm velocity. Three different loop length settings were kept constant for all the samples: 0.25, 0.27 and 0.29 cm, respectively.

Methods

Fabric structural and physical fabric properties like aerial density (ASTM D 3776), thickness (ASTM D 1777), wales and courses per unit length (ASTM D 3887: 1996 (RA 2008)) and loop length (ASTM D 3887) were evaluated (***Table 1***). The air permeability of the fabric was measured using a Textest FX 3300 (Textest Instruments AG, Schwerzenbach, Switzerland) air permeability tester at a pressure of 100 Pa, according to ASTM D737. The water vapour permeability was measured on a Permetest instrument (Sensora Company, Liberec, Czech Republic) according to ISO 11092. An Alambeta instrument (Technical University of Liberec, Liberec, Czech Republic) was used to measure thermal conductivity values. On this instrument, the fabric is kept between the hot and cold plates according to ISO 11092. All measurements were performed under standard atmospheric conditions: 21 ± 1 °C (70 ± 2 °F) and 65 ± 2% relative humidity (RH), as recommended by ASTM D 1776, Standard Practice for Conditioning and Testing Textiles. Ten readings were taken for each of the knitted fabrics and then the averages calculated. Test results of the fabrics produced from spun polyester yarn, continuous filament polyester yarn, and micro denier polyester with two different counts, respectively, were analysed using the analysis of variance method (ANOVA) in order to make a statistical comparison. The significant ‘p’values obtained from the analyses were compared and considered significant if the value was equal to or less than 0.05.

Results and discussion

Fabric physical properties

It is evident from the data given in Table 1 that while the linear density increases, there is an increase in the fabric thickness and fabric weight, and for all the increases in loop length, there is a decrease in the thickness and weight of the fabric samples investigated. These results are validated by the findings of Frydrych et al. [10] and Majumdar et al. [6], who reported that for a given yarn composition, as the loop length increases, it causes a decrease in fabric weight and thickness. The fabric thickness of knitted material mainly depends on the yarn linear density, fabric structure and closeness of loops in the fabric. The structure of the fabric, linear density of the yarn and different properties of the knitted fabric structure have an impact on the GSM of the fabric. As the density of the fabric increases, the weight also increases.

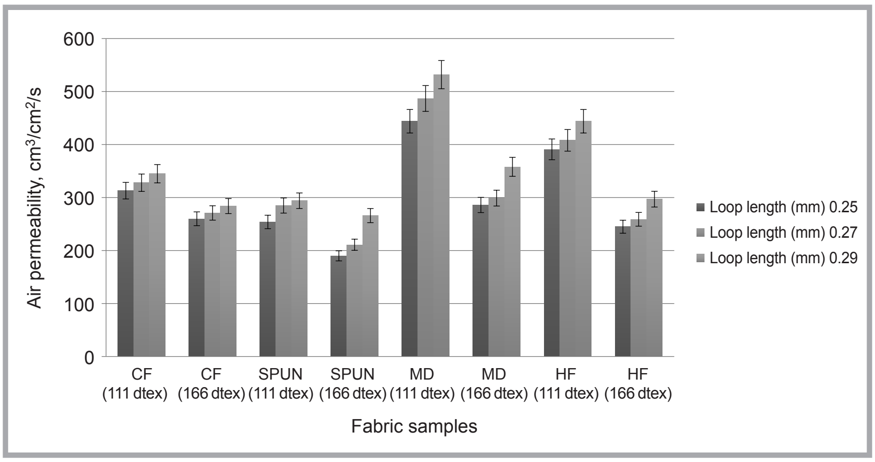

Figure 1. *Air permeability of polyester knitted fabric.*

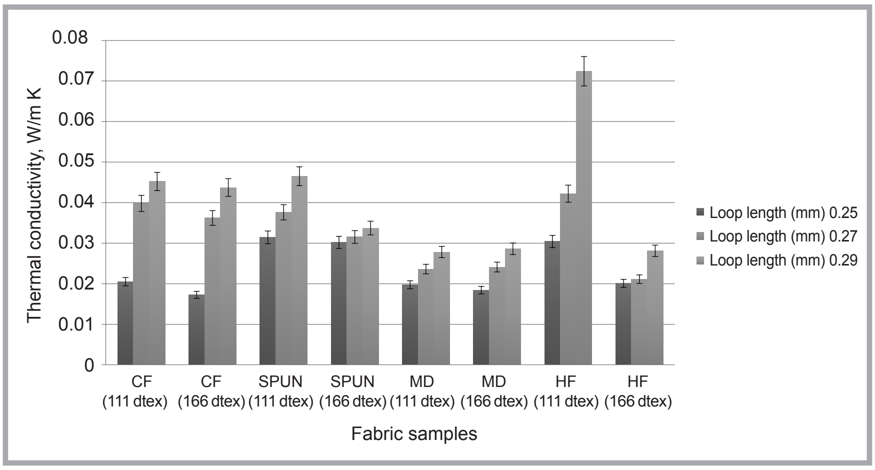

Figure 2. *Thermal conductivity (W/m K) of polyester knitted fabrics.*

If the stitch length is increased for the same yarn linear density, the fabric becomes a loose structure, which results in a lower GSM fabric. From ***Table 1*** it is observed that as the loop length increases, the fabric thickness decreases. This result had already been predicted by Prakash and Ramakrishnan [11], that there is an increase in the loop length when there is a decrease in fabric thickness. ***Table 1*** reveals that the GSM of the fabric decreases with an increase in the loop length for the same yarn linear density, thereby the fabric thickness gets reduced. The fabric thickness of knitted material mainly depends on the yarn linear density, fabric structure and closeness of loops in the fabric. The structure of the fabric, linear density of the yarn and different properties of the knitted fabric structure have an impact on the GSM of fabric. As the density of the fabric increases, the weight also increases. If the stitch length is increased for the same yarn linear density, the fabric becomes a loose structure, which results in a lower GSM fabric. From ***Table 1*** it is observed that as the loop length increases, the fabric thickness decreases. This result had already been predicted by Prakash and Ramakrishnan [11], that there is an increase in the loop length when there is a decrease in the fabric thickness. ***Table 1*** reveals that the GSM of the fabric decreases with an increase in the loop length for the same yarn linear density, thereby the fabric thickness gets reduced.

Air permeability

The air permeability values of spun yarn, continuous filament yarn, and micro denier yarn knitted fabrics of both 111 dtex and 166 dtex are shown in ***Figure 1***. There is a significant difference between the spun yarn, continuous filament yarn, micro denier yarn and hollow fibre yarn polyester knitted fabrics, as well as between the linear densities and loop lengths. The air permeability of micro- denier yarn knitted fabric and hollow fibre yarn knitted fabric was noted to be higher than for spun yarn knitted fabrics. From this, it is also noted that the 111 dtex micro denier yarn fabric of 0.29 loop length has the highest air permeability value and 166 dtex spun yarn fabric of 0.25 loop length the lowest among all the other fabric samples. The fabric made from continuous filament yarn exhibits higher air than the fabric made from spun polyester, due to the higher inter yarn space in the fabric made from continuous filament polyester yarn. Comparatively, coarser spun yarn fabric has a low air permeability value and finer microdenier fabric a higher one. This is due to the fact that coarser fabric has fewer inter yarn spaces and more intra yarn spaces. The fabric thickness and mass per square meter also influence the air permeability. The lower the thickness and fabric weight, the higher the air permeability value [12]. Air permeability is an important aspect of textile material as it transfers the flow of vapour to the environment from the surface of the human body. Thereby it also allows for the flow of fresh air into the body. The results indicate that for the different fabric samples of different loop length, the value of air permeability increases as the fabrics become looser. It is noted from ***Table 1*** that the larger loop length fabric decreases the thickness and weight of the fabric and that the GSM also gets lower for fabrics made from yarn of the same linear density. All these data contribute to the higher value of air permeability.

Moreover, the increased air permeability value is due to the looser surface of the fabric produced by the increasing loop length. The pores between the loops of the fabric gets larger when the yarn linear density gets lower, and the value of air permeability is increased accordingly. The highest thickness results are obtained for the spun polyester fabric of 166 dtex linear density and 0.25 loop length. As the stitch length increases, there is an increase in the air permeability value. As the loop length increases, the fabric compactness decreases, which leads to the decrease in the total number of stitches.

Figure 1 clearly indicates that when the linear density increases, the fabrics have a lower air permeability value when compared with the yarn fabric of lower linear density. Moving across the range from a 0.25 cm loop length to 0.29 cm, it is clear that an increase in loop length increases the air permeability. On the other hand, due to the micro-spaces in the fibre structure in the microdenier fibre, the air permeability value becomes higher. These findings were reported by Majumdar et al. [6], that micro fibre yarns have smaller diameters than other polyester yarns of the same count. The results showed that the thickness of the fabric had a significant effect on the values of air permeability for the different polyester knitted fabrics, as the thickness increasing the value of air permeability tended to decrease, irrespective of the type of fibre.

Thermal conductivity

Thermal conductivity is the ability to conduct heat, which is one of the important and intrinsic properties of fabric. A fabric's thermal property mainly depends on the amount of entrapped air and the type of fibres in the fabric structure. Therefore, the thermal conductivity of the fabric is higher than that of the air entrapped in it [13]. The thermal conductivity values of spun, continuous filament and micro denier yarn knitted fabrics of both 111 dtex and 166 dtex are shown in ***Figures 2***. There is a significant difference between all these 3 different types of single jersey knitted fabrics, as well as between the linear densities and loop lengths. It is observed that the thermal conductivity value is high for the hollow fibre polyester fabric of 111 dtex and 0.29 loop length c and low for the continuous filament polyester fabric of 166 dtex and 0.25 loop length. Afzal et al. [1] reported that the effect is directly related to the courses per inch, wales per inch and mass per unit area of the fabric. The thermal conductivity of the fabric increases with a decrease in the fabric compactness, thickness and areal density of the fabric. The increase in thermal conductivity is due to the proportional decrease in fabric thickness. The low WPI and CPI result in a loose fabric structure, leading to low thermal conductivity [1]. The thermal conductivity of polyester fabric is inherently higher than that of other widely used fibres [14] with a decrease in the thickness of the fabric [15-17].As can be seen from ***Figure 2***, the value of thermal conductivity decreases as the loop length decreases. As the loop length increases, the compactness of the fabric decreases, resulting in a decrease in fibre content in the fabric structure. Also, the higher loop length creates more porosity in the fabric. Moreover, the areal density and thickness of the fabric also decreases, as shown in ***Table 1***. Hence, the thermal conductivity decreases along with the higher loop length. It was shown by Pac et al. [18] that different types of fabrics made of the same fibre can affect changes in the heat transfer. It is shown in ***Figure 2*** that as the linear density of yarn is increased in the fabric, it results in a lower thermal conductivity value. As the areal density of the fabric increases, the interaction between the transfer of heat in between the fibres and air is stronger, thus resulting in a higher thermal conductivity; it is clearly evident that the areal density of the fabric plays a major role in thermal conductivity. The fabric made from spun polyester yarn has higher thermal conductivity, because of the loose structure of the fibre, which will allow more space to transfer thermal heat. The thermal conductivity of the fabric made from continuous filament yarn shows a lower thermal conductivity.

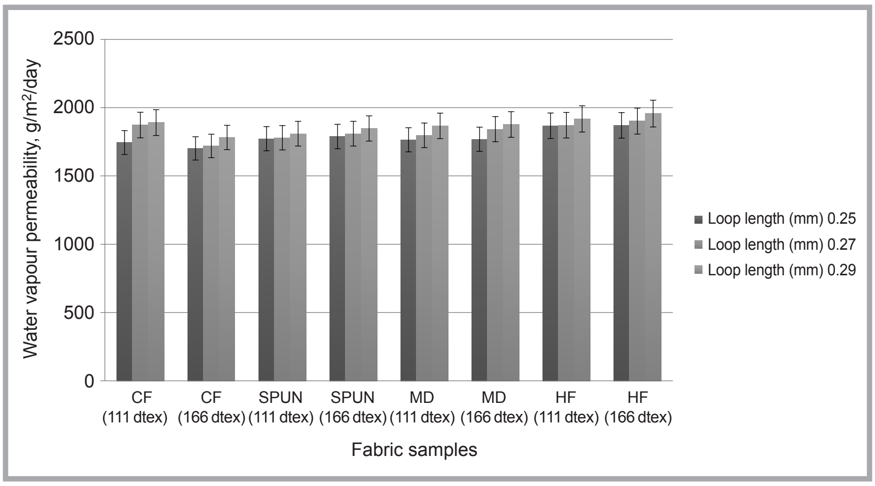

Figure 3. *Water vapour permeability (g/m²/day) of polyester knitted fabrics.*

Water vapour permeability

The water vapor permeability values of spun yarn, continuous filament yarn and micro denier yarn knitted fabrics of both 111 dtex and 166 dtex are shown in ***Figure 3***. From Table 4's ANOVA analysis, it is observed that there are significant differences in the values between spun yarn, continuous filament yarn, micro-denier yarn and hollow fibre polyester knitted fabrics, es well as between the linear densities and loop lengths. The water vapor permeability of hollow fibre yarn of 166 dtex and 0.29 cm loop length in single jersey fabric is higher and that of continuous filament yarn fabric of 166 dtex and 0.25 cm loop length lower than that of all the other fabrics.

The relative water vapour permeability of fabric is defined as the capability to transfer vapour from the surface of the body. The heat generated by the body will not be dissipated out if there is a higher resistance to moisture for heat transfer and if the fabric shows higher thermal resistance, in turn causing a sense of discomfort. ***Figure 3*** represents the water-vapour permeability value of the different fabric samples and it is observed that the water-vapour permeability value increases along with the loop length i. Also, it is identified that the water vapour permeability of continuous filament polyester fabric is higher than for spun polyester fabric, which is due to the channelled structure of the continuous filament of polyester. The higher water vapour permeability of hollow fibre yarn of 166 dtex and 0.29 cm loop length in single jersey fabric can be ascribed to the lower values of the fabric's GSM and its thickness , which facilitates the easy transfer of water vapour through the fabric. The water-vapour permeability of fabric material is dependent on the large-porous structure of the constituent fibres. It is also observed that when the linear density increases, there is an increase in the water-vapour permeability value. The water permeability results are mostly similar to those for air permeability, although the effect is less in the case of the former. Prahsarn et al. [19] correlated certain fibre related factors, such as the cross-sectional shape of fibres and the properties of moisture absorbtion and fabric thickness to the water vapour transmission rate.

Wicking

The fabrics were tested for wicking characteristics – vertical wicking (BS 3424). Ten samples were tested for wicking be-

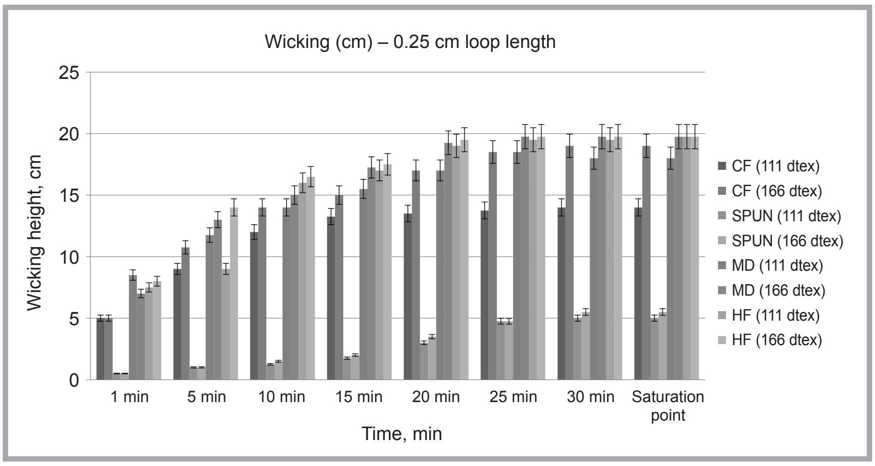

Figure 4. *Wicking (cm) of polyester knitted fabrics of 0.25 cm loop length.*

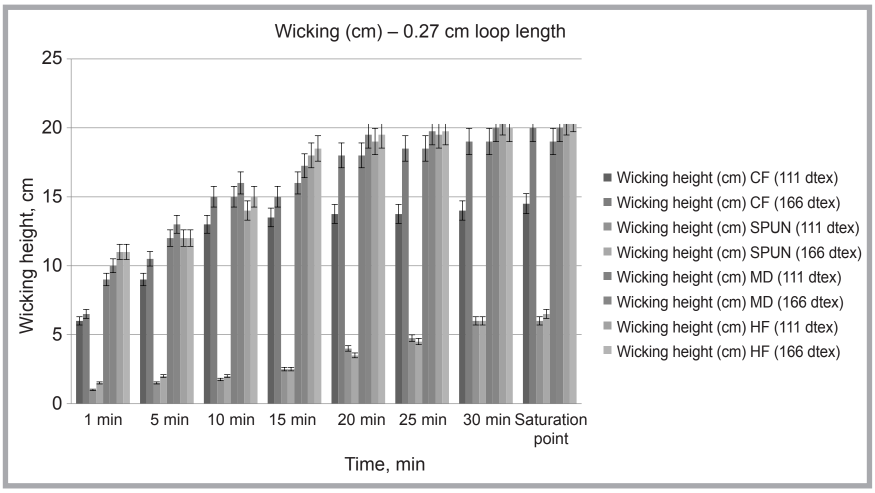

Figure 5. *Wicking (cm) of polyester knitted fabrics of 0.27 cm loop length.*

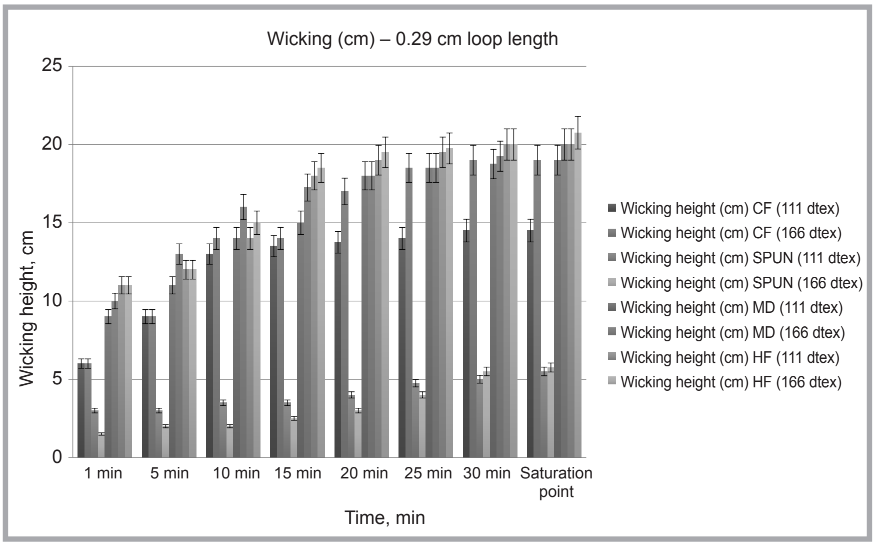

Figure 6. *Wicking (cm) of polyester knitted fabrics of 0.29 cm loop length.*

haviour and their average values taken and discussed. To analyse the wicking behaviour, a fabric strip of 20 cm * 2 cm was taken. Using a stand arrangement, the upper end of the fabric was clipped and the lower end suspended vertically with 2 cm of the fabric immersed in a beaker of distilled water Initially, the vertical movement of the water was observed for a minute. The water transportation took place by the capillary action. Then every 5 minutes for 30 minutes, the movement of the water height was measured in the fabric samples till saturation. The rate of vertical water movement by capillary action was tested. From ***Figures 4-6***, the wicking heights of all six different samples were analysed with respect to the wicking time from 1 minute to 30 minutes. The rate of water spreading by the capillary action was tested Initially, the wicking height of the continuous filament yarn fabric and micro denier yarn knitted fabric was faster, and there was a gradual increase in the height at each time interval of 5 minutes, and the rate of spun yarn fabric shows a slower wicking rate. The 166 dtex hollow fibre polyester fabric of 0.29 cm loop length had the maximum wicking height and the 111 dtex spun yarn of 0.25 cm loop length – the lowest. From the results shown in ***Figures 4-6***, it is revealed that the wicking height of fabrics from coarser yarns is comparatively higher than those from finer yarns. Coarser yarns have a greater number of fibres in the cross-section, which higher capillary action. Also, coarser fabric will have higher thickness, which leads to the higher wicking ability of the fabric [20]. Due to the proper channelled structure of continuous filament polyester, the wicking behaviour is observed as higher when compared to spun polyester fabric. This channel structure will help to transport water easily throughout the fabric [21]. For single jersey fabric, the wicking length increases continuously along with the stitch length. It is observed that single jersey fabric with longer loop lengths improves the wickability of the fabric, due the tightness factor being lower and the increased porosity size, which it is visible in the improved wickability with the increased loop length.

ANOVA statistical summary results are shown in ***Table 2***, from which it can be stated that the effect of loop length on thermal comfort properties is mostly statistically significant. According to the Table values, it is clear that all the variables are significant at a 95% confident level.

Conclusions

In this study the thermal comfort properties of single jersey fabrics produced from spun yarns, continuous filament yarns, micro-denier yarns and hollow fibre polyester yarns for both linear densities and all three loop lengths were investigated. The yarn properties and the distribution of fibres within the yarn, the different loop lengths and yarn linear densities have an effect on the thermal conductivity, water vapour permeability, air permeability properties and wicking of the fabrics. The air permeability values are higher for 111 dtex micro denier yarn knitted fabrics of 0.29 cm loop length and lower for 166 dtex spun yarn knitted fabrics of 0.25 cm loop length. The thermal conductivity value is increased for the hollow fibre polyester fabric of 111 dtex and 0.29 cm loop length and decreased for the continuous filament polyester fabric of 166 dtex and 0.25 cm loop length. When compared with all the other fabrics, the water vapour permeability of 166 dtex hollow fibre single jersey fabric of 0.29 cm loop length is higher and that of continuous filament yarn fabric of 166 dtex and 0.29 cm loop length is lower. The wicking height is maximum for 166 dtex hollow fibre single jersey fabrics of 0.27 cm and 0.29 cm loop length and the wicking height lower for 111 dtex spun yarn fabric of 0.25 cm loop length. The air permeability, thermal conductivity and water vaopur permeability of the polyester fabric increases with a finer linear density and higher loop length. The wicking property of the polyester fabric increases with a coarser linear density and lower loop length.

Table 2. *Data analysis: variance statistics.* ***Note:*** ** Significant for α = .05.*

Source of Variation	Sum of square value (SS)	Degree of freedom (df)	Mean square value (MS)	F-Value	*P*-Value	F crit
Air permeability vs loop length						
Loop length	19696.33	2	9848.166	6.20	0.0139*	19
Air permeability	13160.16	1	13160.166	8.2	0.0102*	18.5128
Error	3176.33	2	1588.166			
Total	36032.83	5				
Thermal conductivity vs loop length						
Loop length	0.000645	2	0.000322	6683.421	0.012*	19
Thermal conductivity	3.7604	1	3.76042	77.90918	0.013*	18.5128
Error	9.6533	2	4.82667			
Total	0.000649	5				
Water vapour permeability vs loop length						
Loop length	3596.333	2	1798.166	3.698	0.0213v	19
Water vapour permeability	88.166	1	88.166	0.181	0.0412*	18.512
Error	972.333	2	486.166			
Total	4656.833	5				

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