Comfort properties of nano-filament polyester fabrics: thermo-physiological evaluation

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REZUMAT – ABSTRACT

Proprietățile de confort ale țesăturilor din polyester nanofilament

Confortul, împreună cu proprietățile estetice ale îmbrăcămintei textile pentru sport sunt extrem de valoroase pentru nevoile consumatorilor. Diferite tipuri de fibre și fire sunt utilizate pentru a îmbunătăți gestionarea umidității și confortul țesăturii în contact cu pielea. În prezent, multifilamentele sau nanofilamentele din poliester cu diametre cuprinse la nivelul de câțiva nanometri și lungimi de până la kilometri sunt utilizate în diferite game de aplicații tehnologice importante, cum ar fi țesături funcționale, biomedicină, compozite etc. Firele de poliester multifilament sunt realizate prin agregarea mai multor filamente continue, caracterizate prin tenacitatea lor ridicată și suprafața mare pe unitatea de masă. Firele nanofilament au, de asemenea, efecte semnificative asupra proprietăților de confort termic, deoarece țesătura din nanofilament are o conductivitate termică mai redusă decât țesătura de bumbac, dar este egală cu țesătura din poliester multifilament, în timp ce țesăturile din nanofilament oferă o senzație mai mare de rece cu o absorbție termică mai ridicată. În plus, țesătura coolmax a prezentat o valoare mai mare a rezistenței termice în comparație cu țesăturile din nanofilament. Țesăturile din nanofilament au prezentat o valoare mai mare a permeabilității la vapori de apă decât țesăturile din bumbac.

Cuvinte-cheie: confort termofiziologic, țesătură din polyester nanofilament, permeabilitate la vapori de apă

Comfort properties of nano-filament polyester fabrics: thermo-physiological evaluation

Comfort along with the aesthetic properties of textile clothing in activewear and sportswear are *utmost worthwhile for costumer demand as latest trends. Different types of fibers and yarns are being used to improve the moisture management and comfort of the fabric for next to skin. Nowadays, multifilaments or nano-filaments of polyester with diameters in the range of a few nanometers and lengths up to kilometers are used in different range of important technological applications such as functional fabrics, biomedicine, composite, etc. Multifilament polyester yarns are made by aggregating many continuous filaments together characterized by their high tenacity and large surface area per unit mass. The nano-filament yarn has also significant effects on thermal comfort properties as a nano-filament fabric has less thermal conductivity than cotton fabric, but equal to multichannel polyester fabric while nano-filament fabrics gave the cool feelings with higher thermal absorptivity. Moreover,coolmax fabric showed the higher value of thermal resistance as compared to nano-filament fabrics. Nano-filament fabrics exhibited higher value of watervaporpermeability than cotton fabric.*

Keywords: thermo-physiological comfort, nano-filament polyester fabric, water vapour permeability

INTRODUCTION

Clothing comfort is mainly split into three divisions like sensorial comfort, thermal comfort and psychological comfort. Sensorial or tactile comfort deals with the mechanical properties of the fabric along with its surface hand feel [1]. Psychological comfort properties relate to the new fashion trend, influenced by culture, status, occasion, gender, age, profession and social attitude. Physiological comfort demonstrates the absence of human body discomfort to fabric, measurement of sweat rate, absorbency and transportation of this sweat from the body by clothing [2]. Physiological comfort and psychological comfort are closely related to know about the perception of the comfort level [3]. Thermo-physiological comfort can be defined in terms of heat and mass transfer through clothing [4]. The mutual relationship of heat and mass transfer properties produces a microclimate all around the human body, which provides a comfort zone [5]. Clothing provides protection against unnecessary effects of environmental conditions while executing physical movements. This layer of clothing should be friendly to the skin [6].

Literature has been reported on the water vapor permeability (WVP) of textile fabrics [7–9], but the term “warm/cool feeling” is not completely known to the researchers. Increase in WVP can be demonstrated by planar conduction of condensed vapors from the border of the calculating area to the directionof fabric fringe [10].

Change in the internal and external condition of the system influences the thermal balance of the body. Thermal properties of textile materials like thermal conductivity and thermal absorptivity are important to consider the thermal comfort study [11–12].Thermal conductivity expresses the material’s abilityto permit the heat passage due to temperature difference. Material structure is significantly related to this property due to anisotropy in nature. Fabrics made of polymer get less moisture and air in the voidsof fabric structure [13–14]. Moisture causes the higher thermal conductivity within fabric composition [12]. Textile clothing comfort technologycomprises a thermal characteristic associates "warm/cool behavior", called thermal absorptivity denoted by "b" $\left(\frac{Ws^{1/2}K}{m^2K}\right)$, firstly introduced in the textile field by L. Hes [15]. The first feeling of human skin when it gets into touch with any object called warm/cool behavior [16]. Fabrics, knitted or woven made of polyester fibresare widely used in textile industry, known by their hydrophobic nature (low moisture regain). In this modern era, surface modification can be used to obtain best moisture transportation, especially, by utilizing multifilament and fine filament yarns [17].

Making endless fabric forced the researcher to invent multifilament polyester. Multifilament polyester yarns became the part of observation when clothing comfort properties were concerned. These multifilaments were produced by assembling continual filaments jointly. Continuous strands of this yarn are depicted by its better mechanical and chemical properties, along with good sensorial properties [18]. Furthermore, the space and voids between all filaments creates capillarity which provides liquidtransport. Garment industry is taking great advantages of this invention. Absorption and capillary channels facilitate the fluid dynamics and mass transfer [19]. In modern technological era, multi-filament (micro or nano-filament) polyester with endless strands (upto kilometers) are being utilized in functional and composite textiles. These nano-filaments are characterized by a high range of capillarity which provides the steady internal nano-scale inertia of the fluid for transportation [20]. Nano-filaments yield a quick passage of moisture away from the body to the environment because of its desired interaction amongst the filament spacing and permeability of fabric [21].

The moisture content of a fabric is directly proportional to the relative water vapor permeability (RWVP) and inversely related to the temperature [22]. This phenomenon is due to the evaporation of the water from the fabric surface. RWVP is the relative heat flow accountable for cooling of the body. Permetester was used to determine the relative water vapor permeability (%) and the evaporation resistance (m^2Pa/W) of fabrics within 3 to 5 minutes [23, 24]. The water vapor resistance (WVR) of textiles under variable conditions is closely concerned with relative humidity (RH). Fundamentally, water vapor resistance comprises of varying the position of the sample in the air gap linking the dry and wet surface while assuming the all other specifications constant [22].

Application of nano-filament fibres affects the cotton industry as well due to hygroscopic nature. Heavy physical tasks in daily life suffers the wearer from perspiration generate discomfort. Multi-filament polyester is much convenient substitution to get rid of discomfort by fast drying. Expeditious evaporation is also preferred in tropical weather and deserts for the comfort point of view. Under garment industry acquired more advantage of multi-filament polyester fiber because of its better water transport properties. The novelty of this work is to define the structural form of yarn used in this fabric. This special fabric is highly hydrophilic as compared to other polyesters. The results of physiological and sensorial comfort properties make it more recommendable for the comfort point of view.

MATERIALS AND METHODS

Continuous yarn composed of thousands nanofibresis most likely attractive due to its versatile ability to provide a huge range of microscopic capillarity. Lubos Hes from the Technical University of Liberec (Czech Republic) introduces the following six aspects of psychological comfort [7]:

1. Climatic: routine clothing concerns the climatic requirements.
2. Economical: it belongs to the resources, political system, food technology and objects manufacture.
3. Historical: tendency to manufacture organic materials, pure natural smell and modern lifestyle.
4. Culture: this aspect is for the religious and cultural clothing especially for women
5. Social: this feature reflects the social status like age and qualification
6. Individual and group aspects: it shows the brand and style craze, personal preferences.

Materials

Samples of nano-filament polyester fabric were collected from Japanese textile industry to evaluate the thermo-physiological properties.

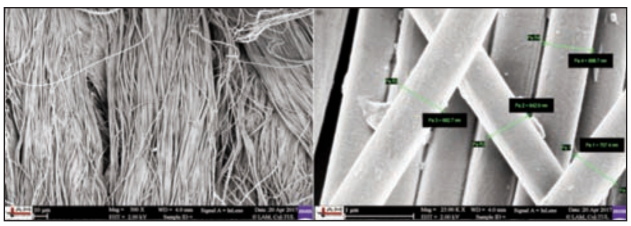

Fig. 1. SEM images of polyester warp knitted fabric (S1) made from nano-filament fibre of 600~710 μm diameter

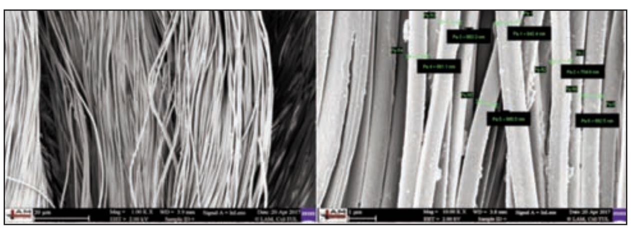

Fig. 2. SEM images of Polyester warp knitted fabric (S2) made from nano-filament fibre of 650~850 μm diameter

Two samples of nano-filament fabric were used for this study in the comparison with cotton and coolmax fabric.

Table 1

Sample #	GSM (g/m^2)	Thickness (mm)	Yarn fineness (Dtex)	Yarn DIA (mm)
S1 Nano-filament	200±2	0.44	152±3	0.08
S2 Nano-filament	250±2	0.55	152±3	0.08
S3 Coolmax (100%)	210±2	0.68	295±3	0.12
S4 Cotton (100%)	200±2	0.62	295±3 cmb	0.15

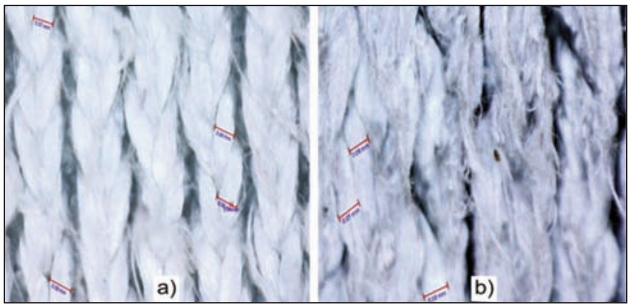

Fig. 3. Microscopic structure of Nano fibre polyester fabric S1 (a) and S2 (b)

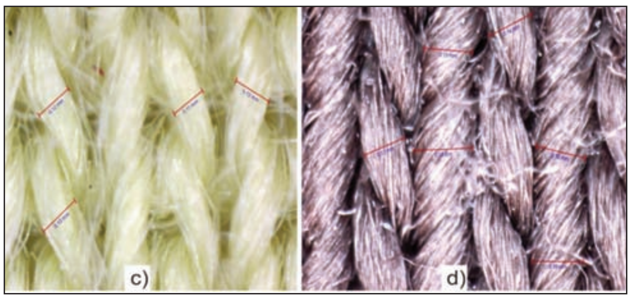

Fig. 4. Microscopic structure of coolmax (c) and cotton (d) fabric

Methods

In this study, thermal contact feeling of skin to fabric Thermal absorptivity, Thermal conductivity and Thermal resistivity were evaluated by the ALAMBETA thermal tester.

ALAMBETA

This instrument developedby L. Hes [16, 25] measures the thermal absorptivity "b" $\left(\frac{Ws^{1/2}K}{m^2K}\right)$, thermal conductivity "λ" $\left(\frac{W}{mK}\right)$, thermal resistance "r" $\left(\frac{m^2K}{W}\right)$ and thickness of the fabric samples (mm). The Contact pressure of this instrument is 200 kPa. 12 cm x 12 cm samples are used to place in the instrument for measurement.

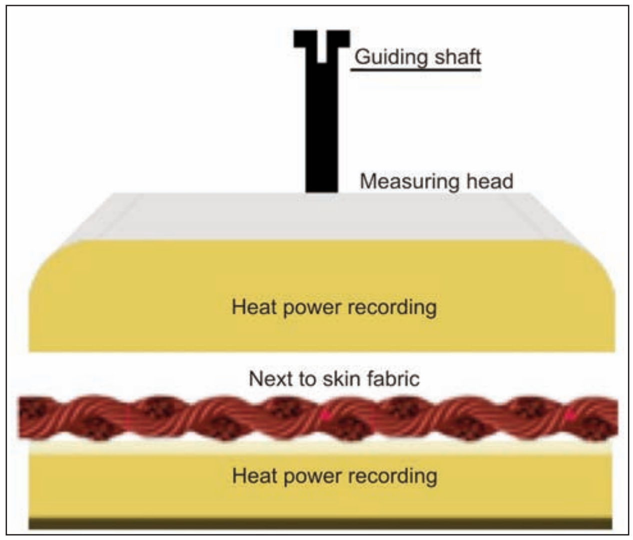

Fig. 5. Measuring head of the computer controlled ALAMBETA instrument

PERMETEST

Permetest is used to measure the water vapor resistance "Ret" $\left(\frac{m^2Pa}{W}\right)$ and Relative water vapor permeability (RWVP) by following the standard ISO 11092 [15, 23].

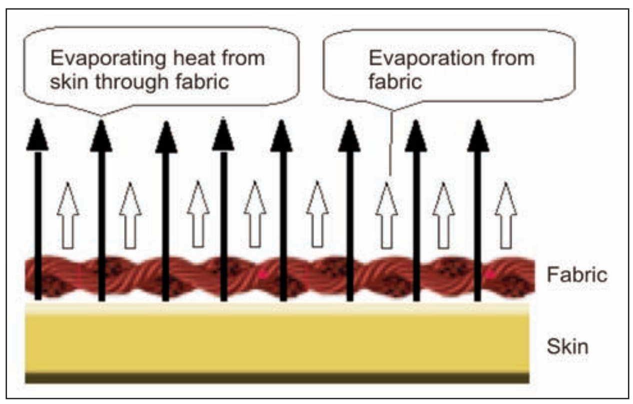

Fig. 6. Schematic diagram of Perme Tester

Table 2

Quantity	Symbol	Multiplier	Unit
Thermal conductivity (coefficient)	λ	10^{-3}	$W \cdot m^{-1} \cdot K^{-1}$
Thermal absorptivity, Thermal activity coefficient	b	1	$W \cdot m^{-2} \cdot s^{1/2} \cdot K^{-1}$
Thermal resistivity	r	10^{-3}	$K \cdot m^2 \cdot W^{-1}$

Atmospheric conditions

The wetness of the atmosphere can be calculated in terms of humidity.

$$RH\ (\%) = \frac{\text{absolute humidity of the air}}{\text{absolute humidity of the air saturated with water}} \times 100$$

RH (%) = 65% ± 2%;
Temperature = 20°C ± 2°C.

ANOVA test

ANOVA is the way to discover the significance of experimental results by the software SPSS statistics 17.0. Degree of freedom (df) of an estimate is the number of independent pieces of information that used in calculating the estimate. Mean squares are estimates of variance across groups and used in analysis of variance and calculated as a sum of squares divided by its appropriate degrees of freedom. The F-value is simply a ratio of two variances.

$$F\ \text{value} = \frac{\text{variance of the group means (Mean Square Between)}}{\text{mean of the within group variances (Mean Squared Error)}}$$

The F-value in the ANOVA test leads to P-value. P-value helps you determine the significance of your results

- p > .10 = not significant
- p ≤ .10 = marginally significant
- p ≤ .05 = significant
- p ≤ .01 = highly significant

RESULTS AND DISCUSSIONS

The present study is the sequel of clothing comfort of nano-filament polyester fabric. In a first part sensory evaluation has been reported which was experimented witha Kawabata evaluation system (KES). Sensorial evaluation of nano filament polyester fabrics were reported with the comparison in PC and PV blended suiting fabrics [26]. Total hand value (THV) resulted in lower stiffness (Koshi), and higher smoothness (Numeri) and fullness (Fukurami). THV of Polyester/Viscose blended fabric andnano-filament polyester fabric were almost same.The tensile, shearing, bending, compression and surface characteristics of nano-filament polyester fabric was notices best as compared to Polyester/Cotton and Polyester/Viscose blended fabric.

Thermal conductivity

The coefficientof thermal conductivity "λ" is used to narrate the heat quantity, passed through 1 m^2 of the material from 1 meter distance in 1 second to make 1 Kelvin temperature difference. The thermal conductivity range for the textile clothing is 0.033 – 0.01 $\left(\frac{W}{mK}\right)$. Thermal conductivity of water is 0.61 $\left(\frac{W}{mK}\right)$ which is 25 times lesser than air 0.025 $\left(\frac{W}{mK}\right)$ [12]. Thermal conductivity (λ) is a fundamental parameter to determine the heat transfer through fabrics. Thermal conductivity is expressed by the equation,

$$\lambda = \frac{Q}{A \cdot \frac{\Delta t}{h}} \quad (1)$$

λ is thermal conductivity;
Q – heat transmitted;
A – area;
Δt – temperature gradient;
h – sample thickness.

According to figure 7, samples made of nano-filament yarns have higher thermal conductivity than other samples.

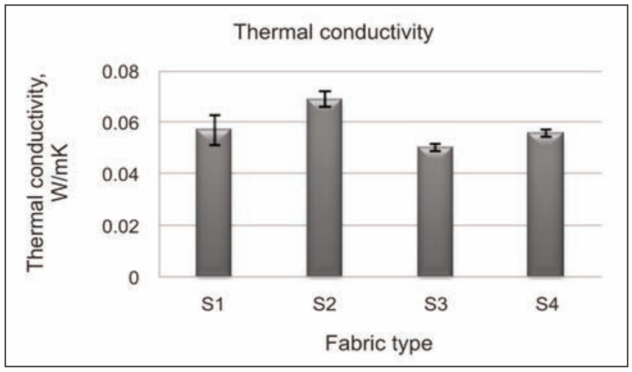

Fig. 7. Thermal conductivity of the tested fabric samples

It can be explained by the amount of entrapped air in the fabric. With the increase in weight (fiber per unit area), the amount of air layer decreases. As known for textile materials, still air in the fabric structure is the most important factor for conductivity value, as still air has the lowest thermal conductivity value when compared to all fibers $\left(\left(\lambda_{air} = 0.025 \left(\frac{W}{mK}\right)\right)\right)$. Thus, heavier fabric (S2) with with more GSM (250 GSM) has the highest thermal conductivity values. However, Coolmax fabric (S3) has the loose structure and the lowest thermal conductivity value. Structures of each fabric samples are clearly demosrated in figure 3, *a, b* and 4, *c, d* by microscope. In table 3, the findings from the statistical results showed that the thermal conductivity hasa high significance effect on fabric type.

Thermal absorptivity

The uncommon parameterthermal absorptivity "b" serves to evaluate the thermal sensation when fabrics get into touch with human skin. Thermal absorptivity (b) is the warm-cool feeling of fabrics and determines the contact temperature of two materials. However, thermal absorptivity "b" is generally the superficial characteristic which can be modified by surface treatment (coating, raising, brushing). It is expressed as:

$$b = (\lambda \rho c)^{1/2}, \left(\frac{Ws^{1/2}}{m^2K}\right) \quad (2)$$

Where λ is the thermal conductivity $\left(\frac{W}{mK}\right)$, ρ is the fabric density $\left(\frac{kg}{m^3}\right)$ and c is the specific heat of fabric $\left(\frac{J}{kgK}\right)$. If the thermal absorptivity is high, it gives a cooler feeling at first contact with the skin. The surface character of the fabric greatly influenced this sensation [15].

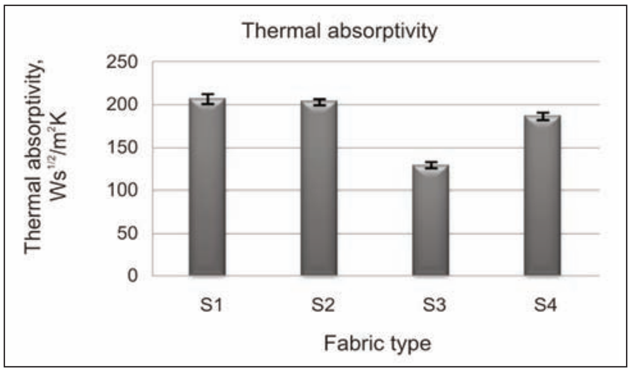

Fig. 8. Thermal absorptivity of the tested fabric samplesss

The results showed that samples made of nano-filaments yarns have higher thermal absorptivity, while coolmax fabric had a lower value. Fabrics with a lower value of thermal absorptivity provided 'warm' feeling, since it provided better thermal insulation and warmer feeling at initial touch. However, fabric having a higher value gave a 'cool' feeling. Thus, sample 3 (coolmax) exhibited a 'warm' feeling rather than other samples. The samples 1 and 2 revealed a higher value, which implies 'cooler' feeling at first contact.It can be explained by the construction of the fabric surface. In fact, the nano-filaments of polyester are characterized by their large surface area per unit mass as shown in figure 8 [20]. In fact, the surface area between the fabric and skin was bigger for smooth fabric surfaces like nano-filament fabrics and these structures caused a cooler feeling, as mentioned by Pac [27]. ANOVA results in table 3 determined that the thermal absorptivity have a high significance effect on the dependent variable (Fabric Type).

Thermal resistance

Thermal resistance expresses the thermal insulation of fabrics and is inversely proportional to thermal conductivity. In a dry fabric or containing very small amounts of water, it depends essentially on fabric thickness and, to a lesser extent, on fabric construction and fiber conductivity [28]. Thermal resistance (*R*) depends on fabric thickness "h" (mm) and thermal conductivity "λ".

$$R = \frac{h}{\lambda}, \left(\frac{m^2K}{W}\right) \quad (3)$$

or

$$R_{ct} = \frac{a - b}{a} \times 100 \quad (4)$$

R_{ct} is thermal resistance [%];

a = heat flow (no sample) [W];
b = heat flow (all samples) [W].

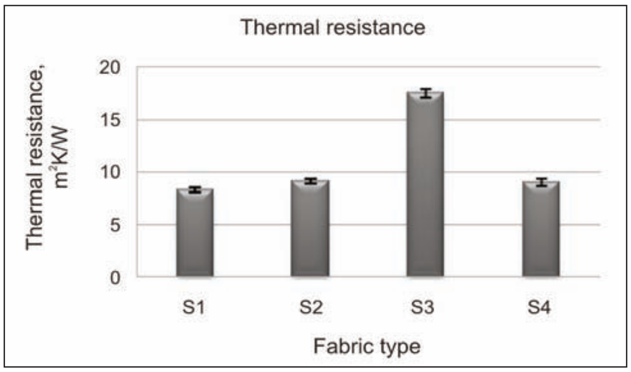

Fig. 9. Thermal resistance of the tested fabric samples

According to figure 9, coolmax fabric (S3) showed the higher value of thermal resistance. Samples made of nano-filaments yarns showed lower values. As the fabric thickness increases the thermal resistance increases. As expected, there is an inverse relationship between thermal conductivity and thermal resistance. ANOVA table given below showed that the independent variable (thermal resistance) has a statistically significant effect on the dependent variable (Fabric Type) as p-value obtained from all factors is less than the alpha value (0.01).

Table 3

Source	Type III sum of squares	df	Mean square	F	P
Thermal conductivity	.001	3	.000	22.619	.000
Thermal absorptivity	19190.000	3	6396.667	281.172	.000
Thermal resistance	285.738	3	95.246	712.118	.000
RWVP	1102.638	3	367.546	1374.003	.000

Relative Water Vapor Permeability (RWVP)

Pore size, air gap and structure of the textile material defines the RWVP. In this study, relative the water vapor permeability (%) and evaporation resistance "Ret" $\left(\frac{m^2Pa}{W}\right)$ of the studied fabrics was quantified by Permetest instrument within 3–5 minutes. Permetester

Table 4

RWVP AND R_{et} VALUES		
	RWVP (%)	**R_{et}** $\left(\frac{m^2Pa}{W}\right)$
S1	69.7	3.6
S2	66.3	4.1
S3	67.1	3.8
S4	50.8	4.8

also allows to simulate the thermal perception of wearer in wet conditions [22–23].
Relative water vapor permeability is the rate of water vapor transmission through a material. RWVP (%) of the textile clothing samples in the isothermal steady state is measured by the given equation:

$$RWVP\ (\%) = \frac{\text{Heat loss measured with sample}}{\text{Heat loss measured without sample}} \times 100$$

According to results, it is apparent that Sample 1 has a higher watervaporpermeability, while cotton sample exhibits lower value. Nano-filament fabrics have almost the same watervaporpermeability as coolmax fabric.

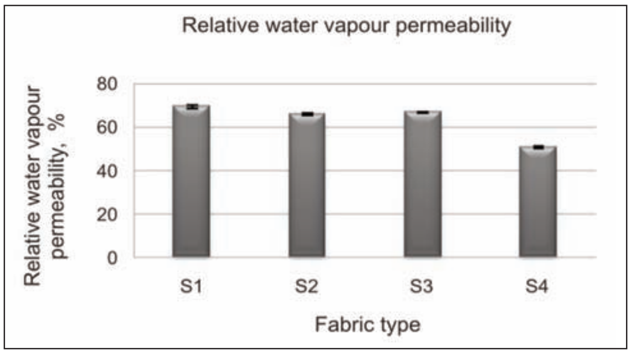

Fig. 10. Relative watervaporpermeability of the tested fabric samples

According to figure 10, nano-filament fabrics provided better water vapor permeability values because it has a larger surface area and nano-fiber structure which improve the transport system that pulls moisture away from the skin to the outer layer of the fabric. These fabrics are characterized by the small gaps between the fibers inside in the yarn. That's why the WPR of these fabrics is quite big as presented in table 4.
Thus, the type of yarn and fiber morphology affects the relative water vapor permeability significantly. Water vapor permeability "WVP" has significant importance in wet state as in dry state. When fabric is introduced to water, a fluid film is created that partially restrict the liquid permeability. Therefore the clothing comfort is also important to the wearer. Measurement of WVP with permetest sensora skin model exhibits certain advantage of giving repeatable values in not only in dry state, but also in wet state [23]. Statistical analysis in table 3 presented that the independent variable (RWVP) have a significant effect on the dependent variable (Fabric Type) as p-value is less than 0.01.

Water vapor resistance

Water vapor resistance presents the water vapor pressure difference between the two sides of the sample divided by the resultant evaporative heat flux per unit area in the direction of the gradient. It depends on the fabric density and structure. According to results, samples made of cotton sample showed a maximum value, while nano-filament sample displays a minimum value. The lower value of water vapor resistance indicates a better moisture transport and a higher value indicates that the fabric is less breathable to vapor transmission. Water vapor resistance is derived from the equation [22]

$$M = \frac{C_1 - C_2}{R} \qquad (5)$$

M is the rate of diffusion of the mass of water vapor per unit area over the specimen $\left(\frac{kg}{m^2 s}\right)$;
C_1, C_2 – concentrations of water vapor in the air on either side of the sample (kg/m^3);
R – resistance of the sample (s/m).
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 [29]. Maximum value of R_{et} for layer of air in clothing is 5 mm.

CONCLUSIONS

Nano-filament fabric sample 2 (with GSM 250) showed the highest thermal conductivity because of lower air permeability as compared to S3 and S4. Similarly nano-filament polyester fabric demonstrated 'cool' feeling with higher thermal absorptivity, while multi channel coolmax fabric provided 'warm' feeling with low thermal absorptivity, since it gave better thermal insulation at initial touch. Coolmax fabric revealed the higher value of thermal resistance, in contrast with nano-filaments fabric because there is an inverse relationship between thermal conductivity and thermal resistance. In fact, nano-filament fabrics exhibited the better water vapor permeability by the reason of a larger surface area and nano-fibre structure implies to improve the transport system that pulls moisture away from the skin to the atmosphere. A fall in water vapor resistance raised the moving speed of water droplets through the nano-filament polyester fabric. ANOVA results showed the statistical significance of independent variables (Thermal properties and RWVP), on the dependent variable (Fabric Type) as p-value is less than 0.01.

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