

# Comfort and microbial barrier properties of garments worn next to the skin

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**Abstract.** Compared with viscose fibre, modal fibre is characterized by some advantageous properties such as higher dry and wet tenacities, higher wet modulus, lower water retention capacity and lower level of swelling. Impact of different knitted fabric structure made of cotton and 97 % CMD/3 % EL fibres on thermo-physiological comfort and microbial barrier properties were investigated. All knitted fabrics have very good physiological properties. The microbial barrier permeability of knitted fabric after extreme contamination with bacterial spores in dry state showed that double jersey offered more effective microbial barrier than the single jersey knitted fabrics respectively the greater thickness of double jersey knitted fabric provide more difficult barrier to bacterial spores to pass. In wet state all knitted fabrics have more effective microbial barrier which could be explained by cellulose fibres swelling. In wet state 97 % CMD/3 % EL single jersey knitted fabric have more effective microbial barrier then cotton double and single jersey knitted fabrics.

## 1. Introduction

Modal viscose fibre is one of the fibres from regenerated cellulose fibres group. Compared with viscose fibre, modal fibre is characterized by some advantageous properties such as higher dry and wet tenacities, higher wet modulus, lower water retention capacity and lower level of swelling [1,2]. Therefore, modal fibre is frequently used as an alternative to cotton or viscose fibre due to its better properties to provide fabrics with more functional and aesthetic fabric properties [3]. The combination of modal fibre with cotton fibre is commonly used in a wide range of knitwear applications including underwear, shirting, blouses, dresses etc. Hygienic problems arise when textiles impair the antimicrobial defence of skin by causing mechanical influence to the barrier function, but also by increased humidity caused by clothing and shoes [4]. Textile materials often present a problem when dealing with microorganism control since microorganisms use textiles to survive due to humidity and easily accessibly [5,6]. Structure and raw material of clothes have a strong effect on sweating and thus odor development. High humidity represents a favorable condition for bacteria growth where sweat is an ideal bacterial breeding ground. Most of odors associated with the human body are the result of microorganisms digesting nutrients present in sweat [7-13]. Development of sweat caused by textile leads to increase of the metabolic activity of skin bacteria, accumulation of odorous products of the bacterial metabolism, loss of textile performance and/or textiles discoloration [14-18]. Research of different textile materials influence on bacterial growth determined by quantitative analysis was recently reported.



A trend for a lower overall growth on natural polymer materials compared to synthetic materials under certain conditions of humidity was observed. Lower overall growth of bacteria was supposed to be because of a reduction in free water content by the water-absorbent natural polymer materials [19-23].

Impact of two different knitted fabric structure made of cotton and modal fibres on thermo-physiological comfort and microbial barrier properties were investigated. Selected knitted fabrics commonly are used for underwear and T-shirt respectively for garments worn next to the skin.

## 2. Materials and Methods

The research work was carried out on 100 % cotton single jersey and double jersey knitted fabric and 97/3 % modal/elastane single jersey knitted fabric. In the analysis of the parameters of the knitted fabric structure basic parameters such as horizontal ( $Dh$ ) and vertical fabric density ( $Dv$ ), fabric thickness ( $t$ ) and mass per unit area ( $m$ ) are significant and therefore tested [19].

### 2.1. Thermo-physiological properties

Thermo-physiological properties was determinate by measuring water-vapour resistance under steady-state conditions, using the Sweating Guarded Hot Plate [Figure 1]. The equipment simulates the flow of moist heat from the skin in the form of insensible sweating. The data is used to measure the water vapour resistance and determine the level of "breathability".



Figure 1. Sweating guarded hot plate, Measurement Technology Northwest

The sample to be tested is placed on the heated plate with the conditioned air ducted to flow along and parallel to its upper surface. During determination of water-vapour resistance, the surface of the porous plate is kept constantly moist by means of a water-dosing device. A smooth, water-vapour permeable, but liquid-water impermeable cellophane membrane shall be fitted over the porous plate. For the determination of water-vapour resistance ( $R_{et}$ ) the temperature of the measuring unit needs to be set at 35 °C, air temperature at 35 °C, relative humidity of 40 % and air speed at 1 m s<sup>-1</sup>. After reaching the test conditions and steady-state the recording of values can be started. Water-vapour resistance of the tested material is determined as the arithmetic mean of the values of three individual specimens. The water-vapour resistance of the fabric is calculated according to the following equation [20]:

$$R_{\text{et}} = \frac{(p_m - p_a) \cdot A}{H - \Delta H_e} - R_{\text{et},0} \quad (1)$$

where:  $R_{\text{et}}$  is the water-vapour resistance in  $\text{m}^2 \text{ Pa W}^{-1}$ ,  $p_m$  is the saturation of water-vapour partial pressure in Pa at the surface of the measuring unit at temperature  $T_m$  in  $^{\circ}\text{C}$ ,  $p_a$  is the water-vapour partial pressure in Pa of the air in the test enclosure at  $T_a$   $^{\circ}\text{C}$ ,  $A$  is the area of the measuring unit in  $\text{m}^2$ ,  $H$  is the heating power supplied to the measuring unit in  $\text{W}$ ,  $\Delta H_e$  is the correction term for the heating power in  $\text{W}$ , and  $R_{\text{et},0}$  is the bare plate evaporative resistance in  $\text{m}^2 \text{ Pa W}^{-1}$ .

## 2.2. Microbial barrier properties

Microbial barrier properties were tested using bacterial spores of the Bacillus genus *Geobacillus stearothermophilus*  $10^5$  (ATCC 12980, DSM 22) and *Bacillus atrophaeus*  $10^6$  (ATCC 49337, DSM 7264) in dry and wet state. Knitted fabric was fastened in a ring-like device (sample diameter of 55 mm). Method of testing microbial barrier permeability in dry conditions involves directly rubbing the microorganisms onto the sterilized samples. Incubation of 24 hours followed. After 24 hours the print was taken using a CT3P agar print plate (bioMe'rieux SA, Marcy l'Etoile, France). The first print was taken from the back side and then with new plate from the front side of the knitted fabric. Agar plates were incubated for 72 h at  $35^{\circ}\text{C}$ . After incubation colony forming units (CFU) were counted [21, 22].

The test of microorganism permeability through the wet sample (sample is actually moist to simulate sweat) is modified to the own method. The microorganism permeability test in wet state gives microorganism permeability of fabrics which become moist during increased physical activity where favorable conditions for the growth of bacteria's are created.

Sterilized sample was fixed on the ring and 1 ml of distilled water was applied to sample. After wetting of the sample microorganisms in the dry state were applied and the above referred procedure is repeated.

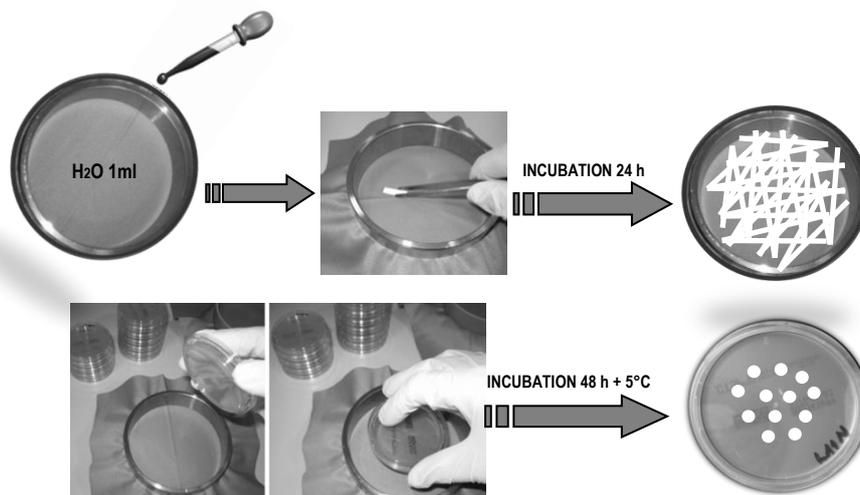


Figure 2. The modified method of testing microbial barrier in wet state

## 3. Results and discussion

The results of knitted fabric parameters, thermo-physiological and microbial barrier properties are given in tables 1-3 and shown oh figure 1. The value of mass per unit area of 100 % cotton single jersey knitted fabric is  $149 \text{ g/m}^2$ , 100 % cotton double jersey knitted fabric amount  $193 \text{ g/m}^2$  and 97/3 %

modal/elastane single jersey knitted fabric is 190 g/m<sup>2</sup> (table 1). Thickness of the both single jersey fabrics are relatively same (0.36 mm respectively 0.38 mm) while thickness of double jersey knitted fabric is 0.60 mm. The double jersey knitted fabric is 38 % respectively 40 % thicker than single jersey fabrics. The horizontal density of single (16 loop / cm respectively 12 loop / cm) and double jersey knitted fabrics (15 loop / cm) are lower than vertical. The vertical density of single jersey knitted fabric is 16 loop / cm respectively 20 loop / cm while double jersey fabric has 22 loop / cm.

**Table 1.** Knitted fabric parameters

Sample	$m$ , g m <sup>-2</sup>	SD	$t$ , mm	SD	$Dv$ , cm <sup>-1</sup>	SD	$Dh$ , cm <sup>-1</sup>	SD
100 % cotton single jersey	149	0.03	0.38	0.01	16.0	0.71	12.4	0.55
100 % cotton double jersey	193	0.03	0.60	0.01	19.9	0.74	15.4	0.42
97 % CMD/3 % EL single jersey	190	0.01	0.36	0.01	20.2	0.84	16.3	0.45

where:  $m$  is the mass per unit area, g/m<sup>2</sup>;  $t$  is the thickness, mm;  $Dh$  is the horizontal fabric density, cm<sup>-1</sup>;  $Dv$  is the vertical fabric density, cm<sup>-1</sup>; SD is standard deviation.

The values of water vapour resistance ( $R_{et}$ ) of knitted fabrics ranged from 3.69 to 4.34 m<sup>2</sup> Pa W<sup>-1</sup> and have very good physiological properties (table 2) [19]. The water vapour resistance of the 97/3 % modal/elastane single jersey is lowest compared to single and double jersey knitted cotton fabrics. Differences of water vapour resistance between two different structures (single and double jersey) and raw materials (cotton and 97/3 % modal/elastane) are not significant considering that human body cant detected and feel such a small difference in comfort. Although results of water vapour resistance suggest that there is no significant difference between cotton and 97/3 % modal/elastane knitted fabric it should be taken into account of smooth modal fabric surface pleasant to touch which makes modal fabrics soft and gentle and thus more comfortable to wear. Modal fabrics are well known for rapid absorption, which could lead to subjective feeling of better comfort.

**Table 2.** Thermo-physiological properties of knitted fabrics

Sample	$R_{et}$ , m <sup>2</sup> Pa W <sup>-1</sup>			M, m <sup>2</sup> Pa W <sup>-1</sup>	SD, m <sup>2</sup> Pa W <sup>-1</sup>	CV, %
	n1	n2	n3			
100 % cotton single jersey	3.8009	3.9870	4.4047	4.0642	0.2525	6.21
100 % cotton double jersey	4.5791	4.3016	4.1349	4.3385	0.1832	4.22
97 % CMD/3 % EL single jersey	3.7528	3.7557	3.5727	3.6937	0.0856	2.32

where:  $R_{et}$  is the water vapour resistance, m<sup>2</sup> Pa W<sup>-1</sup>;  $n_1$ ,  $n_2$ ,  $n_3$  are individual measurements of the water vapour resistance, m<sup>2</sup> Pa W<sup>-1</sup>; M is mean value of the water vapour resistance, m<sup>2</sup> Pa W<sup>-1</sup>; SD is standard deviation, m<sup>2</sup> Pa W<sup>-1</sup>; CV is coefficient of variation, %.

The results of the microbial barrier permeability of knitted fabric in dry and wet state after extreme

contamination are given in table 3. The microbial barrier permeability of knitted fabric after extreme contamination with bacterial spores of *Geobacillus Stearothermophilus* and *Bacillus Atrophaeus* in dry state showed that double jersey offered more effective microbial barrier than the single jersey knitted fabrics. It could be explained by the thickness of double jersey fabric. The greater thickness of double jersey knitted fabric provide more difficult barrier to bacterial spores to pass.

In wet state all knitted fabrics have more effective microbial barrier which could be explained by cellulose fibers swelling. The 97 % CMD/3 % EL single jersey knitted fabric have slightly more effective microbial barrier then cotton double jersey and significantly more effective microbial barrier then cotton single jersey knitted fabrics. By comparing two different structure of 97 % CMD/3 % EL single and cotton double jersey knitted fabric it is visible that double jersey have for 40 % greater thickness while horizontal and vertical density are almost same. More affective microbial barrier of 97 % CMD/3 % EL single jersey knitted fabric in wet state may be explained by greater swelling of modal fibres (up to 50 % considering cotton fibres) where stitches openings as well as openings between stitches of knitted fabrics decrease.

**Table 3.** Microbial barrier properties of knitted fabrics

Sample	Number of isolates	Colonies/plate Mean $\pm$ SD (range)	
		Dry state	Wet state
100 % cotton single jersey	12	124 $\pm$ 50.8 (51-182)	19 $\pm$ 20.7 (1-46)
100 % cotton double jersey	12	20 $\pm$ 5.0 (14-25)	9 $\pm$ 1.7 (8-11)
97 % CMD/3 % EL single jersey	12	58 $\pm$ 16.6 (33-76)	8 $\pm$ 2.6 (5-10)

The thickest sample (0.60 mm) is double jersey knitted fabric which has highest water vapour resistance (4.3385 m<sup>2</sup> Pa W<sup>-1</sup>) as well as smallest differences of microbial barrier properties in dry (20 colonies) and wet (9 colonies) state (figure 3, table 3). The single jersey cotton fabric has biggest differences in microbial properties in dry (124 colonies) and wet (19 colonies) state. The smallest water vapour resistance has 97 % CMD/3 % EL single jersey knitted fabric (3.6937 m<sup>2</sup> Pa W<sup>-1</sup>). The same fabric have best effect of microbial barriers in wet state (58 colonies in dry state and 8 colonies in wet state). It can be concluded that 97 % CMD/3 % EL single jersey knitted fabric in relation to single and double jersey cotton fabrics is more suitable for garments worn next to the skin especially during sport activities.

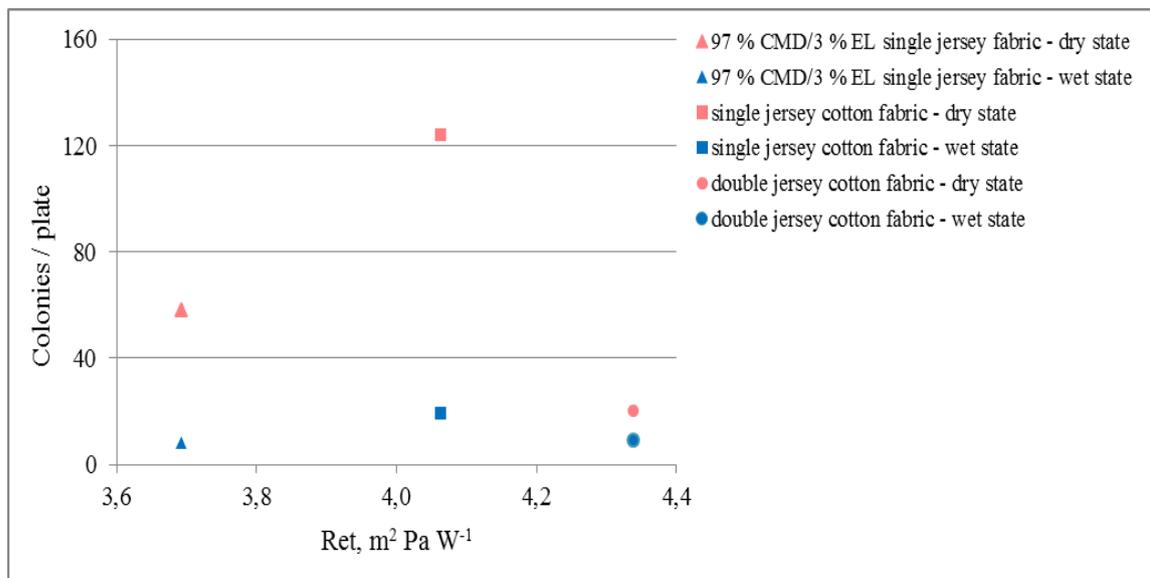


Figure 3. Water vapour resistance and microbial barrier properties of knitted fabrics

#### 4. Conclusion

Comparing the single and double jersey cotton fabrics with the 97 % CMD/3 % EL single jersey it can be observed that there is no significant difference between their water vapour resistances. However, modal fabrics are well known for smooth, soft and gentle surface pleasant to touch including rapid liquid absorption which could lead to subjective feeling of better comfort.

The microbial barrier permeability of knitted fabric after extreme contamination with bacterial spores of *Geobacillus Stearotherophilus* and *Bacillus Atrophaeus* in dry state showed that double jersey offered more effective microbial barrier than the single jersey knitted fabrics. It could be explained by greater thickness of double jersey knitted fabric that provide more difficult barrier to bacterial spores to pass.

In wet state 97 % CMD/3 % EL single jersey knitted fabric have more effective microbial barrier than cotton double and single jersey knitted fabrics. More affective microbial barrier of 97 % CMD/3 % EL single jersey knitted fabric in wet state could be explained by greater swelling of modal fibres where stitches openings of knitted fabrics decrease.

#### Acknowledgments

The research is conducted from the project “Comfort and antimicrobial properties of textiles and footwear”, code: IP-2016-06-5278 with the support of the Ministry of Science, Education and Sports of the Republic of Croatia.

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