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DYNAMIC ASSESSMENT OF WATER VAPOR RESISTANCE OF FABRICS CONTAINING HYDROPHILIC NATURAL FIBERS

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Abstract: *The transfer of water vapor through a textile is a crucial factor for ensuring comfort and performance in various applications that involve exposure to moisture or sweating, including military, firefighting, and outdoor sports activities. This work proposes a new experimental setup to measure the water vapor resistance of fabrics under different temperature and humidity conditions, providing more realistic values compared to conventional steady-state methods. Two different fabrics were analyzed. The first one is a common blend of fibers that mainly contains cotton (95 %) and elastane (5 %), and the second one contains modacrylic fibers (MAC Protex® 60 %) in combination with cotton (40 %). The results showed that the predominance of cotton in the composition of the fabric can lead to an increase of up to 13 % in the resistance to vapor transfer, attributed to the swelling effect of the fibers due to the increase in relative humidity. Blending cotton and PROTEX fibers in such fabrics provides improved moisture management properties in the sense of maintaining constant water vapor resistance even as relative humidity increases, contributing to wearer dryness and comfort.*

Keywords: *moisture transfer, cotton fibers, breathability, relative humidity, temperature.*

1. INTRODUCTION

The garment's primary function is to establish a stable microclimate in proximity to the skin, facilitating the body's thermoregulatory system regardless of environmental conditions or physical exertion. Breathability, defined as a textile's capacity to allow the transmission of moisture vapor through the material, plays a crucial role in sustaining the wearer's thermophysical comfort [1]. Therefore, many studies related to the breathability of various fabrics have been carried out [2], [3], [4], [5], [6]. However, most studies examined breathability characteristics according to two standards: the evaporative dish method (BS 7209) and the Hohenstein measuring method (ISO 11092). The first method involves quantifying the water vapor transmission rate (WVTR) and is a simple and cost-effective method used for quality control under standard conditions. In contrast, the second method, known also as the skin model, involves measuring the moisture vapor resistance (R_{et}) by the evaporative heat loss technique and is a method known for its accuracy and is mainly used in research and product design applications. Although a correlation has already been established between the properties determined by the two methods, WVTR and R_{et} respectively [7], [8], for hydrophilic materials this relationship is not valid.

The objective of this study is to assess the moisture vapor transfer resistance of hydrophilic textile materials under diverse humidity and temperature conditions and to establish a correlation with their moisture content.

2. MATERIALS AND METHOD

Two different textile fabrics were analyzed (Table 1). The first one (Sample A) is a common blend of fibers that mainly contains cotton (95 %) and elastane (5 %), and the second one (Sample B) contains modacrylic fibers (MAC Protex® 60 %) in combination with cotton (40 %). These materials are knitted fabrics used for the manufacture of underwear for protective clothing. Samples were selected to exhibit different characteristics concerning fiber moisture regain.

Table 1: *Characteristics of the fabrics*

Code	**Composition**	**Structure**	**Weight** $(g \cdot m^{-2})$	**Thickness (mm)**	R_{et} $(m^2 \cdot Pa \cdot W^{-1})$	I_{mt}	**Moisture regain (%)**
A	95% Cotton/ 5% Elastane	piqué	253 ± 5	1.16 ± 0.01	2.83 ± 0.10	0.48	6.50 ± 0.2
B	60% Modacrylic/ 40% Cotton	piqué	234 ± 3	0.83 ± 0.01	3.35 ± 0.05	0.41	3.53 ± 0.1

The characteristics of the fabrics listed in Table 1 were evaluated in accordance with established standards. Fabric weights were determined following the ASTMD 3776/D 3776M - 09a procedure, while the thickness of knitted fabrics was measured using the SDL – Digital Thickness Gauge M034A as per NP EN ISO 5084-2013. Thermal and water-vapor resistance were assessed using the sweating-guarded hotplate method (“skin model”), in compliance with ISO 11092:2016. A controlled climatic chamber was utilized to ensure specific environmental testing conditions. Moisture regaining from the textiles was determined through the drying method outlined in ISO 287:2008.

A Sweating Guarded Hotplate tester was employed to assess the water vapor transfer properties of the two types of fabrics (Fig. 1).

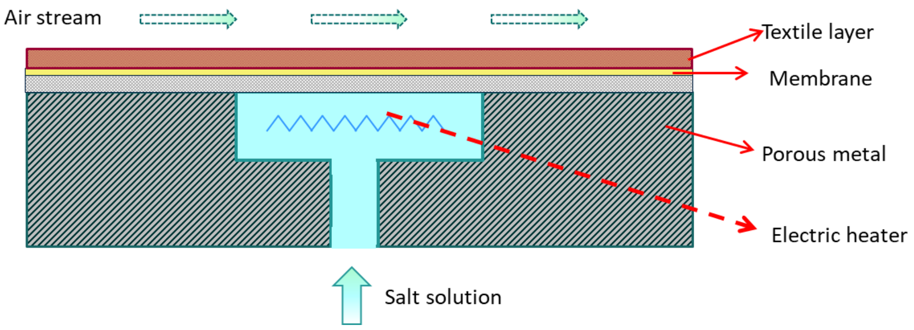

Fig. 1*: Skin Model experimental setup*

The device comprises a porous square metal plate fixed on a thermally conductive block, heated with an electric thermal heater. Sensors monitor the temperature of the thermal protection, water and porous metal plate, ensuring constancy within ±0.1 K. To compensate for the heat absorbed during water evaporation, a heating power H is provided by a suitable device, monitored with a precision of ±2 % throughout the operation. For R_{et} determination, the porous hot plate is protected by a breathable membrane impermeable to liquid water. The test sample is positioned above the membrane, and a conditioned air current (1 ±0.05 ms^{-1}) is flowing over and parallel to its top surface. Four humidity sensors (KFS 140-M SMD) measure the average humidity of the textile material.

To obtain the R_{et} values for different humidity and temperature values, the conditions from ISO 11092:2016 have been modified. The distilled water has been replaced with saturated salt solutions which provide different accurate values of the water vapor saturation pressure at four constant temperatures: 25 °C, 35 °C, 45 °C, and 55 °C. For each sample, choosing the right salt solution and adjusting the humidity of the air, conditions inside of the Skin Model were made so that the average humidity RH % of the textile, measured by sensors, was between 10 % and 90 %, with adjustments steps by steps of 10 %. The moisture content in the samples at the same partial pressure targets was determined by using a gravimetric method that measures uptake and loss of moisture. For that, initially, the samples underwent conditioning under a continuous flow of dry air for approximately 10 hours. Subsequently, they were exposed to the partial pressure of water vapor (pa), ranging from 10 % to 90 % of saturated pressure (ps), with increments of 10 %. The equilibrium criterion was defined by selecting a minimal value (0.005 % per min.) for the mass variation over time variation (dm/dt). This setup enables the software to automatically ascertain the time needed for the sample to achieve its equilibrium moisture content before progressing to the subsequent step (pa/ps). Moreover, this arrangement was employed to determine the minimum time required for R_{et} estimation using the Skin Model test at different relative humidities (RH %).

3. RESULTS AND DISCUSSION

Three determinations were made for each sample. A deviation of less than ±3 % from the average values was found. Figure 2 shows the average values and errors obtained for R_{et} at 25 °C, for different relative humidity values.

Experiments carried out in the relative humidity range between 10 % and 90 % show that the water vapor resistance increases relatively linearly with the moisture content at constant temperature for sample A containing mainly cotton, and remains almost constant in the case of cotton and synthetic fiber sample B (Fig. 2). R_{et} determined according to the ISO 11092:2016 standard (static conditions) was 2.83 $m^2 \cdot Pa \cdot W^{-1}$ for sample A, and 3.35 $m^2 \cdot Pa \cdot W^{-1}$ for sample B (Table 1). Since the structural characteristics of the two samples are different (thickness, mass), it is not the value itself of the R_{et} that interests us in this study, but the variation depending on the relative humidity and temperature. When the composition of fabrics is mostly cotton, the resistance to vapor transfer can increase up to 13 % due to the swelling effect of the fibers that affects the inner structure of the system. Through the integration of PROTEX fibers, the resultant textiles can enhance moisture control by maintaining constant water vapor resistance, even with an escalation in relative humidity. This contributes to keeping the individual dry and comfortable.

Figures 3 and 4 illustrate two-dimensional representations of R_{et}, which demonstrate how the water vapor resistance of a textile layer is impacted by variations in both temperature and mean relative humidity. The study showed that increasing temperature can have a noticeable effect on vapor transfer properties, but this effect is primarily caused by vapor diffusion (properties of air that fill the voids in textile porous media) rather than any intrinsic changes to the textile fibers themselves [9]. The experimental results show a decrease in water vapor resistance when the temperature increases.

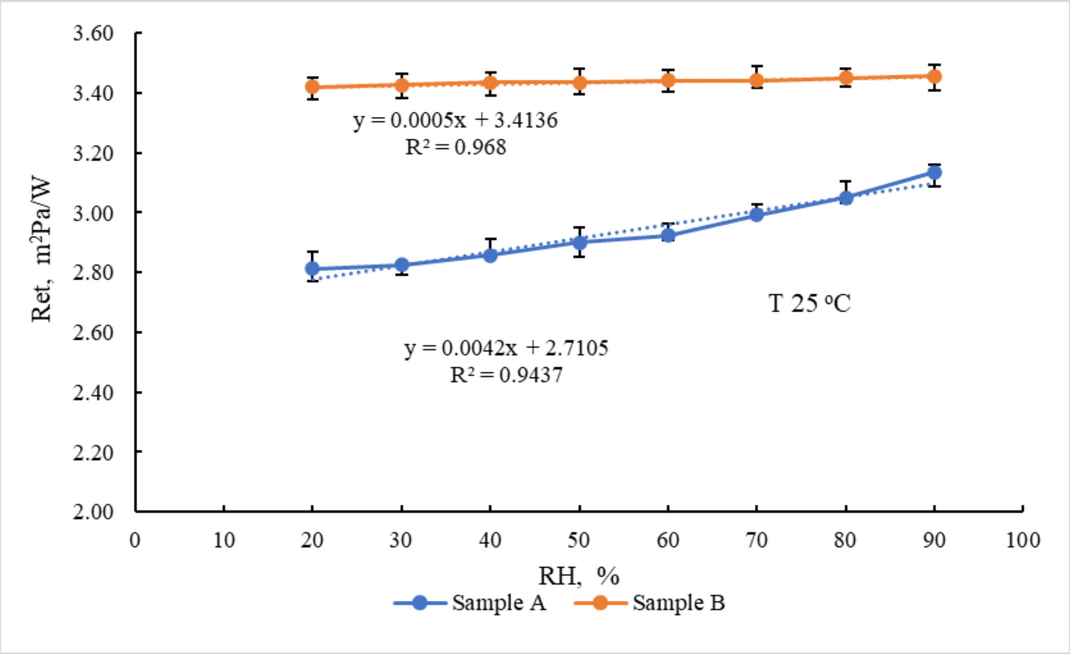

__Fig. 2__: R_{et} at 25 °C as a function of relative humidity

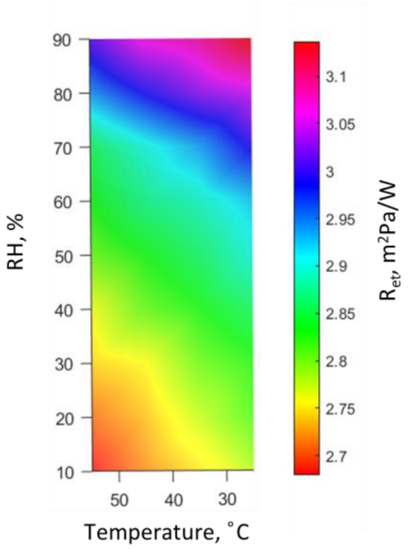

__Fig. 3__: R_{et} of Sample A, at different relative humidity and temperature

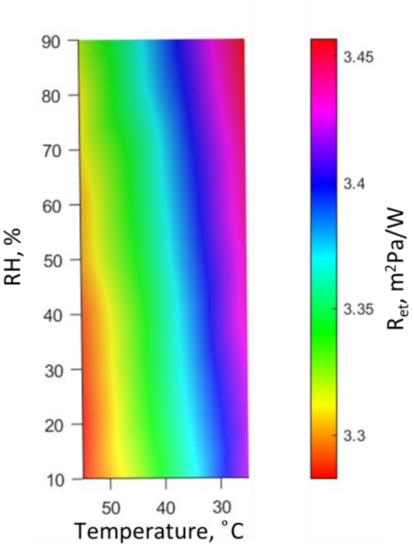

__Fig. 4__: R_{et} of Sample B, at different relative humidity and temperature

So far, in the specialty literature, no other studies are known that refer to a correlation between the evaporative resistance of textiles and ambient humidity. However, many authors have studied the influence of environmental conditions on other parameters closely related to R_{et}, such as air permeability. Miguel [10] found that air humidity can significantly influence the performance of nonwoven filters concurrently with changes in air permeability. Adámek *et al.* [11] observed a linear dependence between Air Permeability and R_{et} determined under standard conditions for various types of textile materials. Hess *et al.* [12] measured air permeability for different fabrics at various humidity and temperature values. The experiments revealed that, in all cases, air permeability decreased with increasing air humidity and temperature. They observed that the effect of humidity was the lowest on the hydrophobic polypropylene fabrics. This can be explained by the lowest swelling of these fibers, contrary to the highest swelling of the hydrophilic cotton fibers.

4. CONCLUSIONS

This paper presents a new method for determining the water vapor resistance of textile materials. The method allows the determination of water vapor resistance under dynamic conditions, a fact with major significance especially in the case of hydrophilic materials. The water vapor resistance of hydrophilic textiles under varying humidity and temperature conditions differs from the values obtained through standard methods for assessing this property. This variation is particularly crucial in the selection of clothing layers in activities like firefighting, military operations, or active sports. While natural fibers offer comfort, their moisture content can adversely affect water vapor transfer properties. In this situation, blending specific synthetic fibers with natural ones can mitigate the swelling effect of natural fibers, thereby minimizing its impact on vapor transfer. Consequently, the dynamic assessment of vapor resistance in textile fabrics proves beneficial for optimizing thermophysiological comfort.

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