Heat, Moisture and Air Transfer Properties of Selected Woven Fabrics in Wet State

Lubos Hes[1], Carmen Loghin[2]

[1]*Technical University of Liberec, Studentska 2, 460 15 Liberec, Czech Republic*
[2]*G. Asahi Technical University, Prof. D. Mangeron Str. 53, 70050 Iasi, Romania*

Abstract: The most important parameters characterizing thermophysiological comfort of sport and protective garments are thermal resistance, water vapour permeability and air permeability. Contrary to common textiles, protective and functional garments and some technical textiles like textile dressings are also used in wet state, which affects their comfort properties. However, common measuring instruments mostly do not enable reliable measurement of wet fabrics, due to long time of measurement, during which the fabrics get dry. In this paper two fast measuring PC evaluated instruments ALAMBETA and PERMETEST commercial instruments are described, which provide reliable non-destructive measurement of thermal conductivity, thermal resistance and water vapour permeability of fabrics in dry and wet state. By means of these instruments, thermal resistance and water vapour permeability of heavy cotton and cotton/PES woven fabrics in wet state were experimentally determined and results were discussed. The effect of structure and composition on the above-mentioned properties of these fabrics has been investigated as well. Some surprising results were achieved: with increasing fabrics humidity, the air permeability almost linearly decreased, whereas the total cooling heat flow (due to water evaporation from the wet fabric surface) slowly increased.

Keywords: Clothing comfort, thermal resistance, water vapour permeability, wet textile fabrics.

1. Introduction

Added value of performance garments depends on their increased comfort and protection functions [1]. Contrary to common textiles, protective and functional garments and some technical textiles like textile dressings, due to sweat sorption, or because of rainy climate or some technological reasons are also in wet state, which affects their comfort properties. Thus, the final thermophysiological comfort is given by two principal components: thermal resistance in wet state, and the active cooling resulting from the moisture evaporation from the skin and passing through the dressing and from direct evaporation of sweat from the fabric surface.

First part of this paper is dedicated to description of special measuring instrument for the measurement of thermal conductivity of fabrics in wet state and to experimental determination of thermal conductivity of selected woven fabrics in wet state. The results are presented and discussed with respect to the fabric structure and composition. Similar attention is paid to the determination of water vapour and air permeability of woven fabrics in wet state in the second part of the paper.

As already mentioned, with the increasing moisture regain, water vapour permeability of fabrics changes and affects (mostly negatively) thermophysiological comfort of the wearer. Therefore, the knowledge of water vapour permeability or resistance of fabrics in wet state is also very important.

Unfortunately, current measuring instruments for the evaluation of thermophysiological comfort of fabrics require more than 30 minutes for full reading, thus avoiding the precise determination of fabrics humidity effect on their thermal resistance and cooling heat flow [W/m^2], due to humidity decrease during the measurement. Moreover, WVP testers based on pure detection of air humidity under and above the wet sample cannot record the effect of heat generated or absorbed in the fabric due to its interaction with water. The advanced WVP measurements reflecting the real human body perception of comfort require the use of very fast skin model. That is why detailed analysis of cooling effect accompanying wearing of wet fabrics is almost missing in the literature.

The effect of moisture regain on effective thermal conductivity of woven fabrics has been studied by Schneider et al. [2], whereas the water vapour permeability of wet fabrics has been studied e.g. by Ruckman [3] without considering the effect of water

*Corresponding author's email: lubos.hes@gmail.com

evaporation from the fabric surface. Recent results were published by Hes and Araujo [4].

2. Thermal properties of textiles in dry and wet state

Thermal properties of textiles such as thermal resistance, thermal conductivity and thermal absorbtivity are influenced by fabric properties such as structure, density, humidity, material and properties of fibres, type of weave, surface treatment, filling and compressibility, air permeability, surrounding temperature and other factors.

Thermal conductivity coefficient λ presents the amount of heat, which passes from 1m^2 area of material through the distance 1 m within 1 s and create the temperature difference 1 K. The highest thermal conductivity exhibit metals, whereas polymers have low thermal conductivity, ranging from 0,2 to 0,4 W/m/K. Thermal conductivity of textile structures generally reaches levels from 0,033 to 0,01 W/m/K. Thermal conductivity of steady air by 20 °C is 0,026 W/m/K while thermal conductivity of water is 0,6 W/m/K, which is 25times more. That is why the water presence in textile materials is undesirable.

Thermal absorbtivity b of fabrics was introduced by Hes [5] to characterise thermal feeling (heat flow level) during short contact of human skin with the fabric surface. Providing that the time of heat contact τ between the human skin and the textile is shorter then several seconds, the measured fabric can be simplified into semi-infinite homogenous mass with certain thermal capacity ρc [J/m^3] and initial temperature t_2. Unsteady temperature field between the human skin (with constant temperature t_1) and fabric with respect to boundary conditions offers a relationship, which enables to determine the heat flow q [W/m^2] course passing through the fabric:

$$q = b\,(t_1 - t_2) / (\pi\tau)^{1/2}, \qquad b = (\lambda\rho c)^{1/2}$$

where ρc [J/m^3] is thermal capacity of the fabric and the term b presents thermal absorbtivity of fabrics. The higher is thermal absorbtivity of the fabric, the cooler is its feeling. In the textile praxis, this parameter ranges from 20 Ws$^{1/2}$/m^2/K for fine nonwoven webs to 600 Ws$^{1/2}$/m^2/K for heavy wet fabrics.

Thermal resistance R [m^{2}K/W] depends on fabric thickness h and thermal conductivity λ:

$$R = h/\lambda$$

2.1 Principle of ALAMBETA instrument - tester of thermal properties of fabrics

This apparatus used in this study enables the measurement of the following thermal parameters: thermal conductivity, thermal absorbtivity, thermal resistance and sample thickness. The Alambeta simulates the dry human skin and its principle depends in mathematical processing of time course of heat flow passing through the tested fabric due to different temperatures of bottom measuring plate (22 °C) and measuring head (32 °C). When the specimen is inserted, the measuring head drops down, touches the fabrics and the heat flow levels are processed in the computer and thermo-physical properties of the measured specimen are evaluated [5]. The measurement lasts for several minutes only. Thus, reliable measurements on wet fabrics are possible, since the sample moisture during the measurement keeps almost constant.

3. Simple model of thermal con-ductivity of woven fabrics in wet state

The simplified mathematical model for thermal conductivity λ includes just conductivity of fabric and water. In this model, the space filled by air will be replaced by water. The separated polymer and air effects on resulting thermal resistance and conductivity are not considered, as it has no sense: they cannot be measured precisely, due to strong effect of the structure. On the other hand, thermal characteristics of fabrics can be measured very precisely. Total thermal resistance of single layer wet fabrics is believed to be a parallel link of thermal resistance of textile R_t and thermal resistance of water Rw, due to presence of continuing water-filled channels between the fabric surfaces.

It is generally known, that for parallel combination of thermal resistances, it is possible to sum up the related conductivities λ_T and λ_W, but as the weighted sum only. They contribute to the resulting wet fabric thermal conductivity λ_{RES} valid for the square area 1 m^2, according to their areal participation expressed through the surface porosity ε:

$$\lambda_{RES} = \varepsilon\, \lambda_T + (1-\varepsilon)\, \lambda_W$$

In our case, when applying substantial simplification by considering the dry fabric mass (and surface) the 100% and the moisture content U (u < 100%), we can write: