Indirect measurement of moisture absorptivity of functional textile fabrics

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Abstract. Modern testing of thermophysiological comfort of functional textile fabrics involves not only their water vapour permeability and thermal resistance in dry state, but also testing of these properties in wet state. Besides stationary properties, also transient properties like warm-cool feeling or thermal absorptivity are important. In the paper, the concept of special version of this parameter, called moisture absorptivity, is explained and used for evaluation of transient moisture transfer (moisture management) between simulated wet human skin and selected dry functional underwear fabrics.

1. Introduction

The main protective property of underwear, besides thermal insulation and permeability for water vapour state, is effective absorption of sweat and its fast in-plane distribution in large area. Cellulosic fabrics exhibit very good moisture absorption, but its spreading into large area is, due to very high adhesion forces, limited. For underwear made of common circular PES fibres is typical low or medium moisture absorption and bad in-plane moisture distribution. The best underwear, like this made of special polyester COOLMAX fibres, exhibits medium moisture transfer between the skin and the fabric and efficient distribution of the moisture in quite large area of the fabric. Thus, successful design of functional underwear requires the use of special testing method, which simulates transient moisture transfer between wet human skin and the fabrics and enables to determine the resulting warm-cool feeling between the skin and fabric as the objective parameter. The first parameter in question is the moisture sorption capacity of shirt fabrics. There are many methods to measure this parameter [1]. Nevertheless, the moisture absorbency characterises just the specific moisture retention corresponding to the state of full saturation of the fabric volume by water or sweat and is directly proportional to the fabric mass. No transient aspects are considered here and no different boundary conditions of moisture transmission between the skin and a fabric are respected. Thus, all the found measuring methods are not suitable for standard measurements of transient fabric wetting due to quite complicate preparation of the measurements. Moreover, the reduced comfort caused by wearing the PES/cotton shirts in hot day is felt mainly in the moment, when the suddenly wetted fabric touches the skin. Consequently, the cool feeling occurs which is considered as unpleasant. Within the contact time, moisture is transferred by conduction or/and convection through a thin intermediate layer created by wet outstanding fibres. Thus, the boundary condition approximates to that of 1st or 3rd order which should be respected within a measuring method in question. Therefore, the first objective of the research work was to develop a method of an indirect experimental determination of the so called surface moisture absorptivity $B$, whose higher level apparently increases the contact comfort of wet fabrics and on the contrary. A new method described in the paper is easy and reproducible and reflects the real moisture and heat transfer conditions between the fabric and the skin.

2. Theoretical part

2.1. Introduction of moisture absorptivity

The amount of liquid inside any porous structure or textile fabric can be expressed in terms of the fabric free volume saturation $s$. Thus, for $s = 0$ the fabric is dry and for $s = 1$ all the pores are full of a
liquid. In this case, the saturation propagation within a fabric, either along its surface but also perpendicularly to its surface, can be characterised by the classical partial differential equation of diffusion processes:

\[
\frac{\partial s}{\partial \tau} = A \frac{\partial^2 s}{\partial x^2}
\]  

(1)

where \( A \) \([m^2\cdot s^{-1}]\) is so called moisture diffusivity. The solution of equation of this kind for \( A = \text{const} \) is generally known. If we consider just short time moisture conduction, then we can convert a textile fabric to a semi-infinite body, where the 1\(^{st}\) order boundary condition is applied. In this case, the moisture saturation propagation in the \( x \) direction is given by the equation

\[
s = \text{erfc}(\frac{x}{2\sqrt{A \tau}})
\]  

(2)

The experimental determination of the moisture diffusivity from the moisture propagation along the measured fabric is possible. Unfortunately, the moisture diffusivity in this form does not characterise the volumetric capacity \( V \) of the fabric expressed in this case in \( m^3/(m^2\cdot s) \) to conduct the moisture (sweat) from the contacted skin away towards a fabric interior. Darcy law was used here as follows:

\[
V = -\lambda_s \frac{\partial s}{\partial x}
\]  

(3)

where \( \lambda_s \) \([m^3\cdot s^{-1}]\) is the volumetric moisture flow conductivity proportional to the fabric permeability. In the next step we should remind that in the first Fick’s diffusion law which is used to express the mass flow in the form formally identical with (3), the same diffusion coefficient \( D \) occurs as in the second Fick’s law for transient mass transfer by diffusion. By simplifying the problem, we can express the moisture conductivity in (3) \( \lambda_s \) by means of the moisture diffusivity \( A \). From application of this relation in Eq. (2) follows:

\[
V = \sqrt{A} \frac{As}{\sqrt{\pi}}
\]  

(4)

The first term here characterises the fabric ability to absorb the moisture from any moist surface which contacts the fabric. Then the moisture absorptivity \( B \) \([m^3\cdot s^{1/2}]\) is defined by the relation:

\[
B = \sqrt{A}
\]  

(5)

Researchers have already measured the time-dependent longitudinal wicking of fabrics. Nevertheless, this approach may produce inaccurate results, due to the complexity of the wicking processes, which besides the diffusion processes includes capillary penetration of moisture inside fabrics and also moisture absorption on the fibre surface. Therefore, the goal of this paper is to develop a technique which would determine not the moisture absorptivity itself, but its real impact on the comfort properties of a surface wetted fabric.

2.2. Tester of thermal absorptivity of fabrics used for indirect method of the moisture absorptivity measurement

New method is based on the objective evaluation of cool feeling effect within an experimental procedure which simulates the real fabric wearing conditions described above. This method is based on the instrument used for the objective warm-cool feeling determination. Warm-cool feeling means the feeling which we get when the human skin touches shortly any object, in our case textile fabric, leather or any polymer used in clothing, furniture or carpets. This parameter characterises well the transient thermal feeling which we get in the moment when we put on the undergarment, shirts, gloves or other textiles, especially these are in wet state. Since this feeling affects the choice of people when buying the clothes or garments, the objective assessment of this feeling became important. In this study, the ALAMBETA instrument was used for the determination of warm-cool feeling between the measuring surface of the instrument and the surface of the fabric simulating wet skin after its contact.
with the tested fabric. This procedure, including the measurement of thermal conductivity \( \lambda \), thermal resistance \( R \), sample thickness, warm-cool feeling parameter and the results evaluation, lasts less than 5 min. As the measure of warm-cool feeling of fabrics, thermal absorptivity \( b \ [\text{W} \cdot \text{s}^{1/2} \cdot \text{m}^{-2} \cdot \text{K}^{-1}] \) was introduced [2]. This parameter (formerly used in engineering) was derived similarly as the moisture absorptivity mentioned above. For short time of thermal contact \( \tau \) between human skin and a fabric, a fabric was again idealised to a semi-infinite body of thermal capacity \( \rho c \ [\text{J} \cdot \text{m}^{-3}] \) and initial temperature \( t_2 \). Transient temperature field between a skin and a fabric is then given by the equation

\[
\frac{\partial t}{\partial \tau} = a \frac{\partial^2 t}{\partial x^2}
\]  

and can be used for the calculation of the initial level of heat flow \( q \) passing between the skin (characterised by a constant temperature \( t_1 \)) and textile fabric according to the next equation, whose derivation for the boundary condition of 1st order is similar to derivation of (4):

\[
q_{\text{heat}} = b \frac{t_1 - t_2}{\sqrt{\pi \tau}}, \text{ where the derived thermal absorptivity } b \text{ is defined as } \ b = \sqrt{\lambda \rho c}
\]  

The scheme of this patented instrument is shown on figure 1. A special heat power sensing block 4 is attached to a metal block 2 with constant temperature 32°C higher than the sample temperature (22°C). When the measurement starts, the measuring head 1 containing the sensing block drops down and touches the measured sample 5 located on the instrument base 6 under the measuring head. In this moment, the surface temperature of the sample suddenly changes and the instrument computer then registers the heat power course and solves the transient temperature field in thin slab subjected to different boundary conditions [2].

![Figure 1 Alambeta non-destructive commercial tester of thermal properties of textiles (www. sensora.eu)](image)

The validity of thermal absorptivity as a new parameter expressing the warm-cool feeling of fabrics was confirmed by several subjective tests. Practical values of thermal absorptivity of dry fabrics range from 20 to 800. The higher is this value, the cooler feeling represents.
2.4. Principle of the indirect measurement of moisture absorptivity of fabrics
Measurement of moisture absorptivity of textile fabric is performed on the instrument ALAMBETA and consists in the evaluation of level of heat power $q$ which passes through upper surface of moistened sample $\Omega$ in the figure 1 which simulates wet human skin and which is in contact with surface of the measured sample. After contact of both fabrics under pressure 200 Pa, the moisture is taken away from the skin simulating fabric and conducted outside of the surface of heat power sensing disc of small diameter. Fabrics with higher sorption and higher capillary conduction of moisture then make the skin simulating fabric more dry and indicate drier (warmer) warm-cool feeling and vice versa. The fabric which is in contact with a model of wet human skin (skin simulator) is thin knitted fabric COOLMAX (sq. mass 170 g/m$^2$) moistened by 0.5 ml of of water. The objective parameter of warm-cool feeling is the thermal absorptivity.

3. Results evaluation
Thermal and indirect moisture absorptivity of 11 different underwear fabrics (in dry and wet state) is displayed in the figure 2. Indirect moisture absorptivity here is expressed in terms of thermal absorptivity of the tested samples subject to simulated sweating. Here, the PP means polypropylene, PL is polyester and CO is cotton. Two woven fabrics on the right containing cotton show low-plane spreading of the moisture. Here, the central part of the sample contains big amount of water which increases the cool feeling and brings thermal discomfort. Contrary to that, the PP samples on the left with surface channels and star section by MOIRA or fibres COOLMAX enable the effective in-plane moisture conduction. Thermal absorptivity of these wetted samples is less than 500 W$^{1/2}$·m$^{-2}$·K$^{-1}$ which means more warm and more dry feeling. Practical wearing tests support these results.

![Figure 2: Thermal absorptivity of various dry underwear and fabrics subject to simulated sweating](image)

4. Conclusions
In this study, a new measuring procedure for the evaluation of the moisture conduction in-plane of fabrics and simultaneously also moisture transfer into the sample surface under the boundary condition of 1$^{\text{st}}$ order, was explained and experimentally verified.

References
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