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Kinetics of Humidification and Drying Clothing Microclimate in Simulating Researches

Abstract
The humidification phenomenon of the space closed by the body and clothing fabric was investigated using physical simulation of mass and heat transfer on a Hy-tester computer system. Measurements were performed at fixed conditions, including water supply rate, temperature and pressure gradients. The humidity of air in the closed space above the specimen was maintained at a fixed level by using an adjustment drying system with a pump. Changes of air properties, such as relative humidity and temperature under the specimen versus time, were measured and recorded. On the basis of the model of water vapour concentration in a cell closed by the specimen and the model of drying pump voltage, a kinetic balance of water vapour mass was determined. The kinetic curves of humidification flux obtained, sorption flow and transferred flow are characteristic for tested materials and they display the moisturising and drying process of a clothing microclimate.

Key words: *clothing, microclimate, water vapour, sorption, transfer.*

Introduction

The fundamental function of clothes is the protection of the human body against adverse environmental conditions. The application of chemical fibres to clothes production has caused new problems in the use of clothes related, among others, to the removal of moisture from a clothing microclimate. The characteristics of the textile barrier between a clothing microclimate and ambient have an impact on the processes of air humidification under the barrier, and its drying due to sorption and the diffusion of water vapour. As is known from literature [1 - 8], there are two basic phases in the processes of humidification and drying of a clothing microclimate. In the first phase, called transient, the processes of humidification of the underclothing space, sorption of vapour and its transfer into ambient are variable The second phase is called steady state because all of the processes are stable.

This paper describes the procedure leading to the kinetic characteristics of humidification processes of under clothing space, vapour sorption by the tested material and vapour transfer into ambient.

Material and measuring method

The research was done by the physical simulation of mass and heat transfers on a Hy-tester computer system [9, 10]. The system allows to adjust temperature, vapour emission and air flow control and this simulates the wearing conditions of clothes and shoes. In the Hy-tester system the examined specimen presents a barrier separating the measuring cell and the closed external space (Figure 1). The principle of simulator operation is based on the balance of water fed under the specimen and removed from the air above the specimen in a controlled way. The air in the measuring cell has higher temperature and humidity than the air in the external circulation. The water fed to the heater of the simulator is immediately converted to steam and fed as a stream of water vapour W. Part M of this stream moistens the air inside the measuring cell. The tested specimen sorbs part S of the vapour. Part J of the vapour passes through the tested material, causing an increase in air humidity in the external circulation (Figure 2, see page 92).

Based on the above, the equation describing the balance of the mass of water vapour within the simulator is as follows:

$$W = M + S + J \qquad (1)$$

The materials were tested in conditions corresponding to assumed wearing conditions, namely:

- Air temperature within the external environment: 298 K (25 °C)

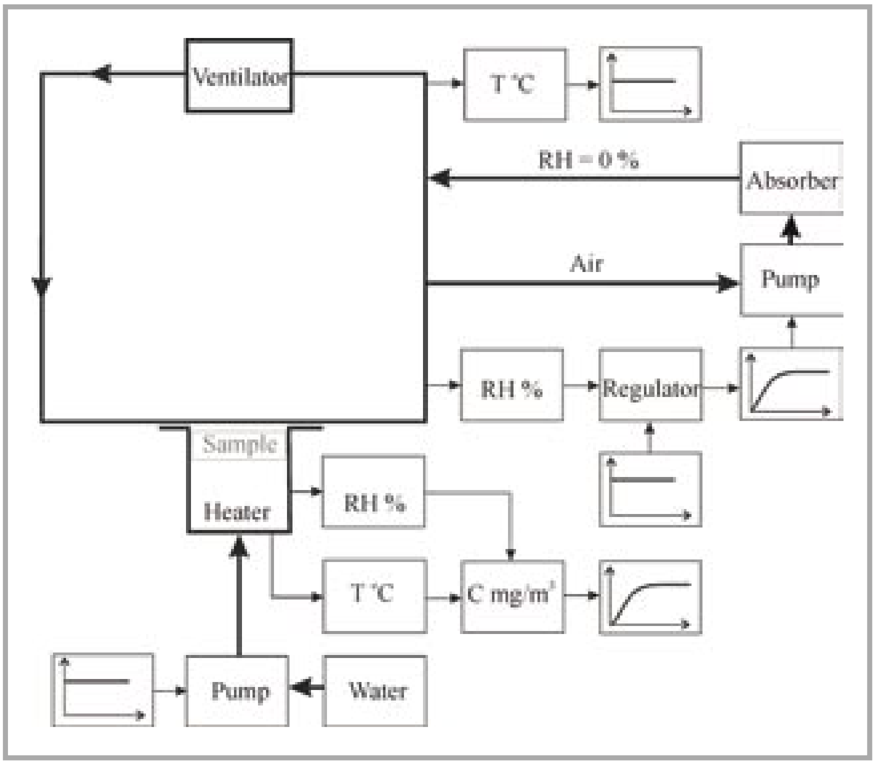

Figure 1. Block scheme of the Hy-tester system.

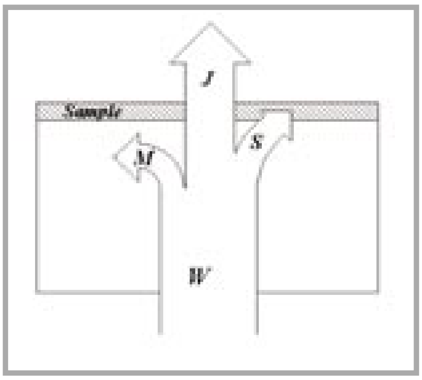

Figure 2. Distribution of water vapour in the Hy-tester system.

Table 1. Structural parameters and properties of materials.

Symbol	Fibre composition	Surface density, g	Thickness, mm		Hygroscopicity, %		Difference in mass, mg
			L	σ	H	σ	Δm
C1	100% cotton	240	0.50	0.02	15.8	0.2	20
C2	100% cotton	252	0.51	0.03	20.9	0.3	34
W	100% wool	242	0.60	0.04	23.2	0.3	30
P	100% polyester	238	0.62	0.05	0.35	0.05	1
P/W1	55%polyester 45% wool	257	0.76	0.02	9.6	0.2	13
P/W2	55%polyester 45% wool	253	0.86	0.03	7.0	0.2	10
P/W3	55%polyester 45% wool	251	0.87	0.06	9.4	0.2	11
P/W4	55%polyester 45% wool	255	1.08	0.04	7.5	0.2	7
P/V1	70%polyester 30% viscose	256	0.49	0.03	9.8	0.2	12
P/V2	70%polyester 30% viscose	261	0.51	0.04	7.8	0.2	9

- Relative humidity within the external environment: 50%
- Linear air velocity within the external environment: 1 m/s
- Water feed rate on the heater: 6.1 mg/min,
- Duration of an individual test: about 90 min.
- Time between subsequent recordings of temperature and relative humidity: 10 s.

The homogenous materials tested (surface density of 250 ± 12 g) were made from either one or two different fibres. Their structural parameters and properties like thickness, hygroscopicity and the difference in mass before and after the test, are shown in Table 1.

Based on the directly measured and recorded values of air temperature and relative air humidity under the tested specimen, the value of water vapour concentration c_k was determined at all testing points. The resulting curves presenting water vapour concentration c_k were approximated by hyperbolic functions, as suggested by Langmaier [11], to describe changes in air humidity in shoes.

$$c_k = \frac{C \cdot t}{D + t} + E \qquad (2)$$

where: c_k - water vapour concentration, mg/dm^3; t - time, s; and C, D, E - estimated model parameters.

The computations were performed by a Statistica 6.1 software package (Stat Soft, Inc). The estimated parameters were significant at significance level $\alpha = 0{,}05$.

For the given estimated volume of testing cell V_c, moistening flow M is defined by the following equation:

$$M = V_c \cdot \frac{dc_k}{dt} \qquad (3)$$

where: V_c volume of testing cell, dm^3.

The result of the above calculation was an equation that describes the moistening flow as follows:

$$M = \frac{V_c \cdot C \cdot D}{(D + t)^2} \qquad (4)$$

The stream of water vapour that goes through the specimen to the external circulation is related to the voltage of the pump that passes a strictly specified volume of air through the drying system. Supported by a fuzzy PID controller, the supply voltage of pump V_p can be presented by a smooth curve, which is defined by a hyperbolic function as follows:

$$V_p = \frac{V_r \cdot t}{D_V + t} \qquad (5)$$

where: D_V and V_r - are estimated model parameters (V_r – is the voltage of the pump in a steady state).

The estimated parameters of the model which are significant to the significance level $\alpha = 0{,}05$ were computed by means of a Statistica 6.1 software package (Stat Soft, Inc).

Due to the fact that supply voltage V_p is proportional to the transferred stream J, and additionally, stream J in a steady state is equal to water feed stream W, thus:

$$J = \frac{W \cdot t}{D_V + t} \qquad (6)$$

Calculations of the equation of mass balance (1) and substitution of equations

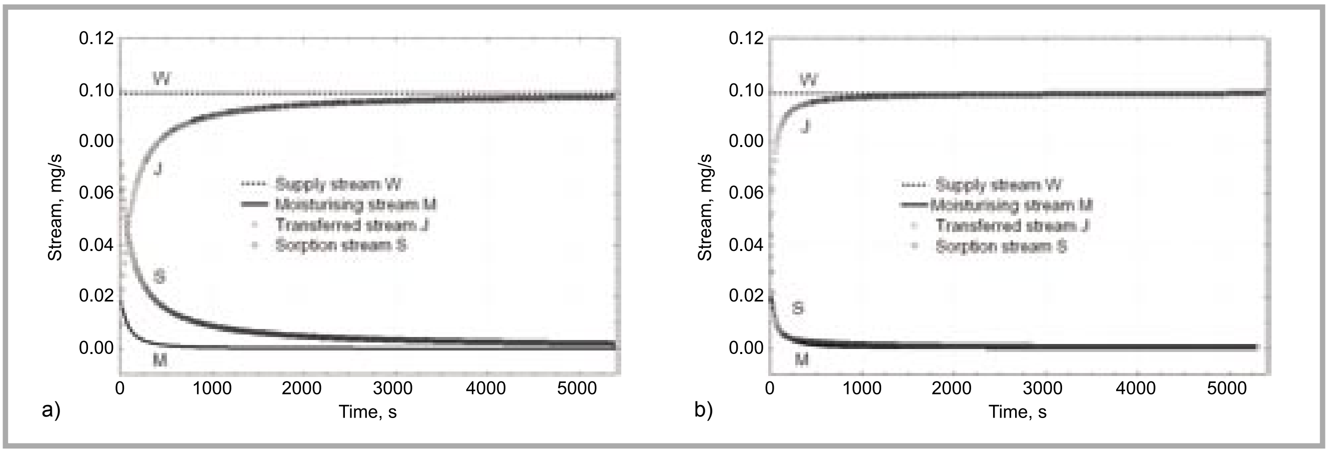

Figure 3. Kinetic curves of humidification, sorption and transferred streams; for a) 100% cotton (C2), and b) 100% polyester (P).

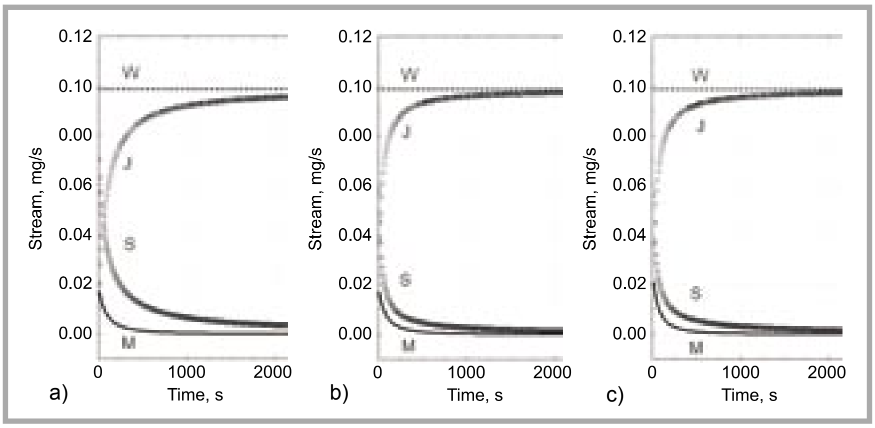

Figure 4. Kinetic curves of humidification, sorption and transferred streams for; a) 100% wool, (W), b) 55% polyester blend, 45% wool (P/W2), and c) 70% polyester blend 30% viscose (P/V2); Designations of the curves as in Figure 3.

(4) and (6) into it resulted in an equation describing the sorption stream:

$$S = W - \frac{V_c \cdot C \cdot D}{(D+t)^2} - \frac{W \cdot t}{D_v + t} \quad (7)$$

Test results

The above-presented procedure allows to estimate the complete kinetic characteristics of processes such as the humidification of a testing cell, water vapour sorption by textile fibres and water vapour permeability through a specimen for all the tested textiles. Figure 3 and 4 show examples of curves illustrating the above processes. Figure 3 presents the whole curve, which are most differentiation this is for 100% cotton (C2), and 100% polyester. Figure 4 presents an example of the first part of the curves (from 0 to about 2100 s) for 100% wool, 55% polyester blend 45% wool (P/W2) and 70% polyester blend 30% viscose (P/V2).

The procedure aiming to determine the total mass of water vapour sorbed by the tested textile is one where a kinetic curve is used for further analysis. The total mass m_t of water vapour sorbed corresponds to the area enclosed under the curve representing the sorption stream and can be described as follows:

$$m_t = \int_0^t S dt \quad (8)$$

and

$$\int_0^t S dt = D_v \cdot W \cdot \ln(D_v + t) + \frac{V_c \cdot C \cdot D}{D+t} \quad (9)$$

The values of water vapour mass concentrated in the textile specimen and determined by this method were compared to the difference in the mass of the specimens before and after the test. The results are presented on a graph (Figure 5). The differences in water vapour mass can be caused by the imprecise estimation of testing cell capacity and by the loss of mass occurring during the weighing procedure after the experiment. The total mass of water vapour transferred through the textile into the external circulation can be determined in a similar way.

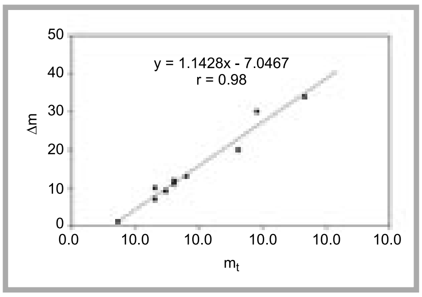

Figure 5. Comparison of mass of water vapour (in the specimen) determined by weighting (Δm) to the one determined by calculation (m_t).

Conclusions

The kinetic characteristics of the humidification and drying processes of a clothing microclimate determined by the measuring and calculating procedure above constitute comprehensive representation of the phenomena analysed. The above way of using kinetic characteristics for calculations of water vapour mass sorbed within a particular time limit is one of many examples of their applications.

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