Factors effecting water-vapor transport through fibers

(a brief review)

A.K.Haghi [*]

Abstract

This review is a brief account of R& D results generated from drying behaviour of carpets. First of all, the mathematical relations are reviewed and then, they are developed in detail, which may be used to describe the moisture sorption mechanisms of carpet. The effect of important parameters during the drying process are discussed and the mathematical relations are formulated to illustrate the range of their applications. However, challenges remain to be overcome through innovations, R& D investigations and advanced engineering, especially in designing process control devices.

Key words: Convective drying, Drying behavior, Heat and mass transfer, Mathematical model, Microwave drying

Nomenclature

C_a	Water-vapor concentration in the air filling the inter-fiber void space (kgm^{-3})
C_f	Water-vapor concentration in the fibers of thefabric (kgm^{-3})
C_P	Specific heat $(Jkg^{-1}K^{-1})$

[*]The University of Guilan, P.O.Box 3756, Rasht, Iran, e-mail: Haghi@Guilan.ac.ir

C_v Volumetric heat capacity of the fabric ($kJm^{-3}\ ^oC^{-1}$)

D   Diffusivity (m^2s^{-1})

D_a Diffusion coefficient of water vapor in the air (m^2s^{-1})

D_f Diffusion coefficient of water vapor in the fibers
           of the fabric (m^2s^{-1})

g   Gravitational constant(ms^{-2})

h   Intrinsic averaged enthalpy (Jkg^{-1})

h_{vap} Latent heat of evaporation (Jkg^{-1})

h_c Convective-mass-transfer coefficient (ms^{-1})

h_t Convective-heat-transfer coefficient (kW $m^{-2}K^{-1}$)

Δh_W Differential heat of sorption (Jkg^{-1})

K   Intrinsic permeability (m^{-2})

K'   Thermal conductivity (kW $m^{-1}K^{-1}$)

K_g Relative permeability of gas

K_m Mass transfer coefficient (ms^{-1})

K_W Relative permeability of water

L   Thickness of the fabric (m)

M   Molar mass ($kg\quad mol^{-1}$)

P_{abs} Power absorbed in the material per unit area (Wm^{-2})

Q   Heat transfer coefficient ($Wm^{-2}K^{-1}$)

R   Universal gas constant ($Jmol^{-1}K^{-1}$)

r   Radial co-ordinate of fiber (m)

S   Volume saturation

t   Real time from change in conditions (s)

T_{ab} Temperature of the ambient air ($^\circ C$)

T   Temperature of the fabric ($^\circ C$)

v   Averaged velocity (ms^{-1})

W_c Water content of the fibers in the fabric, $W_c = C_f/\rho$

x, z   Distance (m)

λ Heat of sorption or desorption of water vapor
           by the fibers (kJ/kg)

θ Non-dimensional temperature

ρ Density of the fibers (kgm^{-3})

σ Surface tension (Nm^{-1})

τ Effective porosity of the fabric

τ Non-dimensional time

ϕ Porosity (m^3m^{-3})

χ Surface porosity $(m^2 m^{-2})$
Φ Internal microwave power source $(W m^{-3})$
Ψ Relative humidity
μ_g Dynamic viscosity of gas (kg $m^{-1} s^{-1}$)
μ_W Dynamic viscosity of water (kg $m^{-1} s^{-1}$)
μ Permeability of free space $(H m^{-1})$

Subscripts

a   Air
c   Capacity
g   Gas
v   Vapor
W   Liquid
o   Atmospheric
l   Initial

1 Introduction

The cost of drying carpets, which is done toward the end of manufacturing process, is quite high. A very common method of removing water from carpet is convective drying. Hot air is used as the heat transfer medium and is exhausted to remove vaporized water. Considerable thermal energy, about 30% of the total energy used, is required to heat make-up air as the hot air is exhausted. Thus, reducing the amount of exhaust is clearly a way to conserve energy, but there is little in the literature that can be used as guidelines for optimizing dryer exhaust flow. In this case the effect of humidity on the drying rates of carpet tile should studied.

When the water is deep within the carpet, combined microwave and convective drying, which have faster heat and mass transfer, may be a better choice. To fully understand the heat and mass transfer phenomenon occurring within the carpet during combined microwave and convective drying, it is required to analyze the moisture, temperature, and pressure distributions generated throughout the process. The water

remaining in the carpet is 50-60% times the weight of carpet after mechanical removal is in its thermodynamically favorable position, largely because the low viscosity of the water and connectivity of the pores insure rapid equilibration. It is approximated the pores as essentially cylindrical, with their axis vertical to the carpet backing. The amount of porosity, i.e., the volume fraction of voids within the carpet, determines the capacity of a carpet to hold water; the greater the porosity, the more water the carpet can hold. The carpet is able to absorb 6 times it weight in water. When the water content is reduced to roughly 50-60% by mechanical extraction, free water is probably situated in pores with an effective capillary diameter of up to 200 μm. The occupied pores are distributed throughout the carpet pile thickness and largely within the yarns.

The flow of air through carpet dryers is very complex, and neither simple concurrent or countercurrent flow of air and material takes place. Usually there are a set of well mixed zones, throughout which the drying conditions are effectively uniform. The commonest strategy for regulating a dryer's behavior is feedback control, in which the controlled variables (such as the moisture content of the material) is compared with the desired set point. The difference signal, suitably processed by the controller, is then used to modulate the input parameter being used as the control variable. An ideal three-term controller incorporates proportional, integral and derivative action. The proportional term gives a rapid response to an error signal, but the controlled variable is permanently offset from its desired value. The integral function compensates for the steady-state error. Derivative action is rarely used, except with well defined signals, because noise in the signal can confuse the controller, resulting in a hunting action about some mean value. The difficulties in obtaining on-line measures of a material's moisture content has led to the use of environmental control of the humidity or temperature within the drying chamber. This strategy, however, can lead to inadequate control, as the wet-bulb depression is the driving force for drying. Use of the dry-bulb temperature or relative humidity of the bulk air as the control variable will only be satisfactory as long as the surface conditions of the material remain constant. The difference in temperature between the surface and the bulk air will give a measure of the surface moisture content, provided the material is hygroscopic and

all unbound moisture has been driven off.

1.1 Basic concepts

In general, drying means to make free or relatively free from a liquid. We define it more narrowly in this paper as the vaporization and removal of water from a material. The typical drying curve begins with a warm-up period, where the material is heated and the drying rate is usually low. The drying rate can be negative in the warm-up period if the gas stream is humid enough. As the material heats up, the rate of drying increases to peak rate that is maintained for a period of time known as the constant rate period. Eventually, the moisture content of the material drops to a level, known as the critical moisture content, where the high rate of evaporation cannot be maintained. This is the beginning of the falling rate period. During the falling rate period, the moisture flow to the surface is insufficient to maintain saturation at the surface. This period can be divided into the first and second falling rate periods. The first falling rate period is a transition between the constant rate period and the second falling rate period. In the constant rate period, external variables such as gas stream humidity, temperature, and flow rate dominate. In the second falling rate period, internal factors such as moisture and energy transport in the carpet dominate.

Although much of the water is removed in the constant rate period of drying, the time required to reduce the moisture in the product to desired value can depend on the falling rate period. If the target moisture content is significantly lower than critical moisture content, the drying rates in the falling rate period become important.

It has been recognized that microwave could perform a useful function in carpet drying in the leveling out of moisture profiles across a wet sample. This is not surprising because water is more reactive than any other material to dielectric heating so that water removal is accelerated.

2 Literature

Many investigators have attempted to explain the effect of humidity drying rates and the existence of inversion temperatures [9-17]. The explanations are usually based on changes that occur in convective heat transfer, radiative heat transfer, and mass transfer as the humidity and temperature of the gas stream change. We will briefly discuss these explanations.

At a given gas stream temperature, convective heat transfer rate can change as the humidity in the gas stream is varied, because product temperature and fluid properties vary with humidity. These effects can be explained using the following relationship for the convective heat transfer rate:

$$\frac{q}{A} = h\left(T_\infty - T_S\right) = h\Delta T \ ,$$

where q/A - convective heat transfer per unit surface area A, h - heat transfer coefficient, T_∞ - free stream temperature of the drying medium, T_S - surface temperature of material being dried.

Since product temperature is dependent on humidity, clearly ΔT is also dependent. Further, the heat transfer coefficient h is a function of both product temperature and fluid properties. Thus, the convective heat transfer rate changes with humidity, as does the drying rate of a material. However, Drying in air will always have an advantage over drying in steam because ΔT is larger for drying in air; this is a consequence of T_S being very nearly the wet bulb temperature. The wet bulb temperature is lowest for dry air, increases with increasing humidity, and reaches the saturation temperature of water for a pure steam environment. Thus, ΔT_{AIR} will be larger than ΔT_{STEAM}, but $\Delta T_{AIR}/\Delta T_{STEAM}$ decreases with increasing T_∞. Further, the heat transfer coefficient increases with humidity. Apparently, the net effect of the changes in h and ΔT is that the convective heat transfer rate increases faster for steam than for air with increasing temperature.

King and Cassie [20] conducted an experimental study on the rate of absorption of water vapor by wool fibers. They observed that, if a textile is immersed in a humid atmosphere, the time required for the fibers to

come to equilibrium with this atmosphere is negligible compared with the time required for the dissipation of heat generated or absorbed when the regain changes. McMahon and Watt [27] investigated the effects of heat of sorption in the wool-water sorption system.They observed that the equilibrium value of the water content was directly determined by the humidity but that the rate of absorption and desorption decreased as the heat-transfer efficiency decreased. Heat transfer was influenced by the mass of the sample, the packing density of the fiber assembly, and the geometry of the constituent fibers. Crank [3] pointed out that the water-vapor-uptake rate of wool is reduced by a rise in temperature that is due to the heat of sorption.

The dynamic-water-vapor-sorption behavior of fabrics in the transient state will therefore not be the same as that of single fibers owing to the heat of sorption and the process to dissipate the heat released or absorbed.

Henry [18,19] was who the first started theoretical investigation of this phenomenon. He proposed a system of differential equations to describe the coupled heat and moisture diffusion into bales of cotton. Two of the equations involve the conservation of mass and energy, and the third relates fiber moisture content with the moisture in the adjacent air. Since these equations are non-linear, Henry made a number of simplifying assumptions to derive an analytical solution.

In order to model the two-stage sorption process of wool fibers, David and Nordon [28] proposed three empirical expressions for a description of the dynamic relationship between fiber moisture content and the surrounding relative humidity. By incorporating several features omitted by Henry [18] into the three equations, David and Nordon [4] were able to solve the model numerically. Since their sorption mechanisms (i.e. sorption kinetics) of fibers were neglected, the constants in their sorption-rate equations had to be determined by comparing theoretical predictions with experimental results.

Farnworth [7] reported a numerical model describing the combined heat and water-vapor transport through fibers. The assumptions in the model did not allow for the complexity of the moisture-sorption isotherm and the sorption kinetics of fibers. Wehner *et al* [29] presented two mechanical models to simulate the interaction between moisture sorption by fibers and moisture flux through the void spaces of a fabric.

In the first model, diffusion within the fiber was considered to be so rapid that the fiber moisture content was always in equilibrium with the adjacent air. In the second model, the sorption kinetics of the fiber were assumed to follow Fickian diffusion. In these models, the effect of heat of sorption and the complicated sorption behavior of the fibers were neglected.

Li and Holcombe [24] developed a two-stage model, which takes into account water-vapor-sorption kinetics of wool fibers and can be used to describe the coupled heat and moisture transfer in wool fabrics. The predictions from the model showed good agreement with experimental observations obtained from a sorption-cell experiment. More recently, Li and Luo [23] further improved the method of mathematical simulation of the coupled diffusion of the moisture and heat in wool fabric by using a direct numerical solution of the moisture-diffusion equation in the fibers with two sets of variable diffusion coefficients. These research publications were focused on fabrics made from one type of fiber. The features and differences in the physical mechanisms of coupled moisture and heat diffusion into fabrics made from different fibers have not been systematically investigated.

The mathematical model describing the coupled heat and moisture diffusion in textiles was first proposed by Henry [18,19] and then further developed by David and Nordon [4] and Li and Holcombe [22]. The conservation of heat and moisture can be expressed by the following equations :

$$\varepsilon \frac{\partial C_a}{\partial t} + (1 - \varepsilon) \frac{\partial C_t}{\partial t} = \frac{D_a \varepsilon}{\tau'} \frac{\partial^2 C_a}{\partial x^2} \ , \qquad (2.1)$$

$$C_v \frac{\partial T}{\partial t} - \lambda \frac{\partial C_t}{\partial t} = K' \frac{\partial^2 T}{\partial x^2} \ . \qquad (2.2)$$

In the equations, both C_v and λ are functions of the concentration of moisture absorbed by the fibers. Most textile fibers are of very small diameter and have a very large surface/volume ratio. The assumption in the second equation of instantaneous thermal equilibrium between the fibers and the inter-fiber space does not therefore lead to appreciable error. The two equations in the model are not linear and contain the

three unknowns, C_p, T and C_a. A third equation is needed to solve the equations.

Henry [18,19] derived a third equation to obtain an analytical solution by assuming that C_f is linearly dependent on T and C_s and that fibers reach moisture equilibrium with the adjacent air instantaneously. Downes and Mackay [6] found experimentally that the sorption of water vapor by wool is a two-stage process, the first stage obeys Fick's law of diffusion with a concentration-dependent diffusion coefficient. The second stage, which involves structural changes within fibers, is much slower than the first.To simulate the two stage-sorption process, David and Nordon [4] proposed an exponential function to describe the rate of change of fiber water content, which needed to be adjusted according to the measured fabric moisture content. Li and Holcombe [24] developed a two stage sorption-rate equation to describe the moisture sorption of wool. The first stage is represented by a Fickian diffusion with a constant coefficient. The diffusion equation was solved by using Crank's truncated solution [3]. The second stage is described by an exponential relationship, which also needs to be adjusted according to the experimental measurements. The relative contributions of the two stages to the total moisture sorption are function of the sorption time and the initial regain of the fibers.

Li and Luo [23] improved the sorption rate equation by assuming that the moisture sorption of wool fiber can be generally described by a uniform-diffusion equation for both stages of sorption :

$$\frac{\partial C_t}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left\{rD_t\left(x,t\right)\frac{\partial C_f}{\partial r}\right\} . \tag{2.3}$$

Here $D_f\left(x,t\right)$ are the diffusion coefficients that have different values at different stages of moisture sorption. In a wool fiber, $D_f\left(x,t\right)$ is a function of water content of the fibers, which is dependent on the time of sorption and the location of the fiber.

In the first stage, the diffusion coefficient is concentration-dependent and is assumed to be quadratic function of water content when the sorption is less than 540 seconds, as given in equation (2.4a).

In the second stage, in which the moisture sorption is much slower than in the first, the diffusion coefficient of moisture in a wool fiber is attenuated along with the time of sorption when $t \geq 540s$ as shown in

equation (2.4b).

$$D_f\{W_c(t)\} = \{1.04 + 68.204W_c(t) -$$
$$1342.5924W_c(t)^2\}\,10^{-14}, \qquad t \le 540s\ , \tag{2.4a}$$

$$D_f\{W_c(t)\} = 1.616405\,[1-$$
$$\exp\{-18.16323\exp(-28.0W_c(t))\}]\,10^{-14}, \quad t \ge 540s\ . \tag{2.4b}$$

The second formula for D_f in equation (2.4b) shows that the rate of moisture diffusion into a wool fiber (when $t \ge 540s$) attenuates in the form of double-exponential function, which may indicate that the attenuating feature of the moisture sorption of wool is due to its microstructural changes and the decreasing number of available polar groups.

Now, we assume that the sorption process for all the fibers can be described by a uniform diffusion equation from equation (2.3), with diffusion-coefficient functions to describe the moisture-sorption kinetics.Through a large number of computational experiments in comparison with the measured water-content changes and temperature changes of various fibers, we try to identify whether the moisture-sorption process needs to be described by a two-stage process or a single Fickian-diffusion process. The diffusion-coefficient functions identified for carpets made from wool, cotton, porous acrylic fiber, and polypropylene fiber which is reported by Li and Planete [25] are listed in the appendix.

To generate a solution to the above-mentioned equations, we need to specify an initial condition and boundary conditions at the fiber surfaces of the humidity, moisture content, and temperature. Initially, a fiber is equilibrated to a given atmosphere of temperature (T_{ao}) and humidity (C_{ao} and H_{ao}), the temperature and moisture content being uniform throughout the fabric at known values :

$$T_a(x,0) = T_{ao}\ , \tag{2.5}$$

$$C_a(x,0) = C_{ao}\ , \tag{2.6}$$

$$C_f\left(x, r, 0\right) = f\left(H_{a0}, T_0\right). \tag{2.7}$$

The fiber then undergoes a step change to a different atmosphere. Its boundaries are exposed to an air stream of a new moisture concentration C_{ab} and temperature T_{ab}. Considering the convective nature of the boundary air layers, the boundary conditions can be described by the following equations :

$$D_a\varepsilon\frac{\partial C_a}{\partial x}\bigg|_{x=0} = h_c\left(C_a - C_{ab}\right), \tag{2.8}$$

$$D_a\varepsilon\frac{\partial C_a}{\partial x}\bigg|_{x=L} = -h_c\left(C_a - C_{ab}\right), \tag{2.9}$$

$$K'\varepsilon\frac{\partial T}{\partial x}\bigg|_{x=0} = h_t\left(T - T_{ab}\right), \tag{2.11}$$

$$K'\varepsilon\frac{\partial T}{\partial x}\bigg|_{x=L} = -h_t\left(T - T_{ab}\right). \tag{2.11}$$

These conditions show that the thermal and moisture fluxes across the boundaries are proportional to the differences in the temperature and moisture concentration between the surrounding medium and the fabric surface respectively.

Equations(2.1) and (2.2) are solved by a finite-difference method by using the Crank-Nicolson scheme, and equation (2.3) is solved by using an implicit-difference scheme, together with specification of the initial condition of equations (2.5) - (2.7), the boundary conditions of equations (2.8) - (2.11), and the fiber properties. Details of the solution method have been reported previously by Li and Luo [23].

Before carpet is conveyed into drying oven, most of the water is typically vacuum extracted. After vacuum extraction, the moisture regain is about 50-60% , indicating that there is still a significant amount of water inside the carpet. This water is usually removed with heat in industrial manufacturing processes. As a general rule, the water is distributed in larger pores.

It seems reasonable to anticipate that many of these pores are formed within the pile yarns throughout the thickness of the carpet. The location of this water is of interest to people in the carpet industry.The carpet surface characteristics can be studied using topographical parameter measurement.

3 Water accommodated by the pores within the yarns

Carpet surfaces are widely different in practice. These can be mathematically described by the composition of the deterministic and random components of irregularities in the given Cartesian coordinate system :

$$h(x, y) = S(x, y) + \zeta(x, y), \qquad (3.1)$$

where $S(x, y)$ is the deterministic function of the surface (x, y) coordinates and $\zeta(x, y)$ is the homogeneous random normal field.

The parameters of carpet surface irregularities can be measured over the whole surface (the topographic parameters) characterize more positively the functional properties of surface than the h profile parameters. In the meantime, surface deviations are functions of two coordinates (x, y) and therefore the profile evaluation gives incomplete information about the surface.

For surface irregularity parameter measurement it is necessary to determine the actual value of the parameter and to know the accuracy of the measurements. In this case the analogue mean value can be taken for the actual value of the parameter, and the measurement error can be determined by the systematic and random components. The series of the surface topographic parameters can be represented as an

averaging operator of the generalized transformation $Gh(x, y)$ of the surface coordinates on the given rectangular area of the surface $L_1 \times L_2$ with sides L_1 and L_2 [35]:

$$P_s = \frac{1}{L_1 L_2} \int_0^{L_1} \int_0^{L_2} G\{h(x, y)\} dx dy. \tag{3.2}$$

Since there is a random component on the measured surface, the topographic parameter measured can have a random value, which should be characterized by the mathematical expectation $E(P_s)$ and the variance $D(P_s)$. Therefore, one of the problems in measuring the topographic parameter is the determination of its probability characteristics, i.e. the mathematical expectation $E(P_s)$ and the variance $D(P_s)$. It is known that the mathematical expectation of the parameters given by equation (3.2) can be derived by integration of the mathematical expectation $E(G)$ of the transformation $G\{h(x, y)\}$ in equation (3.2) by the x and y variables. As an example of the application $E(G)$ of the transformation $G\{h(x, y)\}$ in equation (3.2) by the x and y variables. As an example of the application of measuring methods of the topographic parameters the $P_s = R_{as}$ parameter is used. This is the arithmetic mean deviation of the surface coordinates the mean plane.

$$E(R_{as}) = \frac{1}{L_1 L_2} \int_0^{L_1} \int_0^{L_2} E(|h(x, y)|) dx dy, \tag{3.3}$$

where $|h(x, y)|$ is the absolute value of the $h(x, y)$ surface coordinate. This expression can also be extended for the $h(x, y)$ surface :

$$E(|h(x, y)|) = \left(\frac{2}{\Pi}\right)^{1/2} \sigma \exp\left[-\frac{\{S(x, y)\}^2}{2\sigma^2}\right] + S(x, y)\Phi\left\{\frac{S(x, y)}{\sigma 2^{1/2}}\right\},$$
$$\tag{3.4}$$

where

$$\phi(z) = \frac{2}{\Pi^{1/2}} \int_0^z \exp(-t^2) dt$$

is the Laplace function. The generalized transformation $G\{h(x,y)\}$ is the random field which has the correlation function [35] defined as

$$K_G(x_1, x_2, y_1, y_2) = \int\limits_{-\infty}^{+\infty}\int\limits_{-\infty}^{+\infty} G(h_1)G(h_2)f(h_1,h_2)dh_1dh_2-$$

$$E\{G(h_1)\}\{G(h_2)\}, \tag{3.5}$$

where $h_1 = h(x_1, x_2)$, $h_2 = h(x_2, y_2)$ are the coordinates of the surface at the (x_1, y_1) and (x_2, y_2) points, $f(h_1, h_2)$ distribution density expands into a series in terms of Hermite polynomials. The correlation function (3.5) can be represented as [35] :

$$K_G(x_1, x_2, y_1, y_2) =$$

$$\sum_{n=1}^{+\infty} C_n(x_1, y_1) C_n(x_1 + \tau_1, y_1 + \tau_2) \frac{\{\rho(\tau_1, \tau_2)\}^2}{n!} \tag{3.6}$$

$$C_n(x_1, y_1) =$$

$$\frac{1}{(2\Pi)^{1/2}} \int\limits_{-\infty}^{+\infty} G(\sigma h) H_n\left(h - \frac{S}{\sigma}\right) \exp\left\{-\frac{(h - S/\sigma)^2}{2}\right\} dh \tag{3.7}$$

$$\tau_1 = x_2 - x_1, \qquad \tau_2 = y_2 - y_2,$$

σ is the r.m.s. deviation of the random component $\zeta(x, y)$ and $\rho(\tau_1, \tau_2)$ is the correlation coefficient of the random components $\zeta(x, y), h = h(x, y), S = S(x, y)$. For the generalized transformation $G = \{h(x, y)\} = |h(x, y)|$, which determines the R_{as} parameter, the coefficients C_n in equation (3.7) are written as follows after the transformation :

$$C_1\left(x_1, y_1\right) = \left(\frac{2}{\Pi}\right)^{1/2} S\left(x_1, x_2\right) \exp\left[-\frac{\{S\left(x_1, y_1\right)\}^2}{2\sigma}\right] + \sigma\Phi\left\{\frac{S\left(x_1, y_1\right)}{\sigma 2^{1/2}}\right\}$$

$$C_n\left(x_1, y_1\right) = \left(\frac{2}{\Pi}\right)^{1/2} \sigma \exp\left[-\frac{\{S\left(x, y\right)\}^2}{2\sigma^2}\right] \times$$

$$\left[H_{n-2}\left\{-\frac{S\left(x_1, y_1\right)}{\sigma}\right\} + \frac{S\left(x_1, y_1\right)}{\sigma} H_{n-1}\left\{-\frac{S\left(x_1, y_1\right)}{\sigma}\right\}\right],$$

$$\tag{3.8}$$

where $H_n(z)$ are Hermite polynomials. The variance of the parameter P_S is determined by integration of the correlation function $K_G\left(x_1, x_2, y_1, y_2\right)$ of the generalized transformation $G\{h(x, y)\}$ using the variables x_1, x_2, y_1, y_2:

$$D\left(P_S\right) = \frac{1}{L_1^2 L_2^2} \int\limits_0^{L_1} \int\limits_0^{L_1} \int\limits_0^{L_2} K_G\left(x_1, x_2, y_1, y_2\right) dx_1 dx_2 dy_1 dy_2. \tag{3.9}$$

Calculation of the integral in equation (3.9) involves considerable difficulties; therefore, in the general case, formula (3.9) in not suitable for calculations. However, having $S\left(x, y\right) \geq \sigma$ and $S\left(x, y\right) \leq \sigma$ offers simplified evaluations of the variance. Thus, having $S\left(x, y\right) \geq \sigma$ from equation (3.8),

$$C_1 \approx \sigma, \quad C_n \approx 0 \quad (n = 2, 3, ...). \tag{3.10}$$

The correlation function of the transformation $G\{h(x, y)\}$ from equation (3.6) is reported approximately as

$$K_G\left(\tau_1, \tau_2\right) \approx \sigma^2 \rho\left(\tau_1, \tau_2\right). \tag{3.11}$$

By using $S\left(x, y\right) \leq \sigma$ from equation (3.8) we obtain

$$C_1 \approx 0,$$

$$C_n \approx \left(\frac{2}{\Pi}\right)^{1/2} \sigma H_{n-2}(0).$$

The correlation function of the transformation $G\{h(x, y)\}$ from equation (3.6) is

$$K_G(\tau_1, \tau_2) \approx \sum_{n=2}^{+\infty} C_n^2 \frac{\{\rho(\tau_1, \tau_2)\}^n}{n!}. \qquad (3.12)$$

In both cases the correlation function $K_G(\tau_1, \tau_2)$ is a function of only two variables τ_1 and τ_2. Thus, for the above-mentioned approximations, $D(P_S)$ can be calculated by using the formula:

$$D(P_S) = \frac{4}{L_1 L_2} \int_0^{L_1} \int_0^{L_2} \left(1 - \frac{\tau_1}{L_1}\right) \left(1 - \frac{\tau_2}{L_2}\right) K_G(\tau_1, \tau_2) \, d\tau_1 d\tau_2. \qquad (3.13)$$

The following notation is now used :

$$S_{K_G} = \frac{1}{K_G(0,0)} \int_0^\infty \int_0^\infty K_G(\tau_1, \tau_2) \, d\tau_1 d\tau_2 \qquad (3.14)$$

with $L_1 \times L_2 \geq S_{K_G}$ equation (3.13) may be written approximately;

$$D(P_S) \approx \frac{4}{L_1 L_2} K_G(0,0) S_{K_G}. \qquad (3.15)$$

Here $K_G(0,0)$ is the variance of $G\{h(x, y)\}$. It is not possible to carry out analogue measurements of the topographic parameter P_s. Therefore the analogue-discrete and discrete methods are the only ones that can be used to measure the topographic parameters. With the analogue-discrete measurements the averaging operator is:

$$\hat{P}_S = \frac{1}{N}\frac{1}{L_2}\sum_{i=1}^{N_1}\int_0^{L_2} G\{h\left(i\Delta_1, y\right)\}dy \qquad (3.16)$$

where Δ_1 is the sampling is the sampling interval between the profiles and N_1 is the number of profiles. The evaluation of the parameter in equation (3.2) in the general case is shifted therefore together with the task of determining the parameter probability characteristics, i.e. for its mathematical expectation and variance it is necessary to determine the shift in the value of the evaluation of equation (3.16) with respect to that of equation (3.2). We can regard the probability characteristics of the evaluation (3.16) for that particular transformation as

$$G\{h\left(i\Delta_1, y\right)\} = |h\left(i\Delta_1, y\right)| \qquad (3.17)$$

$\hat{R}_{as}$ represents the analogue-discrete evaluation of the topographic parameter R_{as} (cf.(3.3)). The mathematical expectation of the transformation (3.17) will be determined by the expression in equation (3.4) with $S\left(x, y\right) = S\left(i\Delta_1, y\right)$. The mathematical expectation of the $\hat{R}_{as}$ parameter is identically:

$$E\left(\hat{R}_{as}\right) = \frac{1}{N_1}\frac{1}{L_2}\sum_{i=1}^{N_1}\int_0^{L_2} E\{|h\left(i\Delta_1, y\right)|\}dy. \qquad (3.18)$$

The integrals in equation (18) are not taken into account, but if the deterministic component $S\left(i\Delta_1, y\right)$ is linearized with a small error using the y argument on the terminal number of intervals length of which is Δ_2 then it is possible to obtain an exact expression for the evaluation $E\left(\hat{R}_{as}\right)$ of the topographic parameter R_{as}. For this, we expand the deterministic component $S\left(i\Delta_1, y\right)$ in its Taylor series by using the y argument up to the linear terms at the point $j = 1, 2, ..., n$:

$$S\left(i\Delta_1, y\right) \approx S\left(i\Delta_1, j\Delta_2\right) + \frac{\partial S\left(i\Delta_1, j\Delta_2\right)}{\partial y}\left(y - \Delta_2\right). \qquad (3.19)$$

By substituting equation (3.19) into equation (3.18) and taking into account equation (3.4), we obtain:

$$E\left(\hat{R}_{as}\right) = \frac{1}{N}\frac{1}{L_2}\sum_{i=1}^{N_1}\sum_{j=1}^{n}\int_{(j-1)\Delta_2}^{j\Delta_2}\Im,$$

$$\Im = \left[\left(\frac{2}{\Pi}\right)^{1/2}\sigma\exp\left\{-\frac{(\alpha_{ij}y+\beta_{ij})^2}{2\sigma^2}\right\}+ \right. \qquad (3.20)$$

$$\left. (\alpha_{ij}y+\beta_{ij})\,\Phi\left(\frac{\alpha_{ij}y+\beta_{ij}}{2\sigma^{1/2}}\right)\right]dy,$$

where

$$\alpha_{ij} = \frac{\partial S\left(i\Delta_1, j\Delta_2\right)}{\partial y},$$

$$\qquad (3.21)$$

$$\beta_{ij} = S\left(i\Delta_1, j\Delta_2\right) - \frac{\partial S\left(i\Delta_1, j\Delta_2\right)}{\partial y}j\Delta_2.$$

The integrals in both components of expression (3.20) can be tabulated [36]. Then after transformation we obtain:

$$E\left(\hat{R}_{as}\right) = \frac{1}{N_1 L_2}\sum_{i=1}^{N_1}\sum_{j=1}^{n}\frac{1}{2C}\left\{\left(\frac{A_{ij}C}{\alpha ij} - \frac{1}{4A_{ij}\alpha_{ij}} + 2CD_{ij}\right)\Phi\left(A_{ij}C\right) + \Gamma\right\},$$

$$\Gamma = \left(\frac{B_{ij}C}{\alpha_{ij}} - \frac{1}{4B_{ij}\alpha_{ij}} + 2CD_{ij}\right)\Phi\left(B_{ij}C\right) + \frac{A_{ij}}{\alpha_{ij}\Pi^{1/2}}\exp\left(-C^2 A_{ij}^2\right) +$$

$$\frac{B_{ij}}{\alpha_{ij}\Pi^{1/2}}\exp\left(-C^2 B_{ij}^2\right),$$

$$\qquad (3.22)$$

where

$$A_{ij} = \alpha_{ij}\Delta_1 + \beta_{ij},$$

$$B_{ij} = \alpha_{ij}(j-1)\Delta_1 + \beta_{ij},$$

$$C = \frac{1}{2\sigma^{1/2}},$$

$$D_{ij} = \frac{2\sigma^2}{\Pi^{1/2}\alpha_{ij}}.$$

The $\Phi(z)$ and $\exp(-z^2)$ and the standard calculation program for the $\Phi(z)$ and $exp(-z^2)$ functions can be used to calculate $E\left(\hat{R}_{as}\right)$ on the computer. Formula (3.22) shows that the mathematical expectation of the parameter $\hat{R}_{as}$ depends on the characteristic of the $\partial S(i\Delta_1)/\partial y$, the deterministic component $S(i\Delta_1, y)$ and the random component σ^2. With the definite relationship between the deterministic and the random components, the approximate evaluation of $E(R_{as})$ can be obtained.

Thus, having $S(x, y) \leq \sigma$ and linearizing equation (3.4) we obtain:

$$E(R_{as}) \approx \frac{1}{N_1}\frac{1}{L_2}\sum_{i=1}^{N_1}\int_0^{L_2}|S(i\Delta_1, y)|dy. \qquad (3.23)$$

By using $S(x, y) \leq \sigma$ and linearizing equation (3.4);

$$E(|h(x, y)|) \approx \left(\frac{2}{\Pi}\right)^{1/2}\sigma + \frac{\{S(x, y)\}^2}{(2\Pi)^{1/2}\sigma}. \qquad (3.24)$$

Then

$$E(R_{as}) \approx \left(\frac{2}{\Pi}\right)^{1/2}\sigma + \frac{1}{L_1 L_2\sigma(2\Pi)^{1/2}}\int_0^{L_1}\int_0^{L_2}\{S(x, y)\}^2 dxdy. \qquad (3.25)$$

To analyze the $E(R_{as})$ dependence on S/σ and to determine what relationship with S/σ is needed in order to make formulae (3.23) and (3.25) applicable to the determination of the mathematical expectation

$E\left(R_{as}\right)$, calculations were carried out using formulae (3.22), (3.23) and (3.25). The mathematical models of the composition surface and the experimental calculation of the parameter

$$\overset{t}{R}_{as} = \sum_{i=1}^{N_1} \sum_{j=1}^{N_i} |h_{ij}| \tag{3.26}$$

where h_{ij} is the deviation of the $h(x,y)$ surface from the mean plane at the discrete points. The random component was modeled with the help of the random number generator. The deterministic component was designated by formula (3.19).

4   Continuum approach

It was shown by Ilic and Turner [22] that a theory based on a continuum approach led to the following equations of motion governing the drying of a slab of material:

⋄ Total mass:

$$\frac{\partial}{\partial t}\left(\phi S_g \rho_g + \phi S_W \rho_W\right) + \nabla.\left(X_g \rho_g V_g + X_W \rho_W V_W\right) = 0. \tag{4.1}$$

⋄ Total liquid:

$$\frac{\partial}{\partial t}\left(\phi S_g \rho_{gv} + \phi S_W \rho_W\right) + \nabla.\left(x_g \rho_{gv} V_{gv} + X_W \rho_W V_W\right) = 0. \tag{4.2}$$

⋄ Total enthalpy:

$$\frac{\partial}{\partial t}\left(\phi S_g \rho_{gv} h_{gv} + \phi S_g \rho_{ga} h_{ga} + \phi S_g \rho_{ga} h_{ga} + \phi S_W \rho_W h_W + \right.$$

$$\left. (1-\phi)\rho_S h_S - \phi \rho_W \int_0^{S_W} \Delta h_W(S) dS \right) + \tag{4.3}$$

$$\nabla.\left(X_g \rho_{gv} V_{gv} h_{gv} + X_g \rho_{ga} V_{ga} h_{ga} + X_W \rho_W V_W h_W\right) =$$

$$\nabla.\left((K_g X_g + K_W X_W + K_S(1-X))\nabla T\right) + \phi$$

Here ϕ is the internal microwave power dissipated per unit volume. In equation (4.3) the effects of viscous dissipation and compressional work have been omitted.

The equations (4.1-4.3) are augmented with the usual thermodynamic relations and the following relations:

▷ Flux expressions are given as follows:

— *Gas flux:*

$$X_g \rho_g V_g = -\frac{KK_g(S_W)\rho_g}{\mu_g(T)}[\nabla P_g - \rho_g g].\qquad(4.3a)$$

— *Liquid flux:*

$$X_W \rho_W V_W = -\frac{KK_W(S_W)\rho_W}{\mu_W(T)}[\nabla(P_g - P_C(S_W, T)) - \rho_W g].$$
$$(4.3b)$$

— *Vapor flux:*

$$X_g \rho_{gv} V_{gv} = X_g \rho_{gv} V_g - \frac{X_g \rho_g D(T, P_g) M_a M_v}{M^2}\nabla\left(\frac{P_{qv}}{P_g}\right).$$
$$(4.3c)$$

— *Air flux:*
$$X_g \rho_{ga} V_{ga} = X_g \rho_g V_g - X_g \rho_g V_{gv}.\qquad(4.3d)$$

▷ Relative humidity (Kelvin effect):

$$\psi(S_W, T) = \frac{P_{gv}}{P_{gvs}(T)} = \exp\left(\frac{2\sigma(T)M_v}{r(S_W)\rho_W RT}\right),$$

where $P_{gvs}(T)$ is the saturated vapor pressure given by the Clausius-Clapeyron equation.

▷ Differential heat of sorption:

$$\Delta h_W = R_v T^2 \frac{\partial(\ln\psi)}{\partial T}$$

▷ Enthalpy-Temperature relations:

$$h_{ga} = C_{pa}(T - T_R),$$

$$h_{gv} = h_{vap}^0 + C_{pv}(T - T_R),$$

$$h_W = C_{pW}(T - T_R),$$

$$h_s = C_{ps}(T - T_R).$$

The expressions for K_g, K_W are those given by Turner and Ilic [22], and μ_g, μ_W have had functional fits according to the data by Holman [21]. The diffusivity $D(T, P_g)$ given by Quintard and Puiggali [33] and the latent heat of evaporation given by,

$$h_{vap}(T) = h_{gv} - h_W.$$

After some mathematical manipulations, the one-dimensional system of three non-linear coupled partial differential equations which model the drying process in a thermal equilibrium environment are given by :

$$a_{s1}\frac{\partial S_W}{\partial t} + a_{s2}\frac{\partial T}{\partial t} =$$

$$\frac{\partial}{\partial Z}\left[K_{S1}\frac{\partial S_W}{\partial Z} + K_{T1}\frac{\partial T}{\partial Z} + K_{T1}\frac{\partial T}{\partial Z} + K_{P1}\frac{\partial P_g}{\partial Z} + K_{gr1}\right]. \tag{4.4}$$

$$a_{T1}\frac{\partial S_W}{\partial t} + a_{T2}\frac{\partial T}{\partial t} = \frac{\partial}{\partial Z}\left(K_e\frac{\partial T}{\partial Z}\right) + \Phi(S_W, T) -$$

$$\phi\rho_W h_{vap}\frac{\partial}{\partial Z}\left[K_S\frac{\partial S_W}{\partial Z} + K_T\frac{\partial T}{\partial Z} + K_P\frac{\partial P_g}{\partial Z}K_{gr}\right] + \tag{4.5}$$

$$\left[\phi\rho_W C_{pW}\left(K_{S2}\frac{\partial S_W}{\partial Z} + K_{T2}\frac{\partial T}{\partial Z} + K_{P2}\frac{\partial P_g}{\partial Z} + K_{gr2}\right)\right]\frac{\partial T}{\partial Z}$$

$$a_{P1}\frac{\partial S_W}{\partial T} + a_{P2}\frac{\partial T}{\partial t} + a_{P3}\frac{\partial P_g}{\partial t} =$$

$$\frac{\partial}{\partial Z}\left[K_S\frac{\partial S_W}{\partial Z} + K_T\frac{\partial T}{\partial Z} + K_{P3}\frac{\partial P_g}{\partial Z} + K_{gr3}\right]. \tag{4.6}$$

The capacity coefficients a_{S1}, a_{T1}, a_{p1} and the kinetic coefficients K_{S1}, K_{T1}, K_{P1}, K_{gr1} all depend on the independent variables: Saturation S_W, Temperature T and total pressure P_g. The boundary conditions are written in one dimension as:

○ At z=0 (Drying surface):

$$K_{S1}\frac{\partial S_W}{\partial Z} + K_{T1}\frac{\partial T}{\partial Z} + K_{P1}\frac{\partial P_g}{\partial Z} + K_{gr1} = \frac{K_m M_V}{R\phi\rho_W}\left(\frac{P_{gV}}{T} - \frac{P_{gV0}}{T_0}\right), \tag{4.7a}$$

$$K_e\frac{\partial T}{\partial Z} - \phi\rho_W h_{Vap}\left(K_S\frac{\partial S_W}{\partial Z} + K_T\frac{\partial T}{\partial Z} + K_P\frac{\partial P_g}{\partial Z} + K_{gr}\right) = Q\left(T - T_0\right), \tag{4.7b}$$

$$P_g = P_o. \tag{4.7c}$$

○ At z=L (Impermeable surface):

$$K_{S1}\frac{\partial S_W}{\partial Z} + K_{T1}\frac{\partial T}{\partial Z} + K_{P1}\frac{\partial P_g}{\partial Z} + K_{gr1} = 0, \tag{4.8a}$$

$$K_e\frac{\partial T}{\partial Z} - \phi\rho_W h_{Vap}\left(K_S\frac{\partial S_W}{\partial Z} + K_T\frac{\partial T}{\partial Z} + K_P\frac{\partial P_g}{\partial Z} + K_{gr}\right) = 0, \tag{4.8b}$$

$$(K_{S1} - K_S)\frac{\partial S_W}{\partial Z} + (K_{T1} - K_T)\frac{\partial T}{\partial Z} +$$

$$(K_{P1} - K_{P3})\frac{\partial P_g}{\partial Z} + (K_{gr1} - K_{gr3}) = 0. \tag{4.8c}$$

○ Initially:

$$T(z,0) = T_1, \tag{4.9a}$$

$$P_g(z.0) = P_0, \tag{4.9b}$$

$$\frac{\partial P_c}{\partial Z} = -\rho_W g. \tag{4.9c}$$

The numerical solution technique to be employed to solve the resulting system of three non-linear partial differential equations involves integration over the (z', τ) control volume are discussed in detail by Patankar [31]. The equations are non-dimensionalised via the scaling

$$z' = z/L, \quad \tau = \alpha t/L^2,$$

$$\theta(z', \tau) = (T - T_1)/\Delta T, \quad P(z', \tau) = P_g/P_0,$$

where $\alpha = (K_s(1 - \phi) + K_g\phi)/(1 - \phi)\rho_s C_{ps}$ and $\Delta T = (T_0 - T_1)$.

All other non-dimensional parameters and functions are basically those tabulated in [22].

To ensure accurate results the following balances can be performed;

○ Total water:

$$\frac{d}{dt} \int_0^L (\phi S_w \rho_w + \phi S_g \rho_{gv}) dz = k_m (\rho_{gvo} - \rho_{gv}).$$

○ Total Enthalpy:

$$\frac{d}{dt} \int_0^L (\phi S_g \rho_{ga} h_{ga} + \phi S_g \rho_{gv} h_{gv} + \phi S_w \rho_w h_w +$$

$$(1 - \phi)\rho_s h_s - \phi \rho_w \int_0^{S_w} \Delta h_w(S) ds dz \Bigg) =$$

$$Q(T_0 - T) + K_m h_{gv} (\rho_{gv0} - \rho_{gv}) + h_{ga} (\phi S_g \rho_{ga} v_{ga})_{z=0} + P_{abs}.$$

5 Concluding remarks

The primary parameter monitored during the drying tests was moisture content, which may be calculated as a ratio of wet weight minus the final dry weight over the final dry weight. The weights include the weight of the entire sample, tufts, and backing. Weight loss during drying is predominately due to water evaporation. Although other materials such as finish may be driven off during drying, the associated weight loss is insignificant compared to that of water. Thus, the determination of moisture content is simple yet accurate.

For most industrial carpet tile operations, the target moisture content is set so that the weight of moisture on the tiles is approximately 5% of the weight of the face yarns. Whilst for convective drying there are definite constant rate and falling rate periods, when microwaves are added the use of the words constant and falling rate may no longer apply.

In hot air drying the constant rate period is the period of drying before the drying front recedes below the outer boundary. During this period the convective heat transfer can be used for evaporation only, resulting in a constant surface temperature and drying rate.

As the material begins to dry out, there is a liquid flux up to what can confidently be explained as the position of evaporation front and then there is no movement of liquid from that point to the surface.

Higher fluxes of liquid to the drying surface from the interior of fiber is expected. A good dryer design should take advantage of this fature and optimize exess water removal from the drying surface. This phenomenon highlights the importance of careful consideration of air flow rates over the drying surface so that any exess liguid formation at the dring surface can be eliminated.

Other important conclusions can further summarized by the following observations on the carpet surfaces irregularities:

- If the deterministic component is a piecewise linear function and the random component is a homogeneous normal field, then the mathematical expectation of the parameter R_{as} increases with increasing S/σ.

- If S/σ is less than 1 when $E\left(R_{as}\right)$ is calculated the influence of

the deterministic component can be ignored and the error is less than 10%.

- When S/σ is less than 3, formula (3.25) can be used to calculate $E\left(R_{as}\right)$ with an error of less than 10%.

- If S/σ is greater than 4, $E\left(R_{as}\right)$ can be evaluated with an error of less than 10% by using the deterministic component (formula 3.23).

- Formula (3.22) holds for the whole range of S/σ changes.

- Full agreement with the theoretical expression can be demonstrated by the experimental calculations using formula (3.26).

The theoretical dependence of the mathematical expectation of the parameter R_{as} has been determined for the case when the deterministic component $S\left(x,y\right)$ can be linearized on the separate sections. The dependence of the evaluation bias in the parameter R_{as} on the relationship between the random and deterministic components can been determined.

Appendix A. Physical Characteristics [28]

<u>Wool:</u>

▷ Diffusion coefficient of water vapor in fiber, $(m^2 S^{-1})$
   - 1st stage :

$$D_f = (1.04 + 68.20W_c - 1342.59W_c^2)10^{-14}, \quad t < 540 \ s. \quad \text{(A1)}$$

▷ Diffusion coefficient of water vapor in fiber, $(m^2 S^{-1})$
   - 2nd stage :

$$D_f = 1.6164\{1 - \exp\left[-18.163\exp(-28.0W_c)\right]\}10^{-14}, \quad t \geq 540 \ s. \quad \text{(A2)}$$

▷ Diffusion coefficient in the air:

$$D_a = 2.5e^{-5}. \tag{A3}$$

▷ Volumetric heat capacity of fiber, $(kJm^{-3} \text{ K})$

$$C_v = 373.3 + 4661.0W_c + 4.221T. \tag{A4}$$

▷ Thermal conductivity of fiber :

$$K = \left(38.49 - 0.720W_c + 0.113W_c^2 - 0.002W_c^3\right) 10^{-3}. \tag{A5}$$

▷ Heat of sorption, $(kJkg^{-1})$

$$\lambda = 1602.5 \exp\left(-11.72W_c\right) + 2522.0. \tag{A6}$$

Cotton:

▷ Diffusion coefficient of water vapor in fiber, $(m^2 S^{-1})$
    - 1st stage :

$$D_f = \left(0.8481 + 50.6W_c - 1100W_c^2\right) 10^{-14}, \quad t < 540 \ s. \tag{A7}$$

▷ Diffusion coefficient of water vapor in fiber, $(m^2 S^{-1})$
    - 2nd stage :

$$D_f = 2.5\{1 - \exp\left[-3.5385 \exp\left(-45W_c\right)\right]\}10^{-14}, \quad t \geq 540 \ s. \tag{A8}$$

▷ Diffusion coefficient in the air:

$$D_a = 2.5e^{-5}. \tag{A9}$$

▷ Volumetric heat capacity of fiber, $(kJm^{-3} \text{ K})$

$$C_v = \frac{(1663.0 + 4184.0W_c)}{(1 + W_c)\, 1610.9}. \tag{A10}$$

▷ Thermal conductivity of fiber:

$$K = (44.1 + 63.0W) \, 10^{-3}. \qquad (A11)$$

▷ Heat of sorption: $(kJkg^{-1})$

$$\lambda = 1030.9 \exp\left(-22.39W_c\right) + 2522.0. \qquad (A12)$$

Porous Acrylic Fiber:

▷ Diffusion coefficient of water vapor in fiber, (m^2S^{-1})
   - 1st stage :

$$D_f = \left(1.12 - 410W_c - 8200W_c^2\right)10^{-13}, \quad t < 540s. \qquad (A13)$$

▷ Diffusion coefficient of water vapor in fiber: (m^2S^{-1})
   - 2nd stage :

$$D_f = (6.23)10^{-13}, \quad t \geq 540s. \qquad (A14)$$

▷ Diffusion coefficient in the air :

$$D_a = 2.5e^{-5}. \qquad (A15)$$

▷ Volumetric heat capacity of fiber: $(kJm^{-3}K)$

$$C_v = 1610.9. \qquad (A16)$$

▷ Thermal conductivity of fiber, $(kWm^{-1}K^{-1})$:

$$K = 28.8 \quad \times 10^{-3}. \qquad (A17)$$

▷ Heat of sorption, $(kJkg^{-1})$:

$$\lambda = 2522. \qquad (A18)$$

Polypropylene Fiber:

▷ Diffusion coefficient of water vapor in fiber, $(m^2 S^{-1})$

    - 1st stage:
$$D_f = 1.3e^{-13}, \quad t < 540s. \tag{A19}$$

▷ Diffusion coefficient of water vapor in fiber, $(m^2 S^{-1})$

    - 2nd stage:
$$D_f = 1.3e^{-13}, \quad t \geq 540s. \tag{A20}$$

▷ Diffusion coefficient in the air:

$$D_a = 2.5e^{-5}. \tag{A21}$$

▷ Volumetric heat capacity of fiber, $(kJm^{-3}K)$

$$C_v = 1715.0. \tag{A22}$$

▷ Thermal conductivity of fiber, $(kWm^{-1}K^{-1})$:

$$K = 51.80 \quad 10^{-3}. \tag{A23}$$

▷ Heat of sorption, $(kJkg^{-1})$

$$\lambda = 2522. \tag{A24}$$

Appendix B. Kinetic coefficients

$$K_s = \frac{-KK_W}{\phi\mu_W}\frac{\partial P_c}{\partial S_W}, \quad K_{S1} = K_S + \frac{(1-S_W)DM_aM_V}{\rho_W MRT}\frac{\partial P_{gV}}{\partial S_W},$$

$$K_{S2} = K_S + \frac{(C_{pV} - C_{pa})(1-S_W)DM_aM_V}{C_{pW}\rho_W MRT}\frac{\partial P_{gV}}{\partial S_W},$$

$$K_T = -\frac{KK_W}{\phi\mu_W}\frac{\partial P_C}{\partial T}, \quad K_{T1} = K_T + \frac{(1-S_W)DM_aM_V}{\rho_W MRT}\frac{\partial P_{gV}}{\partial T},$$

$$K_{T2} = K_T + \frac{(C_{pV} - C_{pa})(1 - S_W)DM_aM_V}{C_{pW}\rho_W MRT}\frac{\partial P_{gV}}{\partial T},$$

$$K_p = \frac{KK_W}{\phi\mu_W},$$

$$K_{p1} = K_p + \frac{KK_gM_VP_{gV}}{\phi\mu_g\rho_W MRT}\frac{\partial P_{gV}}{\partial T} - \frac{(1 - S_W)DM_aM_VP_{gV}}{\rho_W RTMP_g}.$$

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Faktori koji utiču na transport voda-para kroz vlakna
(kratak prikaz)
UDK 532.526; 533.15

Ovaj kratki prikaz je posvećen istraživačkim rezultatima dobijenim iz ponašanja tepiha pri sušenju. Pre svega, prikazane su matematičke relacije koje mogu da budu iskorišćene za opis mehanizma isušivanja vlage iz tepiha. Zatim je diskutovan uticaj značajnih parametara na proces sušenja i formulisane su matematičke relacije koje ilustruju opseg njihove primene. Medjutim, ostali su neki izazovi koji treba da se prevazidju inovacijama, istraživačkim naporima i modernom tehnikom posebno u proizvodnji kontrolnih uredjaja.