Effect of the environmental atmosphere on heat, water and gas transfer within hygroscopic fabrics

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Abstract

A dynamic model of simultaneous heat and mass transfer in hygroscopic porous materials was developed. In the model, evaporation/condensation and movement of water, sorption/desorption of fiber and effect of atmosphere on mass transfer in porous media were considered. The theoretically calculated results agree well with the experimental data reported in the literature. The distributions of temperature, moisture concentration, liquid water saturation and atmosphere at different boundary conditions are numerically computed and compared. It could be concluded that the atmospheric pressure has significant impact on heat and mass transport processes in hygroscopic porous materials.

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1. Introduction

The clothing system plays a very important role in determining the human body core temperature and other human thermal responses because it determines how much of the heat generated in the human body can be exchanged with the environment. With the development of new technology, it is more and more important to know how the human body will behave thermally under different environmental conditions with various clothing systems. In order to obtain a comfortable space for human, it is necessary to understand the thermal and hygroscopic behaviors of the clothing. Simultaneous heat and moisture transfer in porous media is of growing interest to a wide range...
# Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>$C_f$</td>
<td>water vapor concentration in the fibers of the fabric (kg/m³)</td>
</tr>
<tr>
<td>$c_v$</td>
<td>volumetric heat capacity of the fabric (J/(m³K))</td>
</tr>
<tr>
<td>$D$</td>
<td>diffusivity of vapor (m²/s)</td>
</tr>
<tr>
<td>$D_f(w_c)$</td>
<td>diffusion coefficient of water vapor in the fibers</td>
</tr>
<tr>
<td>$h_c$</td>
<td>convection mass transfer coefficient (m/s)</td>
</tr>
<tr>
<td>$h_{1-g}$</td>
<td>mass transfer coefficient (m/s)</td>
</tr>
<tr>
<td>$h_t$</td>
<td>convection heat transfer coefficient (J/(m²K))</td>
</tr>
<tr>
<td>$K$</td>
<td>intrinsic permeability (m²)</td>
</tr>
<tr>
<td>$K_{mix}$</td>
<td>thermal conductivity of the fabric (W/(mK))</td>
</tr>
<tr>
<td>$K_{fg}$</td>
<td>relative permeability of gas</td>
</tr>
<tr>
<td>$K_{rw}$</td>
<td>relative permeability of liquid water</td>
</tr>
<tr>
<td>$\bar{m}_a$</td>
<td>the mass flux of dry air under gas pressure gradient driving</td>
</tr>
<tr>
<td>$\bar{m}_w$</td>
<td>mass flux of liquid water</td>
</tr>
<tr>
<td>$\bar{m}_v$</td>
<td>mass flux of vapor under gas pressure gradient driving</td>
</tr>
<tr>
<td>$\bar{m}_Dv$</td>
<td>diffusion mass flux of water vapour</td>
</tr>
<tr>
<td>$p_c$</td>
<td>capillary pressure (kg/(ms²))</td>
</tr>
<tr>
<td>$p_g$</td>
<td>pressure of gas phase (kg/(ms²))</td>
</tr>
<tr>
<td>$p_v$</td>
<td>water vapour partial pressure (kg/(ms²))</td>
</tr>
<tr>
<td>$p_{vs}(T)$</td>
<td>saturated water vapor pressure at $T$ (kg/m³)</td>
</tr>
<tr>
<td>$Q$</td>
<td>heat flux of evaporation or condensation of water (J/(m³s))</td>
</tr>
<tr>
<td>$r$</td>
<td>radius (m)</td>
</tr>
<tr>
<td>$S$</td>
<td>liquid water volumetric saturation (liquid volume/pore volume)</td>
</tr>
<tr>
<td>$S_v$</td>
<td>specific area of the fabric (1/m)</td>
</tr>
<tr>
<td>$T$</td>
<td>temperature of the fabric (K)</td>
</tr>
<tr>
<td>$T_\infty$</td>
<td>environmental temperature (K)</td>
</tr>
<tr>
<td>$W$</td>
<td>evaporation or condensation flux of water in inter-fibers void space of fabric (kg/(m³s))</td>
</tr>
<tr>
<td>$w_c$</td>
<td>water content of the fibers in the fabric (kg/kg)</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>porosity of fabric</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>heat of sorption or desorption water or vapor by fibers (J/kg)</td>
</tr>
<tr>
<td>$\rho_{lw}$</td>
<td>density of liquid water (kg/m³)</td>
</tr>
<tr>
<td>$\rho_v$</td>
<td>water vapor concentration in the air filling the inter-fiber void space (kg/m³)</td>
</tr>
<tr>
<td>$\rho_{v\infty}$</td>
<td>environmental water vapor concentration (kg/m³)</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>surface tension of gas-liquid interface (kg/s²)</td>
</tr>
<tr>
<td>$\mu_g$</td>
<td>dynamic viscosity of gas (kg/(ms))</td>
</tr>
<tr>
<td>$\mu_w$</td>
<td>dynamic viscosity of water (kg/(ms))</td>
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</table>

**Boundary**: $\Gamma$

**Gradient**: grad

**Divergence**: div
of scientific and engineering fields such as civil engineering, safety analysis of dam, meteorology, energy storage etc. Although considerable previous work [4,6] has been carried out on diverse aspects both theoretically and experimentally, those researchers focused mainly on the materials that do not absorb moisture vapor. Of those literature, a few researchers [1] considered the absorption of moisture vapor, which was simply regarded as an instant process only. But the majority of textile materials have a certain degree of moisture absorption capability (called hygroscopicity). For instance, wool fiber can take up 38% of moisture relative to its own weight [13]. Such capability influences the heat and moisture transfer progress significantly as observed in previous research work [2,5,7,8,11,12]. Therefore, the theoretical models developed for non-hygroscopic materials cannot be directly adopted to describe the heat and moisture processes in hygroscopic materials. The first clothing model that describes the mechanism of transient diffusion of heat and moisture transfer into an assembly of hygroscopic textile materials was introduced and analyzed by Henry [5] in 1939. He developed a set of two differential coupled governing equations for the mass and heat transfer in a small flat piece of clothing material. The analysis of Henry was based on a simplified analytical solution. Downes and Mackay [2], and Watt [12] found experimentally that the sorption of water vapor by wool is a two-stage process. In order to describe the complicated process of the two-stage adsorption behavior in textile materials, Nordon and David [11] presented a model in terms of experimentally adjustable parameters appropriated for the first and second stage of moisture sorption. However, their model did not take the physical mechanisms of the sorption process into account. For this reason, Li and Holcombe [7] introduced a new two-stage absorption model to better describe the coupled heat and moisture transport in fabrics. Li and Luo [8] improved the sorption rate equation by assuming that the moisture sorption by a wool fiber can be generally described as a uniform-diffusion equation for both stages of sorption. But the above-mentioned models ignored the effect of liquid water movement. More recently, Luo [10], Zhu [14] and Fan [3] developed new fabric models, in which liquid water movement or mobile condensates is considered. But the above-mentioned models [2,3,5,7,8,10–12,14] ignored the effect of the atmospheric pressure on heat and moisture transfer within hygroscopic fabrics. First, the atmospheric pressure is not a constant value, it changes with the changing of the height above sea level, seasons and climate. And the state parameter of air vibrates with the vibration of atmospheric pressure. Second, the atmospheric pressure gradient significantly affects the mass transfer. For the disadvantage of the above literatures [2,5,7,8,10–12,14], the purpose of this research is to develop a new model that takes the effect of atmospheric pressure on the mass transport through fibrous material into account. Such a model could be ultimately combined with other human thermal models to better simulate the transient response of human.

2. Physical mechanism of multi-phase flux diffusion into the fabric

2.1. Heat and moisture exchange of liquid water

Vaporization of liquid below its boiling point is called evaporation, which occurs at any temperature when the surface of liquid is exposed to an unconfined space. On the water surface a saturated air boundary layer whose temperature equals to that of water surface is formed due to the irregular movement of water molecules. If the vapor pressure of boundary layer is above that of around air,
then water vapor molecules going into the boundary are less than that leaving the boundary. This is the mechanism of evaporation. Whereas, the opposite process is condensation. Wet exchange mass of unit volume with porosity $\varepsilon$ and saturation $S$ is

$$W = \varepsilon(1-S)S_f h_{l-g} \frac{M_w}{RT} ( p_{vs}(T) - p_v ),$$  \hspace{1cm} (1)$$

where $S_f$ is specific area of the fabric in 1/m, $p_v$ is water vapor pressure in Pa, $h_{l-g}$ is mass transfer coefficient in m/s, $p_{vs}(T)$ is the pressure of saturation water vapor in Pa, $M_w$ is the molecule mass of water in kg/mol, and the latent exchange energy is

$$Q = h_{vap} W,$$ \hspace{1cm} (2)$$

where $h_{vap}$ is evaporation heat of water in J/kg.

2.2. Moisture diffusion into fiber

Moisture diffusion into a fiber was first proposed by Henry and then further developed by Nordon, David, Li, Holcombe and Luo. It is recognized as a two-stage sorption process. In this paper the moisture sorption in the fiber is described as a diffusion equation with two sets of variable water vapor diffusion coefficients [8]:

$$\frac{\partial C_f}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} \left( r D_f(w_c, t) \frac{\partial C_f}{\partial r} \right),$$ \hspace{1cm} (3)$$

where $D_f(w_c, t)$ is the diffusion coefficients that have different value at different stages of moisture sorption. For wool fiber, it is a function of the fibers water content, 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 a quadratic function of the water content when sorption is less than 540 s (i.e., $t < 540$ s). In the second stage, in which the moisture sorption is much slower than in the first, the diffusion coefficient of moisture in a fiber is attenuated along with the time of sorption when $t \geq 540$ s. $C_f$ is the moisture concentration in the fiber. The boundary condition around the fiber is determined by assuming that the moisture concentration at the fiber surface is instantaneously in equilibrium with the surrounding air. Hence, the moisture concentration at the fiber surface is determined by the relative humidity of the surrounding air, i.e.,

$$C_f(R_f) = f(RH, T),$$ \hspace{1cm} (4)$$

where $f$ is a nonlinear function, which has been determined experimentally for different fiber. The diffusion coefficient of moisture in a fiber $D_f(w_c, t)$ is obtained at the condition $p_0$. At other atmospheric pressure $p_0$, the coefficient is $D_f(w_c, t)p_0/p_0$ [9].

2.3. Liquid water and vapor transfer within void space of inter-fibers

As the pore sizes in fibrous materials are generally small, the diffusion of flux is largely governed by the Darcy’s law. In the pore of inter-fibers, the Darcy equation applied to the gas phase
gives
\[ \tilde{m}_v = -\rho_v \frac{KK_{rg}}{\mu_g} \text{grad}(p_g), \]  
(5)
\[ \tilde{m}_a = -\rho_a \frac{KK_{rg}}{\mu_g} \text{grad}(p_g), \]  
(6)
where \( p_g \) is the gaseous pressure, \( K \) is the intrinsic permeability, \( K_{rg} \) is the relative permeability of gas, \( \mu_g \) is the gas phase dynamic viscosity, \( \rho_v \) is the water vapor concentration, \( \rho_a \) is the concentration of dry air, \( \tilde{m}_v \) is the mass flux of vapor under gas pressure gradient driving, \( \tilde{m}_a \) is the mass flux of dry air under gas pressure gradient driving.

For the liquid water phase, the Darcy’s law is noted as [1]
\[ \tilde{m}_w = -\rho_w \frac{KK_{rw}}{\mu_w} \text{grad}(p_g - p_c), \]  
(7)
where \( \tilde{m}_w \) is the diffusion mass flux of liquid water, \( \rho_w \) is the density of liquid water, \( K_{rw} \) is the relative permeability of liquid water, \( \mu_w \) is the dynamic viscosity of the liquid water, \( p_c \) is the capillary pressure. In porous media the capillary pressure \( p_c \) is the function of surface tension \( \sigma \) and saturation \( S \), noted as [1]
\[ p_c = a\sigma S^b, \]  
(8)
where the constant \( a, b \) can be obtained by the experiment and is associated with structure of fabrics. The surface tension \( \sigma \) in the gas–liquid interface is a function of temperature. For a small variation of the temperature, the surface tension may be expressed as a linear function of absolute temperature as
\[ \sigma = \sigma_0 + \beta(T - T_0), \]  
(9)
where \( \sigma_0 \) is surface tension at temperature \( T_0 \), and \( \beta \) is the empirical constant.

For the water vapor phase, according to Stefen’s law is noted as [6]
\[ \tilde{m}_v^D = -\varepsilon(1 - S)D \left( \frac{M_w p_g}{RT p_a} \right) \text{grad}(p_v), \]  
(10)
where \( \tilde{m}_v^D \) is the diffusion mass flux of water vapor, \( \varepsilon \) is the porosity of fabric, \( S \) is the saturation, \( M_w \) is the molecular weight of water, \( R \) is the gas constant, \( p_g \) is the gaseous pressure, \( p_a \) is the partial pressure of dry air, \( p_v \) is water vapor partial pressure, the diffusion coefficient of vapor \( D \) is the function of temperature and gaseous pressure
\[ D(T, p_g) = D_0 \frac{p_{g0}}{p_g} \left( \frac{T}{T_0} \right)^{1.80}, \]  
(11)
where \( D_0 = 0.215 \times 10^{-4} \text{ m}^2/\text{s} \) is the diffusion coefficient at \( T = T_0 = 273 \text{ K} \) and \( p_{g0} = p_g = 1.01325 \times 10^5 \text{ Pa} \). The resulting expression for the diffusion mass flux of water vapor in porous fabric is
\[ \tilde{m}_v^D = -1.952 \times 10^{-7}\varepsilon(1 - S) \frac{T^{0.8}}{p_a} \text{grad}(p_v). \]  
(12)
3. Governing equations

Based on the above physical mechanism of multi-phase flux diffusion into fabric, we can establish the mathematical equations for the coupled heat and mass transfer in fibrous batting zone according to the conservation of mass and heat energy balance.

The vapor density distribution is governed by the following conservation of mass equation:

$$\frac{\partial [\varepsilon (1 - S) \rho_v]}{\partial t} + \frac{\partial [C_r (1 - \varepsilon)]}{\partial t} - W = \text{div}(-\tilde{m}_v^D) + \text{div}(-\tilde{m}_v).$$ (13)

The first term on the left side of Eq. (13) represents vapor storage within the void space of the inter-fiber, whereas the second term represents vapor storage within the fiber, i.e., the sorption rate of fibers, the third term is evaporation flux of the water in the inter-fibers void space. The right side of equation represents water-vapor diffusion under partial pressure gradient and total pressure gradient.

The liquid water distribution is governed by the following conservation of mass equation:

$$\frac{\partial [\varepsilon S \rho_w]}{\partial t} + W = \text{div}(-\tilde{m}_w).$$ (14)

The first term on the left side of Eq. (14) represents liquid water storage within the void space of the inter-fiber, whereas the second term represents evaporation or condensation flux of the water in the void space of the inter-fibers. The right side of Eq. (14) represents capillary transfer.

The temperature distribution is calculated from the following conservation of energy equation:

$$c_v \frac{\partial T}{\partial t} - \lambda(1 - \varepsilon) \frac{\partial C_r}{\partial t} + Q = \text{div}(K_{\text{mix}} \text{grad}(T)).$$ (15)

The first term on the left side of Eq. (15) represents energy storage, whereas the second and third term on the left side of Eq. (15) represents latent heat in fiber and inter-fiber, respectively. The right side represents the heat conduction. The parameter of Eq. (15) is given by Ref. [10].

The dry air density distribution is governed by the following conservation of mass equation:

$$\frac{\partial [\varepsilon (1 - S) \rho_a]}{\partial t} = \text{div}(\tilde{m}_v^D) + \text{div}(-\tilde{m}_a).$$ (16)

The term on the left side of Eq. (16) represents dry air storage within the void space of the inter-fiber, The first on the right side of Eq. (16) represents dry air diffusion under partial pressure, whereas the second term represents the dry air diffusion under total gas pressure gradient.

4. Initial and boundary conditions

In order to generate a solution to the equations mentioned above, we need to specify an initial condition and boundary conditions on the fabric surfaces in terms of density, saturation, temperature and atmospheric pressure, respectively. Initially, a fabric is equilibrated to a given atmosphere, temperature, saturation and humidity. The temperature, atmosphere, saturation and density are uniform throughout the fabric at known value:

$$\rho_v = \rho_{v_0},$$
$$S = S_0,$$
The boundary conditions

\[
\tilde{m}_v^D \cdot \tilde{n} |_T + \tilde{m}_v \cdot \tilde{n} |_T = h_c (\rho_v - \rho_{v\infty}),
\]

\[
S |_{T1} = S |_{B}, \quad \tilde{m}_w \cdot \tilde{n} |_{T2} = q,
\]

\[-K_{\text{mix}} \text{grad} \ T \cdot \tilde{n} |_T = h_t (T - T_{\infty}),\]

\[
p_g |_T = p_{gT}.
\]  

(18)

5. Numerical solution and discussion

To derive a numerical solution for the above equations, we discretize the equations by using the finite volume method. The program is written in FORTRAN and is completed on PC.

5.1. Comparison between theoretical predictions and experimental measurements

A fabric sample measuring 3 cm \times 15 cm was suspended in a cell in which the temperature was controlled at 20 $±$ 2\degree C, the atmospheric pressure was controlled at 1 atm, and the relative humidity (RH) was produced by a Flow-divider Humidity Generator, which can change the RH from 0% to 99% in 1% steps to an accuracy of $±$0.1% of total flow. Fabric was equilibrated in the cell at 0% RH for 90 minutes, then the RH in the cell was rapidly changed from 0% to 99% at time zero, and this RH was maintained for 90 minutes. The surface temperature of the specimen was measured by using a fine thermocouple wire attached to fabric surface. The fabric sample is made of wool fiber with thickness 2.96 mm. The above model is simplified in this example. The comparison between theoretical prediction and experimental measurements [8] is shown in Fig. 1.

Fig. 1 shows temperature changes at the surface of fabric during the dynamic-moisture diffusion process. Since the temperature of surroundings was kept constant at 20\degree C, in the testing conditions, no external heat flow was provided to the fabric. Hence the temperature rise in the fabric was purely due to the heat released during the moisture-sorption process. From the goodness of fit between the theoretically calculated temperature changes and those measured from the experiments as shown in Fig. 1, the models show the ability to predict the simultaneous heat transfer that is coupled in the moisture-diffusion process during humidity transients.

5.2. Theoretical predictions and analysis of model

The fabric sample is made of wool fiber with thickness 3.0 mm and porosity 0.8. And the parameters used in the calculation are taken from Refs. [1,8,10]. And the computational cases are listed in Table 1. The corresponding numerical simulations are shown in Figs. 2 and 3.
In Case 1, the temperature and saturation distributions of liquid water, vapor concentration and atmospheric pressure are shown in Fig. 2. Fig. 2(a) shows the pressure distribution in wool fabric. The pressure is uniform because of the same initial and boundary condition. Fig. 2(b) shows the distribution of water vapor concentration. The water vapor diffuses only by the driving force of water vapor partial pressure gradient when there is no total pressure gradient. Because of the water vapor diffusion, the water vapor concentration in fabric increases from 0.01 to 0.015 kg/m³ with time changes. Then, the concentration of water vapor reaches equilibrium. From the Fig. 2(b), we can also see the sorption process. In the first stage, the sorption rate of the wool fiber is larger than that of second stage. So the water vapor concentration on the space between the inter-fibers at the first stage is smaller than that at the second stage. From Fig. 2(c), we can see that temperature rises in the middle layer of the fabric because of the heat released during moisture sorption. In the beginning, temperature rises fast due to the large sorption rate of fiber. Then temperature decreases gradually with the time reach equilibrium with the environmental temperature because of the low sorption rate and the heat exchange with environment. Fig. 2(d) shows the saturation distribution of liquid water in the process of liquid water diffusion into the wool fabric under the capillary action.
We can see that the liquid water diffuses from the side $x=L$ to 0. The reason is that the liquid water diffusion potential is liquid water pressure that equals to the differences in atmospheric pressure and capillary pressure. The capillary pressure in the region of high liquid water saturation ($x = L$) is lower than that in the region of low liquid water saturation ($x = 0$). In Case 1, the atmospheric pressure at $x = 0$ is equal to that at $x = L$. So the total liquid water driving potential at location $x = L$ is higher than that at location $x = 0$.

In Case 2, the distributions of temperature, saturation of liquid water, vapor concentration and atmospheric pressure on the fabric are investigated at different atmosphere and liquid water saturation boundaries. Fig. 3(a) shows the atmospheric pressure variation in the fabric with the time under pressure boundary condition of Case 2. We can see that the atmospheric pressure is uniform constant initially, then it redistributes with the new boundary pressures. The pressure at $x = L$ reach to 6.0135e4 Pa. Fig. 3(b) shows the distribution of the water vapor concentration in Case 2, which at $x = 0$ and $L$ are lower than that at the middle of the fabric. This is because of the effects of atmospheric pressure and liquid water. The atmospheric pressure gradient makes the water vapor diffuse from the high pressure (location $x = 0$) to low pressure (location $x = L$). And the liquid water diffuses toward opposite directions. So the water vapor is compressed at the middle layer of fabric. Its concentration is larger than that at the both sides. In the first stage, the sorption rate of wool fabric is lager than that of second stage. So the water vapor concentration between the inter-fibers at
the first stage is smaller than that at the second stage. Fig. 3(c) shows the temperature distribution in Case 2, whose shape had analogy with Fig. 2(c). The temperature values between Figs. 3(c) and 2(c) are different. The reason is that the atmosphere pressure gradient affects the distribution of the water vapor concentration. The different water vapor concentration affects the amount of water absorbed by fiber, which leads to different sorption heat. And the atmosphere pressure gradient also affects the saturation distribution of the liquid water, which affects the heat capacity and conductivity of the fabric. Fig. 3(d) shows the saturation of the liquid water, whose shape is different from Fig. 2(d). It is because of the effect of atmospheric pressure gradient. The atmospheric gradient discourages liquid water diffusion from the high saturation to the low.

5.3. Effect of atmospheric pressure on heat and mass transport within hygroscopic fabrics

In order to investigate the effect of atmospheric pressure on the temperature distribution, the water vapor concentration and liquid water saturation distribution, a comparison is carried on between results of atmospheric pressure $1.0135e5$ Pa and $5.0135e4$ Pa. The sample is the same as that in Section 5.2. The initial conditions are as follows: temperature, 293.16 K, vapor concentration, 0.01 kg/m$^3$, saturation, 0. The boundary conditions are as follows: left, the temperature, 298.16 K, the vapor concentration, 0.02 kg/m$^3$, the liquid water flux is 0; right, the temperature, 303.16 K, the vapor density, 0.03 kg/m$^3$, the saturation of liquid water is 0.6. The atmospheric pressure was controlled at $1.0135e5$ and $5.0135e4$ Pa, respectively. Fig. 4(a) shows the temperature distribution at left boundary of fabric under atmospheric pressure $1.0135e5$ and $5.0135e4$ Pa.
From Fig. 4(a) we can see that the temperature peak value under low atmospheric pressure is higher than that under the high atmospheric pressure. This is due to the diffusion velocity of vapor under low atmospheric pressure is faster than that under high pressure, the sorption rate of fiber under low atmospheric pressure is larger than that under high pressure. Fig. 4(b) shows the distribution of water vapor concentration at left boundary in fabric under atmospheric pressure $1.0135 \times 10^5$ and $5.0135 \times 10^4$ Pa. From Fig. 4(b) we can see that the vapor concentration under high atmospheric pressure is lower than that under low atmospheric pressure. This is due to the low diffusivity of water vapor because of high atmospheric pressure. Fig. 4(c) shows the distribution of saturation at left boundary in fabric under atmospheric pressure $1.0135 \times 10^5$ and $5.0135 \times 10^4$ Pa. From Fig. 4(c) we can see that the water saturation under high atmospheric pressure is lower than that under low atmospheric pressure. But the difference is no large.

6. Conclusion and prospect

Summarizing the above computational results and discussion, we can find the following conclusion:

1. Water evaporation–condensation and movement, sorption of fiber and effect of atmosphere on mass transfer in porous media are important phenomena, which can greatly affect the coupled heat
and moisture transfer. In our work, such phenomena have been incorporated into a dynamic model for the first time.

(2) The state parameter of air vibrates due to the vibration of atmospheric pressure. The numerical result shows that under low atmospheric pressure the temperature peak, the vapor concentration and saturation of fabric is higher than that under high pressure.

(3) The atmospheric pressure gradient is an important factor to affect liquid water, vapor and heat transfer within hygroscopic fabrics.

It is believed that the model can not only be applied in functional clothing design, but also in other scientific and engineering fields involving heat and mass transfer in porous media.

References