راحتی پوشاک

مدرس:دکتر پدرام پیوندی

فصل ۶

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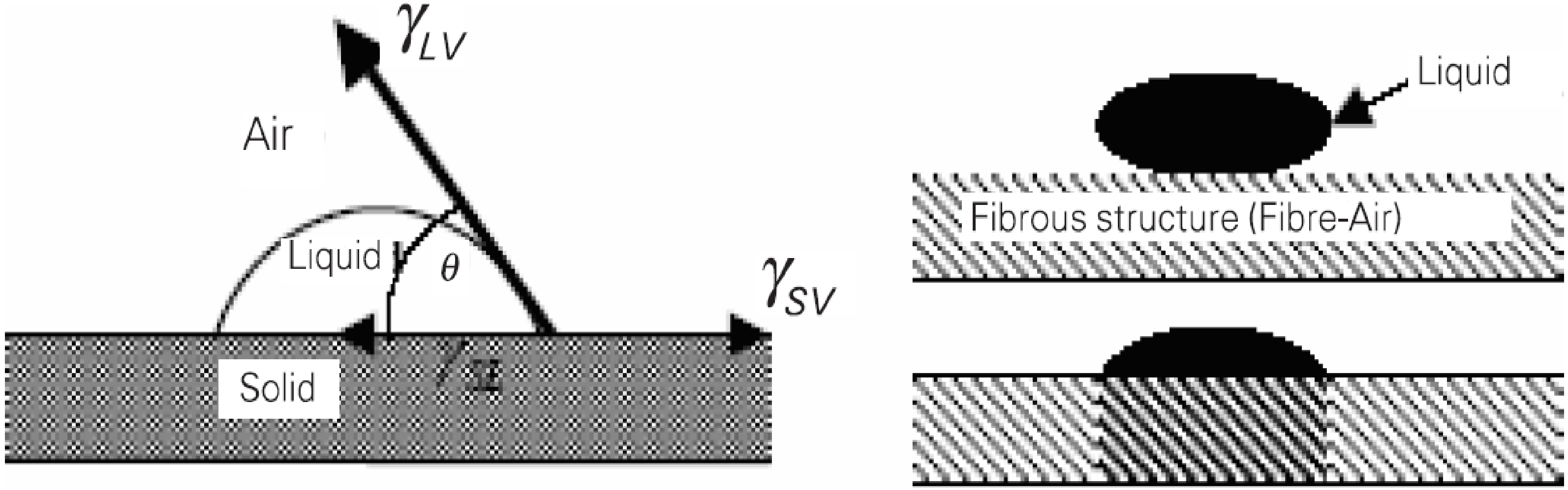
6.2 Liquid water transfer: wicking and water absorption

The transmission of moisture through textile materials in liquid form is mainly due to the fibre–water molecular attraction at the surface of the fibre materials, which is mainly determined by the surface tension and the effective capillary pore distribution. Liquid transfer through a porous structure involves two-stage process, i.e. initially wetting and then wicking [17]. Wetting is the initial process involved in fluid spreading. In this process the fibre–air interface is replaced with a fibre–liquid interface as shown in Fig. 6.1(a) [18]. The forces acting at a solid–liquid boundary under equilibrium are generally expressed by the following Young-Dupre equation,

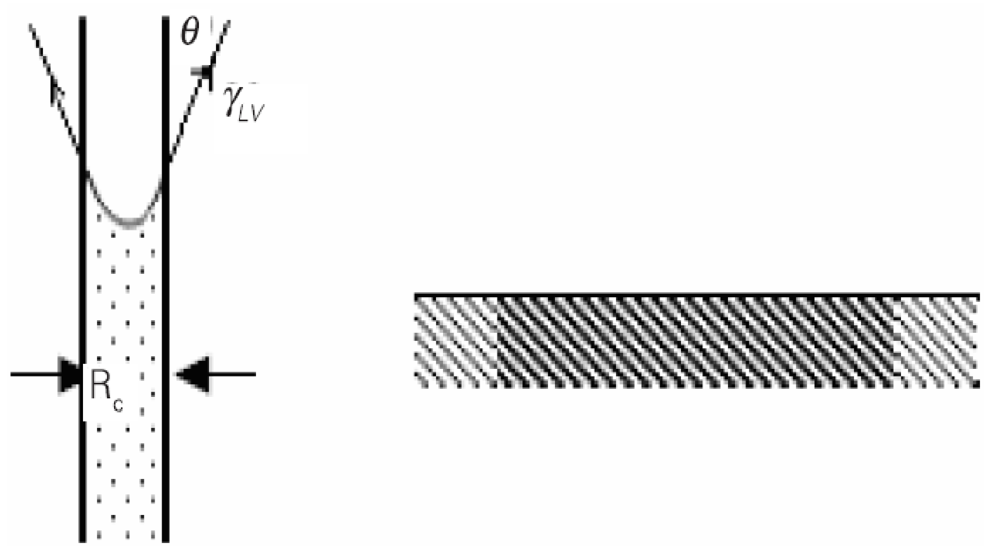
$$\gamma_{SV} - \gamma_{SL} = \gamma_{LV} \cos\theta \tag{6.1}$$

Where, γ represents the tension at the interface between the various combinations of solid (S), liquid (L) and vapour (V), and θ is the contact angle between the liquid drop and the surface of the solid to be wetted. In the case of a textile material, the fibre represents the solid portion. There are several factors influencing the wettability of the material. The contact angle is a direct measurement of the fabric wettability. A low contact angle between the fibre and the liquid means high wettability. The wettability also increases, as the surface tension between the solid and the liquid interface diminishes. With an increase in the temperature of the liquid, its

surface tension is reduced, resulting in higher wetting. Also, with an increase in the liquid's density and viscosity, the surface tension of the material increases, thus reduces wettability. With an increase in surface roughness, the spreading of water along the surface becomes faster due to the troughs offered by rough surfaces as the apparent wetting angle is decreased. The wettability of the material also changes with the chemical nature of the surface and so with an increase in hydrophilicity, the contact angle is reduced, thus increasing the surface wettability. As the roundness and the diameter of the fibres are reduced, the cosine values of the advancing angle increase, thus increasing the surface wettability [18].



(a) 1st Phase: Wetting



(b) 2nd Phase: Capillary wicking

6.1 Liquid transfer processes through a porous media [18]

In sweating conditions, wicking is the most effective process to maintain a feel of comfort. In the case of clothing with high wickability the moisture coming from the skin spreads throughout the fabric offers a dry feeling, and the spreading of the liquid enables moisture to evaporate quickly from larger surface. When the liquid wets the fibres, it reaches the spaces between the fibres and produces a capillary pressure. The liquid is forced by this pressure and is dragged along the capillary due to the curvature of the meniscus in the narrow confines of the pores as shown in the Fig. 6.1(b) [18]. The magnitude of the capillary pressure is given by the Laplace equation:

$$P = \frac{2\gamma_{LV} \cos\theta}{R_c} \tag{6.2}$$

where P is the capillary pressure developed in a capillary tube of radius R_c. The difference in the capillary pressure in the pores causes the fluid to spread in the media. Therefore a liquid that does not wet the fibres cannot wick into the yarn or fabric [19]. The ability to sustain the capillary flow is known as wickability [20]. The distance travelled by a liquid flowing under capillary pressure, in horizontal capillaries, is given by the Washburn-Lukas equation:

$$L = \sqrt{\frac{R_c \gamma \cos\theta}{2\eta}} t^{1/2} \qquad (6.3)$$

Where, L is the capillary rise of the liquid in time t and η is the viscosity of the liquid. The amount of water that wicks through the channel is directly proportional to the pressure gradient. The capillary pressure increases as both the surface tension in the solid–liquid interface and the capillary radius decrease. A textile material consists of open capillaries, formed by the fibre walls [21]. From the Washburn-Lukas equation, it is expected that capillary rise at a specific time will be faster in a medium with larger pore size. However, Miller [22], using a comparative wicking study, showed that this is not always the case. He found that higher initial wicking through the capillaries with bigger diameter has been overtaken with time by the capillaries with smaller diameter. A larger amount of liquid mass can be retained in larger pores but the distance of liquid advancement is limited. This may be explained by the Laplace equation, as the radius of the capillary decreases, the pressure generated in the capillary will be higher, causing faster flow through the capillary. The model developed by Rajagopalan and Aneja [23] also predicts that at a constant void area increasing the perimeter of the filaments increases the maximum height attained by the liquid. Conversely, increasing the void area at a constant perimeter

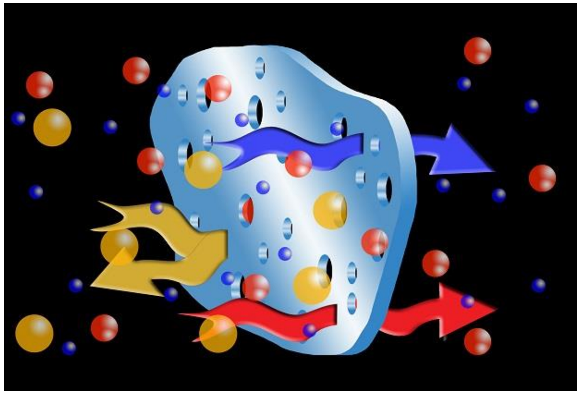
6.2.1 Evaluation of liquid water transfer

Wettability

The wettability of textile materials is tested to evaluate the wetting performance. This can be measured by the following methods.

(i) *Tensiometry* – Tensiometer is an instrument used to measure the wettability of the fabric by measuring the wetting force by Wilhelmy method. In this method the wetting force (force applied by the surface, when liquid comes in contact with the surface) is measured. The contact angles are calculated indirectly from the wetting force when a solid is brought in contact with the test liquid using Wilhelmy principle [11].

(ii) *Goniometry* – In this method the wettability of a material is measured by measuring the contact angle between the liquid and the fabric by image processing method [32]. Automated Contact Angle Tester (ASTM D 5725-99), HTHP contact angle tester, drop analyzer tester have been developed based on this principle. Two processes are used, namely static wetting angle measurement and dynamic wetting angle measurement [33]. The dynamic contact angle is required as a boundary condition for modelling problems in capillary hydrodynamics, including certain stages of the droplet impact problem. The dynamic contact angle differs appreciably from the static advancing or receding values, even at low velocities. The dynamic contact angle can also be measured directly through low-power optics, but it leads to manual error. The dynamic contact angle depends on the spreading velocity of the contact line. To investigate the dynamic contact angle of impacting liquid droplets, a series of experiments were conducted by S¡ikalo et al. with individual droplets impacting onto dry and smooth solid surfaces [34]. To observe the spreading of a droplet, high resolution CCD camera (Sensicam PCO 1240 ×1024 pixels) equipped with a magnifying zoom lens was used. The magnification can be manipulated so that the image can accommodate the maximum spread of droplet [34]. Kamath et al. [35] have developed an apparatus to measure wettability of filament specimen using liquid membrane technique. The force exerted by the liquid membrane on the filament specimen as the ring with liquid membrane moves up or down the filament specimen is measured in this instrument, thus measures the wetting force. Manchester University developed UMIST wettability tester which gives the idea of wettability as well as initial wicking rate of the fabric.



۶.۵ سنجش انتقال بخار رطوبت

سنجش انتقال بخار رطوبت از پارچه ها یک عمل تدریجی وکوتاه حساس است اما می تواند به طور موثری انجام شود.روش های استاندارد متفاوتی برای تعیین کردن مشخصات انتقال بخار رطوبت از مواد نساجی به کار رفته است

۱)روش ظرف تبخیر یا کنترل به روش ظرف(BS 7209)

۲)روش فنجان روش فنجان Gore (ASTM F 96-66)

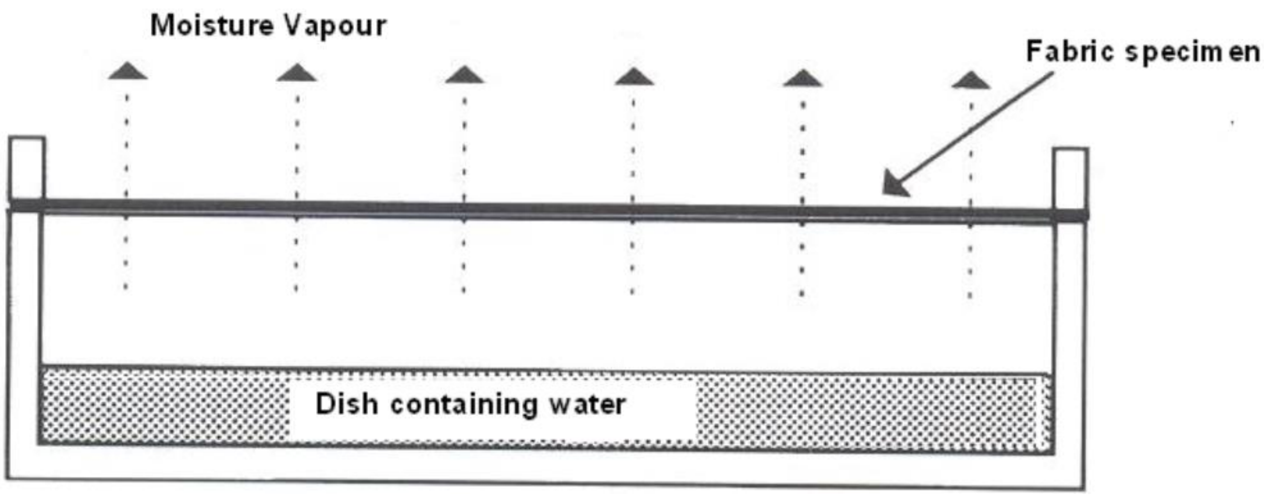
۳)روش فنجان وارونه و روش فنجان وارونه خشک کن (ASTM F 2298)

۴)روش اندازه گیری رطوبت انتقالی(ASTM F 2298)

۵)روش تعرق بوسیله مانکن پوست (ISO 11092)

- The percentage water vapour permeability index, WVP (%), is used in the evaporative disc method (BS 7209). This method uses water at 20°C and an atmospheric condition of 20 ± 2°C and 65 ± 2% relative humidity. This standard is based on the control dish method (CAN2-4.2-M77) and the Gore modified disc method (BPI 1.4).
- The moisture vapour transmission rate (g/m^2/Day) is used in the cup method (ASTM E96-66).
- The resistance to evaporative heat transfer, R_{et} (m^2Pa/W), is used in the sweating guarded hot plate (ISO 11092:1993, EN 31092). It is an indirect method of measuring the vapour transmission property of a fabric. In this test method, the experiment is carried out in an isothermal condition at the standard atmospheric condition.
- The resistance of equivalent standard still air (cm) is used in the holographic visualization method. In this method it is possible to measure the resistance offered by the fabric layer and the air layer separately. The resistance of the fabric can be expressed in terms of the standard still air (cm) providing the same vapour resistance.

- ۶.۵.۱روش ظرف تبخیر
- در این روش میزان انتقال بخار آب از پارچه اندازه گیری می شود وبا توجه به استاندارد این روش بر اساس سنجش وابسته به ثقل سنجی است که نمونه تحت آزمایش بالای یک ظرف دهانه باز چسبیده شده است که ظرف شامل آب و در هوای استاندارد برای آزمایش قرار داده شده است پس از یک دوره زمانی کل سیستم به تعادل می رسد با وزن کردن ظرف به طور متوالی میزان انتقال بخار آب از پارچه محاسبه می شود.
- در این روش قابلیت نفوذ پذیری بخار آب یکنواخت اندازه گیری می شود .قابلیت نفوذ پذیری بخار آب نسبی نمونه بوسیله مقایسه با نتیجه پارچه مرجع محاسبه میشود.



Water vapour permeability (WVP) = $24\ M/A.\ t$ (g/ m^2/day); and

Relative water vapour permeability index (%) = $(WVP)_f \times 100 / (WVP)_r$

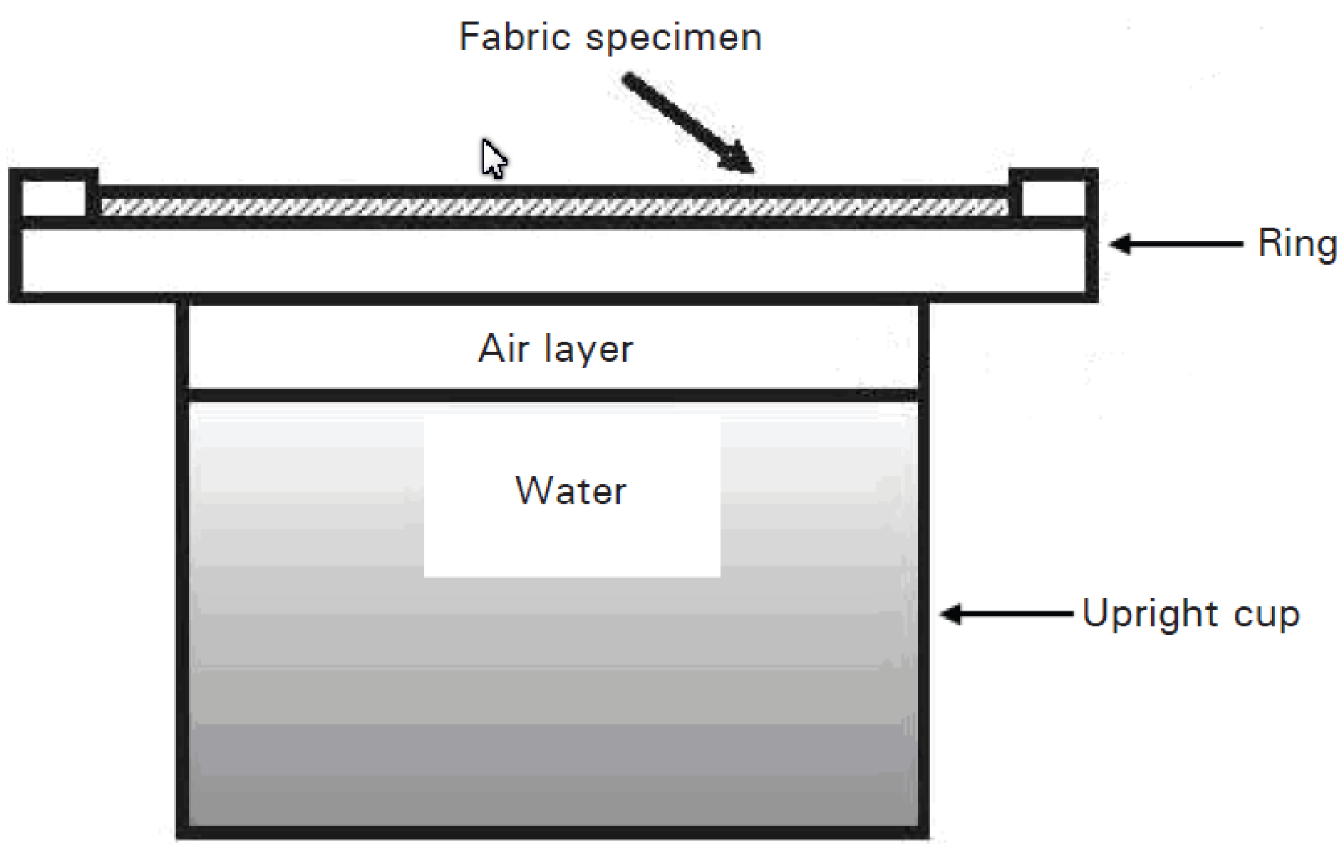
where M is the loss in mass (g) of water vapour through the fabric specimen, t is the time between weighing (h), A is the internal area of the dish (m^2), $(WVP)_f$ and $(WVP)_r$ are the water vapour permeability of the test fabric and reference fabric, respectively.

6.5.2 Upright cup method

This method is similar to that of evaporative dish method. In this method the water vapour transmission rate of fabric is measured according to ASTM E 96-80 procedure B. A shallow cup is filled with 100 ml distilled water and a circular sample with a diameter of 74 mm is mounted on the cup by covering with a gasket and clamping into its position (Fig. 6.7). The cup assembly is housed in an environmental chamber. The air temperature in the chamber is set to 23°C, and the relative humidity is controlled at 50%. The air velocity in the chamber is maintained at 2.8 m/s. The cup assembly is weighed to the nearest 0.001 g on a top loading balance periodically throughout one day. The water vapour transmission rate is calculated as,

$$WVT = \frac{24 \times G}{A \times T} \ g/m^2/24h \tag{6.12}$$

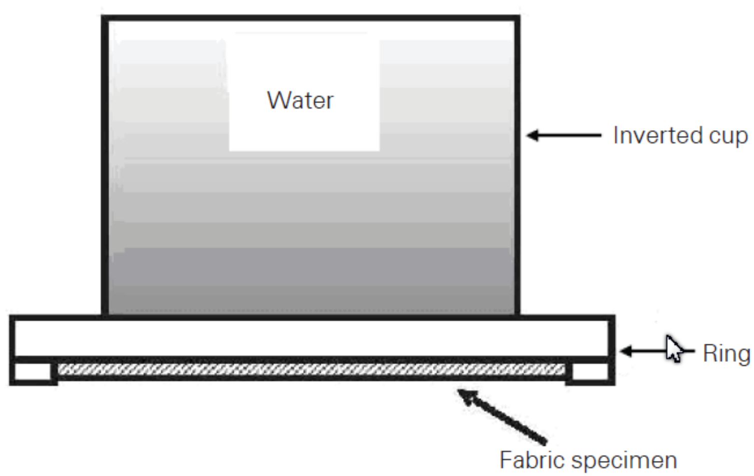
where WVT = water vapour transmission rate ($g/m^2/day$); G = change in mass (g); T = testing time (h); A = test area (m^2).



6.7 Upright cup mthod

6.5.3 Inverted cup test method

In this method the water vapour transmission rates of fabrics are measured according to ASTM E96, Procedure BW. To prevent the water in the cup from wetting the specimen in the inverted test, a piece of hydrophobic PTFE membrane is used to seal over the mouth of the cup. The test specimen is placed over the membrane. The cup assembly, as shown in Fig. 6.8, is placed in an inverted position on the upper deck. The cup assembly is weighed periodically throughout one day. The calculations are the same as that for the upright cup test. The inverted cup method is designed mainly for use with waterproof samples, because the fabrics which allow the passage of liquid water may not be inverted as they will leak.



6.8 Inverted cup method.

6.5.4 Desiccant inverted cup method

This method for measuring water vapour permeability of fabrics works as per ISO 15496 2004 standard [78]. In this method water vapour transmission rates of fabrics are measured in the same way as inverted cup test method. Only difference is that in this method the cup used in this method is partly filled with desiccant such as potassium acetate, calcium chloride, anhydrous CaSO4 or anhydrous $MgClO_4$. The drying agent stays in direct contact with fabric minimizing the path of water vapour. The inverted cup is covered by the specimen and the specimen is covered by another piece of waterproof and vapour permeable membrane. The inverted cup along with specimen is immersed into the water bath filled with distilled water with the help of specimen holder. The measuring cup initially is weighed by means of a balance then inverted and inserted into the specimen holder. After certain time (t), the measuring cup is removed and reweighed. The water vapour permeability of the specimen is then calculated by using the following equation:

$$WVT = t \times (w_2 - w_1) / a \qquad (6.13)$$

Where WVT is water vapour transmission rate; w_2 = mass of cup assembly after test; w_1 = mass of test cup assembly body before test; a = test area.

6.5.5 Sweating guarded hot plate method

The sweating guarded hot plate apparatus or "Hohenstein" skin model [72, 80] is used to measure the thermophysiological comfort of clothing. It works as per ISO 11092 standards. It simulates the moisture transport through textiles and clothing assemblies when worn next to the human skin. This model measures the water vapour resistance of the fabric by measuring the evaporative heat loss in the steady state condition. The temperature of the guarded hot plate is kept at 35°C (i.e. the temperature of the human skin) and the standard atmospheric condition for testing (65% R.H. and 20°C) is used. In this skin model, A is the test area; P_m is the saturation water vapour partial pressure at the surface of the measuring unit; P_a is the water vapour partial pressure of the air in the test chamber;

H is the amount of heat supplied to the measuring unit; ΔH_C is a correction factor and R_{et0} is the apparatus constant. The water vapour resistance of the fabric (R_{et}) may be calculated as follows:

$$R_{et} = \frac{A(P_m - P_a)}{H - \Delta H_c} - R_{et0} \ (\mathrm{m^2Pa/\ W}) \qquad (6.14)$$

6.5.7 Moisture vapour transmission cell

This is a faster and more simplified method for measuring the water vapour transmission behaviour of fabrics. In principle, the cell measures the humidity generated under controlled conditions as a function of time. There are two cells, namely lower and upper cells. The cells are separated by the test specimen. The lower cell is partially filled with water and the upper cell is almost dry at the start of the test. As the moisture vapour is

transmitted through the fabric sample the relative humidity of the upper cell increases with the time. The change in humidity at a given time interval represents the moisture vapour transmission rate (T) of the fabric. The standard relationship is,

$$T = \left(269 \times 10^{-7}\right)\left(\Delta\% RH \times \frac{1440}{Time\ Interval}\right) \text{ g/in}^2\text{/day} \qquad (6.16)$$