Water Vapor Permeability and Measurement Principles

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Abstract –

The transmission of water is essential as clothing comfort is concerned. Human body produces heat in the form of perspirations during its activity and is used to evaporate perspiration, resulting in the dissipation of heat and cooling of the body. However, if water vapor cannot escape to atmosphere then RH inside clothing increases, causing discomfort. Hence, knowledge of water vapor transmission is necessary. In this paper, we have tried to simulate the information about the water vapor permeability and factors influencing it.

1. Water Vapor Transmission

Water vapor transmission is essential in determining breathability which is ability of clothing to allow water vapor to penetrate.

Water vapor permeability is defined as 'fabric's ability to transport water vapor from skin surface through fabric to external environment'.[1]

Water vapor can be transferred by

1. Diffusion of water vapors through layers
2. Absorption, transmission and desorption of water vapor by fibers
3. Adsorption and migration of water vapor along fiber surface
4. Transmission of water vapor by forced convection

2. Mechanism Of Water Vapor Diffusion

Diffusion is main mechanism for transferring moisture. This occurs through air space of fibers, diffusion into fiber, followed by vapor diffusion from fibers back into air and so on [2]

Diffusion depends on the porosity of fabrics. Also, if moisture resistance is too high to transmit heat by transport of mass and at same time, thermal resistance of the textile layer is high, stored heat in the body cannot be dissipated and causes discomfort.[5]

3. Measurement Of Water Vapor Transmission Rate (WVTR)

There are two forms of perspirations

1. Vapor - which comes out from the body and passes through clothing
2. Sweat- liquid discharge from skin pores

The perspiration mechanism affects water-vapor transport capabilities of clothing; sometimes it accumulates on the inner layer or in-between the clothing layers and chokes pores of clothing. This situation affects thermal insulation of clothing and wearer may feel uncomfortable.

3.1 Cup Method

The specimen 1, is sealed 2, over a disc of open mouth. The dish 3, is filled with distilled water with an air gap of 10 mm between fabric and water level. Then by sealing it make sure that water-vapor can pass only through the sample. Side by side, another set up is also kept having a reference fabric. Internal standard diameter of disc and specimen is 96 mm.

While testing, first weighing is done when equilibrium is set (~1 hr.) then instrument is left for overnight and final weight is taken.

The WVTR of reference fabric is

$$WVTR = \frac{G}{tA}, \quad [g/m^2/h]$$

Where,

G= Weight loss of cup with fabric sample [g]

t = Time during which G occurred [hrs]

A= Testing area [m2] [6]

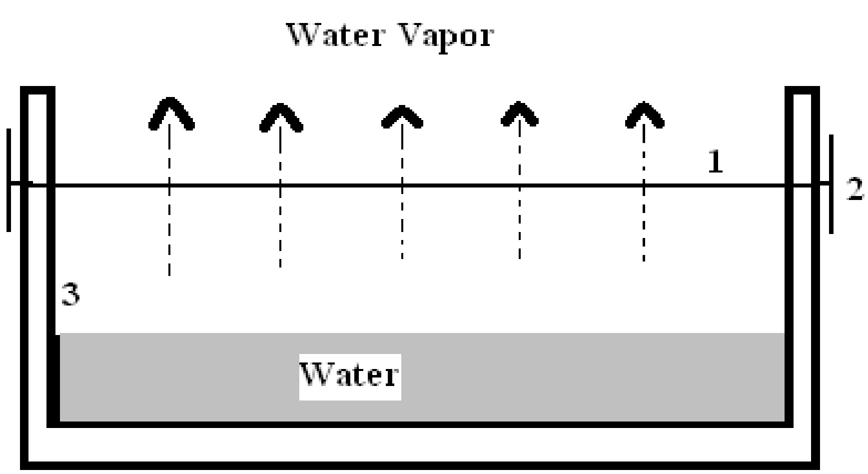

Figure 1 - Cup Method

3.2 Sweating Hot Plate Method

In this, one hot plate with pores is kept over water, it makes sweating possible from plate. To keep temperature of sweating plate is constant a known power supply is provided to plate.

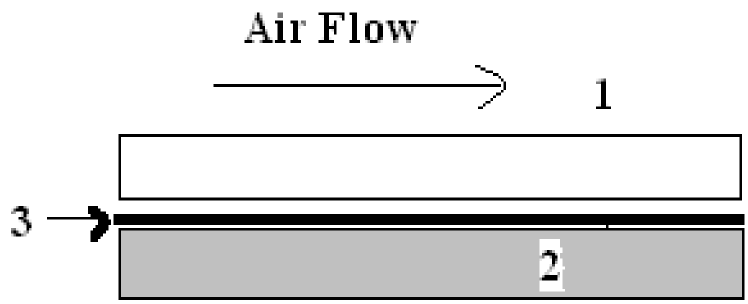

Figure 2 - Sweating Hot Plate Method

1 – Fabric Sample 2 – Saturated Porous Plate 3 - Saturated Cellophane Film

In order to measure the water vapor permeability of a material, first measure the dry thermal transmittance U1

$$U_1 = \frac{P}{A \times (T_p - T_a)}$$ W/m2k

Where,

P = power loss from test plate (W)
A= area of test plate (m2)
Tp= test plate temp (oC)
Ta= air temperature (oC)
And moisture vapor permeability index im

$$i_m = \frac{\left[\frac{PR_{tot}}{A}\right] - (T_p - T_a)}{S(p_s - \phi p_a)}$$

Where,
Rtot = 1/U1 = resistance of fabric plus boundary layer (m2K/W)

A – Surface area (m2)
Tp – Temperature of saturated plate (0C)
Ta- Temperature of ambient air (0C)
P – Power required maintaining constant saturated plate surface temperature (W)
S- Lewis relation between evaporative mass transfer coefficient and convective heat transfer coefficient (1.65*10-2 K/Pa)
Ps – Saturated water vapor pressure at plate surface (Pa)
Pa - Saturated water vapor pressure of ambient air (Pa)
Ø – Relative humidity of air
The im value varies between 0 for completely impermeable materials and 1 for completely permeable materials. [2,8]

4. Factors Affecting Water Vapor Transmission

4.1 Effect of Structure

Diffusion process is influenced by fabric structure, specifically fabric thickness and openness.[9] As thickness determines the distance through which moisture vapor and heat pass in traversing from one side of to the other [2,10]

E.g. as polypropylene is a hydrophobic material and as magnitude of water vapor transmission across fabric is dependent on porosity of fabric, nature of filament, diameter and number of single filaments per yarn, fiber type is relatively unimportant in connection with the water vapor permeability of fabrics that are low in bulk density because of very large proportion of air spaces present in fabric. Hence, contribution of fiber type is insignificant. A finer filament diameter and higher number of filaments per yarn increase the specific surface area, as space between fibers decreases and offers higher drag resistance to moisture flow. In most cases, the relative difference between water vapor permeability values is ultimately determined by effect of fiber diameter and number of single filaments per yarn.[4]

4.2 Effect of Fiber Type

The role of fiber hygro - scopicity of fabrics is to absorb and buffer humidity created by sweat [9]. It is common belief that water vapor transmission behavior of a fabric is significantly affected by the regain property of constituent fibers [12]. But some studies suggests that the variation of Water Vapor Resistance observed with fiber composition of the fabrics seems to be due solely to the fact that the inter yarn pore size and thickness are affected by yarn diameter which is determined by the fiber composition. Some studies also reveal that water vapor transmittance for the blend levels increases as the amount of synthetic fiber increases. Since moisture vapor flow occurs primarily, through the fabric interstices, the effect produced by blending is only slightly affected by the hygroscopic properties of the fibers [13].

Most textile fibers are able to absorb a certain amount of moisture from the adjacent air; damper air means that the fibers will absorb more water vapor. The rate at which water vapor passes through a fiber depends on the nature of the fiber. With hydrophobic fibers, the rate is very slow whereas with hydrophilic fibers, it is relatively fast.

Another important factor apart from all above is surrounding temperature. Osczevski measured mass transport through the film, and found that water vapor resistance is an exponential function of temperature. In his experiment, water vapor permeability vanishes nearly completely with decreasing textile temperature. This is because diffusion in hydrophilic materials is non-Fickian [14].
The resistance to the water vapor transfer depends on the resistance of the air layer and the outer clothing. The resistance offered by the fabric layer in vapor transmission from the skin to the atmosphere, is much lower than that offered by the external boundary air layer and often much lower than that of the inner confined air layer between the skin and the fabric. [3]

5. Conclusions

Thermo-physiological balance is maintained by the clothing through perspiration in form of vapor as well as liquid. The clothing should be capable enough to allow perspiration to be transferred to the surrounding environment for maintaining the thermal balance of the body.

The resistance to water vapor permeability is mainly due to the geometrical aspects of fabrics and constituent yarns; mostly on fabrics thickness and openness. Fiber composition and their proportions also affect the water vapor transmission; in case of filament yarns it depends on no of filaments in yarn and diameters of them also. Some studies also reveal that water vapor transmittance for the blend levels averaged over fabric and fiber types increases as the amount of synthetic fiber increases. The resistance to water vapor transmission is also governed by the outside temperature and it gets vanishes as temperature goes down.

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