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Moisture vapour transmission behaviour of cotton fabrics

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The moisture transmission properties of a series of cotton fabrics have been investigated. Water vapour transport increases with wind velocity, irrespective of the weft count and cover factor of the woven fabrics. For the same fabric, effect of time on moisture vapour transmission behaviour is also studied. Swelling phenomena of hygroscopic fibres are found to play significant role in determining the moisture vapour transmission characteristics of cotton fabrics.

Keywords*:* Cup method, MVTR cell method, Permetest method, Porosity, Water vapour permeability

1 Introduction

Clothing is designed to maintain a hygienic and comfortable zone for the human body in which one feels well, even if inner or outer influences change rapidly. The zone in which the temperature, moisture and air circulation are properly matched is called the "comfort zone". The so-called microclimate, that prevails there, is defined by physical and physiological conditions. The three basic parameters of clothing physiology (temperature, moisture and air circulation) must be adapted to the different internal and external influences, like rest or body exertion and to the changes in outside climate. Hence, clothing must assure rapid adjustment to new conditions through appropriate heat and moisture transport and air permeability. The main task of clothing is therefore temperature regulation for the body and thus relief of the circulatory organs, maintaining body and mental performance and imparting a sense of comfort, even under the least favorable climatic conditions. The water vapour permeability of clothing materials is a critical property of clothing systems that must maintain thermal equilibrium for the wearer. Clothing materials with high water vapour permeability allow the human body to take advantage of its ability to provide cooling due to sweat production and evaporation[1]. When perspiration takes place to cool the body, the water exuded through skin appears initially as liquid which evaporates at once (in comfortable situations) and forms moisture vapour. This vapour is then removed from the vicinity of the body, either by convection or through the clothing worn on the person, carrying heat away with it. When the moisture vapour reaches the inner surface of the fabric, several events can take place. The vapour may pass through the fabric system to its outermost surface, which is then carried away by the air. At the other extreme, it may be prevented from escaping through the fabric system if a component of the latter is impermeable, and hence will condense at some position in the system[2]. The fabrics should allow moisture, in the form of sensible and insensible perspiration[3], to be transmitted from the body to the environment in order to cool the body and reduce the degradation of the thermal insulation of the fabric caused by moisture build-up[4]. This characteristic of fabric is commonly known as fabric breathability.

Thus, it is important to measure the rate at which a material can transmit moisture vapour for assessing of the potential of that material in enhancing or reducing comfort[3]. In this study, moisture vapour transmission behaviour of a series of cotton fabrics has been investigated using different test methods.

2 Materials and Methods

2.1 Materials

Ten 100% cotton plain woven fabrics were manufactured in airjet loom with five different pick densities (14, 17, 20, 23 and 26 ppcm) and two different weft counts (30s and 40s Ne). Warp yarn count (40s Ne) and end densities were kept constant for all the fabrics. Some of the important properties of the cotton fabric samples are shown in Table 1.

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Table 1 — Properties of cotton fabric samples

Fabric sample code	Count, Ne (warp × weft)	Nominal PPCM	Actual PPM	Actual EPM	Areal density g/m^2	Thickness mm
C1440	40×40	14	1444	3896	90.6	0.295
C1430	40×30	14	1483	3911	99.9	0.333
C1740	40×40	17	1797	3924	97.5	0.292
C1730	40×30	17	1772	3976	106.5	0.313
C2040	40×40	20	2087	3990	103.0	0.278
C2030	40×30	20	2152	3950	116.9	0.313
C2340	40×40	23	2454	4003	110.1	0.277
C2330	40×30	23	2428	3924	120.9	0.303
C2640	40×30	26	2743	3950	116.3	0.280
C2630	40×30	26	2730	3976	129.7	0.315

2.2 Methods

2.2.1 Fabric characteristics

Fabric sett was measured using counting glass according to ASTM D3775-03 standard. Yarn linear density and fabric weight per unit area were determined according to ASTM D1059 standard. The thickness was measured as per the ASTM D1777-96(2002) standard test method using Essdiel thickness tester at a pressure of 20 gf/cm^2 with an accuracy of 0.01mm. An average of 10 readings was taken for each sample in case of each test.

Porosity (ϕ) is defined as the fraction of void space in a porous medium, which can be expressed as:

$$\phi = 1 - \frac{\rho_b}{\rho_s}$$

where ρ_b and ρ_s are the bulk and medium densities respectively. In case of fabrics, ρ_b is the fabric density and ρ_s is the fibre density. Fabric density (g/cc) can be calculated using following relationship:

ρ_b= Fabric weight (g/cm^2)/Thickness (cm)

Porosity values of the fabrics were calculated as explained above. Standard atmospheric conditions have been maintained for all the experiments.

2.2.2 Air Permeability

Air permeability of the fabric was measured using TEXTEST FX 3300 air permeability tester at an air pressure of 100Pa using ASTM D737 test standard. An average of 10 readings for each sample is reported.

2.2.3 Water Vapour Permeability

For determination of the water vapour permeability of the samples three instruments were used, viz. Permetest method, cup method and MVTR cell method.

2.2.3.1 Permetest Method

The water vapour permeability of the samples was measured using the Permetest[5] instrument, according to ISO 9920 testing standard. The instrument works on the principle of heat flux sensing. The temperature of the measuring head was maintained at room temperature for isothermal conditions. When water evaporates from the measuring head, the heat lost from it is indirectly sensed by the heat sensor. This instrument measures the heat loss from the measuring head due to the evaporation of water in bare condition and with being covered by the fabric. The results of measurement are expressed by the instrument in terms of relative water vapour permeability (%) and water vapour resistance R_{et} (m^{2}Pa/W). The relative water vapour permeability (p_{wv}) of the fabric sample has been calculated by the ratio of heat loss from the measuring head with fabric sample (u_s) and without fabric (u_0), and is determined using the following equation:

$$p_{wv}(\%) = 100\frac{u_s}{u_o}$$

2.2.3.2 Cup Method

The water vapour permeability of the samples has been measured using the cup method, according to ASTM E96 (Procedure B) testing standard[6]. This method is the straight forward one, involving the determination of weight loss[7], with evaporation time (24 h) of water contained in a cup, the top of which is covered by the cover ring. In this method, test fabric is placed in an airtight manner over the top of a cup. Another cup contains the reference fabric secured in the same airtight manner and the experiment is performed in triplicate, so that three cups with sample fabric and three with reference fabric are tested. The dimensions of the cup were calculated to give a

10 mm deep layer of air between surface of the water and underside of the specimen. The technique compares the rate of water mass transfer through fabric from six cups, three of which are covered with a reference fabric and other three with test samples. The weight of the cups was measured firstly at the starting of the test and then periodically after a certain time interval by the balance with resolution of 0.01g to determine how much water has been lost from each one. The difference in water loss between a cup covered with the standard fabric and one with test fabric enables to study the relative rates of moisture movement through the test fabrics, so that the moisture vapour permeability of the test specimen can be calculated.

The water vapour permeability index was calculated by expressing the water vapour permeability (WVP) of the fabric as a percentage of the WVP of reference, as shown below:

$$\mathrm{WVP} = \frac{24\times M}{A\times T}\ \mathrm{g/m^2/24h}$$

where M is the loss in mass (g); T, the time interval (h); and A, the internal area of the cup (m^2). A was calculated using the following relationship:

$$A = \frac{\pi d^2}{4}\times 10^{-6}$$

where d is the internal diameter of cup (mm). Water vapour permeability index (I) in % was calculated using the following equation:

$$I = \left[\frac{(\mathrm{WVP})_f}{(\mathrm{WVP})_r}\right]\times 100$$

Table 2 — Porosity, air permeability and cloth cover of cotton fabric samples

Fabric sample code	Cloth cover, %	Porosity %	Air permeability cm^3/cm^2/s
C1440	63.0	80.0	229
C1430	64.8	80.5	222
C1740	65.5	78.3	186
C1730	67.6	77.9	180
C2040	68.0	75.9	156
C2030	70.1	75.7	140
C2340	70.4	74.2	140
C2330	71.9	74.1	109
C2640	71.8	73.0	111
C2630	74.5	73.3	83

2.2.3.3 MVTR Cell Method

The Grace, Cryovac Division has developed a moisture vapour transmission cell (MVTR cell), which offers a faster and more simplified method for measuring the water vapour transmission behaviour of a fabric. In principle, the cell measures the humidity generated under controlled conditions as a function of time. The change in humidity at a time interval gives the moisture vapour transmission rate (T) of the fabric, as shown below:

$$T = (269\times 10^{-7})\times(\Delta\mathrm{RH}\%\times\frac{1440}{t})\times H\ \ \mathrm{g/m^2/24h}$$

where ΔRH% is the average difference in successive %RH values; t, the time interval in minute; and H, the gram water per m^3 of air at cell temperature.

3 Results and Discussion

3.1 Porosity

Porosity, fabric cover and air permeability of different cotton fabric samples are shown in Table 2. It is observed that porosity of cotton fabrics decreases as fabric cover increases for both sets of fabric (30s Ne and 40s Ne weft). This may be attributed to the fact that as fabric cover increases the solid content in the fabric increases, and as a result open spaces in the fabric reduce.

3.2 Effect of Fabric Cover on Water Vapour Transmission Behaviour

The water vapour permeability (WVP) values of the different cotton fabrics are given in Table 3. The results show that three different methods have different range of WVP values for the same fabric but the trends are identical in nature. It is clear from the

Table 3 —Water vapour permeability of cotton fabric by different methods

Fabric sample code	Cup method WVPI, %	MVTR cell method MVT rate g/m^2/24h	Permetest method Rel. WVP, %
C1440	610 (2.72)	120.60 (2.99)	60.90 (5.13)
C1430	488 (1.79)	74.64 (2.51)	57.65 (5.02)
C1740	580 (4.28)	98.50 (3.33)	59.13 (4.37)
C1730	441 (3.86)	67.58 (3.48)	56.88 (4.99)
C2040	460 (3.26)	97.20 (1.95)	58.03 (6.01)
C2030	430 (4.56)	60.66 (3.29)	56.25 (4.43)
C2340	458 (3.03)	90.70 (2.54)	57.97 (4.42)
C2330	410 (2.56)	60.59 (4.14)	55.90 (3.66)
C2640	433 (3.28)	88.40 (2.38)	57.77 (8.95)
C2630	400 (4.37)	59.55 (3.89)	55.75 (6.18)

Values in parentheses are CV%.

Figs 1 - 3 that WVP reduces as fabric cover increases in all the three methods, irrespective of the weft count. This is ascribed to the fact that as fabric cover increases open spaces in fabric reduce which diminish diffusivity of the fabric samples.

It can also be seen from Figs 1 - 3 that WVP of fabrics with weft count 40s Ne is higher than the fabrics with weft of 30s Ne in all three experimental setups. Table 1 shows that fabrics with weft of 40s Ne are thinner than the fabrics with 30s Ne weft yarn for all constructions. According to Darcy's law, flow rate (Q) is inversely proportional to fabric thickness (d), as shown below:

$$Q = k\,\frac{A \times \Delta P}{d \times \mu}$$

where Q is the flow rate through porous medium; A, the cross sectional area; ΔP, the pressure drop across the fabric; d, the thickness; k, the proportionality constant; and μ, the dynamic viscosity.

Therefore, due to lower thickness, fabrics with 40s Ne weft show higher WVP than the fabrics with 30s Ne weft in all three testing methods. It is clear from Figs 4 - 6 that as the solid content in fabrics increases, the WVP of fabrics reduces in all three test methods, and as stated earlier 40s Ne weft fabrics show higher permeability, irrespective of solid content of fabric.

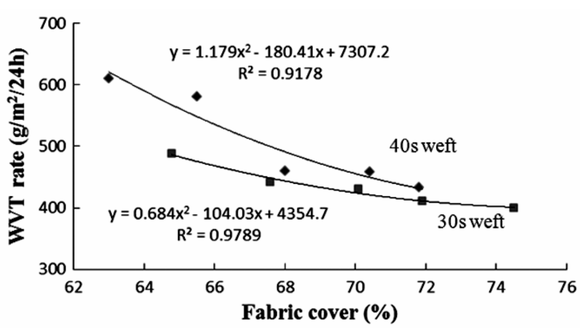

Fig.1 — WVP of different cotton fabrics by cup method

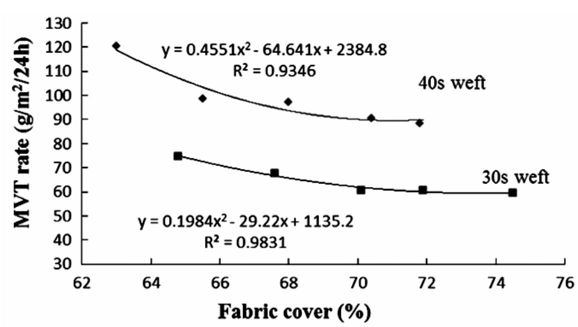

Fig.2 — WVP of different cotton fabrics by MVTR cell method

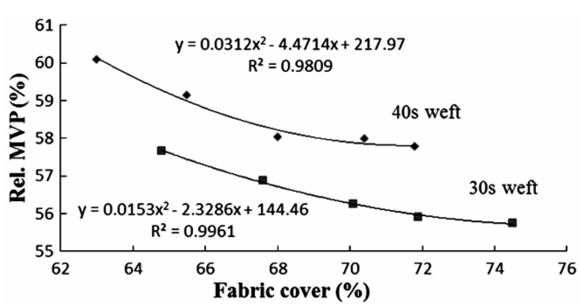

Fig.3 — WVP of different cotton fabrics by Permetest method

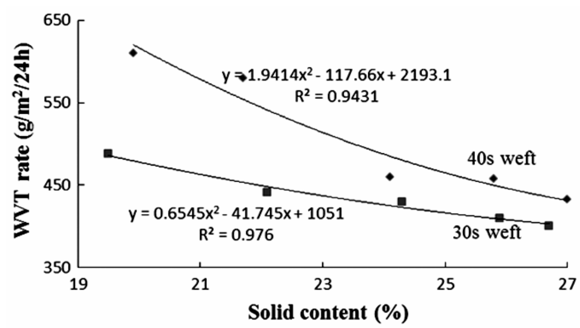

Fig. 4 — WVP with solid content of different cotton fabrics by cup method

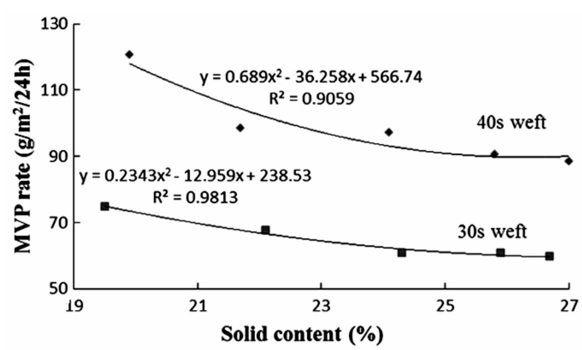

Fig.5 — WVP with solid content of different cotton fabrics by MVTR cell method

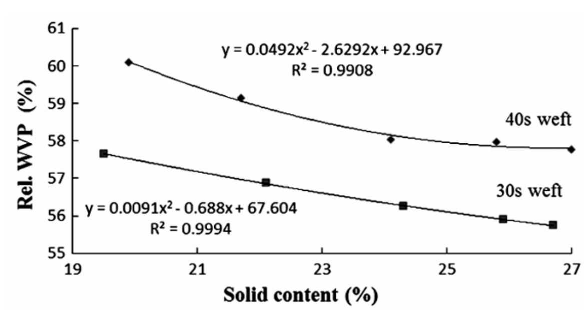

Fig.6 — WVP with solid content of different cotton fabrics by Permetest method

Table 4 — WVP index (%) of cotton fabrics with time by cup method

Time, h	C1440	C1430	C1740	C1730	C2040	C2030	C2340	C2330	C2640	C2630
2	799	702	792	717	739	684	699	653	600	519
4	707	676	682	667	653	676	637	644	623	488
6	759	544	633	530	624	513	611	530	533	413
12	680	532	597	519	588	507	529	483	488	405
24	610	488	580	441	460	430	458	410	433	400

Table 5 — Effect of wind on WVP

Fabric sample code	Permetest method Rel. WVT, %		Cup method WVP index, %	
	1.6m/s	2.9 m/s	Still air	1.9 m/s
C1440	60.90	67.08	610	1446
	(5.13)	(5.32)	(2.72)	(3.62)
C1430	57.65	65.00)	488	1263
	(5.02)	(3.65	(1.79)	(3.01)
C1740	59.13	66.08	580	1446
	(4.37)	(5.01)	(4.28)	(2.20)
C1730	56.88	64.43	441	1096
	(4.99)	(3.61)	(3.86)	(3.98)
C2040	58.03	65.80	460	1148
	(6.01)	(3.17)	(3.26)	(1.31)
C2030	56.25	63.63	430	1046
	(4.43)	(5.35)	(4.56)	(3.23)
C2340	57.97	66.00	458	1009
	(4.42)	(3.14)	(3.03)	(3.70)
C2330	55.90	63.00	410	985
	(3.66)	(5.01)	(2.56)	(2.64)
C2640	57.77	64.05	433	999
	(8.95)	(5.60)	(3.28)	(4.63)
C2630	55.75	60.50	400	775
	(6.18)	(3.96)	(4.37)	(3.55)

Values in parentheses are CV%.

3.3 Effect of Time on WVP Behaviour of Cotton Fabrics

Table 4 shows the change in WVP index value measured by cup method with time for different cotton fabrics. It can be seen that the water vapour transfer rate decreases as the time increases.This is because of non-Fickian diffusion process of hygroscopic material. In this kind of diffusion, at the initial stage it follows Ficks law[8] but at later stages, the diffusion rate is lower than that predicted by Ficks law. According to Morton and Hearle[8] and Nordon *et al.*[9], the decrement in diffusion rate happens because of the swelling phenomenon of the hygroscopic material, due to moisture absorption, resulting in blocking of the pores. Swelling phenomenon is likely to affect the vapour transmission by diffusion over time period; as a result water vapour permeability index falls down with time.

3.4 Effect of Wind Velocity on WVP Behaviour of Cotton Fabrics

Table 5 shows the effect of wind velocity on WVP obtained by a short term method (Permetest method) and a long term method (cup method). With increase in wind velocity from 1.6 m/s to 2.9 m/s, the WVP obtained on Permetest method increases for all the fabrics. The effect of air flow over the fabrics is similar, irrespective of the fabric cover. The fabrics with 30s Ne weft show lower moisture transmission through fabrics as compared to the fabrics with 40s Ne weft at all wind velocity.

Under windy condition, there is not only diffusion of water vapour through the fabrics, but also mass movement of air through and over it, which evacuates the water vapour by convection process when tested by cup method. Experiment was carried out with the air passing in a direction parallel to the surface of the fabric. This is due to the fact that as the wind speed increases, the relatively dry air gets in motion above the sample fabric, thus increasing water vapour transfer.

4 Conclusion

The water vapour transfer rate of cotton fabrics with different fabric covers has been studied by different test methods. It is attributed from the study that apparent water vapour permeability of cotton fabrics reduces as the fabric cover and solid content of fabrics increase, irrespective of weft count. Water vapour permeability of 100% cotton fabrics diminishes with time because swelling of hygroscopic fibres reduces pores of the fabric. It has also been observed that water vapour permeability of thinner cotton fabrics with 40s Ne weft are higher than the fabrics with 30s Ne weft. Under windy condition convection process plays a major role in water vapour transmission through fabrics and moisture vapour transmission rate of cotton fabrics is increased with wind speed.

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