Moisture Flow through Blended Fabrics – Effect of Hydrophilicity

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ABSTRACT

Moisture flow through blended material is a complex phenomenon. Clothing should possess good water vapour as well as liquid moisture transmission property, for providing the thermophysiological clothing comfort. The clothing should take up the moisture from the skin as well as transmit it to the atmosphere. Higher hydrophilicity of a material is known for good absorption, but how it really helps to transmit the moisture, has been studied in the present work. Polyester and viscose have been chosen as the blending fibers and 8 fabrics with different blend proportions were developed. Water vapour transmission of the fabrics was measured using the PERMETEST. Liquid water transmission property of the fabrics was examined using a gravimetric in-plane wicking tester and a vertical wicking tester. From the experimental result it has been observed that water vapour permeability and absorbency of the material increases with the increase in number of hydrophilic group in the material, but it has an adverse effect on the liquid moisture transmission behavior of the material. The vertical as well as horizontal wicking of the material decreases with the increase in viscose proportion in the polyester/viscose blended fabrics.

INTRODUCTION

Although the major purpose of blending fibers in textiles is to provide better balance of mechanical and comfort properties, exact influence of incorporating hydrophilic fiber on moisture flow is least explored. Moisture flow through the textiles is an important parameter governing the comfort properties. Hydrophillic fibers absorb higher number of water molecules and thus show higher moisture regain at a standard atmospheric condition. Regain of a blended material can be considered as a scale for quantifying hydrophilicity. Moisture regain and liquid water absorbency of the material respectively determines how much water vapour or liquid water can be absorbed by the clothing material from the skin. Along with the absorption characteristic there are other moisture related properties which affect the thermophysiological clothing comfort, such as drying time, water vapour permeability and wicking property of the material.

Human body perspires in two forms – insensible (in vapour form) and sensible perspiration (in liquid form), and to be in a comfortable state, the clothing which will be worn should allow both the type of perspirations to transmit from the skin to the outer surface.

Water vapour permeability determines breathability of the clothing material. The mechanism involved in water vapour transmission through fabric from the skin to the outer surface by diffusion and absorption-desorption method [Das et al.[1]]. In absorption-transmission-desorption method hygroscopic material acts as a sink, by absorbing the perspiration from the skin and water vapour get transmitted from it to the outer surface. It maintains a constant vapour concentration in the air immediately surrounding it. During a movement cycle, it will absorb and desorb small amounts of moisture while maintaining a constant relative humidity in the adjoining air [Nordon and David[2], Yasuda, Miyama and Yasuda[3]]. According to Yasuda, Miyama and Yasuda[4] water vapour transport through a fabric is mainly governed by the differential pressure across the fabric layer and if the porosity of the fabrics is similar, the characteristics permeability of the fabrics is nearly identical regardless fiber type being used. Whereas according to Wehner, Miller and Rebenfeld[5] the moisture vapour transmission during the transient stage is higher in case of hygroscopic material due to the combined effect of diffusion and absorption-desorption. Water vapour transmission plays very important role when there is only insensible perspiration or else very little sweating. An amount of moisture slightly in excess of the equilibrium regain for the surrounding ambient conditions, produce sensations of dampness during skin contact [Plante, Holcombe and Stephens[6]]. When the moisture content in the fibers reaches to saturation capillary action starts and at saturation or above that moisture level, capillary wicking is the major mechanism of moisture transport; although diffusion takes place but the amount of moisture transported due to the diffusion reaches maximum at around 30% regain for cotton cloth and after that remains constant; as per the study conducted by Adler and Walsh[7]. So at higher activity condition when liquid perspiration production becomes high, to feel comfortable the clothing should possess good liquid transmission property. Wicking characteristic of the material determines how fast it can transfer the sweat to another layer or to the outer surface. Number of studies has been carried out on the influence of different fiber properties as fiber diameter, fiber cross section, and spin finish on the fiber, on the wicking behavior of fabric [Goswami[8], Das et al.[9], Kamath et al.[10]]. But the effect of the hygroscopicity of the blended materials on moisture flow is least investigated.

In the present study, work has been done to understand the influence of the hydrophilic nature of a blended material on its moisture transmission properties. Commonly used blends in apparel industries are polyester – cotton, polyester – viscose, wool – polyester. In the present study polyester and viscose have been chosen as the blending fibers due to their contrasting nature with respect to hygroscopicity and it was possible to select the fiber of same denier and length. Proportion of viscose is responsible for hydrophilicity which in turn has been observed to increase the regain, liquid water absorbency% and water vapour permeability through the experiment. But a considerable reduction in the wicking property has been noticed with the increase in hydrophilicity of the material.

MATERIALS AND METHODS

Materials

Eight sets of plain woven fabrics have been developed using polyester/viscose blended spun yarns with different blend proportion.The yarns have been spun by the following processes - blowroom, card, draw frame, roving frame and ring frame. The fineness and staple length of polyester and viscose fibers are 5.4 dTex and 33 mm. The blending has been done during blow room stage. The spindle speed of the ring frame was kept at 18000 rpm, yarn count is 20^s Ne and T.M. 3.5. The spinning condition has been kept same for all the samples in order to assure same yarn structure for all the samples. Using the same yarn in warp and weft the fabrics were woven in a CCI narrow loom (rapier). Fabric sett has also been kept same for all the fabrics during weaving stage. Scouring of the loom stage fabric has been done using 0.5% soap solution (Lisapol) at 80-90^0 C for 1 hour and bleaching has been done using hydrogen peroxide (8 g/l) for 1 hr at 90^0 C at a PH 10.5. The details of the processed polyester/viscose fabric samples have been given in *Table I*.

Methods

Measurement methods have been briefly explained below.

Fabric Particulars

The fabric samples were analysed after processing. The fabric details measured were: warp and weft sett, warp and weft count, fabric weight per unit area and fabric thickness. Warp and weft densities were measured using the counting glass according to ASTM D3775-03 standard. Yarn linear density and fabric weight per unit area were determined according to ASTM D1059 standard using electronic weighing scales. The thickness of the fabrics was measured according to ASTM D1777-96 standard with the SDL digital thickness gauge at a pressure of 100 Pa. Standard atmospheric conditions have been maintained for all experiments. The fabric parameters have also been mentioned in *Table I*.

Air Permeability

Air permeability of the fabric has been measured using TEXTEST FX 3300 air permeability tester at a pressure of 100Pa; ASTM D737 has been followed.

Water Vapour Permeability

The water vapour permeability of the samples has been measured using the PERMETEST according to ISO 11092 standard. The instrument works on the principle of heat flux sensing. The temperature of the measuring head is maintained at room temperature for isothermal conditions. When water flows into the measuring head, some amount of heat is lost. 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 relative water vapour permeability of the fabric sample is calculated by the ratio of heat loss from the measuring head with fabric (u_1) and without fabric (u_0) as given in Eq. (1).

Relative water vapour permeability (%)

$$= \frac{\text{Heat lost with fabric on the measuring head } (u_1)}{\text{Heat lost from the bare measuring head } (u_0)} \times 100 \quad (1)$$

PERMETEST characterizes the capability of the fabric to transfer water vapour, by measuring two parameters, the relative water vapour permeability and the absolute vapour resistance.

Moisture Regain

The Moisture regain of a material is expressed as a percentage of the amount of moisture present in it to its moisture-free weight. Moisture regain of the samples were measured by using Sartorius moisture analyser, works on the principle of Infra-red drying. The samples were conditioned for 36 hrs at 65-67% R.H. and at 20^{o}C. During the test in Sartorius the time taken by the samples to get oven dried has been noted down.

TABLE I: Fabric Parameters

Sample name	Nominal Poly:Vis proportion	Actual Poly:Vis proportion	Thread density End/cm	Thread density Pick/cm	Crimp % Warp	Crimp % Weft	Fabric cover factor	Fabric g/m^2	Fabric thickness (mm)
PV1	80:20	81.7:18.3	25.91	23.39	4.11	12.22	21.02	163.49	0.370
PV2	75:25	77.6:22.4	26.10	23.72	7.08	11.11	21.16	152.93	0.374
PV3	70:30	72.6:27.5	26.38	23.45	6.89	12.78	21.17	152.84	0.375
PV4	65:35	69.9:30.1	26.28	23.75	6.25	13.22	21.23	156.11	0.379
PV5	60:40	66.8:33.2	26.18	24.09	7.22	13.00	21.29	153.76	0.376
PV6	50:50	53.0:47.0	25.98	24.41	9.72	15.28	21.31	160.88	0.378
PV7	40:60	43.7:56.3	25.91	23.39	6.67	12.36	21.02	152.24	0.381
VIS	0:100	0:100	27.13	24.77	10.14	15.67	21.73	162.26	0.344

Absorptive Capacity and Absorbency Time

The test for absorptive capacity and absorbency time were conducted following the principles of test described in ASTM D1117-80. Absorbency time is the time required for the complete wetting of a specimen strip which has been loosely rolled into a cylindrical wire basket and dropped on to the surface of the water from a height of 25mm. For each sample five specimens were tested. Each specimen dimension was 76mm$\times$76mm. Specimens were tested in distilled water at 20 ºC. The time taken for the basket to completely sink below the surface of the liquid was recorded. The specimens used to determine absorbency time were also used to determine absorptive capacity. Absorptive capacity provides a measure of the amount of liquid held within a test specimen after specified times of immersion and drainage. After determining absorbency time specimens were left submerged for a further 10 seconds before removing specimen and basket and allowing draining for 10 seconds prior to weighing. The liquid absorptive capacity is given as a percentage of the original mass of the test specimen.

$$\text{Water absorbency\%} = \frac{(B - A)}{A} \text{ x } 100 \quad (2)$$

Where, A = specimen weight before immersion, g and B = specimen weight after immersion, g.

Vertical Wicking Test

Effect of viscose proportion on the vertical wicking of the fabrics has been determined by measuring the wicking height against gravity along the warp and weft direction of the fabric. The test has been conducted using a vertical wicking tester according to DIN 53924 method [Das et al.[9]]. A strip of fabric (200mm × 25mm) was suspended vertically with its lower end (30mm) immersed in a reservoir of distilled water, to which 1% reactive dye (Prussian blue) was added for tracking the movement of water and at a regular time interval, the height reached by water in the fabric was measured with respect to the clamped scale by capturing images at regular interval by a fixed camera.

In Plane Wicking Test

In-plane wicking behaviour of the fabrics has been determined by measuring the initial wicking rate (g/min) using a gravimetric in-plane wicking tester [Das et al.[9]]. The instrument offers the water uptake value of the fabric sample with time, which is kept horizontally on the base plate having a hole at the middle, connected with a constant water source. 16cm × 16cm sample was taken for the test purpose.

RESULTS AND DISCUSSIONS

Moisture Regain

Moisture regain of the fabric has been observed to be increased with the increase in viscose proportion. The result of the measured moisture regains and the theoretical moisture regains (as calculated in Table II, taking moisture regain value of 13 for viscose and 0.4 for polyester at 65 R.H.% and 20^0 C [Morton[11]]) were compared, the result has been plotted in *Figure 1*. As the viscose proportion increases in the fabric, number of water absorbing group increases, leading to higher hydrophilicity, which comes as higher moisture regain of the material. As the viscose proportion increases the time required for oven drying of the sample also increases.

$$\text{Moisture regain (R)} = \frac{M_w \times C}{\gamma \times M_0} \times 100 \qquad (3)$$

Where, M_w is the molecular weight of water, C is the total number of water molecule per absorbent site, γ is the ratio of total mass of material and mass of absorbing material (amorphous portion) and M_0 is the molecular weight of the absorbing site. With the increase in the viscose proportion the mass of absorbing sites increases, increasing the regain of the material. The time taken by the material to get oven dried, increases with the increase in viscose proportion as shown in *Table II*.

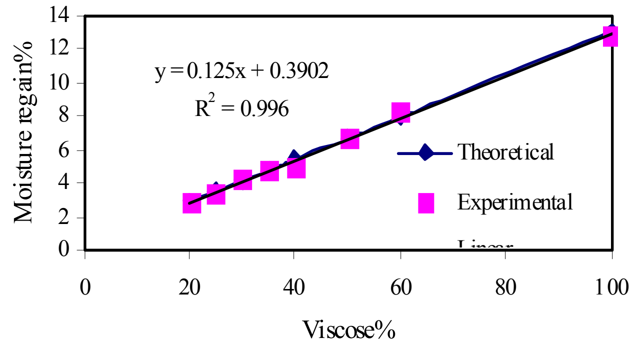

FIGURE 1. Effect of viscose proportion on moisture regain% of the fabrics

TABLE II: Theoretical calculation of moisture regain of the fabrics

Sample number	Sample name	Polyester%	Viscose%	Theoretical
1	PV1	80	20	2.92
2	PV2	75	25	3.55
3	PV3	70	30	4.18
4	PV4	65	35	4.81
5	PV5	60	40	5.44
6	PV6	50	50	6.7
7	PV7	40	60	7.96
8	VIS	0	100	13

Absorbency and Sinking Time

Considering absorption the first thing come into account is the interaction of the water molecules and the molecules of the fiber substance. But in this method the liquid water absorption capacity of the material is being measured. The effect of blend proportion on absorbency of the material has been shown in *Figure 2*. It has been observed that as the viscose proportion increases the absorbency of the material increases linearly (the data fits in a straight line equation with very good correlation co-efficient value), the similar effect as has been seen in case of moisture regain. This behavior can also be explained by the hydrophilic property of the material. The method used for the absorbency test are basically provides the combined value of absorption of water by fiber molecules as well the moisture fill up in the inter-fiber and inter-yarn pores of the material. So the absorption of the water molecules by fiber is going to be increased as the number of hydrophilic group will increase in the material. On the other hand the amount of water taken up by the pores will be dependent on the porosity of the material. If the porosity increases water entrapment by the pores will also increase. Here as the cover of the fabrics are nearly similar, all the materials are having same porosity. So, the absorption value mainly has been changed by the presence of hydrophilic group in the material. Regarding sinking time though there is a trend that with higher viscose proportion, the time is decreases but there is a very poor correlation, as per the curve in *Figure 3*. The perception of dampness will be higher when the moisture is held as free liquid, rather than an internally absorbed [Plante[12]]. So, due to very low moisture regain of polyester wearer with polyester fabric will feel damper than the viscose one at same percentage of excess moisture.

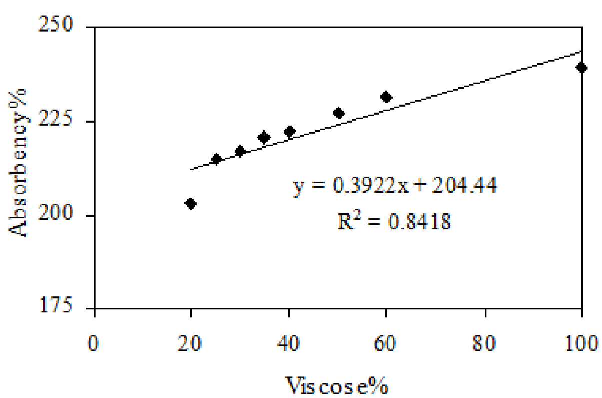

FIGURE 2. Effect of viscose proportion on absorbency% of the fabrics

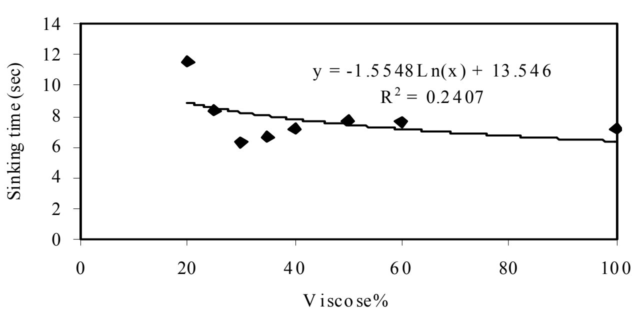

FIGURE 3. Effect of viscose proportion on sinking time

Water Vapour Permeability

From the experimental results obtained from PERMETEST measurement it is seen that with the increase in polyester% in PV blended fabrics, water vapour permeability of the fabric reduces, as has been plotted in *Figure 4*. In the same way it has been seen that vapour resistance (*Figure 5*) of the fabric increases as the polyester proportion increases in the fabric. The measured values of permeability, resistance and absorbency of the fabrics have been given in Table III. From the air permeability test it has been observed that all the fabrics are having nearly same air permeability, which interprets that all the fabrics are having similar porosity. So the difference in the water vapour permeability of the fabric happens because of something else rather than the openness of the material. This behavior can be explained by the moisture vapour transmission mechanism. When vapour transmits through a textile layer two processes are involved in that; diffusion and sorption-desorption. Water vapour diffuses through a textile structure in two ways, simple diffusion through the air spaces between the fibers and yarns and along the fiber itself [Das et al.[1]]. At a specific concentration gradient the diffusion rate along the textile material depends on the porosity of the material and also on the water vapour diffusivity of the fiber.

Diffusivity of the material increases with the increase in moisture regain [Morton[11]]. So as the fabric sett and structure of all the fabric were same diffusion through air will be same for all the fabrics. As the viscose proportion in the fabric will increase, moisture regain of the material will be increased causing higher diffusivity. In the same way moisture transfer through sorption-desorption process will increase with the hygroscopicity of the material. A hygroscopic fabric absorbs water vapour from the humid air close to the sweating skin and releases it in dry air. This enhances the flow of water vapour from the skin to the environment comparatively to a fabric which does not absorb and reduces the moisture built up in the microclimate. Whereas fabric with less hygroscopicity will provide higher resistance to the water vapour transfer.

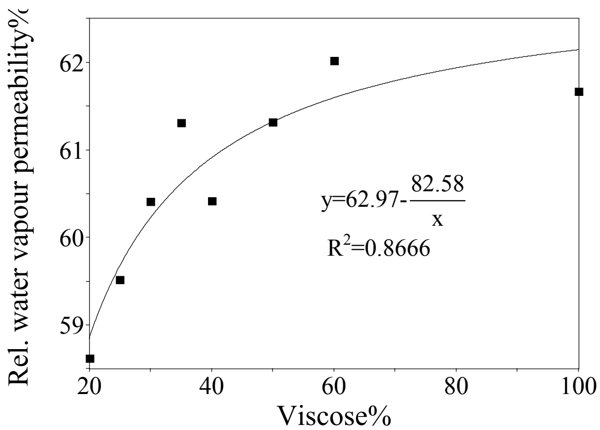

FIGURE 4. Effect of viscose proportion on water vapour permeability of the fabrics

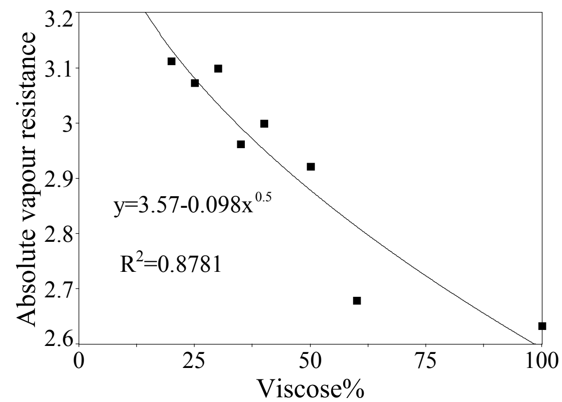

FIGURE 5. Effect of viscose proportion on water vapour resistance of the fabrics

TABLE III: Fabric properties

Sample name	Air permeability $cm^3/cm^2/sec$	Rel vapour permeability %	Absolute vapour resistance ($Pa.\ m^2W^{-1}$)	Absorbency%	Sinking time (Sec)	Moisture regain%	Drying time (sec)
PV1	29.09(3.15)	58.62(3.15)	3.11(10.01)	203.19(2.70)	11.53(10.00)	2.91(4.86)	1.4
PV2	30.19(2.294)	59.52(3.89)	3.07(10.61)	215.09(1.79)	8.35(17.65)	3.36(6.33)	1.4
PV3	32.21(2.16)	60.41(2.99)	3.10(6.22)	217.08(0.15)	6.30(11.89)	4.23(5.37)	1.48
PV4	32.78(1.99)	61.31(3.53)	2.96(14.98)	220.69(2.68)	6.63(13.33)	4.88(4.56)	1.46
PV5	29.39(1.28)	60.42(5.19)	3.00(8.66)	222.51(2.31)	7.77(10.28)	5.07(3.85)	1.88
PV6	30.83(2.14)	61.32(1.06)	2.92(5.07)	227.28(2.9)	7.70(18.07)	6.67(3.35)	1.72
PV7	31.51(2.52)	62.02(3.27)	2.68(7.42)	231.27(1.13)	7.66(15.09)	8.25(4.19)	2.33
VIS	31.76(1.75)	61.67(2.35)	2.63(7.84)	239.55(5.70)	7.20(3.14)	12.76(8.59)	2.4

*Values in parenthesis indicate CV%

Vertical Wicking

From the result it has been observed that addition of a small portion of polyester increase the water wicking height to a great extent, in comparative to that of, in case of 100% viscose fabric. The empirical equations fitted using the experimental results in *Figure 6* and *7* respectively for warp and weft direction of the fabric, describe as the viscose proportion increases wicking of polyester-viscose blended fabric reduce. This behaviour can be explained by absorption and wicking phenomena. Viscose is a highly hydrophilic fiber; it has a good absorbency but due to its high affinity to water when water molecule reaches in the capillary, it forms bond with the absorbing group of the fiber molecules, which inhibits the capillary flow along the channel formed by the fiber surfaces, so in case of 100% viscose the movement of water is mainly governed by the absorption of water by the fibers and its movement along the fiber, which results very less movement of water along the fabric. Whereas being hydrophobic in nature polyester does not form bonds with water molecules, but also due to its positive contact angle (75^{o}), liquid surface is dragged very smoothly, which offers high wicking in case of polyester. So, when a small proportion of polyester is added in the system, it acts as a channel to the water which comes in the capillary and enhances the wicking phenomena. The height of water at different time period has been tabulated in *Table IV*.

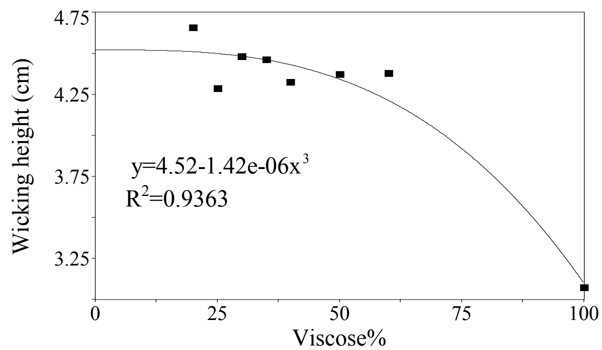

FIGURE 6. Effect of viscose proportion on vertical wicking (Warp way, at 1 min)

TABLE IV: Fabric Wicking Properties

Sample name	**Water uptake in In-plane wicking (g)**			**Vertical wicking height (cm)**					
				Warp			Weft		
	0.5 min	1 min	2 min	1 min	5 min	10 min	1 min	5 min	10 min
PV1	3.82(6.33)	6.65(4.01)	10.39(3.88)	4.66(2.45)	8.64(1.32)	10.98(0.87)	4.27(2.94)	7.75(2.74)	9.85(0.72)
PV2	3.13(5.81)	5.60(4.60)	9.25(3.94)	4.29(4.50)	8.28(1.74)	10.85(1.35)	3.98(0.69)	7.55(1.96)	9.75(1.56)
PV3	2.82(4.83)	4.74(4.03)	8.11(4.13)	4.48(0.56)	8.527(1.19)	10.93(0.61)	4.30(3.98)	7.89(5.62)	10.27(5.42)
PV4	2.42(7.79)	4.71(6.78)	8.28(3.88)	4.46(0.56)	8.30(0.98)	10.80(0.38)	4.02(1.44)	7.43(0.39)	9.45(0.53)
PV5	2.19(6.61)	4.01(5.74)	7.07(4.64)	4.33(0.82)	8.05(1.76)	10.50(1.35)	4.08(0.87)	7.23(0.49)	9.23(1.15)
PV6	2.32(6.61)	4.22(5.74)	7.36(3.99)	4.38(2.14)	8.09(1.81)	10.53(1.37)	4.03(2.68)	7.53(5.66)	9.71(7.54)
PV7	2.10(6.27)	3.84(5.14)	6.81(4.04)	4.38(3.29)	8.17(1.60)	10.63(0.98)	4.06(2.02)	7.34(1.48)	9.37(1.39)
VIS	1.81(6.32)	3.32(5.03)	5.92(3.93)	3.08(3.11)	5.55(1.64)	7.00(1.17)	2.83(1.25)	4.94(1.15)	6.26(0.11)

*Values in parenthesis indicate CV%

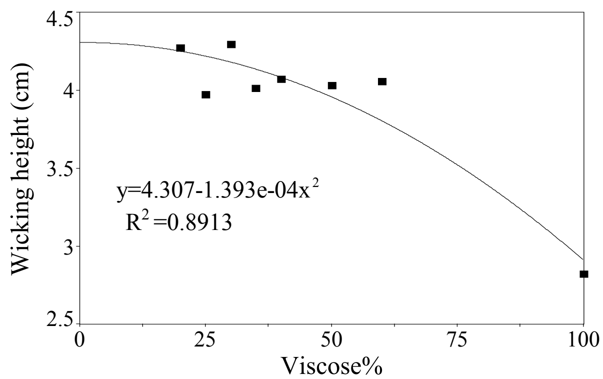

Figure 7. Effect of viscose proportion on vertical wicking (Weft way, at 1 min)

In-Plane Wicking

Water uptake by the fabric samples at different time period in in-plane wicking test has been tabulated in *Table IV*. Water uptake has been found to decrease with the increase in viscose proportion. By analysing the curves it is observed that the distance travelled by water is very short in the case of the 100% viscose fabric but it increases markedly with the addition of small percentages of polyester and it increases till 80:20 polyester:viscose sample (the maximum range which has been taken here). In *Figure* 8 the water uptake at 0.5 min by the fabrics with different blend proportion has been plotted. The simple empirical equation clearly tells as the viscose proportion (x) increases the water uptake value by the fabric (y) decreases.

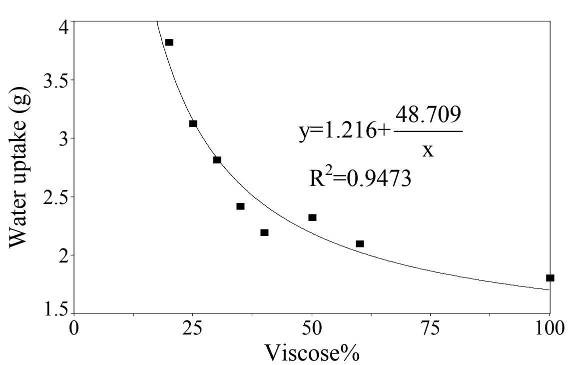

FIGURE 8. Effect of viscose proportion on in-plane wicking of the fabrics (At 0.5 min)

Conclusions

Blending has an important role in moisture related comfort properties of clothing. From the present study it has been observed that water vapour permeability and absorbency of the material increases with the increased hydrophilicity of the material. A hygroscopic material can absorb water vapour from the humid air close to the sweating skin or in direct contact with the skin and releases it in dry air. The rapidity or rates here greatly influence the thermophysiological comfort, but hydrophilic proportion has an adverse effect on the liquid moisture transmission behavior. The vertical as well as horizontal wicking of the material decreases with the increase in viscose proportion in the polyester/viscose blended fabrics. So higher is the hydrophilic proportion in the blended material, it will offer quicker absorption of the sweat from the skin, leaving it dry. But higher hydrophilicity causes reduced liquid spreading, which accounts for moisture accumulation in the clothing causing damp and sticky feeling. Therefore when sweat production is high, a higher proportion of polyester fiber will be helpful. Small viscose proportion will act for the quick absorption of the perspiration from the skin and higher polyester proportion will help to spread the absorbed liquid to the outer surface of the fabric, due to its high wicking property.

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