11

Liquid Transport in Nylon 6.6. Woven Fabrics Used for Outdoor Performance Clothing

A. B. Nyoni
National University of Science and Technology,
Department of Textile Technology
Zimbabwe

1. Introduction

Humans rely on the evaporation of sweat to remain comfortable and prevent overheating in hot environments and during exercise.[1] Discomfort results from the build up of sweat on the skin and if it doesn't evaporate quickly, the body core temperature heats up producing more sweat exposing the wearer to potential afflictions such as post-exercise chill and even hypothermia. Therefore, with properly engineered dynamic or responsive fabrics [2,3] less energy to cool the body will be required resulting in increased performance and endurance.
Researchers [4,5] generally agree that liquid transport properties are significantly affected by fibre type, yarn construction and fabric construction. The fibre length, width, shape and alignment all have a great influence on the quality of the capillary channels in the inter-fibre spaces and size of the pores present. The density and structure of yarns can greatly influence the dimensions and structure of inter- and intra-yarn pores[4] and pore sizes and distribution are determined by the manner in which fibres are assembled into the woven, nonwoven, or knitted structure.[6] Finishing treatment of the fabric surface and its surface roughness and the bulk properties of the liquid (i.e. viscosity, surface tension, volatility and stability) also play a significant role during wicking.
Additional important variables which exert influence on wicking are the level of physical activity and environmental conditions such as the relative humidity of the atmosphere which combined with the ambient temperature, determine the water vapour pressure of the ambient atmosphere and hence the rate of water vapour transfer through clothing. The wind speed which affects the thermal and water vapour resistance of the air adjacent to the fabric also plays a significant part during wicking.[7] Therefore, to design textile materials with specific functional properties of moisture management, it is essential to establish the relationship between the wicking properties of yarns and the structure of the fabric they are part of. In this chapter the effect of these variables on the wicking performance of a selected fabrics made from a combination of textured and flat continuous Nylon 6.6 yarns[8] were determined by The Longitudinal Wicking "Strip" Test using BS3424 Method 21 (1973).
In all the fabrics, saturated, unsaturated and dry zones were exhibited and the simultaneously occurrence of wetting, wicking, liquid dispersion and evaporation influenced the time exponent values *k* obtained.
The critical volume of liquid at which transfer wicking occurred at yarn cross over regions termed as the "transfer rate" was influenced by two competitive effects, i.e. the tendency to

spread in the capillary space between the filaments of "absorber" textured yarns and the tendency to wick the liquid by the "runner"flat continuous filament yarns yarns

2. Fabric sample preparation and test methods

Fabrics woven from different combinations of nylon 6.6 filament yarns were selected and the characteristics determined as shown in Table 1.
Prior to testing, the samples were conditioned in a standard atmosphere of 20±2ºC and 65±2% relative humidity for 24 hours. Sample strips of 3.5cm x 33cm each were cut in the warp and weft directions from the conditioned sample. To aid observation of the wicking distance, a pen filled with water soluble ink was used to mark a graduated scale in 1cm intervals on the strips. The samples were then mounted on the pinned frame for the vertical, horizontal and syphon tests as shown in Figures 1, 2 and 7 respectively. The dipping ends of the samples were aligned leaving a length of 1cm to dip into the infinite reservoir containing distilled water. A ruler with millimeter divisions was placed parallel to the sample strip to enhance the accuracy of the measurement.
For washed fabric tests, the fabric samples were washed with a non-biological detergent in an automatic front loading domestic washing machine and tumble dried according to the ISO 6330:2000 which specifies domestic washing and drying procedures for textile testing. The dry fabrics were then conditioned in a standard atmosphere of 20± 2°C and 65±2% relative humidity for 24 hours before testing. Sample strips of 3.5cm x 33cm each were cut in the warp and weft directions from the conditioned fabric sample and tested with the frame in both the vertical and horizontal positions above the water basin containing distilled water and the results are shown in Table 2.

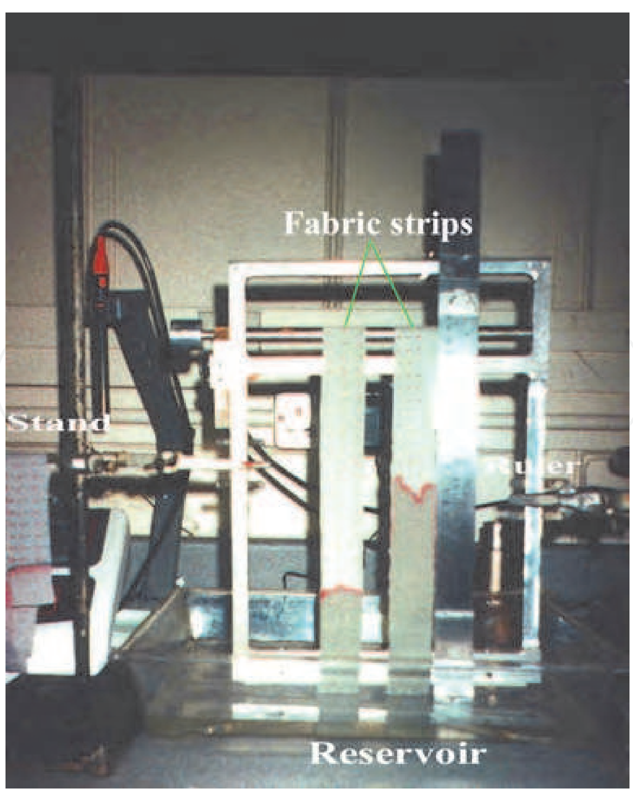


Fig. 1. Vertical Strip Wicking Test

The height of the advancing liquid front as a function of time was recorded by visual observation of the running ink through a travelling microscope at 5 minutes intervals for the first hour, and then at hourly intervals thereafter until the maximum wicking height (equilibrium point) was reached. To avoid contamination by the indicating ink the test liquid was changed after each test. Constant temperature and humidity in the ambient atmosphere were achieved by testing in the conditioned room.
The strip method has been used by Hollmark and Peek[9] to characterize the wicking behaviour of porous materials and they found it readily applicable under different conditions with a relatively high degree of reproducibility. Zhuang[10] also found good correlation between results obtained by manual and automatic testing.

3. Vertical strip wicking test results

3.1 Fabric sample S1F–unwashed

The results obtained from the wicking tests are shown in Table 2 and in Figures 3. Figure 3 shows that there was rapid wicking for the first 5-10 minutes in both the warp and weft directions and then a significant decrease to a slow rate with the lapse of time until it was difficult to note the level of liquid rise in 5 minutes time intervals. Observations done at hourly intervals thereafter tabulated in Table 2 indicate that from 60-180 minutes the fabrics continued wicking at a slow rate until an equilibrium point was reached.

Property	Test Method	Sample S1F	Sample S2F
Ends/cm	BS 2862:1984	70	70
Picks/cm	BS 2862:1984	30	50
Linear Density Warp (dtex)	BS 946:1970	44dtexf34 flat fully dull PA 6.6	44dtexf34 flat fully dull PA 6.6
Linear Density Weft (dtex)	BS 946:1970	195dtexf170 Airjet Textured Bright PA6.6	44dtexf34 flat fully dull PA 6.6
Fabric Weight g/m^2	BS 2471:1978	43.75	26.31
Filaments x-section	Microscopy-SEM	Circular	Circular
Warp FilamentØ Weft	Microscopy-SEM	11.673µm 11.673µm	11.673µm 11.673µm

Table 1. Fabric and Yarn Characteristics

Multiple comparison between means of the actual liquid advancement in the first 15minutes (1st Quarter) Table 3 and the second 15 minutes (2nd Quarter) Table 4 of the hourly test shown in Tables 5 indicate that that there was a significant difference in the distance moved by the liquid in both the warp and weft direction wicking with the lapse of time. Wicking in the weft direction was more rapid than in the warp direction and multiple comparison of the actual liquid advancement in the first 15minutes (1st Quarter) of the hourly test in Tables 5 show that there was a significant difference in warp and weft direction wicking. Microscopic examination of fabrics during wicking exhibited an almost linear leading edge in the weft direction and a spiked pattern in the warp direction.

Wicking time (t)min	Vertical Wicking								Horizontal Wicking							
	S1F-warp (*lmm*)		S1F-Weft (*lmm*)		S2F-Warp (*lmm*)		S2F-Weft (*lmm*)		S1F-warp (*lmm*)		S1F-Weft (*lmm*)		S2F-Warp (*lmm*)		S2F-Weft (*lmm*)	
	Uw	**W**	**Uw**	**W**	**Uw**	**W**	**Uw**	**W**	**Uw**	**W**	**Uw**	**W**	**Uw**	**W**	**Uw**	**W**
5	15	35	40	70	28	37	18	25	25	34	50	73	27	32	9	23
10	30(15)	45(10)	56(16)	100(30)	39(11)	45(8)	23(5)	32(7)	33(8)	49(15)	65(15)	101(29)	32(5)	38(6)	13(4)	30(7)
15	35(5)	55(10)	70(14)	119(19)	41(2)	49(4)	27(4)	39(7)	40(7)	55(6)	80(15)	120(19)	36(4)	41(3)	16(3)	32(2)
20	38(3)	62(7)	80(10)	130(11)	44(3)	50(1)	30(3)	41(2)	43(3)	60(5)	90(10)	135(15)	38(2)	43(2)	18(2)	32(0)
25	40(2)	67(5)	90(10)	140(10)	46(2)	51(1)	31(1)	43(2)	46(3)	66(6)	95(5)	149(14)	39(1)	47(4)	19(1)	36(4)
30	45(5)	70(3)	95(5)	146(6)	49(3)	53(2)	31(0)	44(1)	50(4)	71(5)	100(5)	157(8)	40(1)	49(2)	19(0)	38(2)
35	47(2)	72(2)	100(5)	153(7)	49(0)	54(1)	31(0)	44(0)	51(1)	74(3)	103(3)	166(9)	41(1)	49(0)	19(0)	38(2)
40	48(1)	73(1)	104(4)	157(4)	49(0)	55(1)	31(0)	44(0)	52(1)	75(1)	108(5)	169(3)	41(0)	50(1)	19(0)	39(1)
45	49(1)	74(1)	107(3)	158(1)	49(0)	55(0)	32(1)	44(0)	54(2)	78(3)	109(1)	176(7)	41(0)	52(2)	19(0)	39(0)
50	50(1)	75(1)	110(3)	158(0)	49(0)	55(0)	32(0)	44(0)	55(1)	81(3)	111(2)	182(6)	42(1)	52(0)	20(1)	39(0)
55	51(1)	79(4)	112(2)	163(5)	49(0)	55(0)	32(0)	44(0)	56(1)	81(0)	113(2)	185(3)	42(0)	52(0)	20(0)	40(1)
60	52(1)	80(1)	113(1)	165(2)	49(0)	55(0)	32(0)	44(0)	57(1)	84(3)	114(1)	188(3)	42(0)	50(0)	20(0)	40(0)
120	56(4)	89(9)	121(8)	180(15)	50(1)	55(0)	32(0)	48(4)	58(1)	110(26)	125(11)	220(32)	47(5)	61(11)	23(3)	49(9)
180	56(0)	89(0)	121(0)	180(0)	50(0)	55(0)	32(0)	48(0)	58(0)	110(0)	129(4)	227(7)	50(3)	61(0)	23(0)	49(0)

Note: Figures in parentheses indicate the actual liquid advancement per time interval
Key: Uw-Unwashed
W-Washed

Table 2. Fabric Vertical and Horizontal Wicking Test Results

Sample	Vertical Wicking								Horizontal Wicking							
	S1F-warp (*lmm*)		S1F-Weft (*lmm*)		S2F-Warp (*lmm*)		S2F-Weft (*lmm*)		S1F-warp (*lmm*)		S1F-Weft (*lmm*)		S2F-Warp (*lmm*)		S2F-Weft (*lmm*)	
	Uw	**W**	**Uw**	**W**	**Uw**	**W**	**Uw**	**W**	**Uw**	**W**	**Uw**	**W**	**Uw**	**W**	**Uw**	**W**
1	35	55	70	119	41	49	27	39	40	55	80	120	36	41	16	32
2	33	54	72	120	40.5	50	28	39	40.5	55	82.5	126	37.5	39.5	15.5	31.5
3	34.5	53.5	69	123	39	51	25	40	40	55	81	123	36	42	16.5	32
4	33	55.5	70.5	115.5	42	48	25.5	38	39	54	78	120	38	41.5	17	33
5	34	54	69	118.5	42	48	29	37.5	41	55	84	120	36	42	17	31
Mean	33.9	54.4	70.1	119.2	40.9	49.2	26.9	38.7	40.1	54.8	81.1	121.8	36.7	41.2	16.4	31.9
SD	2.6	3.3	3.74	4.88	2.86	3.14	2.32	2.78	2.83	3.31	4.03	4.94	2.71	2.87	1.81	2.53
SE	1.3	1.65	1.87	2.44	1.43	1.57	1.16	1.39	1.42	1.66	2.01	2.47	1.36	1.44	0.91	1.26
CV	7.68	6.06	5.34	4.1	4.1	6.99	8.62	7.19	7.06	6.04	4.97	4.05	7.38	6.97	11.04	7.92

Key: Uw-Unwashed
W-Washed

Table 3. Fabric Wicking Test 1st Quarter (15 minutes).

Sample	Vertical Wicking								Horizontal Wicking							
	S1F-warp (*lmm)*		S1F-Weft (*lmm)*		S2F-Warp (*lmm)*		S2F-Weft (*lmm)*		S1F-warp (*lmm)*		S1F-Weft (*lmm)*		S2F-Warp (*lmm)*		S2F-Weft (*lmm)*	
	Uw	**W**	**Uw**	**W**	**Uw**	**W**	**Uw**	**W**	**Uw**	**W**	**Uw**	**W**	**Uw**	**W**	**Uw**	**W**
1	10	15	20	27	8.0	4	4	5	10	16	25	37	4	8	3	6
2	9.5	15	19	25.5	6.5	4	3	3.5	11	16	25	36	4	7.5	4	6.5
3	10	15	20	25	8.0	4.5	3	4.5	11	17	26	37.5	4.5	6.5	2.5	6
4	9.5	14.5	18.5	29	7.5	4.5	4	5.5	11	16.5	24.5	37	4	7.5	3	6
5	9	15.5	18	27.5	7.5	4.5	3	5	10.5	15	25.5	36	4	8.0	3.5	6
Mean	9.6	15	19.1	26.8	7.5	4.3	3.4	4.7	10.7	16.1	25.2	2.71	4.1	7.5	3.2	6.1
SD	1.39	1.73	1.96	2.32	1.23	0.93	0.83	0.97	1.46	1.79	2.25	1.36	0.91	1.23	0.8	1.11
SE	0.69	0.87	0.98	1.16	0.61	0.46	0.41	0.49	0.73	0.9	1.12	7.38	0.45	0.61	0.4	0.55
CV	14.43	11.55	10.23	8.64	16.33	21.57	24.25	20.63	13.67	11.15	8.91	12.78	22.09	16.33	25	18.11

Key: Uw-Unwashed
W-Washed

Table 4. Fabric Wicking Test 2nd Quarter (30 minutes).

Fabric samples	Significance	Difference
V15min-warp-uw Vs.		
V15min-weft-uw	0.000↑	***
H15 min-warp-uw	0.000↑	***
V15min-warp-w	0.000↑	***
V30 min-warp-uw	0.000↓	***
V15min-weft-uw Vs.		
H15 min-weft-uw	0.000↑	***
V15min-weft-w	0.000↑	***
V30 min-weft-uw	0.000↓	***
H15min-warp-uw Vs.		
H15min-weft-uw	0.000↑	***
H15 min-warp-w	0.002↑	***
H30min-warp-uw	0.000↓	***
H15min-weft-uw Vs.		
H15 min-weft-w	0.000↑	***
H30min-weft-uw	0.000↓	***

W = Washed fabric W = Unwashed fabric
H = Horizontal wicking V = Vertical Wicking
↑= Wicking decrease ↓= Wicking increase
Significance of differences of fabric wicking:
*****P≤ 0.001,**P≤0.01,*P≤0.05 and Not significant (ns) at P>0.05.**

Table 5. Multiple Comparison Between Wicking Means of Fabric S1F

Fabric samples	Significance	Difference
V15min-warp-uw Vs.		
V15min-weft-uw	0.000↓	***
H15 min-warp-uw	0.000↓	***
V15min-warp-w	0.000↑	***
V30 min-warp-uw	0.000↓	***
V15min-weft-uw Vs.		
H15 min-weft-uw	0.000↓	***
V15min-weft-w	0.000↑	***
V30 min-weft-uw	0.000↓	***
H15min-warp-uw Vs.		
H15min-weft-uw	0.000↓	***
H15 min-warp-w	0.000↑	***
H30min-warp-uw	0.000↓	***
H15min-weft-uw Vs.		
H15 min-weft-w	0.000↑	***
H30min-weft-uw	0.000↓	***

W = Washed fabric UW = Unwashed fabric
H = Horizontal wicking V = Vertical Wicking
↑= Wicking decrease ↓= Wicking increase
Significance of differences of fabric wicking:
*****P≤ 0.001,**P≤0.01,*P≤0.05 and Not significant (ns) at P>0.05.**

Table 6. Multiple Comparison Between Wicking Means of Fabric S2F

3.2 Vertical wicking fabric sample S2F-unwashed

The results in Table 2 and Figures 4 to 5 show that there was rapid wicking for the first 5-10minutes in both the warp and weft directions which became less rapid with the lapse of time. Multiple comparison of wicking results in Table 6 show a significant decrease in weft direction wicking compared to warp direction wicking. The wicking rate significantly decreased to a slow rate with the lapse of time in the warp and weft directions. The rapid attainment of the equilibrium point when wicking the fabrics in the warp and weft direction indicates that the liquid is rapidly spread over a large area for quick evaporation.

4. Horizontal strip wicking tests

Wicking occurs when a fabric is completely or partially immersed in a liquid or in contact with a limited amount of liquid such as a drop placed on the fabric. In a vertically held substrate, wicking is affected by gravitational forces and ceases when capillary forces are balanced by the hydrostatic head.[11] At that point, the capillary pressure that raises the liquid is balanced by the effect of gravity, that is, by the weight of raised liquid.[12] To determine the extent to which gravity affects wicking, horizontal wicking tests were carried out on nylon 6.6 fabrics samples S1F and S2F and the results are shown in Table 2.

4.1 Horizontal strip wicking test sample S1F-unwashed fabric

The results in Table 2 and Figures 3 to 6 exhibited a similar wicking trend as fabrics wicked in the vertical direction in which wicking in the weft direction was more rapid than in the

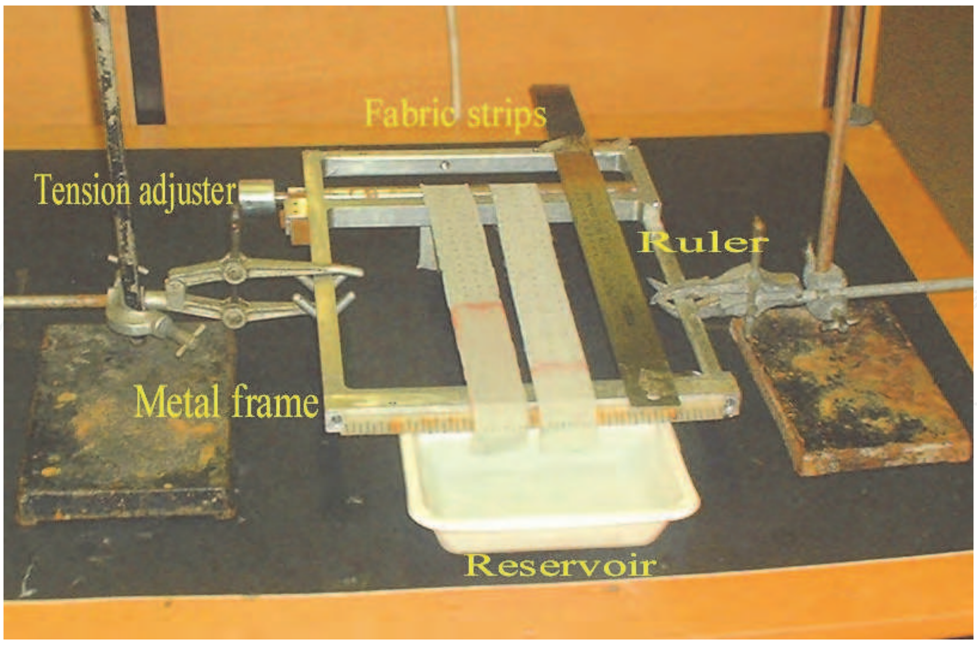


Fig. 2. Horizontal Wicking Test

warp direction. However, even though the trend was similar, there was a significant difference in the distance travelled by the wicked liquid compared to vertically wicking in both the warp and weft directions as shown by the results of multiple comparison of the actual liquid wicked during the 1st and 2nd quarters of an hourly test in Table 5. As was the case with vertical wicking, there was rapid wicking for the first 5-10 minutes in the warp and weft directions.

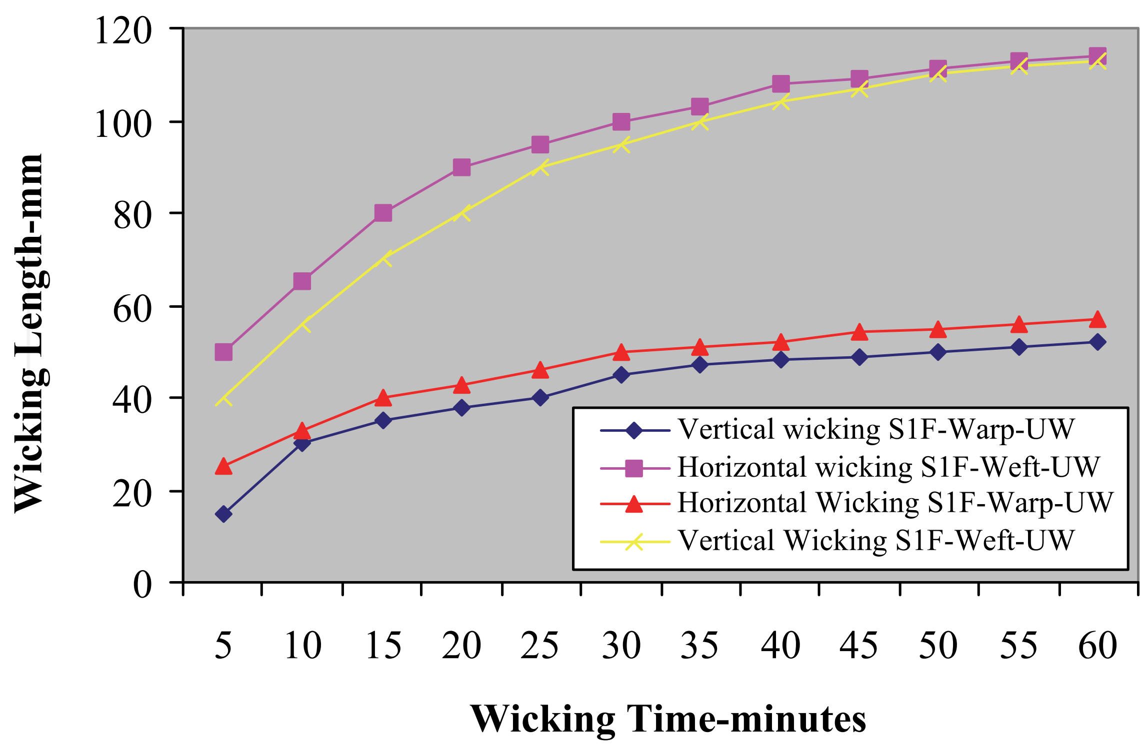


Fig. 3. Wicking test of fabric S1F – unwashed fabric

4.2 Horizontal strip wicking test-sample S2F-unwashed fabric

Table 2 and Figures 4 and 5 shows that there was rapid wicking for the first 5-10 minutes but wicking in the warp direction was more rapid than wicking in the weft direction. At the start of wicking there is a variation in lift off followed by the same wicking trend in both the weft and warp directions. Results of multiple comparison of the actual liquid wicked within the 1st and 2nd quarters of an hourly test in Table 5 show a significant decrease in the liquid wicked in both the warp and weft horizontal directions.

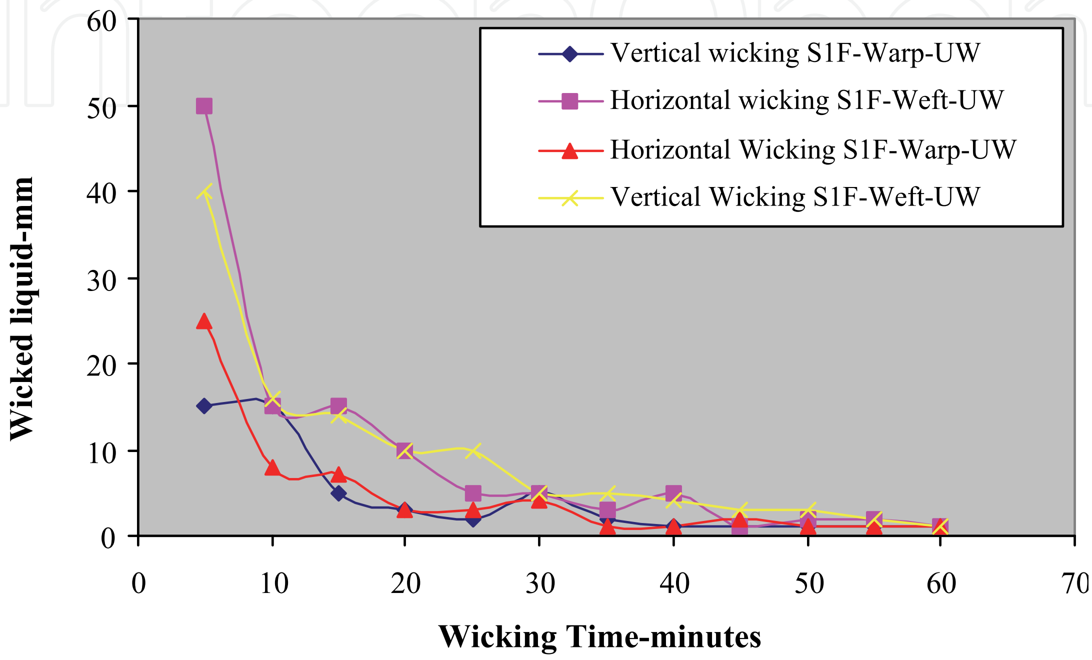


Fig. 4. Actual Liquid Advance Sample S1F - Unwashed Fabric

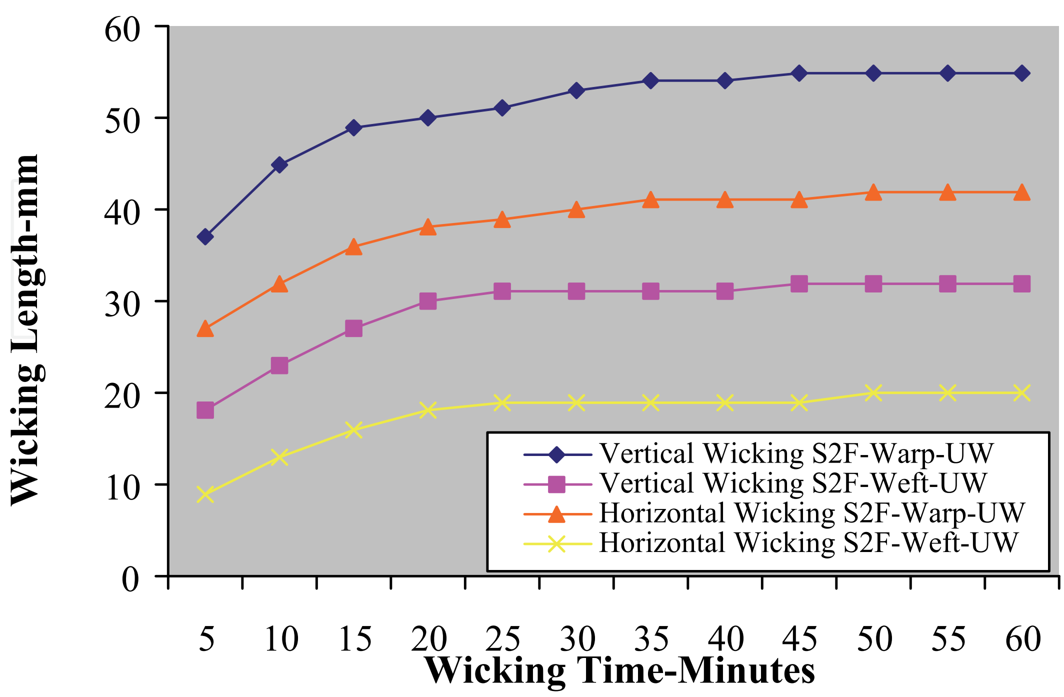


Fig. 5. Wicking Tests of Fabric S2F-Unwashed Fabric

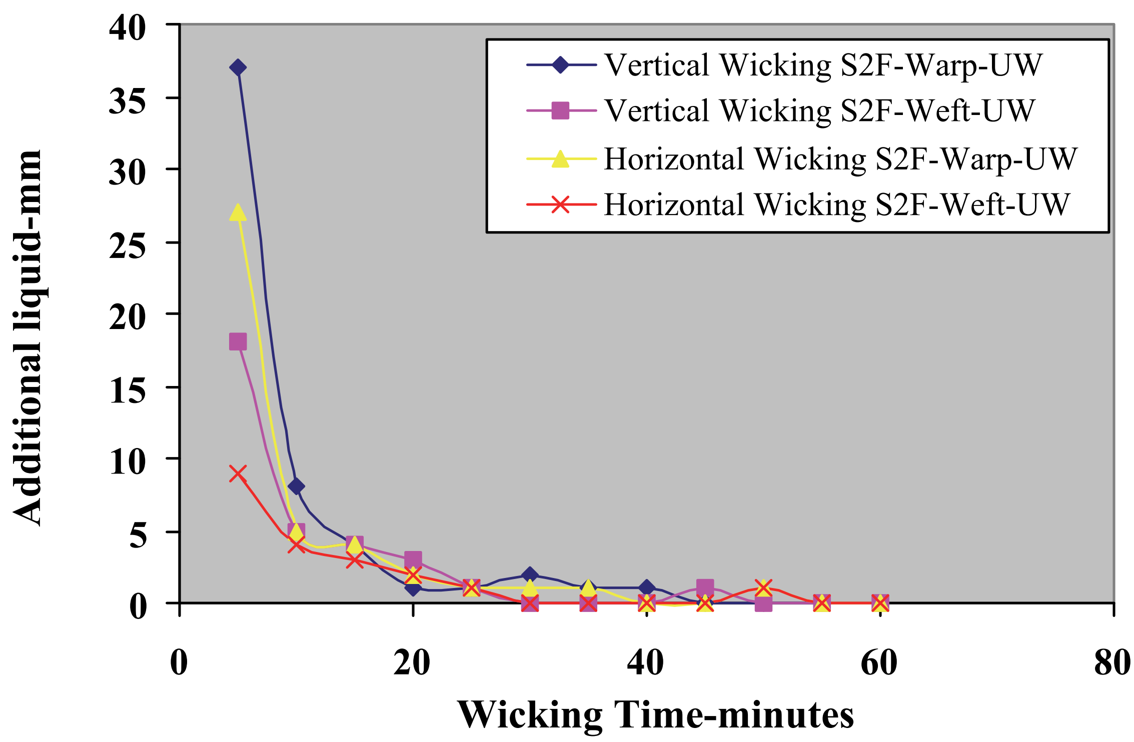


Fig. 6. Actual Liquid Advance S2F-Unwashed Fabric

5. Syphon wicking

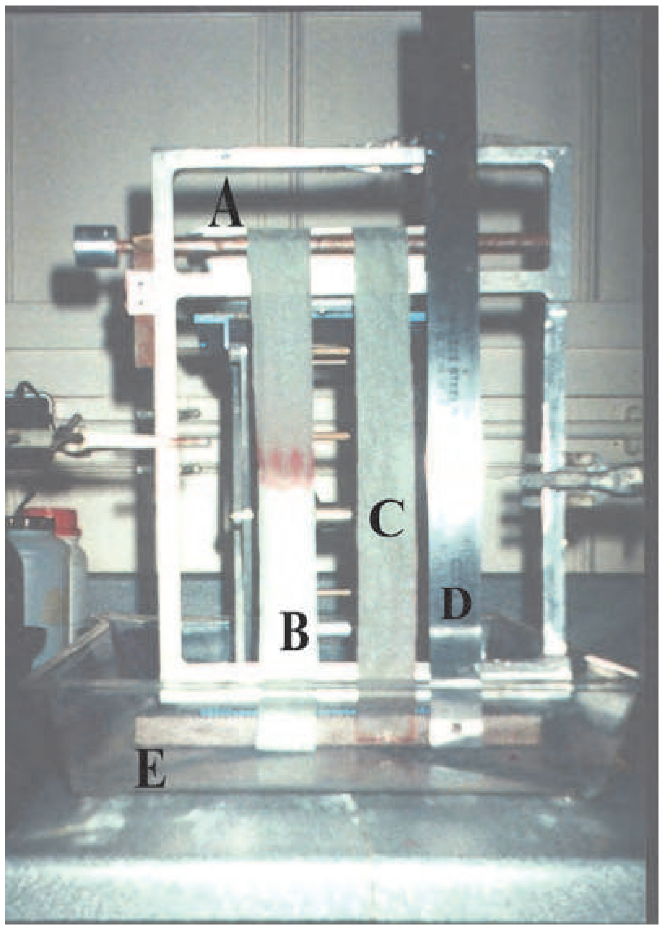
It is a known fact that the liquid flow in downward wicking is aided by gravity and occurs more rapidly through an already saturated fabric with a lower resistance to flow than an initially dry fabric.[13] A further study to determine the extent to which the structure of the constituent yarns affects wicking in fabrics S1F and S2F was carried out by wicking washed fabrics in the warp and weft directions using the Syphon[11] Test Method.

In downward wicking, Figure 7 a rectangular strip of the test fabric is used as a syphon, by immersing one end in a reservoir of water or saline solution and allowing the liquid to drain from the other end at a lower level, into a collecting beaker. The amount of liquid transferred at successive time intervals can be determined by weighing the collecting beaker. No published standards exist and evaluation of results differ between researchers with some authors [14] taking the rate of mass transfer of the liquid when a constant flow through the syphon has been attained as an indicator of wickability.

Hardman[14] distinguished this as a "rate of drainage," using the elapsed time between the initial moment of contact between the fabric strip and liquid and the moment when dripping from the lower fabric end commences as a measure of wicking.

Because of the limited amount of liquid retained by the fabrics S1F and S2F due to the effects of rapid evaporation observed in preceding experiments, determination of their downward wicking behaviour was done by observing the actual distance traveled by the liquid towards the bottom end of the fabric as a function of time.

Samples were prepared as in section 2 and the rectangular strip of the test fabric used as a syphon by immersing 1cm of the top end in the liquid reservoir. The distance of water travel as a function of time was taken at 5 minutes intervals for an hour or terminated when the liquid dripped at the bottom of the fabric or when wicking ceased due to evaporation.



A-liquid reservoir
B/C Strips of Fabrics
D-Ruler
E-Collecting tray

Fig. 4.7. Syphon Wicking Test

5.1 Syphon wicking test- fabric sample S1F and S2F

The results in Tables 7 show the distance travelled by the liquid leading front and the figures in parentheses indicate the actual liquid advancement per time interval.
Fabric sample S1F made from 195f170 weft yarn and 44f34 warp yarn with 70 ends/cm and 30 picks/cm (43.75g/m^2) was wicked in the warp and weft directions. Figure 8 shows that after wicking fabric sample S1F for 50 minutes in the weft direction, the liquid had travelled to the lower end of the fabric strip whereas in the warp direction the leading head was still 202mm from the lower end of the fabric.
When the fabric is wicked in the warp direction, the textured weft yarns cause retardation of the liquid's progress due to their absorption capacity. The absorption of the liquid into the heterogeneous structure of the yarn causes a temporary slowing down of its advancement as it is dispersed in the yarn structure before a critical volume is achieved [15] to enable liquid transfer to the capillaries of the warp yarns. The nature of the liquid flow in the warp direction therefore is in fast-slow fast (warp-weft-warp) steps resulting in a haphazard flow as shown in Figure 9. In wicking the fabric in the weft direction, the high volume textured weft yarns rapidly flood the capillaries of the flat continuous filament yarns and this speeds

Sample	S1F-Warp direction (l-mm)		S1F-Weft direction (l-mm)		S2F-Warp direction (l-mm)		S2F-Weft direction (l-mm)	
Wicking Time-t minutes	Vertical	Syphon	Vertical	Syphon	Vertical	Syphon	Vertical	Syphon
5	35	35	70	42	37	58	25	48
10	45 (10)	47(12)	100(30)	84(42)	45 (8)	69(11)	32 (7)	56(8)
15	55 (10)	60(13)	119(19)	129(45)	49 (4)	74(5)	39 (7)	62(6)
20	62 (7)	69(9)	130(11)	156(27)	50 (1)	79(5)	41 (2)	67(5)
25	67 (5)	78(9)	140(10)	199(43)	51 (1)	81(2)	43 (2)	70(3)
30	70 (3)	98(20)	146 (6)	220(11)	53 (2)	82(1)	44 (1)	71(1)
35	72 (2)	110(12)	153 (7)	253(33)	54 (1)	84(2)	44 (0)	73(2)
40	73 (1)	116 (6)	157 (4)	268(15)	55(1)	*84(0)*	-	-
45	74 (1)	122(6)	158 (1)	282(14)	55(0)	-	-	-
50	75 (1)	128(6)	158 (0)	330(48)	-	-	-	-
55	79 (4)	139(11)	163 (5)	-	-	-	-	-
60	80 (1)	150(11)	165 (2)	-	-	-	-	-
120	89 (9)	-	180(15)	-	-	-	-	-
180	89 (0)	-	180 (0)	-	-	-	-	-

Note:Figures in parentheses indicate the actual liquid advancement per time interval.

Table 7. Washed Fabric Wicking Tests-Vertical Vs. Syphon Wicking

the rate of wicking. The actual advancement of the wicked liquid shown in Figure 9 is directly proportional to the wicking time in both cases (warp and weft) but was found to be 61% more in the weft compared to warp direction wicking. This indicates that for this fabric, the wicking rate does not only depend on the yarn and fabric structure but also on the direction of orientation of the constituent yarns in the structure.

Results in Table 7 show the wicking behaviour of an almost balanced fabric sample S2F made from 44f34 warp and weft flat continuous filament yarns with 70 ends/cm and 50 picks/cm (26.31 g/m^2). The graphical representation in Figures 10-11 plotted from the results tabulated in Table 7 show that the rate of warp and weft wicking follow a similar trend. The difference of the actual liquid wicked was 15% more in the warp direction due to the high number of ends/cm compared to picks/cm therefore the packing of the additional filaments in the warp yarns introduced more capillary spaces between the nylon filaments. Due to its light-weight (26.31 g/m^2), the fabric allowed rapid liquid evaporation. Results in Table 7 show that the wicking rate had significantly slowed down after 20 minutes despite the fact that the liquid flow in this test was through an already saturated fabric with a lower resistance to flow and was also aided by gravity. After 35minutes wicking, liquid advancement had ceased and when the fabric was left to wick to the end of the hour there was no change in the position of the liquid edge. In the absence of gravity, this indicates that there is significant rapid evaporation of liquid from the fabric which is a desired functional property of fabrics designed to rapidly transmit perspiration to the exterior where it can evaporate.

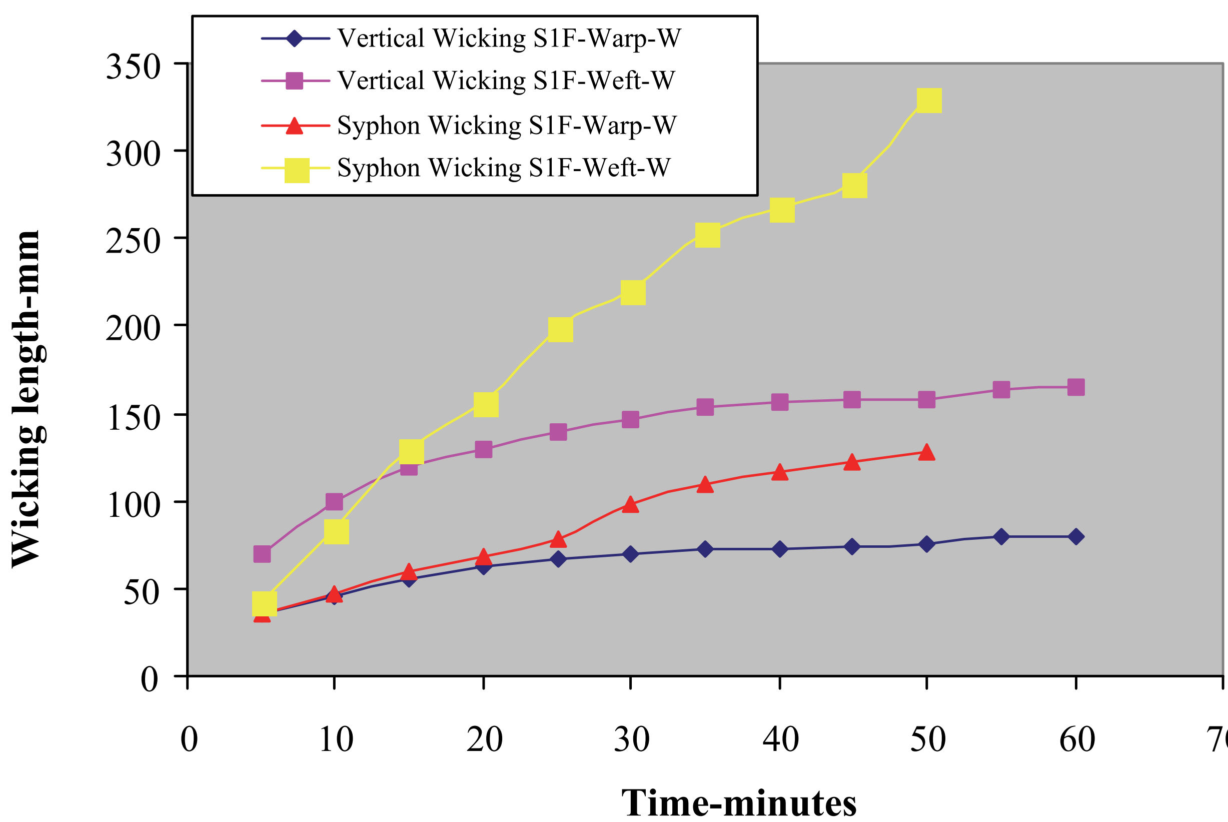


Fig. 8. Vertical Vs Syphon Wicking Fabric S1F-Washed

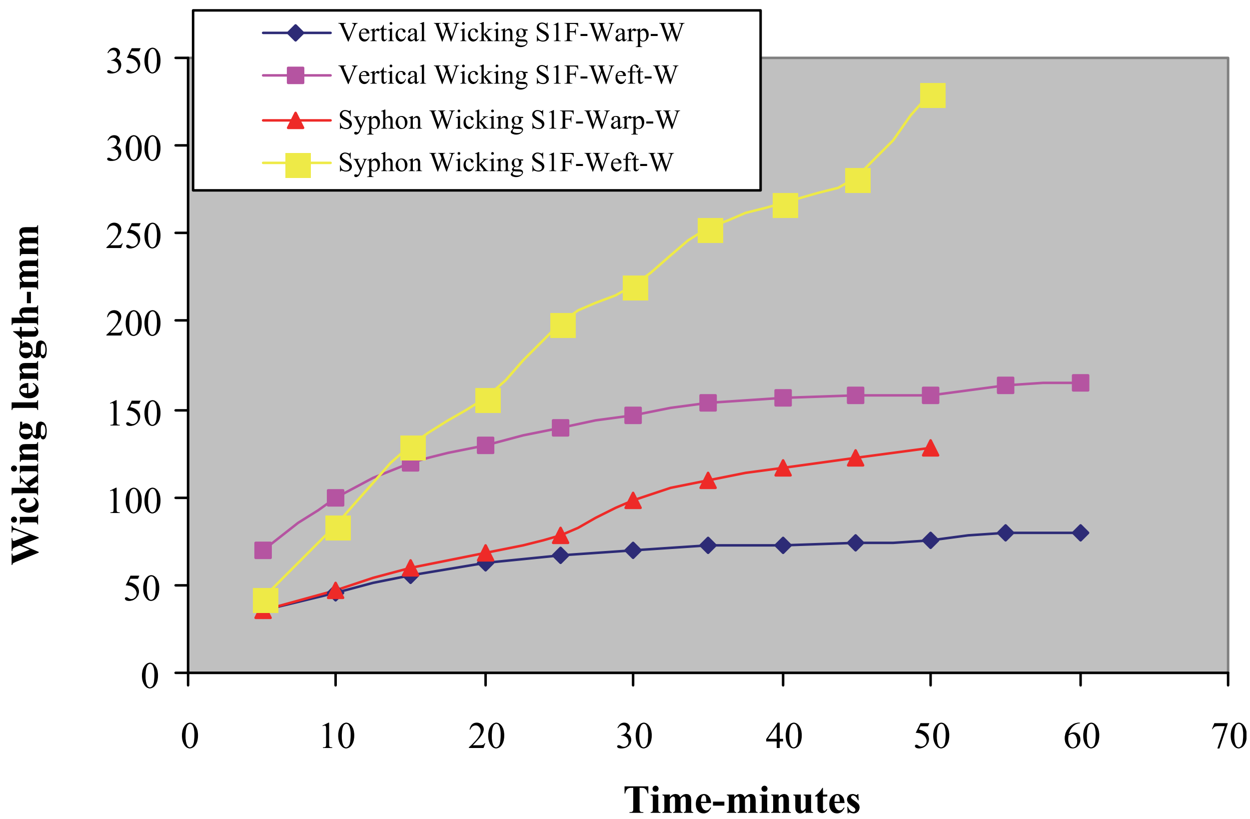


Fig. 9. Actual Liquid Advance-Vertical Vs. Syphon Wicking Fabric S1F-Washed

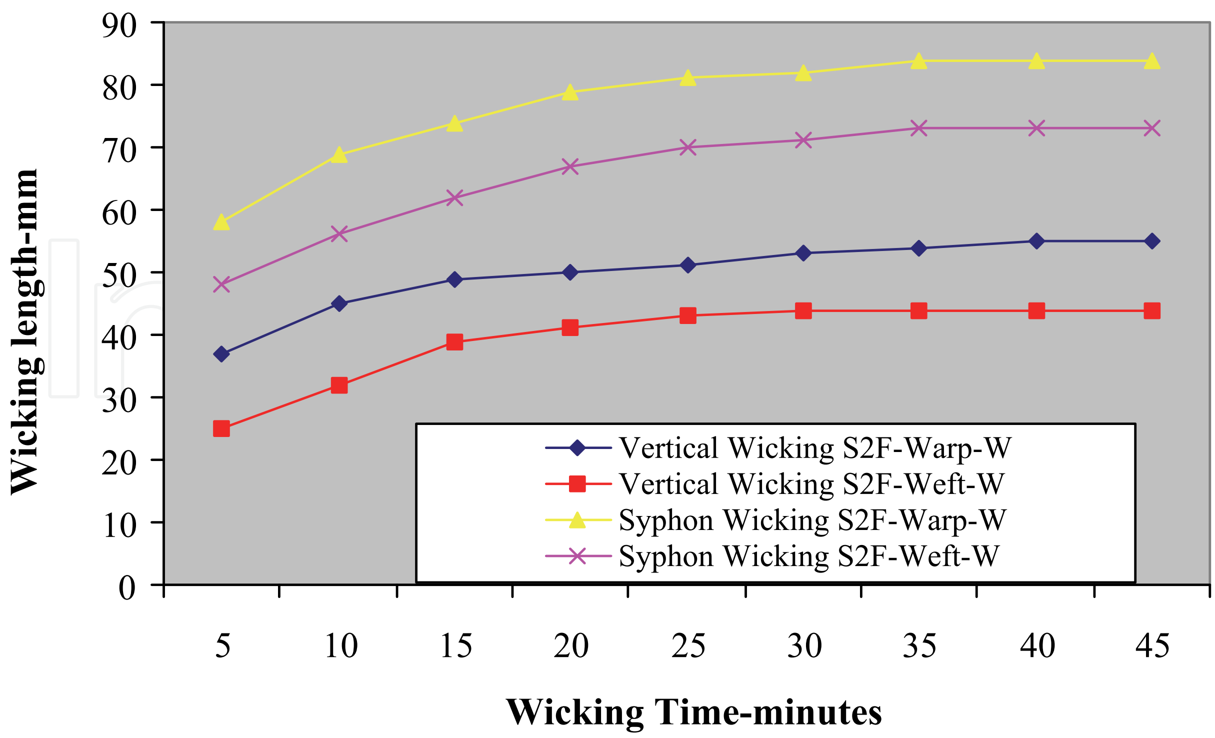


Fig. 10. Vertical Vs. Syphon Wicking-Fabric S2F-Washed

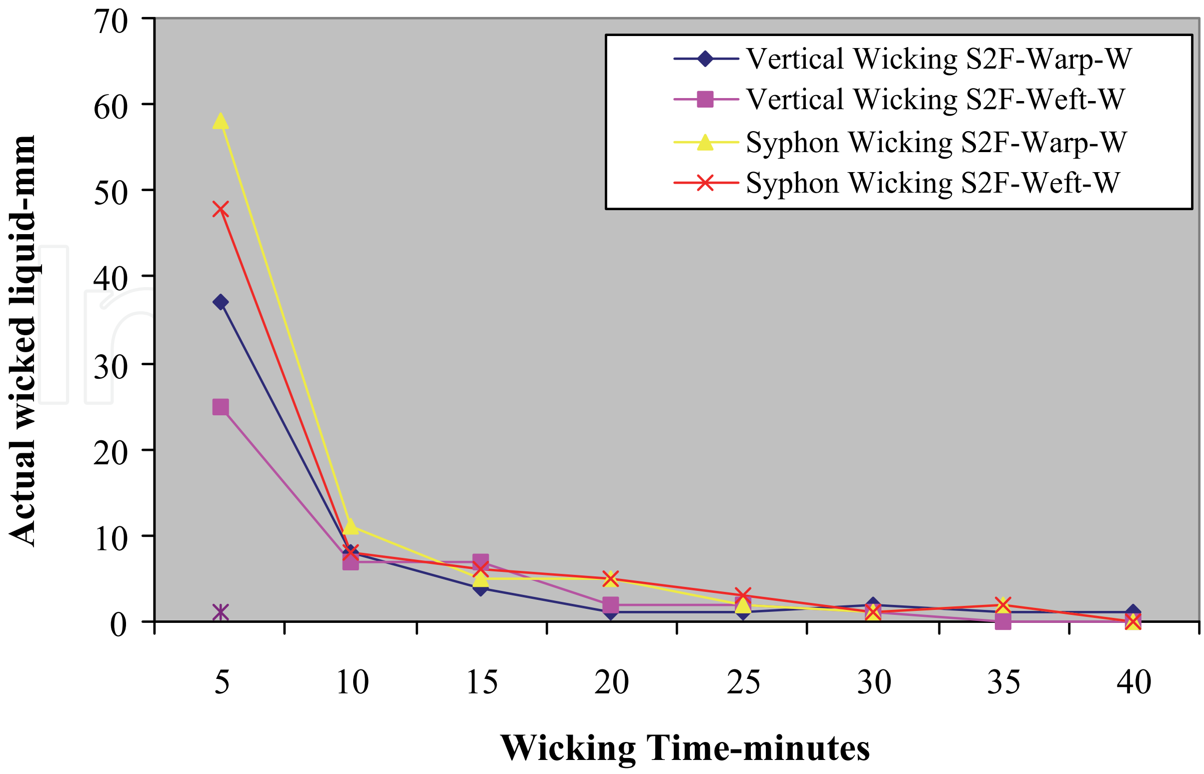


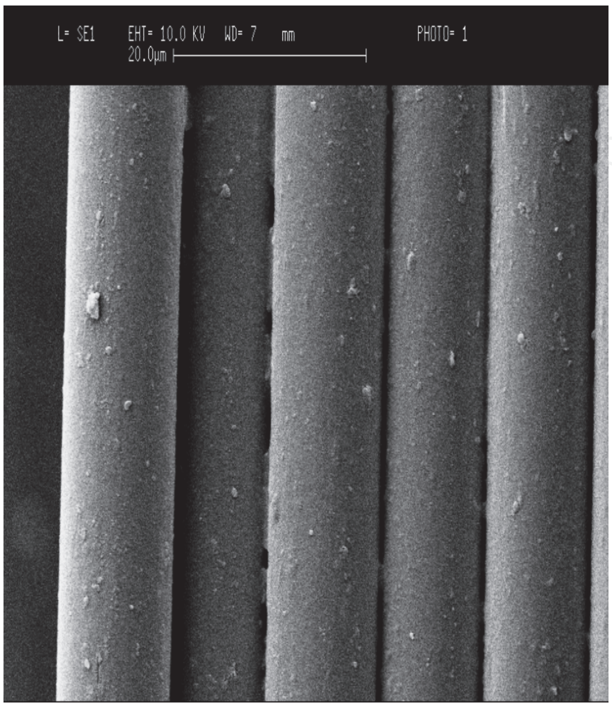
Fig. 11. Actual Liquid Advance: Vertical Vs. Syphon Wicking Fabric S2F-Washed

6. Wicking characteristics of washed fabrics

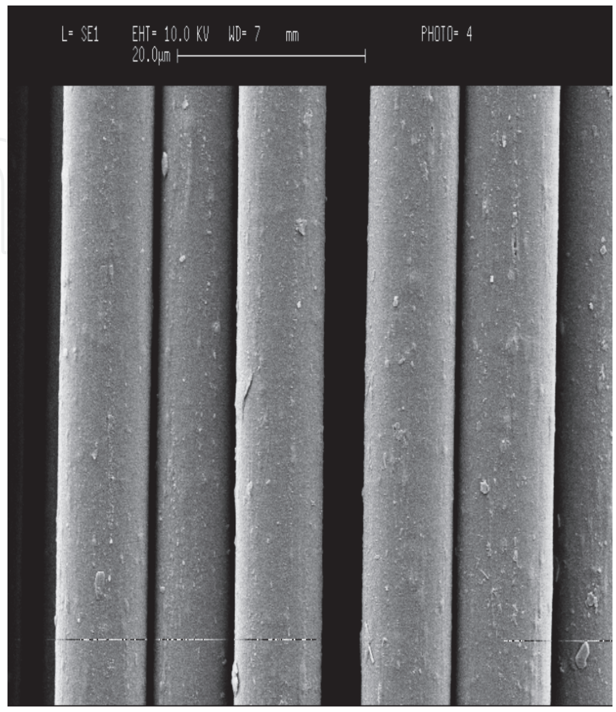
The ability of a fibre to facilitate migration of liquid water or water vapour molecules depends on its surface hydrophilicity or affinity for water, the textile finish applied and the fibre substrate.[7,16] The surface properties of man-made fibres are generally adjusted with spin finishing agents during the fibre spinning process.[17] Hydrophobic fibres can be modified in finishing to give surface properties which can allow liquid flow.[18] Leijala and Hautojarvi[17] using Scanning Force Microscopy (SFM) studied the structure, distribution, and composition of spin finish layers on a polypropylene fibre surface. They noted that the coverage and homogeneous distribution of the finish on the fibre surface even though only a few nanometers in thickness is an important factor affecting tribological and antistatic properties as well as the wettability of fibres. In another study[14], the wickability attributed to the conventional (non porous) acrylic as was found to be the case with polypropylene was due to spin finish which could be easily removed by washing. Gogalla[4] also noted that the uneven distribution of chemical finish on the surface of a fabric greatly affected its wicking behaviour.
Electron micrographs of yarns from which the fabric samples S1F and S2F were woven in Figure 12 a-c show traces of spin finish on all the yarns which was removed during the scouring process.
During use, out-door and performance textiles fabrics are exposed to soiling which comes from two different sources, namely,

a. from the body of the wearer and
b. from the environment.

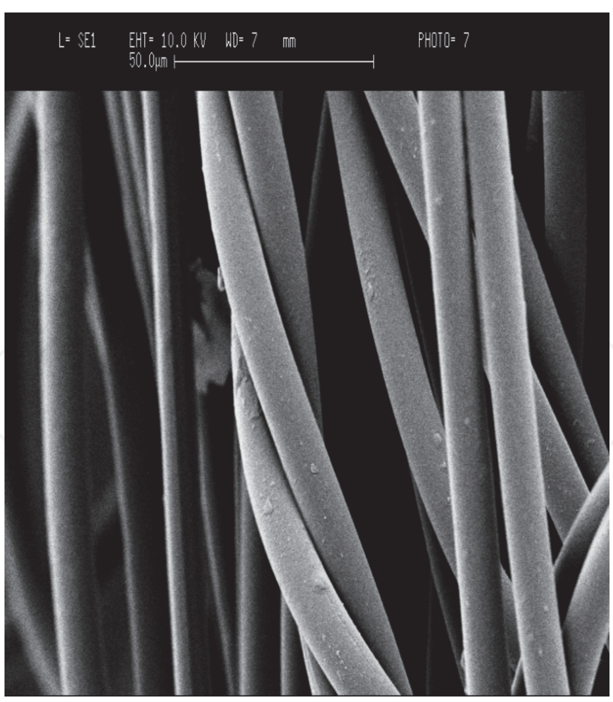
therefore, it will be necessary at some stage to wash the fabrics. However, it is important that such a treatment does not alter the functional properties of these garments. Therefore, it was of interest to study the effect of laundering on the wicking behaviour of fabric samples S1F and S2F.



(a) Sample S1Y 44F34 Flat Fully Dull PA 6.6



(b) Sample S2Y 33F34 Flat Fully Dull PA 6.6



(c) Sample S3Y Air Textured Bright PA6.6

Fig. 12. Nylon 6.6 Yarn Micrographs

6.1 Results and discussion

6.1.1 Vertical wicking sample S1F- washed fabric: Warp and weft directions

Figures 17 to 20 show the graphical representation of the wicking rate of the washed and unwashed fabrics plotted from results in Table 2. Multiple comparison of the fabric wicking behaviour after a single wash in Table 5 show that there was a significant increase in the wicking rate of sample S1F in both the vertical and horizontal directions. In all cases, the weft direction wicking rate of washed fabrics remained higher than warp direction wicking regardless of the orientation of the fabrics as was the case with the unwashed fabric.

6.1.2 Vertical wicking sample S2F -washed fabric: Warp and weft directions

Table 2 and Figures 23 to 24 show the vertical wicking results of sample S2F. Results in Table 6 show that there was a significant increase in wicking in both directions after the fabrics were washed. Wicking in the warp direction was more rapid than in the weft direction and the difference gradually decreased with the lapse of time.

6.1.3 Horizontal wicking of washed fabrics

Fabrics wicked in the horizontal direction (Table 2 and Figures 13 and 19) show a similar change in wicking trend as the fabrics wicked in the vertical direction. Figures 15 to 18 show that there was marked increase in the wicking rate of samples S1F and S2F after a single wash. Results of multiple comparison of the actual liquid wicked within the 1st and 2nd quarters of an hourly test for fabric S2F exhibited a significant decrease in the liquid wicked in the horizontal direction compared to wicking in the vertical direction. This deviation from the general trend that horizontal wicking leads to a significant increase in wicking could not be explained.

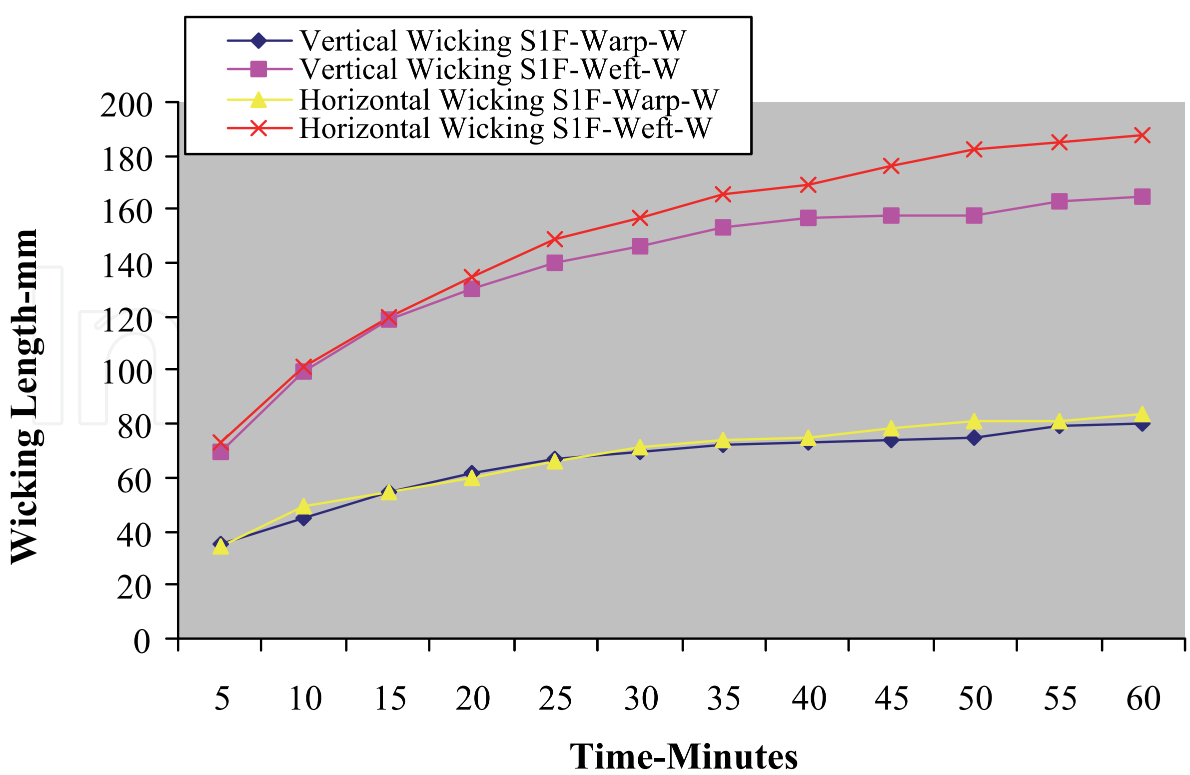


Fig. 13. Wicking Tests Sample S1F- Washed Fabric

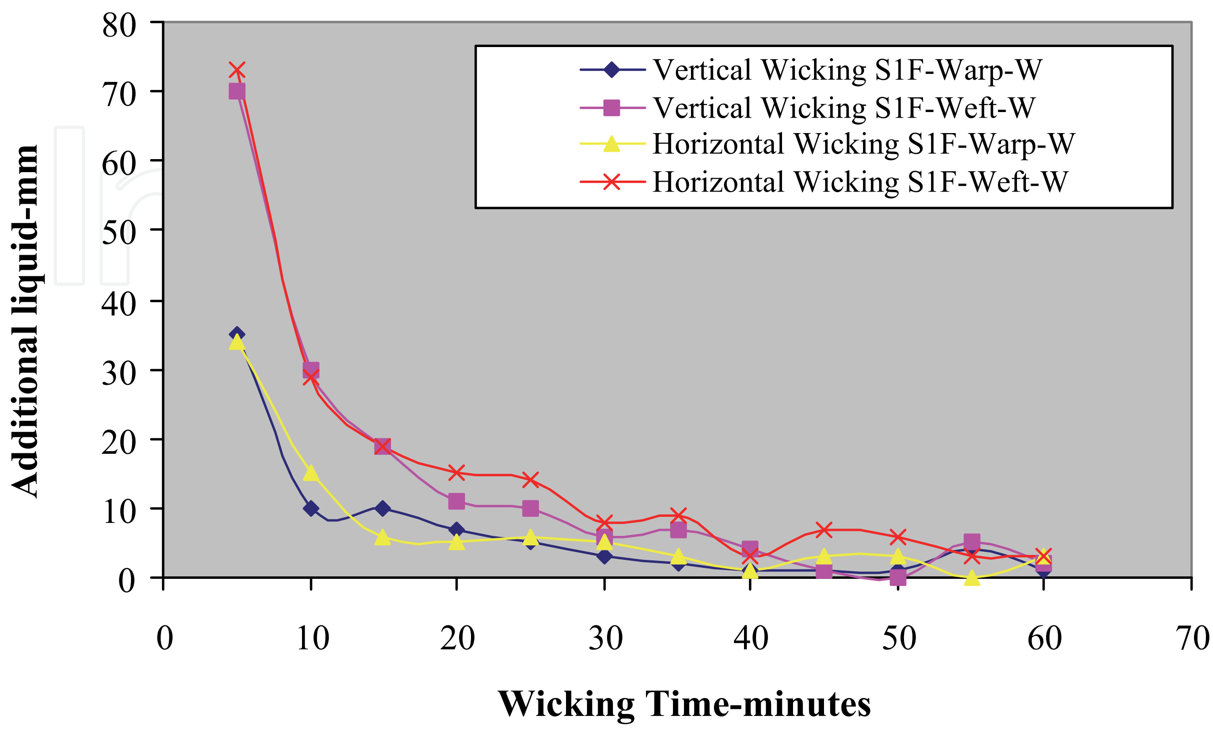


Fig. 14. Actual Liquid Advance Sample S1F-Washed Fabric

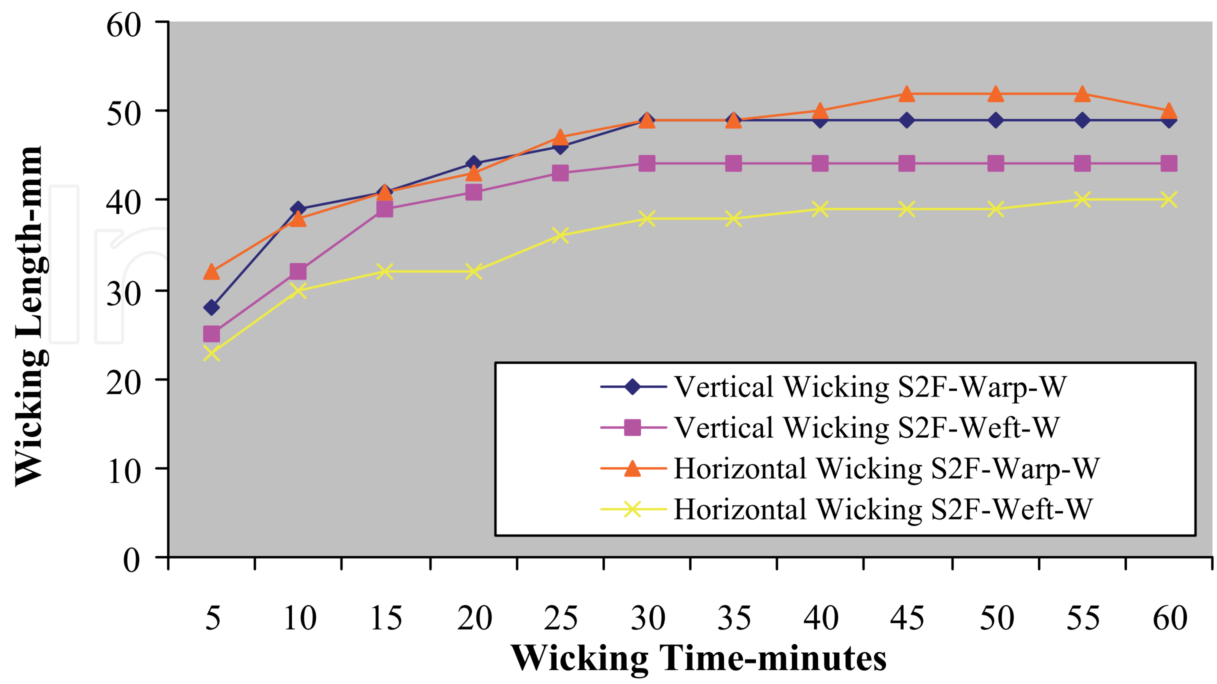


Fig. 15. Wicking Tests Sample S2F-Washed Fabric

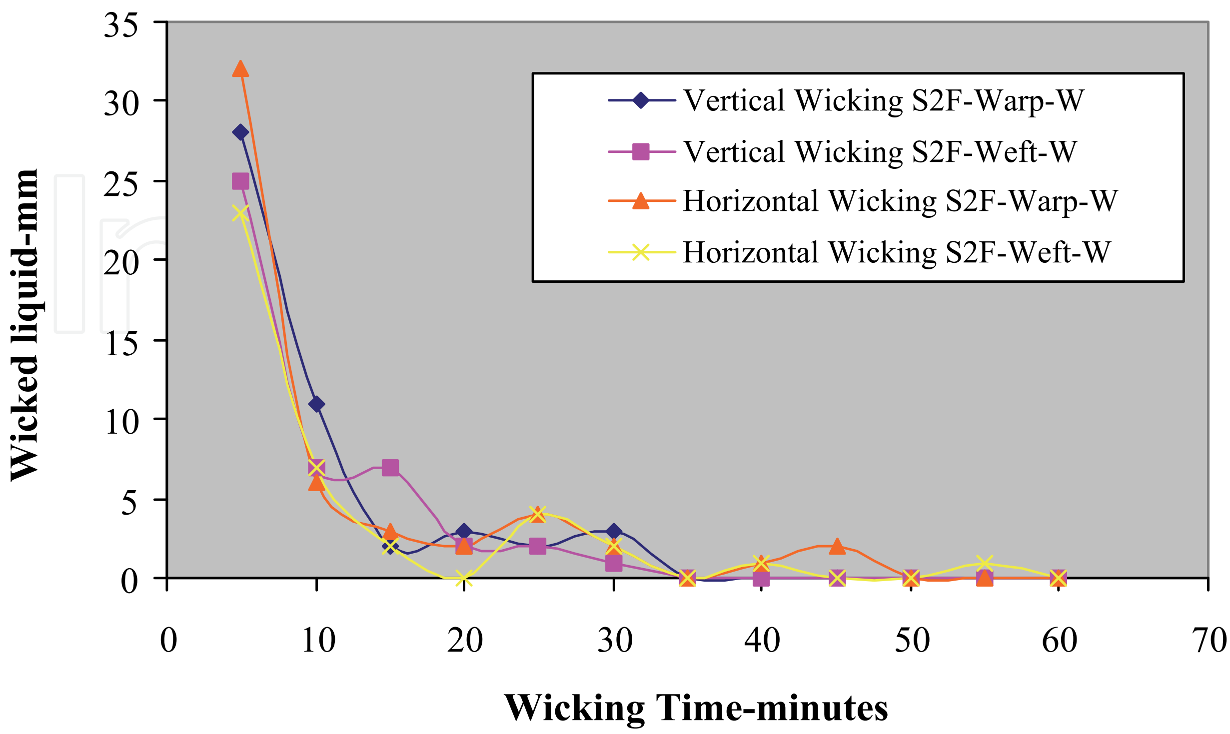


Fig. 16. Actual Liquid Advance Sample S2F- Washed Fabric

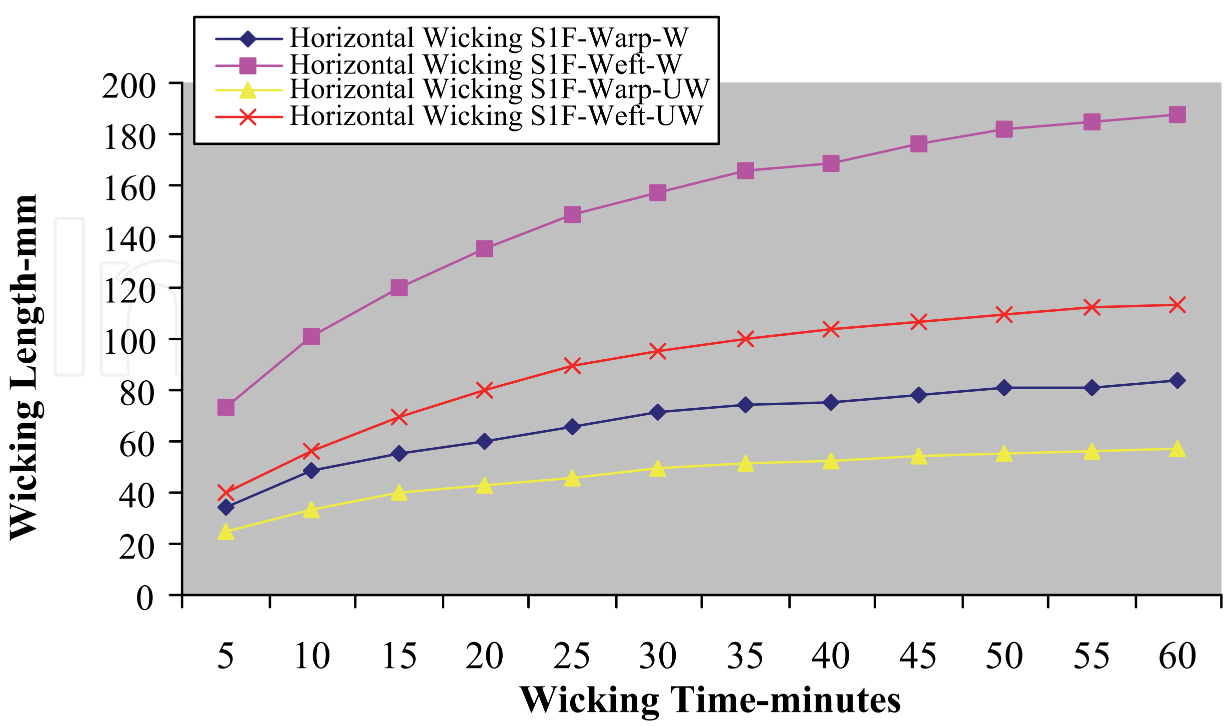


Fig. 17. Wicking Tests Sample S1F-Washed Vs. Unwashed Fabrics

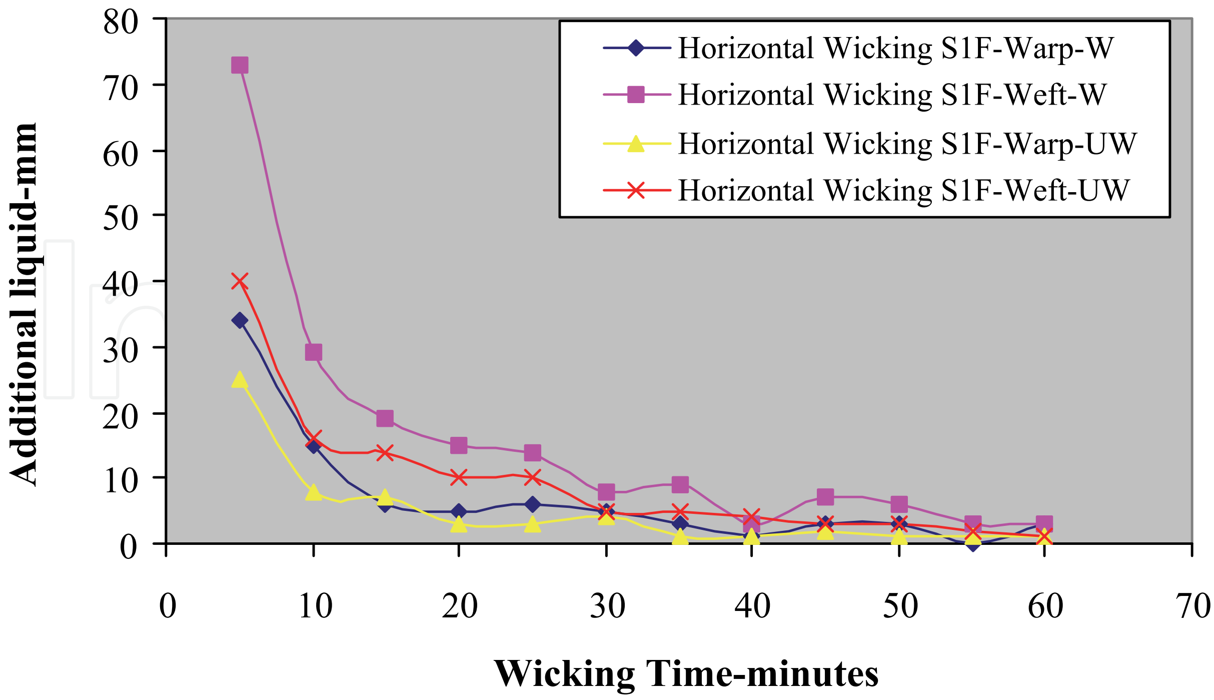


Fig. 18. Actual Liquid Advance Sample S1F-Washed Vs. Unwashed Fabrics

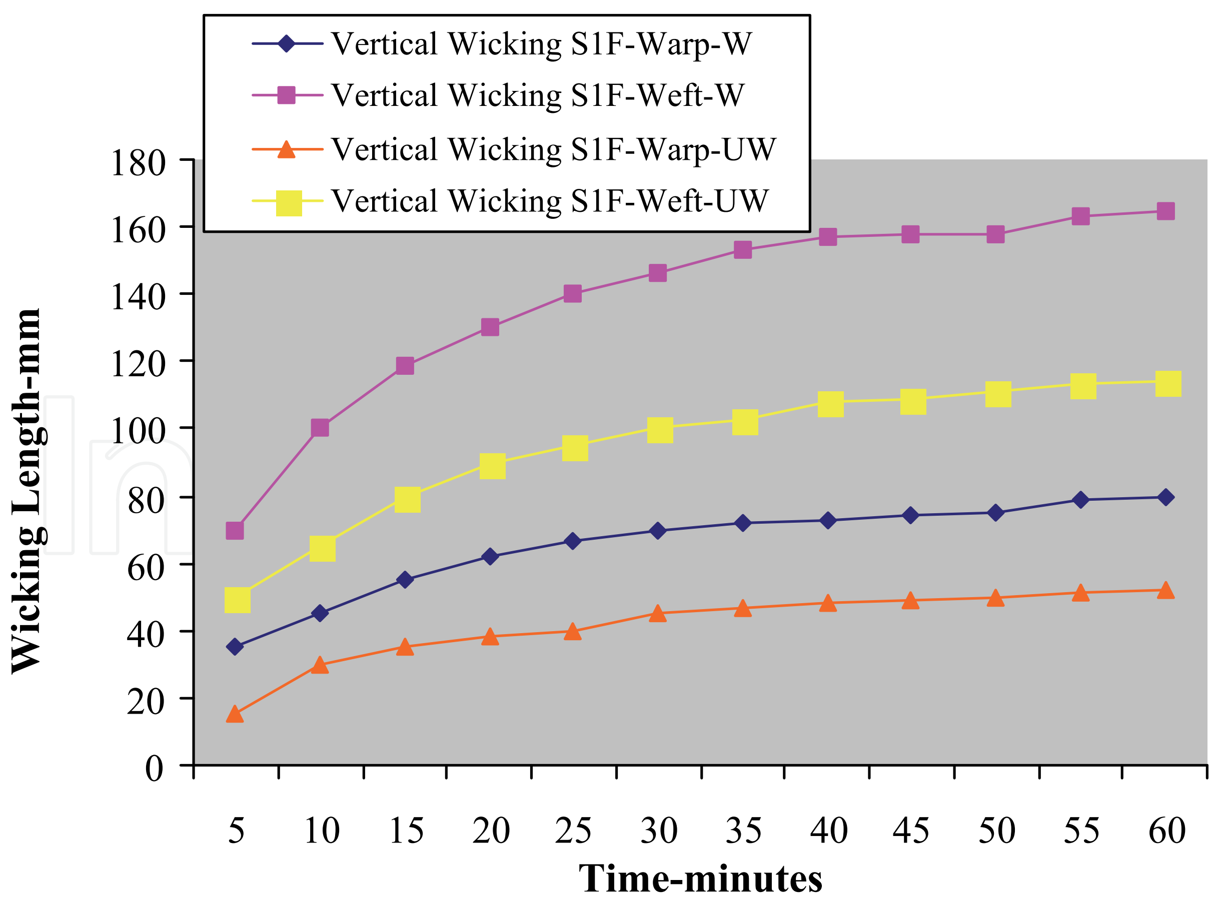


Fig. 19. Wicking Test Sample S1F- Unwashed Vs Washed Fabrics

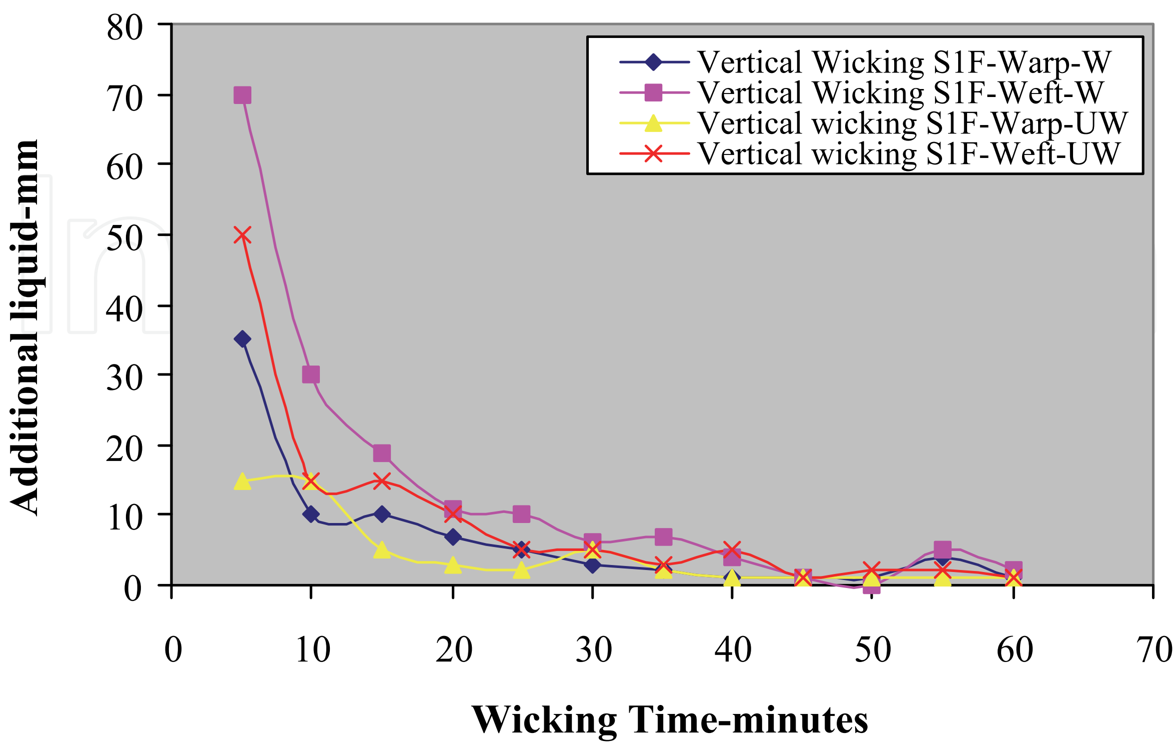


Fig. 20. Actual Liquid Advance Sample S1F -Washed Vs Unwashed Fabrics

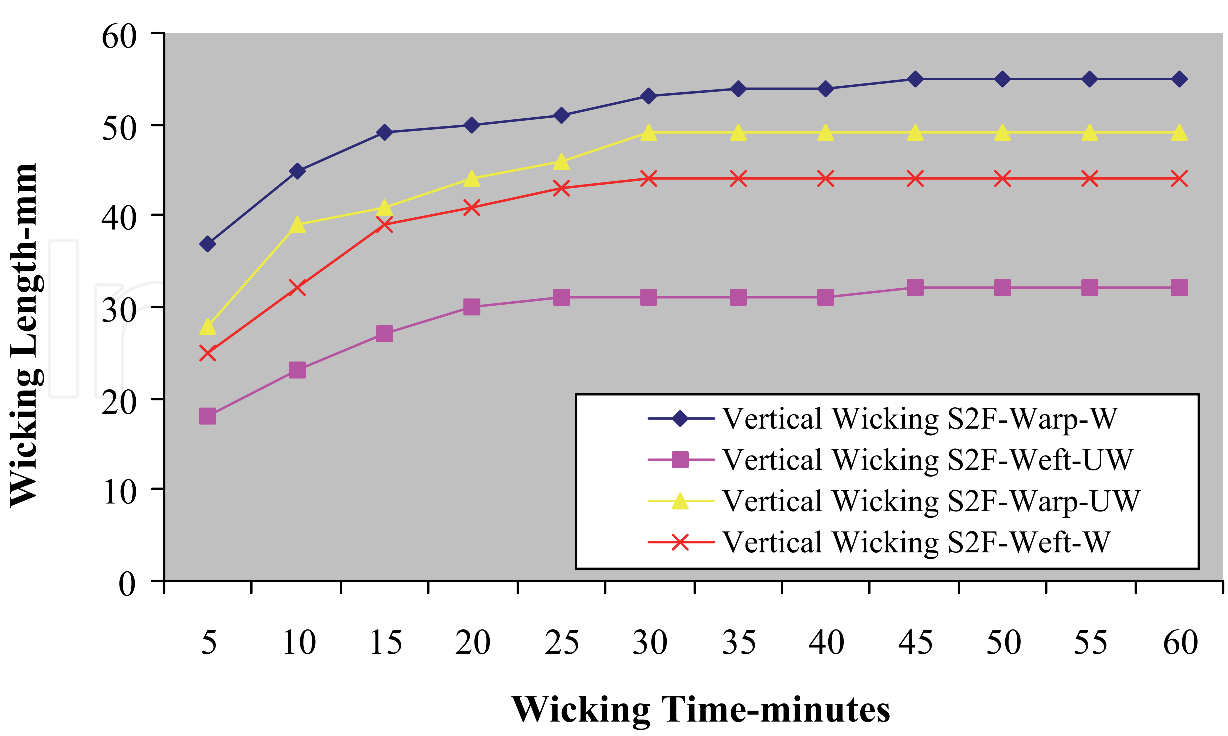


Fig. 21. Wicking Tests Sample S2F-Washed Vs. Unwashed Fabrics

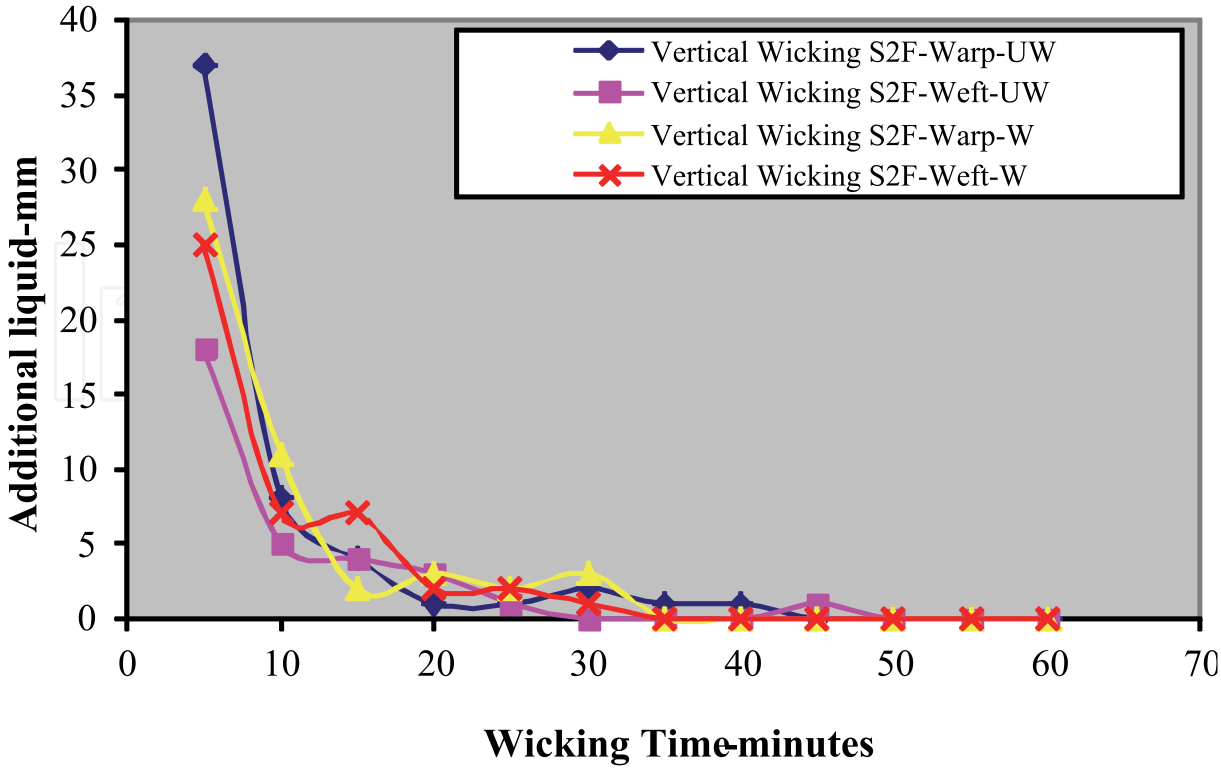


Fig. 22. Actual Liquid Advance Sample S2F -Washed Vs Unwashed Fabrics

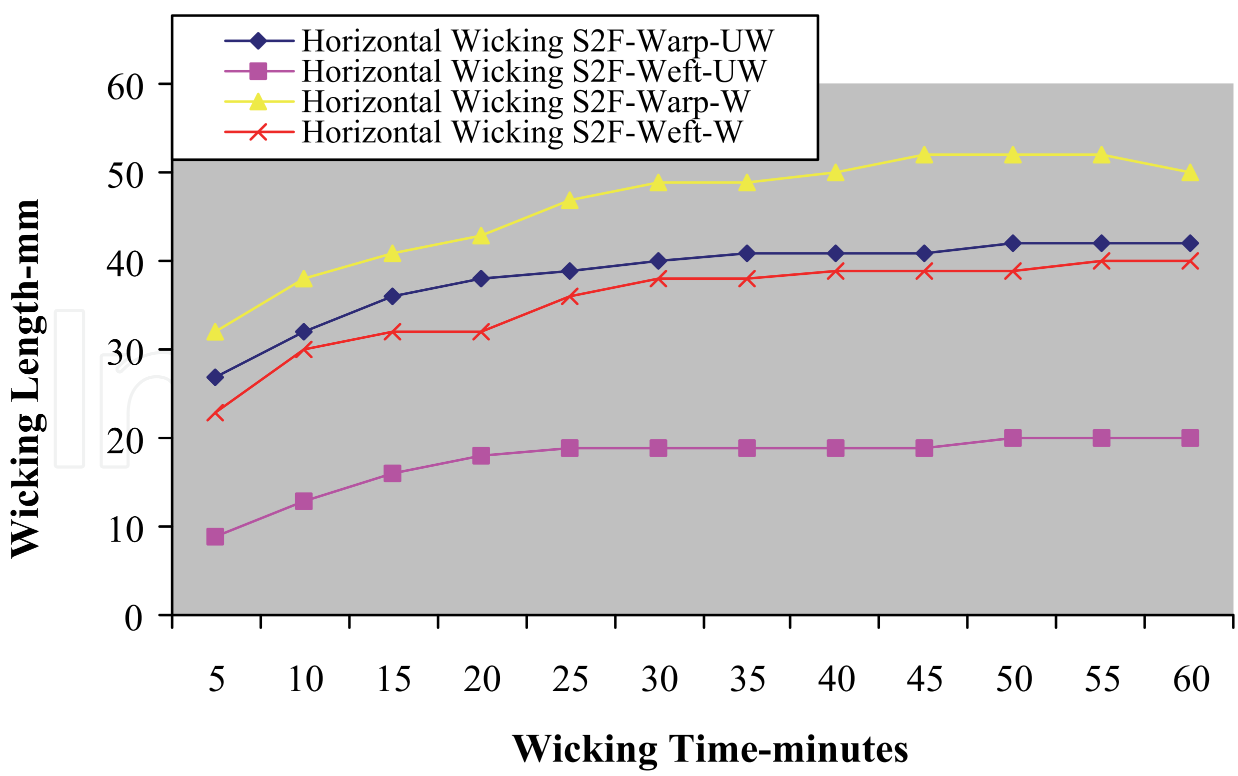


Fig. 23. Wicking Tests Sample S2F-Washed Vs. Unwashed Fabrics

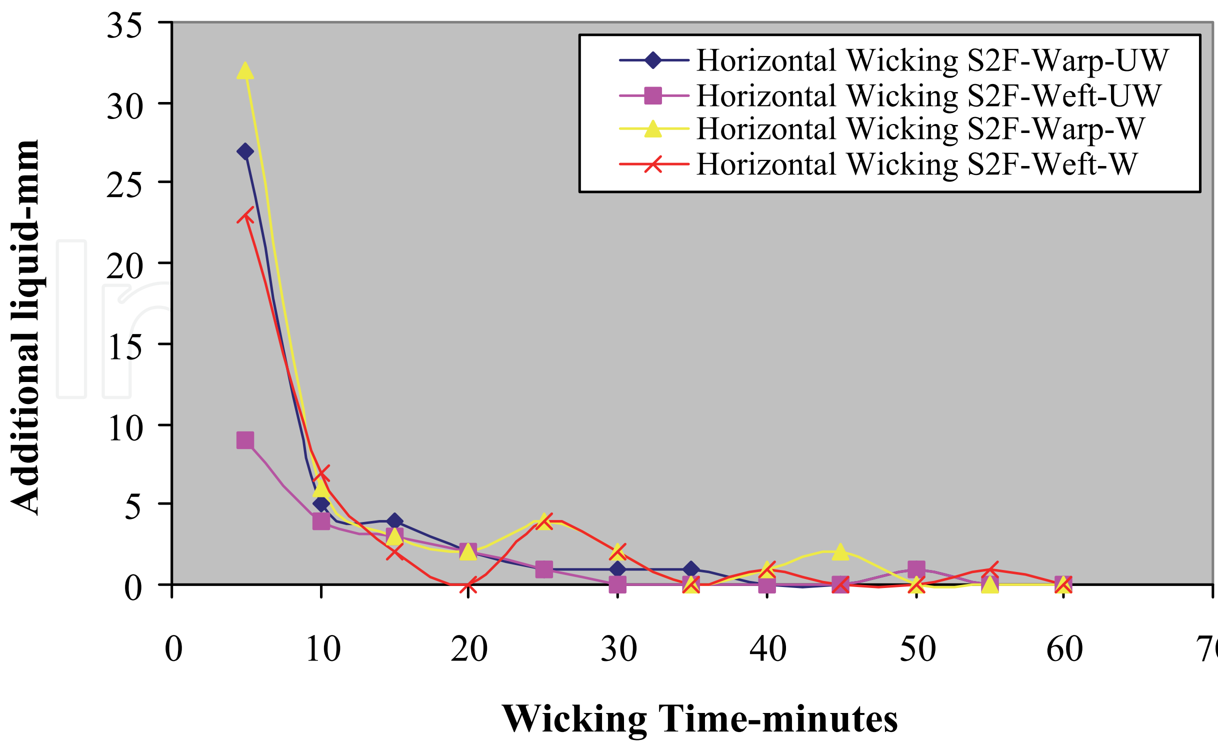


Fig. 24. Actual Liquid Advance Sample S2F -Washed Vs Unwashed Fabrics

7. Consistency with Washburn's equation: Fabrics

The general laws that govern capillary flow in simple cylindrical tubes as expounded by Washburn's well-known equation shown in **(1)** is frequently used to study liquid transport in textile substrates as information obtained from such treatment is useful for the qualitative characterization of the process of liquid transport[13] in complex textile structures.

$$h = Ct^{\frac{1}{2}} \tag{1}$$

Where *h* is the distance travelled by a liquid in time *t* and C is proportional to the set of factors

$$\left(\frac{\gamma r \cos\theta}{\eta}\right)^{\frac{1}{2}} \tag{2}$$

Where γ = liquid surface tension, η = viscosity of the wicking liquid, θ = contact angle of the liquid against the fibre substance and *r* = capillary radius.
Several researchers have modified the expression as a basis for calculation of liquid movement in textiles. Laughlin[19] modified the equation into a general form

$$h = ct^{k} \tag{3}$$

Taking logarithms of both sides of this equation gives

$$\ln(h) = k\ln(t) + \ln c \tag{4}$$

This equation has the form of a straight line.

Plots of the logarithm of the height of rise h and the logarithm of the duration of time t in Figures 19 to 26 have a form of a straight line indicating that the wetting liquid follows diffusive capillary dynamics.[20] The tabulation of the k values of fabric S2F made from flat continuous filament yarns given in Table 8 ranged from 0.1487-0.2925 and for fabric S1F composed of continuous filament warp and textured filament weft yarns the range was from 0.3312-0.4427. In all the cases the time exponents k were less than Washburn's predicted time exponent of 0.5. which was attributed to the non-uniformity of the weft filament arrangement and the simultaneously occurrence of wetting, wicking, liquid dispersion and evaporation. Data points deviating from the trend line (Figures 25-32) mostly towards the end is an indication that with a significantly volatile liquid like water, evaporation from the wet surface of the fabric strip can compete with capillary process that advances the liquid.[12]

Sample	Description	Vertical wicking k-value	Horizontal wicking k-value
S1F-warp direction	Unwashed Washed	0.4427 0.3262	0.3255 0.3478
S1F-weft direction	Unwashed Washed	0.3312 0.3277	0.4217 0.3773
S2F-warp direction	Unwashed Washed	0.1487 0.2051	0.1725 0.1965
S2F-weft direction	Unwashed Washed	0.2179 0.2133	0.2925 0.2125

Table 4.8 Strip Wicking Test k-values

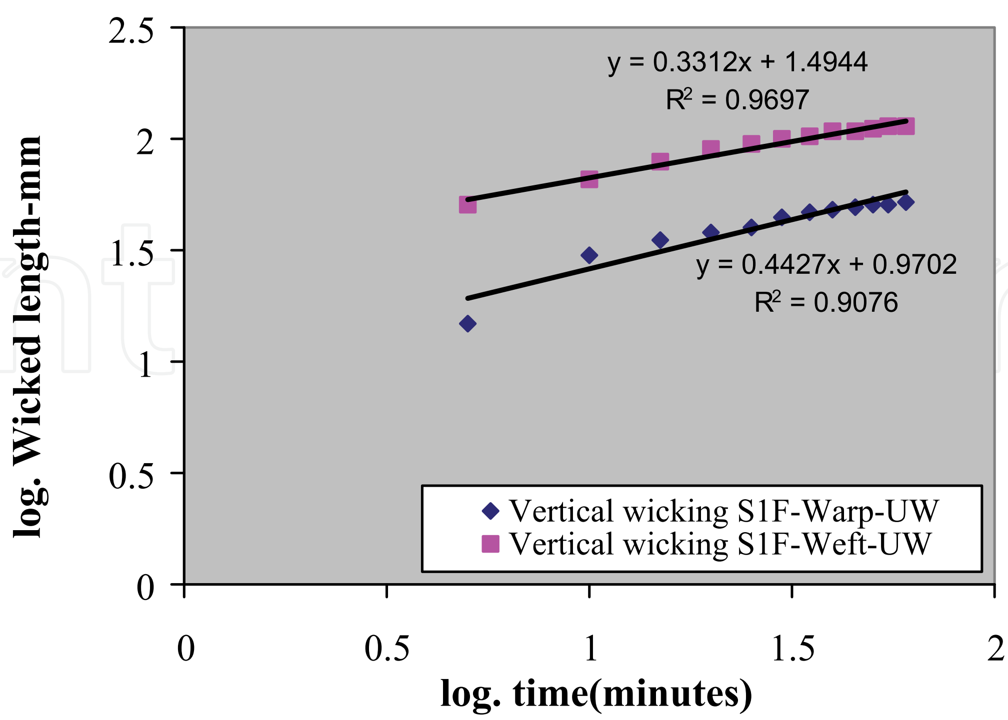


Fig. 25. Vertical Wicking Sample S1F-Unwashed Fabrics

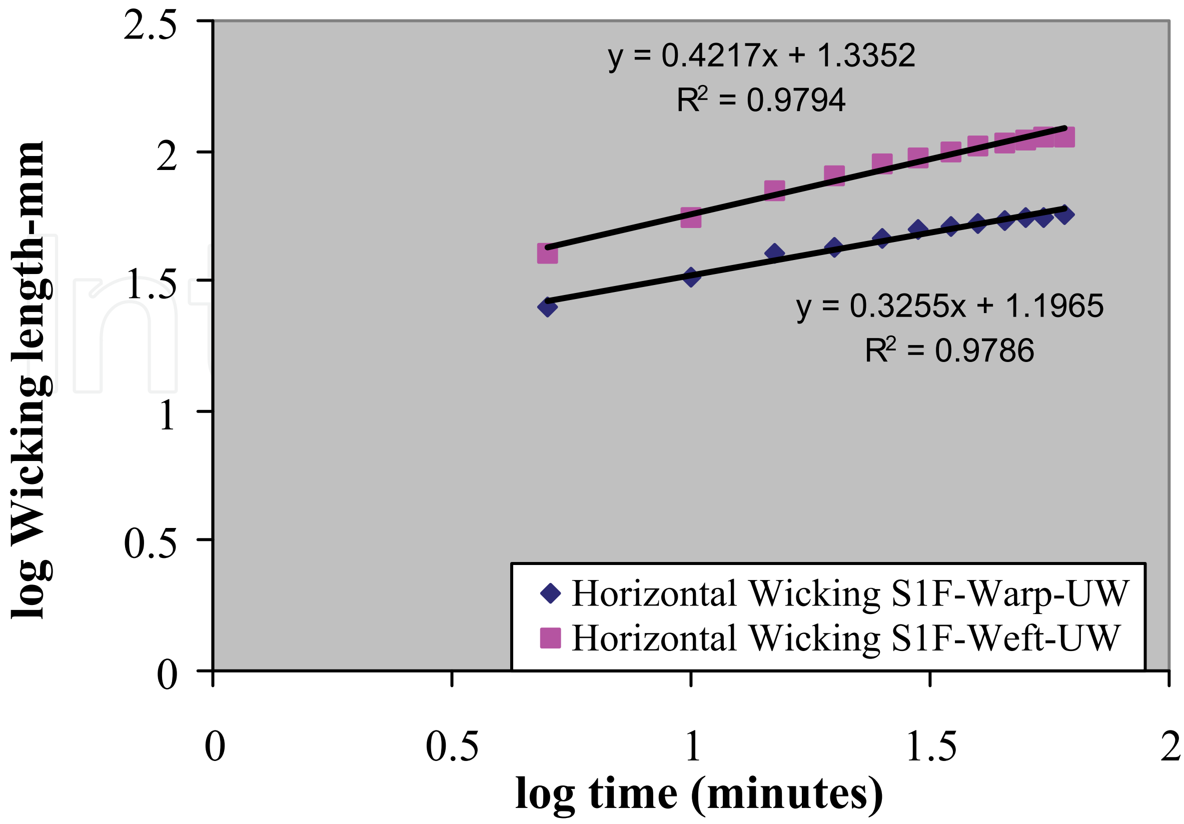


Fig. 26. Horizontal Wicking of Sample S1F -Unwashed Fabrics

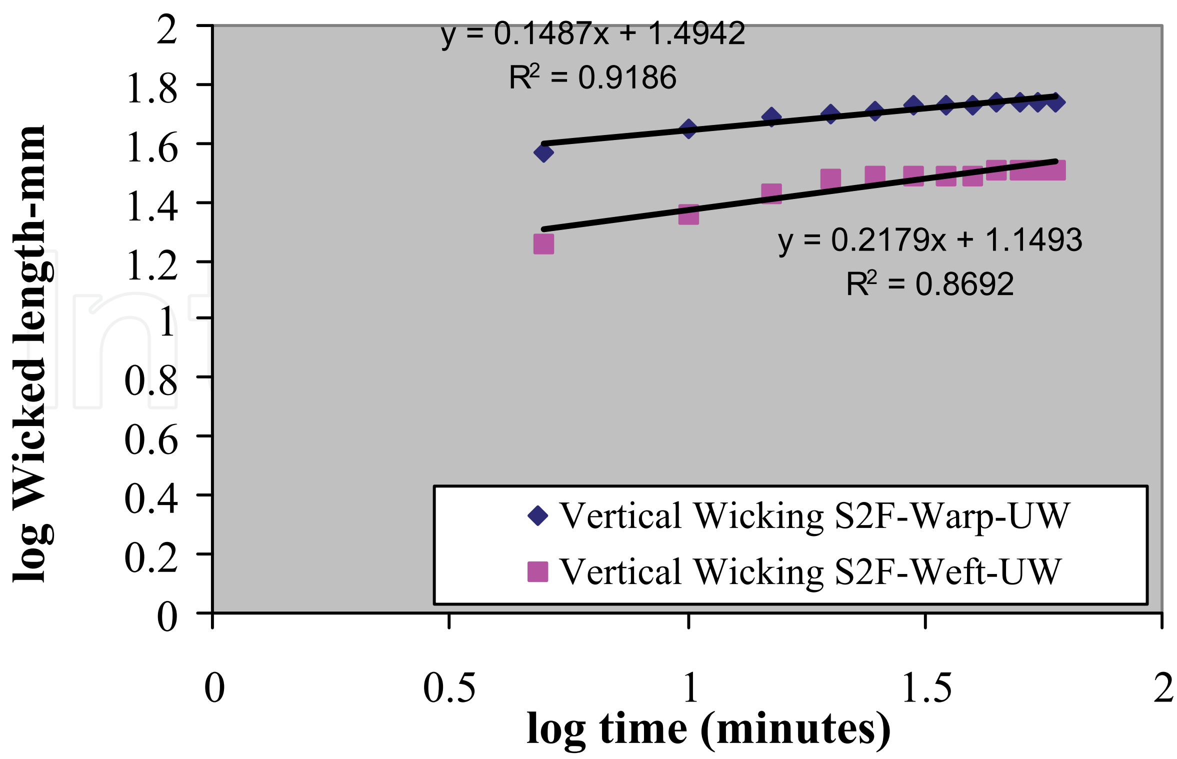


Fig. 27. Vertical Wicking Samples S2F-Unwashed Fabrics

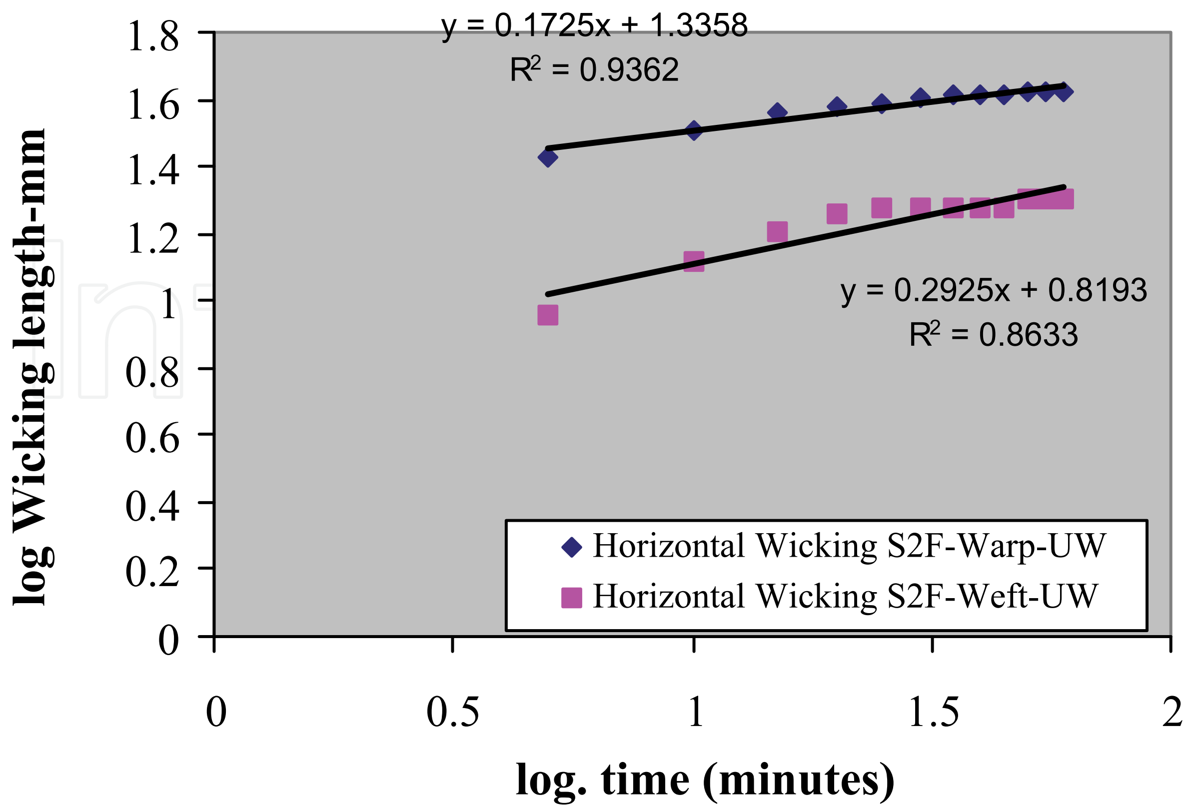


Fig. 28. Horizontal Wicking Sample S2F-Unwashed Fabrics

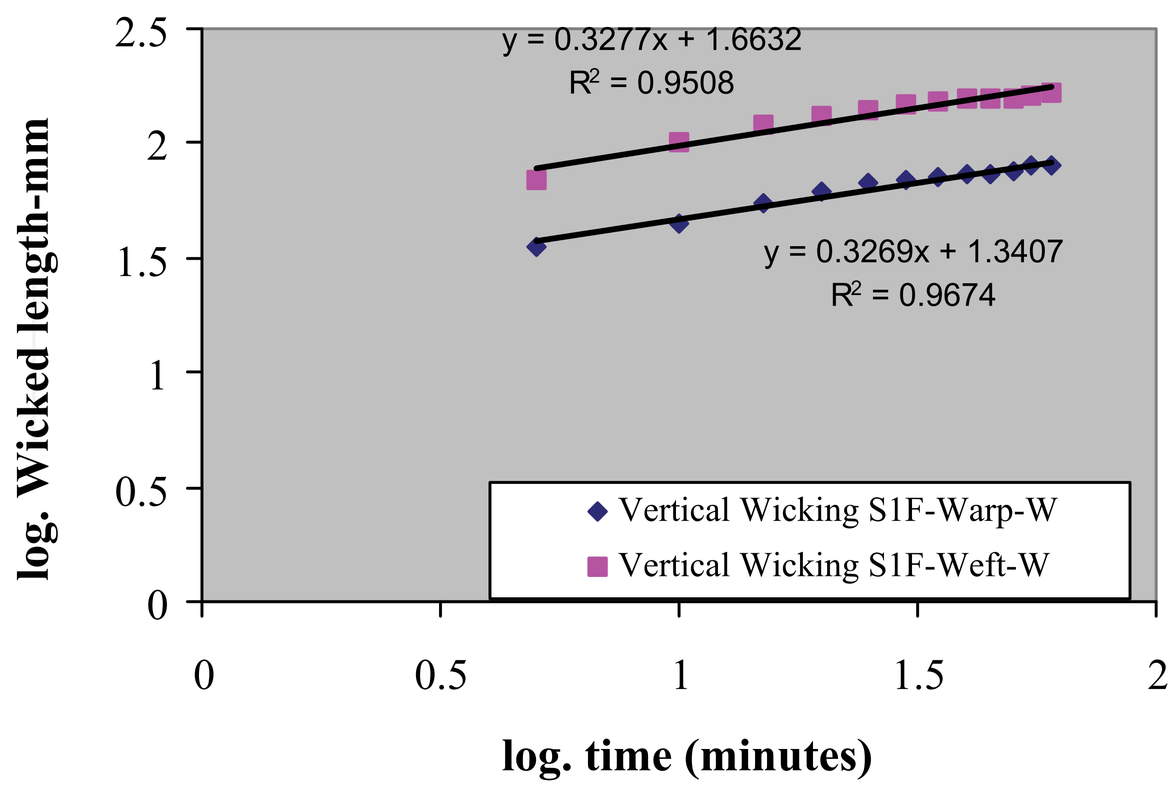


Fig. 29. Vertical Wicking Sample S1F-Washed Fabrics

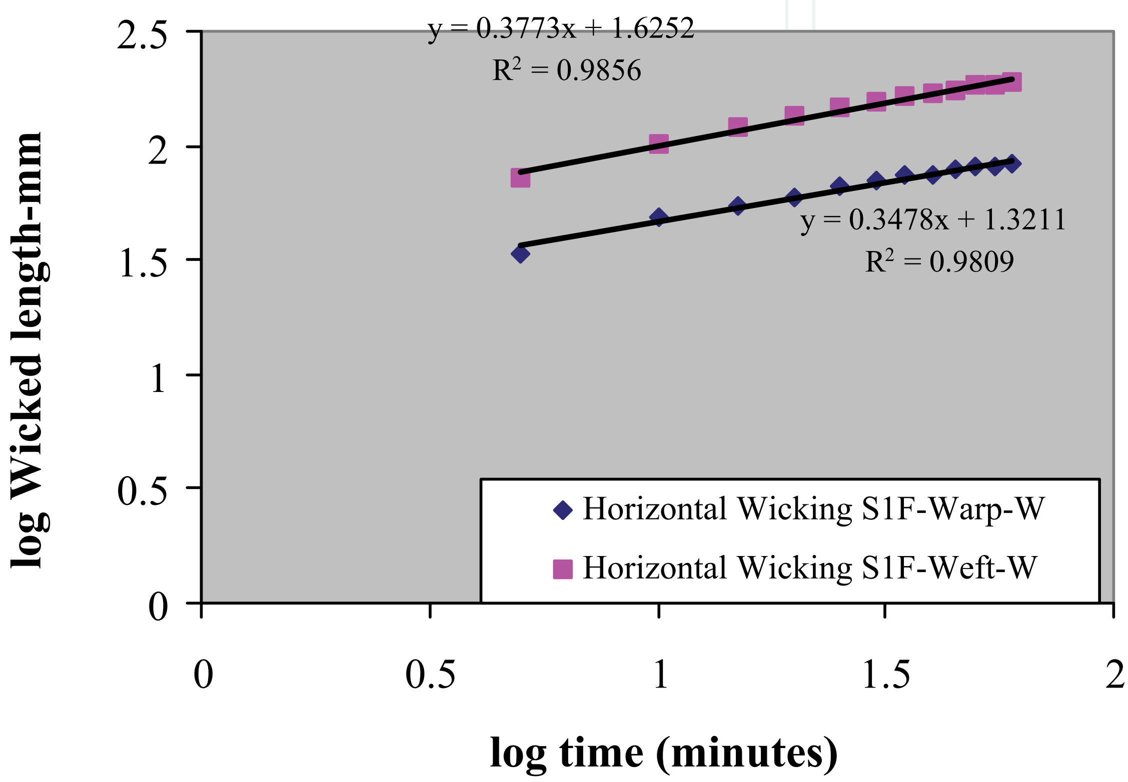


Fig. 30. Horizontal Wicking Sample S1F-Washed Fabrics

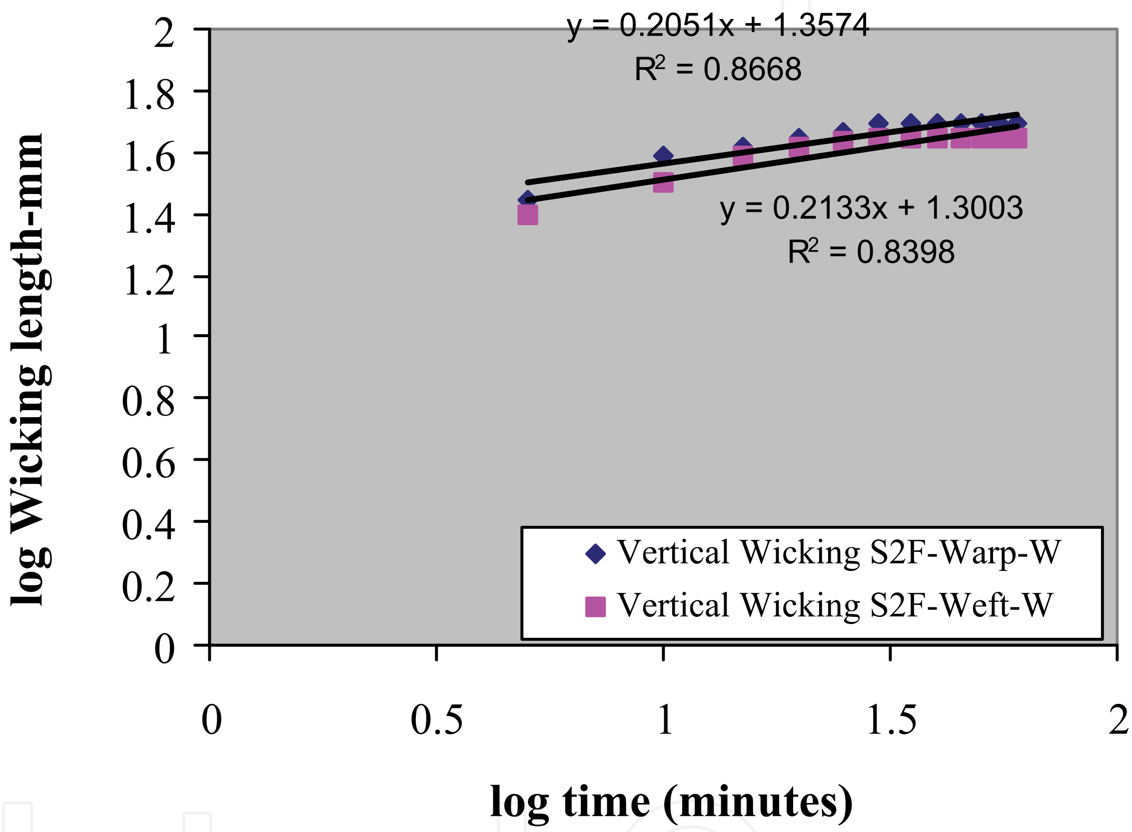


Fig. 31. Vertical Wicking Sample S2F-Washed Fabrics

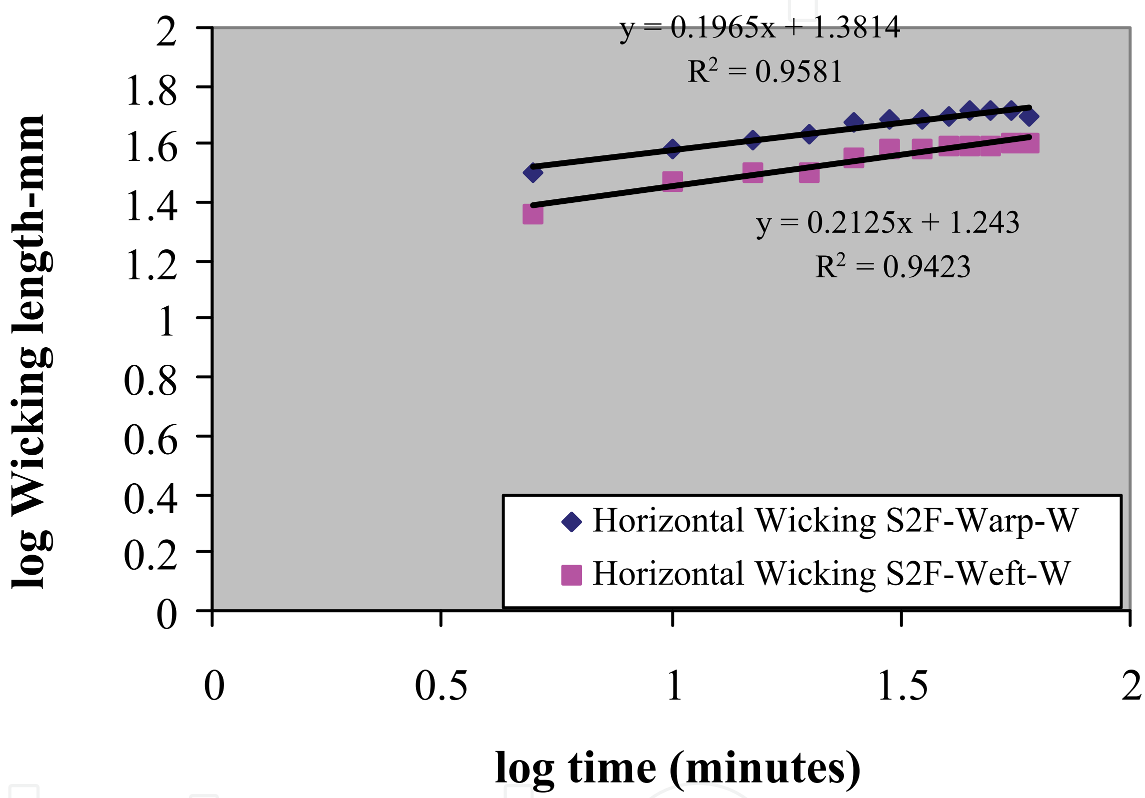


Fig. 32. Horizontal Wicking Sample S2F-Washed Fabric

8. Conclusion

Miller and Tyomkin[21] state that when a porous material such as a fabric is placed in contact with a liquid, spontaneous uptake of liquid may occur. Law[9] observed that if the wicking distance is plotted against time, the graph is expected to have an initial rapid rate of change which decreases subsequently because water is first sucked into wider capillary channels by the action of surface tension. As the wicking process proceeds further, the total viscous resistance to the flow increases and the rate of flow decreases. In the case of the vertical strip test, the height and the mass of the water absorbed in the sample strip will gradually reach a quasi-equilibrium state when they are balanced by the hydrostatic head of water. In the case of the horizontal strip test, if the supply water is unlimited, the rate of penetration will gradually become constant.[9] In thick fabrics vertical wicking would continue with little effect of evaporation until a quasi-equilibrium state is reached when the wicking level in the fabric is balanced by gravity.[10]

In this work vertical and horizontal wicking of samples S1F and S2F did not continue indefinitely indicating that due to the combination of low fabric weight and thickness the maximum wicking height was not only influenced by gravity but also by evaporation. The rate of evaporation of liquid therefore determined the equilibrium point for both vertical and horizontal wicking of samples S1F and S2F indicating good properties required for eliminating perspiration discomfort which would cause fabric wetness with resulting problems of freezing in winter or clamminess[22] in summer. In most cases, the leading front of the water rise observed at the end of each test period felt dry to the touch which can be attributed to the rapid liquid evaporation of the fabrics.

In textured yarns, the manner in which the liquid is transported through the fabric is determined by the minute loops or coils that characterize air –textured yarns which act as pores that vary in shape and distribution and may or may not be interconnected. Hsieh[6] noted that pore variation and distribution leads to preferential liquid movement towards smaller pores, resulting in partial draining of previously filled pores in the fibrous structure. In all cases studied in this work, tests showed that there is a good linear relationship between the logarithm of the wicked liquid (l) and the logarithm of the wicking time (t) indicating that the wetting liquid follows diffusive capillary dynamics[20] even though for sample S1F in most cases the exponential values were high compared to sample S2F due to evaporation from the parallel packed filaments of the yarn structures.

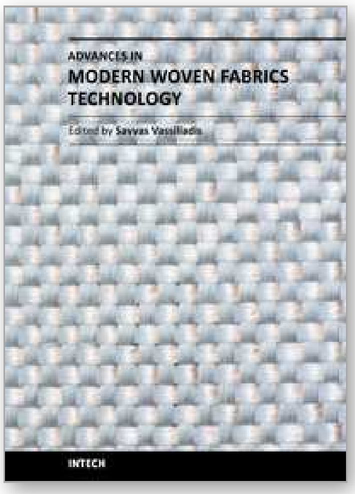
The high **k** values of fabrics containing textured weft yarns indicate the characteristics of a non-homogenous capillary system where wicking is a discontinuous process due to the irregular capillary spaces of varying dimensions.[11] Rapid wicking is retarded by the 'absorber' textured weft yarns which are more bulky and act as temporary liquid reservoirs as all the voids are filled up. On the other hand, the inter-filament wicking rate is increased once the liquid is transferred to the flat 'runner'continuous filament warp yarn due to capillary sorption[11] resulting in spiked wicking behaviour observed.

Wicking is also affected by fabric construction. Fabric sample S2F wicked more rapid in the warp than in the weft direction due to the high density of ends in the fabric. If the filament packing in the yarn is assumed to be an idealized or closely packed assembly[23] there will be more capillaries in the warp than in the weft direction due to the distribution in the number of ends and picks.

Outdoor active wear such as jackets are infrequently washed and research[24] results have shown that a standard 5 washes of vests used for mountaineering resulted in a significant increase in their wicking performance. Even though a spin finish was applied to fabrics S1F and S2F during finishing to give surface properties which can allow liquid flow, the durability of the spin finish to washing was insignificant since laundering of fabrics resulted in a significant increase in their wicking performance. Washing therefore did not lead to the collapse of the capillary system of the fabric but results in the re-arrangement of the capillaries between filaments due to the washing liquid movements and the relaxation of the textile structure during drying.[24]

9. References

[1] Barnes J.C and Holcombe B.V., Textile Res. J., 66(12), 777-786, 1996
[2] Brownless N.J., Anand S.C., Holmes D.A. and Rowe T., J. Text. Inst., 87 Part 1, No.1, 172-182, 1996.
[3] Brownless N.J., Anand S.C., Holmes D.A. and Rowe T., Textile Asia, August 1996, 77-80.
[4] Slater K.,Comfort Properties of Textiles, Textile Progress, Volume 9, Number 4, 1-91, Textile Institute 1977.
[5] Yoon H.N. and Buckley A., Text. Res. J., 54, 289-298, 1984.
[6] You-Lo Hsieh, Text. Res. J., 65(5), 299-307, 1995
[7] Brownless N.J., S.c. Anand, D.A. Holmes and T. Rowe, World Sports Activewear, Volume 2, No.2, 36-38, 1996
[8] A.B. Nyoni and D. Brook, J. Text. Inst., Vol.97, No.2, 2006, 119-128.
[9] Law Y.M.M., Ph.D Thesis, University of Leeds, 1988.
[10] Zhuang Q., Ph.D. Thesis, University of Leeds, 2001.
[11] Kissa E., Text. Res. J., 66 (10), 660-668, 1998
[12] Miller B., International Nonwovens Journal, Volume 9, No.1, Spring 2000.
[13] Pronoy K. Chatterjee and Hien V. Nguyen., Mechanism of Liquid Flow and Structure Property Relationships., Absorbency, Chapter II., Edited by Pronoy K. Chatterjee, Elsevier Scientific Publishers; Amsterdam; New York, NY: 1985.
[14] Harnett P.R. and Mehta P.N., Tex. Res. J., 54, 471-478, 1984
[15] A.B Nyoni., (2003), PhD Thesis, University of Leeds.
[16] Hepburn C.D., PhD. Thesis, University of Leeds 1998
[17] Leijala A and Hautojarvi. J, Text. Res. J.,68(3), 193-202, 1998.
[18] Blyth G.T., Ph.D. Thesis, University of Leeds, 1984.
[19] Laughlin R.D. and Davies J.E., Text. Res. J., 31,904-910, 1961.
[20] Anne Perwuelz, Mthilde Casetta and Claude Caze, Polymer Testing, Volume 20, Issue 5, 553-561, 2001.
[21] Miller B. and Tyomkin. I., Text. Res. J., Volume 54, 706-712, Nov. 1984
[22] Rees W.H., Text. Month, 59-61, August 1969
[23] Hearle J.W.S., Grosberg P., and Backer S., Structural Mechanics of Fibres, Yarns, and Fabrics. Volume 1, 1969, John Wiley; New York, NY, USA.
[24] A.B Nyoni and D.Brook, Textile Research Journal ,Vol.80(8), 2010, 720-725.



Advances in Modern Woven Fabrics Technology
Edited by Dr. Savvas Vassiliadis

ISBN 978-953-307-337-8
Hard cover, 240 pages
Publisher InTech
Published online 27, July, 2011
Published in print edition July, 2011

The importance of woven fabrics increases constantly. Starting from traditional uses mainly in clothing applications, woven fabrics today are key materials for structural, electronic, telecommunications, medical, aerospace and other technical application fields. The new application fields of the woven fabrics is directly reflected in the contents of the book. A selected collection of papers in the technological state-of-the-art builds the book â€œAdvances in Modern Woven Fabrics Technologyâ€. It is written by internationally recognized specialists and pioneers of the particular fields. The chapters embrace technological areas with major importance, while maintaining a high scientific level. This interdisciplinary book will be useful for the textile family member as well as for the experts of the related engineering fields. The open access character of the book will allow a worldwide and direct access to its contents, supporting the members of the academic and industrial community.

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821