〔보 문〕

Journal of the Korean Society
of Clothing and Textiles
Vol. 24, No. 8 (2000) p.1167~1176

신개발된 편성포의 조직이 수분전달에 미치는 영향

Maureen M. Grasso · Charles J. Kim · 신 정 숙* · David G.Herr

Dept. of Textile Products Design and Marketing, University of North Carolina at Greensboro. Greensboro, NC 27402 U.S.A.
*서경대학교 패션디자인학과

Moisture Transport of Three Different Fabric Structures of an Innovative Knit Fabric

Maureen M. Grasso · Charles J. Kim · Jung-Sook Shin* · David G.Herr

Dept. of Textile Products Design and Marketing, University of North Carolina at Greensboro. Greensboro, NC 27402 U.S.A.
*Dept. of Fashion Design Seokyeong University

(2000. 4. 17 접수)

Abstract

운동화 안감으로 사용되는 부드러운 천연 가죽의 내부 구조 및 쾌적성과 유사하게 개발한 3종류의 편성포에 관하여 수분 전달 능력을 비교 측정하였다. 편성포 표면에서 이면으로 땀액의 이동성을 측정하기 위하여 새로운 실험 절차를 고안하여 측정한 결과, 편성포에 가한 압력은 수분 이동 능력에 영향을 미치지 않았다. 그러나 편성포의 기모가 있는 표면과 기모가 없는 이면의 수분 이동 능력이 달랐고, 3종류중 한 편성포에서는 표면의 기모는 수분전달을 저하시켰다. 표면은 기모, 이면은 평편조직으로 두껍고 무거운 편성포의 수분전달이 가장 좋았고 이 편성포와 같은 조직이면서 두께와 중량이 적은 편성포는 수분전달이 감소되었다. 수분이동 능력을 향상시키기 위하여 편성포의 섬유와 구조를 고려할때 기모량은 중간 정도이고 기모된 표면을 수분에 접하도록 하는것이 바람직하다. 이렇게 함으로서 더 효과적인 수분 이동이 이루어져서 피부 표면에서 땀증발이 좋았다. 이 연구에 사용된 실험 방법은 편성포의 수분 이동 체계에 관한 이해 증진에 기여할 수 있다고 본다.

Key words: moisture transport, napping, capillary, knit fabric; 수분전달, 기모, 모세관, 편성포

I. Introduction

With an emphasis on improvements in active wear, manufacturers and consumers have focused their attention on the important aspects of moisture management properties of fabrics(Tom, 1997). Moisture management, the ability of a fabric to transportmoisture, is an important component of wearing comfort. It becomes particularly relevant during periods of high activity when the body produces sensible perspiration (hereafter referred to as perspiration), which serves as an evaporative cooling mechanism for the body. The evaporative cooling process is most effective when perspiration can be transported away from the skin; how well perspiration can be removed from the body, therefore, depends not only on the environmental climatic conditions, but also on the moisture transport(or resistance) properties of a fabric. Fabrics with high moisture resistance impede the evaporation of perspiration, resulting in excessive heat storage within the body, which causes discomfort. Thus, fabric properties play a key role in the evaporative cooling process.

As the body produces perspiration, it is adsorbed by the fabric from the skin, transported through the fabric structure by capillary action(wicking), and passed to the outer surface where the liquid is spread vertically or horizontally before evaporating to the environment. Several factors influence the initial adsorption of perspiration. These include the distance between the fabric and the skin, the number of contact points made between the fabric and the skin, the fabric structure, and the surface of the fabric. Fiber type(hydrophilic, hydrophobic), yarn structure(spun, textured, twist), fabric structure (woven, knitted, count or gauge, size of interstices, pore structure), finish(napping, water repellent, surfactants) and fabric thickness also affect the transport of perspiration through the fabric(Hatch, 1993; Kissa, 1996; Crippen, 1975; Fourt & Hollies, 1970; Bogaty, et.al. 1953; Wallenberger, 1980; Brundrett, 1990; Crow & Sczeuski, 1998; Hsieh, 1995; Hong et al., 1988; Harnett & Mehta, 1984).

The purpose of this study was to analyze the moisture management properties of three different structures of a new knit fabric designed for use as a liner in athletic shoes. In this study the specific application was the movement of perspiration across(or through) the fabric from one side to the other. This application is important, because it relates directly to the comfort of the wearer as perspiration is passed from the foot to the shoe liner and through the liner to the outer shell of the shoe. It was assumed that the perspiration would be from the foot(absence of a sock) to the knit liner. To facilitate the analysis a laboratory procedure was developed to measure the moisture transfer.

Three fabric structure variations of the new knit fabric were made and evaluated. The specific objectives of the study were to determine 1) if differences existed between the three fabric structure variations in the transport of moisture across the fabric sample, 2) if differences existed between the face(napped) and the back of the fabric in the transport of moisture across the sample, and 3) if differences in the amount of pressure applied to the fabric affected the moisture transport across the sample. The goal was to determine the best combination of fabric structure variation, side(face or back), and pressure for effective moisture transport.

II. Experimental

1. Materials

Three different knit fabric structures are shown in Fig. 1. The white knit sample was a 80/20% microdenier/macrodenier polyester in a terry-velour looped and brushed structure. The black knit sample was a 55/35/10% microdenier/ macrodenier polyester/Lycra spandex triple plated jersey purl brushed structure. The blue sample had the same fiber content and structure as the black sample but varied by thickness, weight and knit gauge. All three fabrics varied by thickness, weight, and amount of napping(surface fuzziness) on the face. Table 1 provides structural characteristics of each fabric structure.

ASTM methods were used to measure each descriptive characteristic: thickness(ASTM D 1777-96), mass per unit area(ASTM D 3776-96), and knit gauge(ASTM D 3887-95)(Annual Book of ASTM Standards, 1996). The white fabric was the thickest and had the heaviest napping. In contrast, the black fabric was the thinnest and

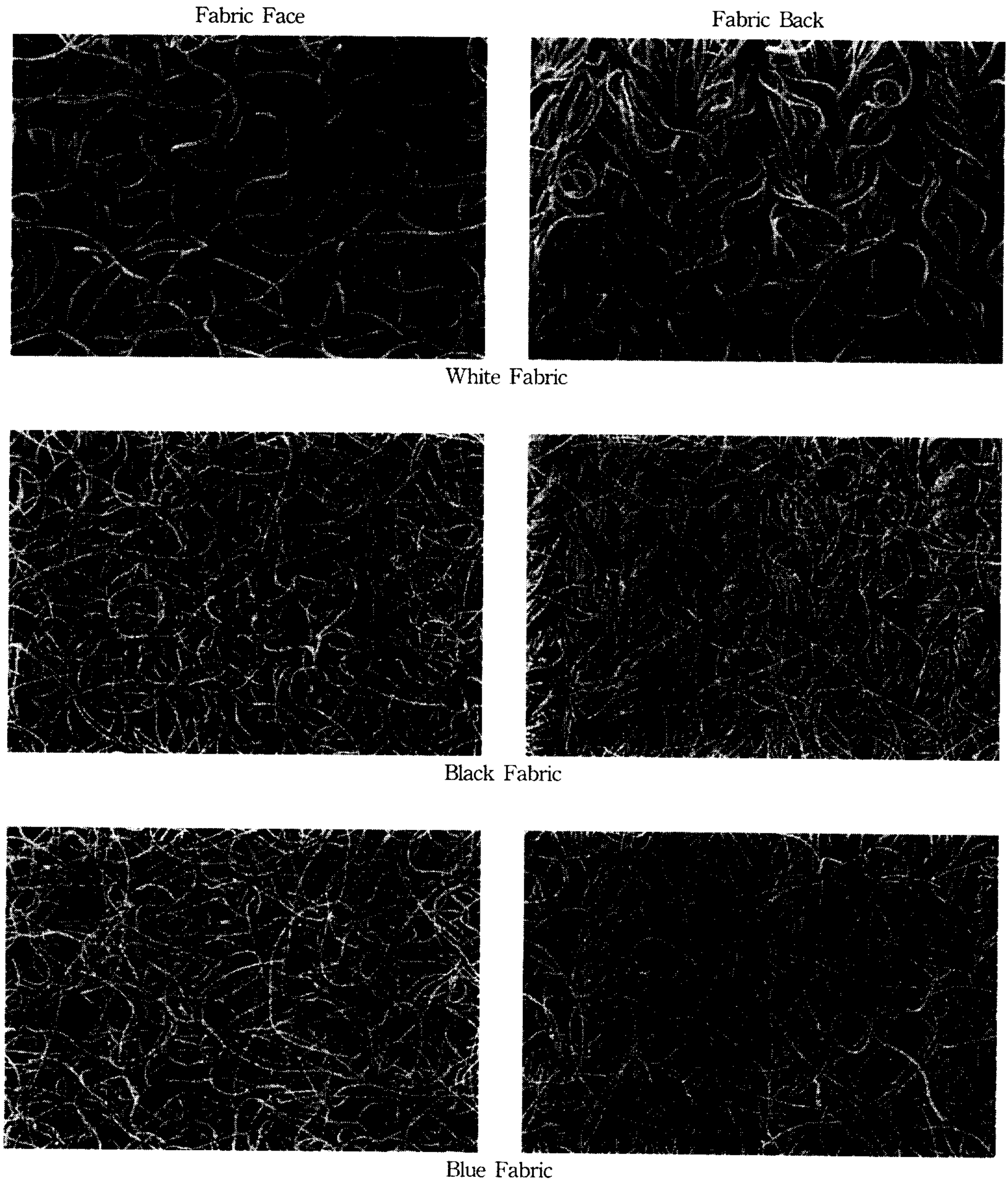

Fig. 1. SEM Micrographs(100X) of Three Knitted Fabric Structures

had only a slight amount of napping. The white and black fabrics were comparable in weight, while the blue fabric was heavier by approximately one ounce per square yard. The blue and black fabrics were more dense in construction than the white fabric, as indicated by the gauge.

2. Measurement of Moisture Transport

In reviewing the literature it was evident that

Table 1. Characteristics of the Three Knit Fabric Structures

Fabric	Thickness(mm)	Weight(g/m²)	Knit Gauge
White sample: (terry-velour looped, brushed, 80/20% microdenier/denier polyester)	3.9	267.6	24×34
Black sample: (triple plated jersey purl, brushed, 55/35/10% microdenier/denier polyester/spandex)	3.1	264.0	36×31
Blue sample: (triple plated jersey purl, brushed 55/35/10% microdenier/denier polyester/spandex)	3.3	293.1	36×66

there are numerous methods or techniques used with each having its own limitations(cost, simplicity, elaborate equipment, variables measured). Harnett and Mehta(1984) provided a critical survey of laboratory test methods used to measure wicking including the longitudinal wicking "strip" test, transverse wicking "plate" test, areal wicking "spot" test, and the syphon test(not relevant to clothing comfort studies). Watkins and Slater(1981) used a relative-humidity-gradient tube method for measuring the resistance of fabric to moisture-vapor permeability. They reported that it was competitive with the standard dish method. Miller and Tyomkin(1984) used a sensitive gravimetric method, a variation of the porous plate technique, to measure the transplanar uptake of liquid. Wehner et al.(1988) developed an experimental apparatus to measure moisture sorption by and moisture flux through a fabric when the fabric was exposed to a humidity gradient. Farnworth and Dohlan(1984) developed an apparatus to measure water vapor resistance of textiles.

Adler and Wash's(1984) technique to study moisture transport used a fabric system of a wetted fabric sample on the bottom with a conditioned piece of fabric on top. The fabric system was sealed in Saran Wrap and sealing frames for a designated period of time to allow for the transport of water from the wet layer to the dry layer. Hong et al.(1988) used a simulated sweating skin(fully wetted chamois heated to skin temperature) to measure dynamic surface wetness. The sweating skin was used by Kim and Spivak(1994) as they simultaneously measured surface temperature changes and moisture vapor transfer. Meinander(1988) used a sweating cylinder(which produced heat and moisture to simulate the human body) to measure heat and moisture transmission through clothing under different environmental conditions. Gibson(1993) reported that the upright cup(simple and inexpensive) and the sweating skin(elaborate equipment), two common methods used, correlated well for permeable materials. Ghali et al.(1994) developed an experimental technique that allowed capillary pressure and permeability to be measured over a wide range of saturations.

After reviewing the methods reported above and in keeping with the objectives of this study a simple, inexpensive, small scale moisture transport test was developed using the concepts presented in the Adler and Walsh(1984) research to simulate the process under study. The researchers felt that adapting Adler's and Walsh's methods best fit the objectives of this study and met the requirements of the fabric manufacturer to have a simple and inexpensive method to screen fabrics. The preliminary test method developed was refined using suggestions from American Association of Textile Chemists and Colorists (AATCC) members. The refined test method and resulting data are presented here.

Fabric samples were cut into 50mm×50mm(2×2 in.) specimens. AATCC blotter paper 44 mm×44mm(1.75×1.75 in.) was used to transfer the moisture to the fabric specimen and to adsorb the moisture from the fabric specimen on the opposite side; the fabric specimen was sandwiched between the two blotter papers. A perspiration solution of AATCC Test Method 15−1994 was used as the liquid medium(AATCC Technical Manual, 1997). Two AATCC perspiration plates were used, one as the base for the experiment and one as the top to sandwich the combined blotter paper−fabric specimen−blotter paper. Weights(25g, 50g, 100g, 150g) were then put on top of the perspiration plate in the center of the specimen to produce pressures of 0.01 g/mm^2(6.25 g/in^2), 0.02 g/mm^2(12.5g/in^2), 0.04 g/mm^2(25g/in^2), and 0.06g/mm^2(35g/in2).

The bottom blotter paper was placed in a 250 ml beaker with the perspiration solution, submerged and allowed to soak for two minutes. After the wet weight of the bottom blotter was recorded, it was placed on the perspiration plate with the dry fabric specimen on top(fabric face down if testing transfer of moisture through the face to the back, or fabric back down if testing transfer of moisture through the back to the face of the fabric). The dry top blotter paper was placed on top of the fabric specimen with the second perspiration plate(completing the "sandwich") and the appropriate weight on top. After five minutes, the top blotter paper, fabric specimen, and bottom blotter paper were weighed to the nearest 0.001 gram.

The following formulas were used to determine the independent variables for each of the eight replications and the results were used in the analysis of the data:

$$\%\ \text{Change for fabric specimen weight} = \frac{(\text{after 5min. weight in grams}) - (\text{original weight in grams}) \times 100\%}{(\text{original weight in grams})} \quad \cdots\cdots 1)$$

$$\%\ \text{Wet pickup of the bottom blotter paper} = \frac{(\text{wet weight in grams}) - (\text{original weight in grams}) \times 100\%}{(\text{original weight in grams})} \quad \cdots\cdots 2)$$

$$\%\ \text{Change in the wet bottom blotter paper} = \frac{(\text{after 5 min. wet weight in grams}) - (\text{original wet weight in grams}) \times 100\%}{(\text{original wet weight})} \quad \cdots\cdots 3)$$

$$\%\ \text{Change in the top blotter paper} = \frac{(\text{after 5 min. weight in grams}) - (\text{original weight in grams}) \text{ x } 100\%}{(\text{original weight in grams})} \quad \cdots\cdots 4)$$

Ⅲ. Results and Discussion

The challenge was to find the best combination of fabric structure(white, black, blue), side(face, back) and pressure(0.01g/mm^2, 0.02g/mm^2, 0.04g/mm^2, 0.06g/mm^2) for transporting moisture from the bottom blotter, through the fabric structure, and to the top blotter. To determine the effects of these independent variables on moisture transport, the dependent variable, data was analyzed using various statistical procedures.

1. Effect of Pressure

Linear regressions were performed on the data for each of the six fabric structure/side combinations. The results did not indicate a linear relationship in any of the fabric structure/side combinations for either the percent change in moisture in the bottom blotter or the percent change in moisture in the fabric. Similar regressions were analyzed for the percent change in moisture in the top blotter on pressure. In only one case(blue fabric, back side) was the role of pressure significant(β=0.006764, standard error= 0.0027, p=0.0195); moisture transport increased as the pressure increased.

For completeness of the analysis, quadratic and cubic regressions were performed on the pressure variable using data from the bottom blotter, fabric, and top blotter on pressure for each of the six fabric structure/side combinations. The results did not indicate a quadratic or cubic relationship between the percent change in moisture for the bottom blotter and pressure for any of the six fabric structure/side combinations. However, this was not the case for the fabric and the top blotter. There was evidence of a quadratic relationship with pressure for fabric in the fabric structure/side combinations, black/back and blue/back. For the top blotter, there was evidence of a quadratic relationship with pressure in the fabric structure/side combination, black/face. There was little or no evidence of a cubic relationship in any fabric structure/side combination for the bottom blotter, fabric, or top blotter.

2. Effects of Fabric Structures and Fabric Side

Since pressure did not play a significant role in moisture transport, data analysis was focused on identifying the best combination of fabric and side. The process under study was the transport of moisture from the bottom blotter through the fabric to the top blotter. When examining the data, a large percentage of change in the bottom blotter would indicate that the bottom blotter was transferring a greater percentage of moisture. For the fabrics, a small percentage change would suggest that the fabric retained only a small amount of the moisture transmitted to it. Finally, a large percentage change in the top blotter would indicate that the top blotter experienced a greater adsorption of moisture. Thus, the ideal combination would be a large percentage change in the bottom blotter, a small percentage change in the fabric, and a large percentage change in the top blotter.

An analysis of variance(ANOVA) was run to compare each of the percentage changes in bottom blotter wet weight, fabric weight and top blotter weight among the 24 combinations of fabric(white, black, blue), side(face, back) and pressure(0.01g/mm^2, 0.02g/mm^2, 0.06g/mm^2). The percentage change in bottom blotter wet weight is the percent loss of moisture in the bottom blotter over a five minute period. Thus large, positive values indicate a drier bottom blotter, with an ideal value being 100(i.e., all the original moisture being transmitted). The percentage change in fabric weight is the percent increase in moisture of the fabric. Small, positive values mean drier fabrics and more moisture being transferred to the top blotter. Here, the ideal value would be zero(i.e., no additional moisture present in the fabric after 5 minutes). The percentage change in the top blotter weight reflects the percent gain in moisture by the top blotter after 5 minutes. Large, positive values indicate that the top blotter absorbed moisture from the fabric; the larger the value, the more moisture transferred.

In the ANOVA, there were eight observations in each of the 24 cells. When the data was averaged over the four pressures(pressure was not a significant factor), the resulting means were based on 32 observations. These means are reported in Table 2. It can be seen that for a drier bottom blotter, the back of the fabric was more effective than the face. However, if a drier fabric was the goal, then the face side was more effective than the back. In general, if the bottom blotter lost a significant amount of moisture, the fabric retained it. This was evident in the fabric structure/side combination(blue/back), where the bottom blotter transmitted the most moisture and the fabric retained the most moisture. In the opposite scenario, for the fabric structure/side combination where the bottom blotter transmitted the least amount of moisture(white/face), the fabric retained the least amount of moisture. In fact, this inverse relation was perfect; the rankings of the bottom blotter and the fabric(as shown in Table 2) had a correlation of −1. This indicates that when the bottom blotter transmitted more moisture, the fabric stayed wetter and vice versa.

The difference between the average percent change in moisture from the best(blue/back) to the worst(white/face) combination for the bottom blotter was 2.33%(.064g/cm^2). The comparison between the best(white/face) and the worst (blue/back) combination for the fabric was 12.81%(.096g/cm^2). Since there was a larger difference between the best and the worst fabric than there was between the best and the worst bottom blotter, a compromise ought to favor the fabric. However, it was the top blotter that was important in understanding the capability of the fabric to transfer moisture that it received. Note that even though the blue/face was the fourth driest bottom blotter and the third driest fabric, it had the wettest top blotter(Table 2). This suggests that blue/face was transporting relatively more moisture than the other samples. It appears that the combination blue/face was a good compromise for keeping both the bottom blotter and the fabric dry.

3. Planned Comparisons

Nine planned comparisons were performed in the ANOVA for each of the three variables and the results are shown in Table 3. They are listed in such a manner that in each comparison, the better fabric structure/side combination is listed first. For example, white/back versus white/face can be interpreted as the white fabric structure/back side being better than white fabric

Table 2. Average Percentage Change in Moisture Content

Fabric Structure		Bottom Blotter Wet Weight			Fabric Weight			Top Blotter Weight		
Side		%	Std Err	Rank	%	Std Err	Rank	%	Std Err	Rank
Face										
	White	8.93	0.26	6	0.94	0.87	1	2.18	0.34	6
	Black	8.96	0.26	5	1.58	0.87	2	4.26	0.34	2
	Blue	9.73	0.26	4	4.24	0.87	3	5.01	0.34	1
Back										
	White	10.24	0.26	3	7.57	0.87	4	2.41	0.34	5
	Black	10.98	0.26	2	10.35	0.87	5	3.24	0.34	4
	Blue	11.26	0.26	1	13.75	0.87	6	3.26	0.34	3

Note: The ranks refer to the relative merit of the fabric structure/side combination for a particular variable. Therefore, a rank of 1 means this is the best fabric structure/side combination for this variable. A rank of 6 means it is the worst.

structure/face side for the percentage change in bottom blotter wet weight. The comparisons are grouped in three groups of three. The first trio represents back to face comparisons within a fabric. The second trio provides fabric comparisons when the fabric face is towards the moisture source. The third trio gives fabric comparisons when the fabric back is towards the moisture source.

First Trio — For each fabric, the back was significantly better than the face from the perspective of the bottom blotter losing moisture. In contrast, the face was significantly better than the back for all fabrics from the viewpoint of the fabric transferring moisture. Thus to resolve this impasse, the role of the top blotter became important. When analyzing the data for the top blotter, no difference was found between sides(face/back) of the white fabric(p=0.63), but there was a difference in the other two fabrics. In both the black and blue fabrics, the face was better than the back with the blue face(p=0.0003) being much better than the black face(p=0.03). It is this finding that indicates that the blue/face combination was the best choice of fabric structure/side combination in this study.

Second Trio — Examination of the bottom blotter data indicated that when the face side of the fabric was down towards the moisture source, the blue fabric was significantly better than either the black or white fabric(p=0.04, p=0.03). The black and white fabrics were not significantly

Table 3. Planned Comparisons of Average Percentage Change in Moisture Content(t value, p-value)

	Bottom Blotter Wet Weight	Fabric Weight	Top Blotter
Back to Face Within a Fabric:			
	White Back vs White Face (t=3.56, p=0.0005)	White Face vs White Back (t=−5.48, p=0.0001)	White Back vs White Face (t=0.49, p=0.63)
	Black Back vs Black Face (t=5.46, p=0.0001)	Black Face vs Black Back (t=−7.25, p=0.0001)	Black Face vs Black Back (t=2.15, p=0.03)
	Blue Back vs Blue Face (t=4.13, p= 0.0001)	Blue Face vs Blue Back (t=−7.87, p=0.0001)	Blue Face vs Blue Back (t=3.70, p=0.0003)
Fabric Face Toward Moisture:			
	Blue Face vs Black Face (t=2.10, p=0.04)	Black Face vs Blue Face (t=−2.20, p=0.03)	Blue Face vs Black Face (t= 1.59, p=0.11)
	Black Face vs White Face (t=0.08, p=0.94)	White Face vs Black Face (t=−0.53, p=0.60)	Black Face vs White Face (t=4.41, p=0.0001)
	Blue Face vs White Face (t=2.18, p=0.03)	White Face vs Blue Face (t=−2.73, p=0.007)	Blue Face vs White Face (t=6.00, p=0.0001)
Fabric Back Toward Moisture:			
	Blue Back vs White Back (t=2.75, p=0.007)	White Back vs Blue Back (t=−5.11, p=0.0001)	Blue Back vs White Back (t=1.81, p=0.07)
	Black Back vs White Back (t=1.98, p=0.05)	White Back vs Black Back (t=−2.30, p=0.02)	Black Back vs White Back (t=1.77, p=0.08)
	Blue Back vs Black Back (t=0.77, p=0.44)	Black Back vs Blue Back (t=−2.81, p=0.0055)	Blue Back vs Black Back (t=0.04, p=0.96)

Note: For each comparison the better fabric structure/side is listed first.

different(p=0.94). These findings were reversed with respect to the fabric(from the perspective of keeping the fabric dry). The white and the black fabrics were significantly better than the blue fabric(p=0.007, p=0.03), but not significantly different from each other(p=0.60). The results support the idea that the top blotter behaved more like the bottom blotter when the face side was down. The blue fabric was better than the black fabric, but not significantly so(p=0.11), and both were significantly better than the white fabric (p=0.0001, p=0.0001). The results support the idea that the top blotter behaved more like the bottom blotter when the face side was down. The blue fabric was better than the black fabric, but not significantly so(p=0.11), and both were significantly better than the white fabric(p=0.0001, p=0.0001).

Third Trio – When the back side of the fabric was down towards the moisture source, the ordering for the bottom blotter was the same as with the face side down. The blue fabric was significantly better than the white fabric(p=0.007) and better than the black fabric, but not significantly so(p=0.44). The black fabric was also significantly better than the white fabric(p=0.05).

The ordering for the fabric was the same with the back side down as it was when the face side was down. The white fabric was significantly better than the black fabric(p=0.02) and the black fabric was significantly better than the blue fabric(p=0.0055). The ordering for the top blotter matched that for the bottom blotter. The blue fabric was better than the black fabric which was better than the white fabric, but none of the differences was significant.

Ⅳ. Conclusions

The purpose of the study was to determine the combination of fabric structure variation, fabric side and pressure that transported the most moisture across the structure. Differences existed between the three fabric samples and their moisture transport properties. The white fabric was the least effective in moisture transport. The heavyweight blue fabric with a medium amount of napping and high knit gauge demonstrated the most effective moisture transport properties.

Differences did exist between the face(napped) and the back of the fabrics with respect to their ability to transport moisture. This was evident with the blue and black fabrics, but not so for the thick, heavily napped white fabric. Its napped fabric surface structure provided a barrier to moisture transport, either by reducing the capillary effort due to increased fabric bulk or by increasing the distance between top and bottom layers of the fabric surfaces. The face of the blue fabric was the best combination(fabric structure/side) for transporting moisture, with the black face being the next best combination(fabric structure/side). Previous research indicates that napping is effective in interposing a barrier to the transfer of water(Fourt and Hollies, 1970). This was evident with the white fabric, a looped terry velour, which was both the thickest and most heavily napped, but created a poorer capillary system due to the fabric structure.

The results led the researchers to conclude that in general, pressure played little or no role in the transfer of moisture in this study. The researchers would recommend that future replications of the small scale moisture transport test method used here not include the application of weights. When controlling for fiber content and fabric structure, important moisture management guidelines would be to use a medium amount of napping and to place the face of the fabric(napped side) toward the moisture source. This will enhance the ability of the fabric structure to effectively transport the moisture away from the skin and to assist in the evaporative cooling process. The test method used in this study was simple, easy to perform, inexpensive, and provided a good understanding of the moisture transport system as defined by the objectives of this study.

V. Acknowledgment

The authors wish to express special gratitude to Naturally, Knits, Inc. for its partial financial support for this research. Appreciation is also extended to Mark Taylor, a graduate research assistant, for his assistance in producing the scanning electron micrographs of the fabric samples and to UNCG Biology Department for its SEM facilities.

References

AATCC Technical Manual, 72, 21–23, 1997.

Miller, B & Tyomkin. I., Spontaneous Transplanar Uptake of Liquids by Fabrics, *Text. Res. J.*, **54**(10), 706–712, 1984.

Annual Book of ASTM Standards, 7(2), ASTM, West Conshohocken, Pa, 1996.

Bogaty, H., Hollies, N. R. S., Hintermaier, J. C., & Harris, M., *Text. Res. J.*, **23**, 536–544, 1953.

Brundrett, G. W., Criteria for Moisture Control, Butterworth & Co. Ltd., London, 1990.

Crippen, L. K., Moisture Transport Properties of Selected Knit Fabrics, dissertation, University of North Carolina at Greensboro, 1975.

Crow, R. M., & Osczevski, R., The Interaction of Water with Fabrics, *Text. Res. J.*, **68**(4), 280–288, 1998.

Farnworth, B., & Dolhan, P., Apparatus to Measure the Water Vapour Resistance of Textiles, *J. Text. Inst.*, **75**(2), 142–145, 1984.

Fourt, L., & Hollies, N.R.S., Clothing Comfort and Function, Marcel Dekker, Inc., New York, 1970.

Ghali, K., Jones, B., & Tracy, J., Experimental Techniques for Measuring Parameters Describing Wetting and Wicking in Fabrics, *Text. Res. J.*, **64**(1), 106–111, 1994.

Gibson, P., Factors Influencing Steady–state Heat and Water Vapor Transfer Measurements for Clothing Materials, *Text. Res. J.*, **63**(12), 749–764, 1993.

Harnett, P. R., & Mehta, P. N., *Text. Res. J.*, **54**(7), 471–478, 1984.

Hatch, K. L., *Textile Science*, West Publishing Company, Minneapolis/Saint Paul, 1993.

Hsieh, Y., Liquid Transportion Fabric Structures, *Text. Res. J.*, **65**(5), 299–307, 1995.

Hong. K., Hollies, N. R. S., & Spivak, S. M., Dynamic Moisture Vapour Transfer Through Textiles (Part Ⅰ: Clothing Hygrometry and the Influence of Fiber Type) *Text. Res. J.*, **58**(12), 697–706, 1988.

Kim, J. O., & Spivak, S. M., Dynamic Moisture Vapour Transfer Through Textile (Part Ⅱ: Further Techniques for Micro) *Text. Res. J.*, **64**, 112–121, 1994.

Kissa, E., Wetting and Wicking, *Text. Res. J.*, **66**(10), 660–668, 1996.

Meinander, H., Clothing Physiological Measurements on winter Workwear Materials with a Sweating Cylinder, *J. Text. Inst.*, **79**(41), 620–633, 1988.

Tom, P. A., Apparel Ind. Mag., November, **58**, 64–68, 1997.

Wallenberger, F. T., Franz, K., Dullaghan, M. E. Schrof, W. E. J., *J. of Eng. for Ind.*, **102**, 1–6, 1980.

Watkins, D. A., & Slater, K., The Moisture Vapour Permeability of Textile Fabrics, *J. Text. Inst.*, **72** 11–18, 1981.

Wehner, J. A., Miller, B. & Rebenfeld, L., Dynamics of Water Vapour Transmission Through Fabric Barriers, *Text. Res. J.* **58**(10), 581–592, 1988.