Water Transmission through Chemical Protective Clothing Materials

Mehreen Ijaz[1*], Samia Kalsoom[2], Niaz Ahmed Akthar[3]

1. *Department of Home Economics, Lahore College for Women University*
2. *Government College of Home Economics, Gulberg Lahore*
3. *University of the Punjab, Lahore*

∗ **Corresponding author**: Email: mehreenijaz@hotmail.com

Abstract

This present study aims at investigating the role of water transmission in the clothing materials used for manufacturing chemical protective coveralls for various chemical industries in Pakistan. The research was conducted at Nishat Mills Limited (Dyeing and Finishing Unit). The samples were tested for their water transmission behavior both in water and vapour form at various laundering intervals by following AATCC 79-2010 and AATCC 197-2011 respectively. The results indicated that all the tested samples were unable to resist water and completely wet even at initial washing intervals and their condition became worse with an increasing number of laundering cycles. At 20th wash, the sample S-1 made with polyester fiber was able to resist wetting only for 0.15 seconds and cotton fiber S-2 resisted water for 8.84 seconds, whereas, sample S-3 made with a combination of cotton and polyester with a blend ration of (45/55) resisted up to 29.94 seconds which showed its better performance as compared to the other samples. Similarly, in the case of their wicking behavior, the water travelled from the sample S-3 was 14.5 cm at 10 minutes in the warp direction and 13.3 cm in the weft direction at the 20th wash. The water travelled from sample S5 was 17cm in its warp and weft directions which completely wet the whole specimen. It shows the poor performance of the specimen in evaluating its wicking behavior.

Key words: Water Transmission, Absorbency, Wicking Behavior, Protective Clothing, Laundering intervals

1. Introduction

Protective clothing is not only manufactured for its aesthetic appeal, but to protect the wearer from certain hazards such as physical, chemical or biological around the environment. It should be critically evaluated for its comfort and performance characteristics. These materials must be manufactured to manage moisture and regulate body temperature in order to provide comfort to the wearer while at work [1].

Fabrics are designed to produce certain desired characteristics with appropriate type of fiber, bonding procedures and various finishes. There are certain parameters which should be kept in mind while manufacturing protective clothing. One of the major components is the fiber; its kind and nature plays an important role in determining the performance behavior of fabrics throughout their life [2]. Chemical protective clothing must act as water/fluid barrier, resist burning action, and be able to give protection against extreme high temperatures. Various types of fabrics are used for manufacturing chemical protective clothing. These fabrics can be made from natural fibers such as cotton and wool or synthetic fibers like plastic or rubber. Reusable protective clothing materials should retain their required features throughout various laundering cycles [3] Evaluation of such fabrics in terms of providing protection becomes hard in its theoretical approach so it has to be verified through certain experiments for their mechanical and chemical characteristics. Testing of chemical protective items is necessary due to great differences in the generic materials from which they are developed [4].

A lot of research has been conducted to study the relationship of water and fabric in order to improve and enhance the better performance of manufactured garments for various end uses [5]. Water transmission in clothing materials refers to the wicking behavior and their absorbent action [6].

Liquid absorption in clothing materials is affected by the size of capillaries in them. Wider capillaries are the major cause of low capillary action whereas; narrow capillaries result in high capillary action because they assist in taking up moisture quickly and easily. This action is stopped when all parts of clothing structure are equally wet. This phenomenon is based on cohesion and adhesion forces. The capillary action initiates when adhesion forces of liquid are greater as compared to cohesion intermolecular forces [7]. The fabric surface is wet by the liquid and enters into the spaces present between them to initiate a capillary action. The liquid is dragged into the capillaries due to the narrow spaces and the curved nature of yarns [8].

Wetting and wicking are inter-related terms. Wetting is a pre requirement for wicking action. A liquid such as water that cannot wet the fiber will also be unable to wick the material. Wetting is considered as the initial contact of liquid with fabric and wicking is its next stage. These two stages are helpful in determining the ability of water to transmit through clothing structures [2] and [9]. The process of wetting rises with a decrease in the surface tension between the surface of fabric and liquid. On the other hand, an increase in the surface tension due to an increase in the liquid viscosity results in the reduction of wetting [10]. There are many forces that play a major role in water transmission through fabrics such as physical activity of the wearer, moisture content in the surrounding air, structure of fabric, nature of fiber, yarn type and count, fabric density etc. [2] and [11].

The main objective of the current study was to evaluate the process of water transmission through clothing materials. The objective was achieved by studying the absorbent action and wicking behavior of clothing materials. Thus, this information plays a significant role in designing protective clothing materials for working in an industry.

Table 1: Construction parameters of samples

Code	Fiber	Fabric weight	Thread count	Linear Density (Warp)	Linear Density (Weft)
S-1	Polyester 100%	125	216	17.216	17.938
S-2	Polyester 100%	132	104	36.575	35.542
S-3	Cotton 45% Polyester 55%	155	140	19.949	18.806
S-4	Cotton 100%	110	228	26.599	26.362
S-5	Cotton 95% Polyester 5%	121	136	13.301	15.321

2. Materials and Methods

Locally manufactured clothing materials (n=5) used for chemical coveralls were randomly selected from various chemical units in Pakistan. Companies with their head offices located in the vicinity of Lahore were approached to gather the sample. Selected companies provided the required sample under non-disclosure agreement barring the researcher from publishing their identities in any part of the research work. As it was observed that few units / industries totally ignored safety measures in terms of providing accurate protective clothing to their employees. The samples were characterized according to their construction parameters such as fiber content, fabric mass, linear density and thread count. These materials were evaluated for their water absorbency and wicking behavior. These clothing materials are mentioned in the Table 1 along with their construction specifications. The clothing materials were labeled accordingly and evaluated for their water transmission action. The obtained samples were laundered by AATCC test procedure [12]. 20 laundering cycles were given to each sample. After every five laundering cycles, the materials were assessed for their absorbency and wicking action. The water absorbency was evaluated by following 'Drop test' AATCC 79-2010 [13].

This method helped to measure the rate of water resistance in the tested fabrics and also determined the durability of particular finish applied on the surface of fabrics. Wicking behavior was determined by following 'Vertical Wicking Test' AATCC 197-2011 [14]. This procedure was used to measure the rate of liquid flow along the vertical length of tested sample. Before testing each specimen was brought into moisture equilibrium under a standard atmosphere by following ASTM D1776 test method [15]. The test specimens of 200 mm x 200 mm were cut from collected samples to measure their water absorbency. Wrinkle free specimen was mounted in an embroidery frame, which was placed under the burette in a tilted manner. A drop of distilled water dropped on the surface of specimen. Five drop tests were dropped on each specimen. The drop site was 25mm away from the loop edge and from each of the other drop-site. Stopwatch was turned on as the droplet dropped on the fabric surface and it was turned off when the drop lost its reflectivity and turned into a wet spot. The time was recorded in seconds. In order to evaluate the wicking action, the specimens were cut with dimensions of 170mm x 25mm both in warp and weft directions. One end of the cut strip was clamped in a vertical position and the other edge was immersed 3mm in a beaker with distilled water at 21◦C. The rate of water flow in liquid form was evaluated at various intervals of 1, 5 and 10 minutes. The readings were recorded in centimeters.

Table 2: Drop penetration of samples

Sample Code	Drop test (Measured in seconds)				
	0-Wash	5-Washes	10-Washes	15-Washes	20-Washes
S-1	60	33.08	18.82	0.52	0.15
S-2	60	21.58	9.26	6.96	3.72
S-3	60	60	50.72	41.82	29.94
S-4	57.94	39.04	15.88	10.22	8.84
S-5	60	4.72	4.02	3.38	1.68

3. Results and Discussion

Water molecules in the fibers lost their strength by reducing the forces that hold the molecular chains together [16]. After evaluating the water penetration of all samples through the drop test, (Table 2) it was clearly seen that more water was penetrated through the clothing materials with an increasing number of laundering cycles. Most of the tested samples did not penetrate water at zero wash, but with an increasing number of washing cycles, their time of absorption became less and the fabric wetted soon. This fact was also supported by [17], that the type of fiber plays a major role in transmitting water molecules. The hydrophilic nature of fibers has the capacity to absorb water molecules and then diffuse in the fibrous structure. This absorption of water causes the swelling of fibers and then size of air space reduces that finally reduces this diffusion process. The main reason is the reduction in the fabric relaxation during this process. It was clearly observed that sample S-3 composed of cotton and polyester with a blend ration of (45/55) performed well till the last wash. But as the number of washing cycles increased, it also penetrated water within few seconds. According to the specifications international standard of drop penetration method, the sample should resist water for 60 seconds at each Micropourous films or coatings applied on the textile materials assist in making breathable and water replellent products [18, 19, 20]. It was observed [21] that finished fabrics had lower rate of wick-ability than unfinished textile materials. So, these fabrics are considered to be safer for use by workers involved in chemicals. These materials do not provide discomfort to the wearer by wetting their body with transfer of liquid from surface of the material to the outer skin. Wetting makes hydrophilic fibers to swell and create a change in their capillary spaces which results in poor wicking action. These materials are laminated or coated to resolve such issues [22]. On the other hand, synthetic fibers such as polyester are hydrophobic and provide higher rate of wick-ability as compared to natural fibers [23]. These materials are often treated with hydrophilic coatings and finishes for improved moisture transport behavior [24]. The tested samples of protective clothing materials were not considered appropriate for chemical workers as if vapours of toxic chemicals reach the skin of the wearer, can result in skin irritation, burn injuries or even cause skin cancer. It was also observed that finishing treatments from tested materials broke out easily with increasing number of washing cycles due to their inferior quality. Water transmission through clothes is largely dependent on liquid-fiber molecular attraction forces, their pore size, distribution pattern of spaces in the yarns and surface tension. The transmission process of moisture content as well as capillary action should be studied to get the deep understanding of this phenomenon [25]. According to the international safety standard for vertical wicking of chemical clothing materials, the sample should not wick more than 2cm within first 5 minutes of observation. It was observed that water travelled quickly in all tested samples and their rate of travelling was increased with an increasing number of washing cycles (Table3).

Table 3: Wicking action of samples in warp direction

Code	Wicking at 1 minute in warp direction (Measured in centimeters)					Wicking at 5 minutes in warp direction (Measured in centimeters)					Wicking at 10 minutes in warp direction (Measured in centimeters)				
	0 W	5 W	10 W	15 W	20 W	0 W	5 W	10 W	15 W	20 W	0-W	5 W	10 W	15 W	20 W
S-1	1.9	4.9	6.5	6.9	7.6	3.2	6.9	10.7	11.6	13.5	5.5	9.6	13.1	14.5	16.7
S-2	1.5	5.1	6.6	7.1	7.7	1.9	7.5	10.9	12.1	13.6	2.3	9.8	13.5	14.8	16.9
S-3	2	4.3	5.5	5.8	6.5	3.5	6.7	9.9	10.7	11.3	4.5	8.2	11.8	12.4	14.5
S-4	3.1	5.1	6.4	6.6	7.3	5.2	7.2	10.6	11.4	13.1	6.9	8.9	12.9	13.9	16.6
S-5	1.2	7.1	8.6	9.2	10.1	1.9	10.6	12	13.3	15.9	2.6	15.1	17	16.3	17

Out of these samples, sample S-3 performed better. It can be stated that the rate of absorbency and moisture transmission in clothing materials may help to determine the amount of liquid and vapors absorbed by fabrics from the human body. In such cases, wicking action, drying time and permeation characteristics greatly affect the thermal properties of textile materials [22]. Yarn type has a significant role in determining the wicking properties of fabrics. It was studied that low twisted yarns had capillaries with a wide diameter that resulted in poor wick-ability of tested materials [26].

The low quality of fibers and yarns used in manufacturing tested samples was the main reason of their poor performance both in drop and wicking test (Table 4). Moreover, poor use of and an absence of lamination and coatings aggregate this problem. The need and importance of coatings have also been investigated by Laamanen and Meinander [27]. Substandard coatings are unable to bond with the fabric surface and cracks up more quickly with rubbing and washing procedures. This cracking allows the liquid / water to penetrate through the fabric structure.

Fung [28] and Leonas [29] also emphasized the use of adequate and uniform coatings in order to resist wetting in clothing materials for better protection against fluids liquids. These finishes help the textile material to perform better as compared to the unfinished article.

Table 4: Wicking action of samples in weft direction

	Wicking at 1 minute in weft direction (Measured in centimeters)					Wicking at 5 minutes in weft direction (Measured in centimeters)					Wicking at 10 minutes in weft direction (Measured in centimeters)				
	0 W	5 W	10 W	15 W	20 W	0 W	5 W	10 W	15 W	20 W	0 W	5 W	10 W	15 W	20 W
S-1	1.5	4.3	6.1	6.6	7.2	2.9	6.5	9.8	10.1	11.9	5.1	9.2	12.6	13.9	15.8
S-2	1.9	5.6	6.9	7.8	8.4	2.3	8.1	11.3	12.7	14.3	2.9	10.2	13.9	15.3	17
S-3	1.8	2.8	4.9	5.6	6.1	2.9	6.1	8.5	9.9	10.6	3.7	8.1	11.6	12.1	13.3
S-4	2.5	4.7	5.9	6.4	6.9	4.1	6.8	9.9	10.6	12.1	6.1	8.2	11.9	13.1	15.3
S-5	1.7	7.5	9.1	10.3	11.2	2.2	10.9	12.6	14.2	15.3	3.1	16.2	17	17	17

4. Conclusion

This study concludes that all the tested samples failed to meet international safety standards and even their behavior deteriorated with each washing cycle. The protective clothing material manufactured with a blend of cotton (45%) and polyester (55%) performed comparatively better. Findings of this study can assist manufacturers to review their construction parameters in designing chemical protective clothing materials for the safety of the wearer.

5. References

[1] Mani, K. and Sivakkumar, V (2011). Chemical protective clothing. *Pakistan Textile Journal*: 40-43

[2] Hepburn, C. D. (1998). *The wicking of water through multi-layer fabric*

assemblies. Doctoral dissertation. University of Leeds.

[3] Cerbini, S., & Ioco, P. L. (2004). U.S. Patent No. 1,446,200. Washington, DC: U.S. Patent and Trademark Office.

[4] Bassett, R. J., Postle, R., & Pan, N. (1999). Experimental methods for measuring fabric mechanical properties: A review and analysis. *Textile Research Journal*, 69(11), 866-875.

[5] Ding, X. (2008). *Fabric testing*. New York: CRC Press, 189-224.

[6] Singh, K. V. P., Chatterjee, A., and Das, A (2010). Study on physiological comfort of fabrics made up of structurally modified friction-spun yarns: Part II-Liquid transmission. *Indian Journal of Fibre and Textile Research*, 35(1): 134-138.

[7] Simile, C. B. (2004). *Critical evaluation of wicking in performance fabrics*. Master thesis, Georgia Institute of Technology.

[8] Das, B., Das, A., Kothari, V. K., Fanguiero, R., and Araujo, M (2007). Moisture transmission through textiles. Part I: processes involved in moisture transmission and the factors at play. *Autex Research Journal*, 7(2): 100-110.

[9] Ghali, K., Jones, B., & Tracy, J (1994). Experimental techniques for measuring parameters describing wetting and wicking in fabrics. *Textile Research Journal*, 64(2): 106-111.

[10] Chatterjee, P. K. (1985). *Absorbency*. New Jersey: Elsevier Scientific Publishing Company.

[11] Berger, X., & Sari, H. (2000). A new dynamic clothing model. Part 1: Heat and mass transfers. *International Journal of Thermal Sciences*, *39*(6): 673-683.

[12] AATCC. (2013). Monograph M6. Standardization of home laundry test conditions. American Association of Textile Chemists and Colorists: 444-446.

[13] AATCC. (2010). Absorbency of Textiles. American Association of Textile Chemists and Colorists. Retrieved from http://members.aatcc.org/store/tm79/499/

[14] AATCC. (2011). Vertical wicking of Textiles. American Association of Textile Chemists and Colorists. Retrieved from http://members.aatcc.org/store/tm79/499/

[15] ASTM. (2010). ASTM D1776 Standard practice for conditioning and testing textiles. West Conshohocken, PA: ASTM International. Retrieved from http://www.astm.org/Standards/D1776.htm

[16] Booth, J.E. (1996). *Principles of textile testing*. New Delhi: CRC Press.

[17] Pause, B. (1996). Measuring the water vapor permeability of coated fabrics and laminates. *Journal of Industrial Textiles*, 25(4): 311-320

[18] Whelan, M. E., MacHattie, L. E., Goodings, A. C., & Turl, L. H (1955). The Diffusion of Water Vapor through Laminae with Particular Reference to Textile Fabrics Introduction. *Textile Research Journal, 25*(3): 197-198.

[19] Fanglong, Z., Weiyuan, Z., & Minzhi, C (2007). Investigation of Material Combinations for Fire-fighter's Protective Clothing on Radiant Protective and Heat-Moisture Transfer Performance. *Fibres & Textile in Eastern Europe*. 15(1): 72-75.

[20] Holmes, D. A. (2000). *Textiles for survival*. Handbook of Technical Textiles,12, 461.

[21] Li, Y. C. (2011). *Environmentally Benign Flame Retardant Nano coatings for Fabric*. Doctoral dissertation. Texas A&M University.

[22] Das, B., Das, A., Kothari, V., Fanguiero, R., & Araujo, M. D. (2009). Moisture flow through blended fabrics–Effect of hydrophilicity. *Journal of Engineered Fibers and Fabrics*, 4(4): 20-27.

[23] Kadolph, S. J. (2007). *Quality assurance for textiles and apparel*. Fairchild Publications.

[24] Lee, K. (2014). *Design Implementation, Fabric Analysis, and Physiological and Subjective Testing of a Sportswear Garment Prototype*. Doctoral dissertation, Auburn University.

[25] Slater, K. (1986). The assessment of comfort. *Journal of the Textile Institute*, 77 (3): 157- 171.

[26] Chinta, S.K & Gujar, P.D. (2013). Significance of moisture management for high performance textile fabrics. *International Journal of Innovative Research*, 2(3): 814-819.

[27] Laamanen, H., and H. Meinander (1996). *Environmental Ergonomics. Recent*

Progress and New Frontiers. England: Freund Publishing House, Ltd, 221-224.

[28] Fung, W. (2002). *Coated and laminated textiles*. England: Woodhead Publishing, 24-71.

[29] Leonas, K. K. (1998). Effect of laundering on the barrier properties of reusable surgical gown fabrics. *American Journal of Infection Control*, 26(5): 495-501.