Characterizing the Transplanar and In-plane Water Transport Property of Fibrous Materials under Different Sweat Rate: Forced Flow Water Transport Tester

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ABSTRACT

Water absorption and transport property of textiles is important since it affects efficiency of treatment, product's functionality and comfort. Moisture in clothing may lead to clamminess sensation, fabric which could keep skin dry and maintain thermo-physiological comfort is desired. Thus, a sensitive, accurate and reliable water absorption and transport measurement method is required. A measurement tester based on gravimetric and image analysis technique, with the ability to trace the direction of water spread and measure the amount of water on simulated skin, is to be developed. Throughout the experiment, water supply is continuous and controllable simulating different sweating levels based on end-uses, assuming the sweat rate is dependent on activity level and environment (constant physiological response with the change in garment). For product developer, this is useful when selecting fabric for a particular activity and environment. Correlation with subjective wetness sensation is planned to examine its reality to actual wear condition. Compared with conventional testing methods like wettability, moisture management tester, vertical and horizontal wicking test, the proposed instrument is simple, versatile and closer to wear condition with short testing time and low cost. With this instrument, fabric could be characterized efficiently which would be beneficial to the textile industry.

Keywords: Water absorption and transport, transplanar wicking, in-plane wicking, sweat rate, fabrics

1 INTRODUCTION

Moisture in clothing has been widely acknowledged as one of the fundamental factors contributing to discomfort during wear [1, 2]. Fukazawa and Havenith [3] found that in warm environment or during exercise, moisture in skin is highly correlated to thermal discomfort, even more than skin surface temperature, proving the importance of water absorption and transport property of the fabric. Galbraith et al. [4] also found that the major factor causing discomfort was the excess amount of sweat remaining on skin surface. Thus it is worthwhile to study the absorption ability and transport property of fabric since it is crucial in facilitating the evaporation of sweat, cooling our body, minimizing the wetness sensation of skin and aiding comfort.

Despite the comfort perspective, liquid absorption and transport property of fabric is important during the processing stage. Fabrics with hydrophilic nature could ensure uniformity, efficiency and evenness of the treatment. That is the reason why wetting agent is usually recommended in the conventional flame retardant finishing recipe. Also, a desizing and scouring process is required before the bleaching process of cotton so as to remove the wax and increase its affinity with water; otherwise the poor absorbency of the grey cotton fabric could hamper the efficiency for further processing. In addition, wettable substrate is desirable for the dyeing and printing process to ensure uniform and efficient coloration. All these examples demonstrate the needs for absorbing fabrics and thus the demand of an effective measurement method on water absorbency.

In order to realistically study the wetness sensation, subjective test was traditionally adopted. However, the variability between the participants and many uncontrollable errors do exist. In order to reduce error by some extremities, a large sample size should be tested and this would be a time-consuming and costly task. This hinders the use of subjective test to quantify the performance of fabric and so objective evaluation methods have gained its importance. However, majority of the conventional testing methods have limited implication in clothing comfort and obtain inadequate information about water transport property of fabric. The testing duration is rather long and the cost for machinery is costly with low repeatability. All these shortcomings associated with the growing demand on clothing comfort pose an insatiable desire on an innovative evaluation method. Therefore, the aim of this study is to fill this research gap to develop a novel testing method. Different testing parameters, such as effect of injection rate (simulating different sweat rate), applied pressure, wind speed, and the selection of reference material, sample stage and simulated skin layer, will be investigated. Meanwhile, based on the calibration result, a Forced Flow Water Transport Tester for characterizing the transplanar and in-plane water transport property of fibrous materials under different sweat rate will be assembled.

2 IMPORTANCE OF WATER ABSORPTION AND TRANSPORT PROPERTY OF FABRIC

Water transport property of apparel fabric is important in determining thermo-physiological comfort of the wearer. Textile fabric, located in-between skin and the ambient environment, determine the efficiency of sweat to leave our body. If the resistance to water transport of a fabric is high, water movement is impeded, the skin will cover with a film of water and the wearer may have a discomfort sensation of dampness and clamminess. The extent of sweat produced varies with activity level, heat and moisture transport property of the garment and the ambient condition [5-7]. If sweat cannot be dissipated quickly, the humidity between the skin and the fabric rises. In hot conditions, this increased humidity prevents evaporation of sweat on skin and gives a hot sensation. Consequently, the body responds with increased sweating to dissipate excess thermal energy [8] and suffer from fatigue. In cold condition, trapped moisture decreases body temperature, gives chilling sensation and may cause hypothermia. Thus an ideal fabric should prevent the accumulation of sweat on the skin surface by allowing the respired body water to pass to the outside environment or outer layer of clothing.

The perceived comfort is affected by the distribution of sweat in textiles, its location and spreading area. Wet fabric has higher coefficient of friction [9], stimulating the mechanoreceptor in skin and evoking discomfort sensation. This problem will be more severe if sweat is distributed next to skin surface and the sweat-covered area is large. Instead, if the sweat could be absorbed and transported immediately to outside environment, wetness sensation could be relieved. Once again, it demonstrated the importance of liquid transport property of fabric and the significance of knowing the direction of water transport. The distribution of liquid on different sides of fabric has been studied extensively. Moisture management tester (MMT) [10] uses two sets of metal pins to measure the resistance change on both sides of fabrics. However, the direction of water transport does not simulate the actual wear condition. Cao et al. [11] mentioned a method that a wetted fabric was sandwiched between two filter papers and the amount of water absorbed by each filter paper was weighted to study the water distribution on different sides of a fabric. Nonetheless, the water supply was dropped from the top and not continuous, gravitation may pull the droplet down in addition to a pure capillary action. Scheurell et al. [12] have used an indirect method - a chemical moisture indicator (cobalt chloride) to measure dynamic moisture movement at fabric surfaces next to skin, but the addition of chemical may change the surface tension and viscosity of the liquid, limiting its implication in real wear situation. Overall, the belief of these methods is that the amount of moisture in fabric-skin interface is reversely proportion to wear comfort. A comparison of the proposed tester and the conventional testing methods are shown in Table 1.

Method	Advantages	Limitations/ Potential problems
Proposed method – Forced Flow Water Transport Tester	- Continuous water supply simulating profuse sweating condition - Water was supplied at the bottom of fabric and this direction of water flow is close to the actual wear situation - Capable of simulating different sweat rates - With the possibility to differentiate the direction of water flow - Applicable to test multi-layers - Can measure and differentiate transplanar and in-plane water transport	- Not accessible to study the time-dependence of moisture distribution within a textile layer.
Areal wicking 'spot' test (BS 4554) (AATCC 79)	- Simple - Low operation cost - Short operation time - No specific equipment required	- Prone to be interfered by subjective factors - The use of sucrose solution does not simulate the actual wear condition - Discontinuous water supply - Designed for absorptive fabric, but not applicable to highly absorptive one (with absorption time longer than 60 s is defined as unwettable) - Only measure the in-plane wetting
Longitudinal wicking 'stripe' test (AATCC 197) (BE 3424-18) (DIN 53924)	- Simple - No specific instrument required	- The uneven spreading pattern complicates the measurement - Not accessible to study the space- and time-dependence of

Method	Advantages	Limitations/ Potential problems
		moisture distribution within a textile layer - Time-consuming for sample preparation - The direction of water flow has limited implication in clothing comfort - Only measure in-plane water transport
Horizontal wicking test (AATCC198)	-Simple - No specific instrument required - Short testing duration	- The dynamic wicking behavior is not measured - The volume of material being wet might not be proportional to the wetted area observed from the top (especially for moisture management fabric or multilayer fabric due to different spreading speed in different sides of fabric) → Poor accuracy - Not suitable for dark color fabric - Not suitable for fabrics with poor absorbency - Only measure in-plane water transport
Moisture Management Tester [10]	- Wetting times can be compared with the drop test result and was performed in a more objective way - Applicable to dark color fabrics and fabrics with fast absorption rate - Simple and user-friendly - The transplanar and wicking properties could be measured and estimated from the electrical value of the pins	- The drop of water was from top of fabric and gravitation may pull the droplet down in addition to a pure capillary system. - Does not resemble the profuse sweating condition - Not suitable for long pile fabrics, conductive material, coated, laminated fabrics or complex fabric constructions - The use of saline water may oxidize the metal pins - Certain time is needed to dry the pins to ensure reproducible result - Lack of systematic good calibration method

Table 1: Different tsting methods of water absorption and transport.

3 SET-UP

The proposed Forced Flow Water Transport Tester is diagrammed in Figure 1.

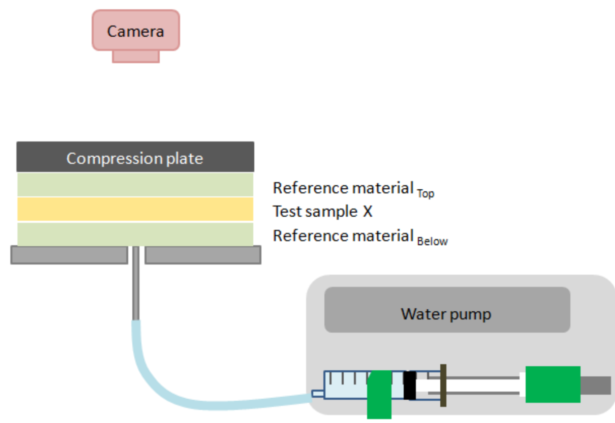

Figure 1: Construction of the Forced Flow Water Transport Tester.

Highlights of the Forced Flow Water Transport Tester as shown in Figure 1 are listed below:

- The rate of water supply is adjustable to simulate varying sweat rates with reference to the specific end-use conditions ranging from sitting, walking, running to other strenuous activities,
- Capability of simulating the wearing condition with differential stress levels,
- Capability of tracing the direction of water transport with the ability to estimate the amount of water left on skin when sweating,
- Versatility in terms of the types of fabrics can be tested (including hydrophobic fabrics, towels, diapers, moisture management fabrics or fabrics having very high water absorption rate),
- water was supplied from the bottom to the back side of the sample to minimize the gravitational effect on absorption,
- Efficient, and
- Simple setup

4 DATA COLLECTION

In the Forced Flow Water Transport Tester, a series of data can be collected which is summarised in Figure 2

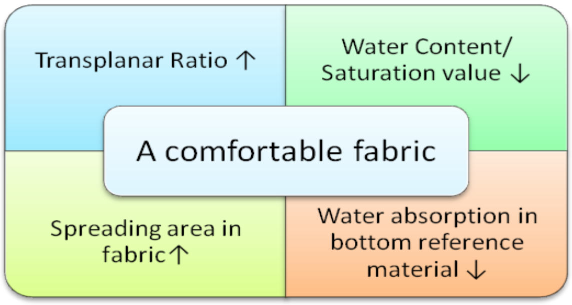

Figure 2: Data can be collected by Forced Flow Water Transport Tester

5 CONCLUSION

Proper evaluation of fabric's water absorption and transport property could ensure the quality of the product. Due to improved lifestyle of people, an ordinary cotton fabric can no longer fulfil customers' requirements and expectations in all wearing situations. When exercising with a cotton shirt, sweat will accumulate within the fabric clinging to the skin with minimum transportation to the outer layer, inhibiting evaporation of water and evoking a clammy sensation. The uncomfortable feel will be more severe when it is used for summer-wear, sportswear or other functional clothing. Recently, many innovative functional fabrics which claimed to have good moisture management property existed to solve the shortcoming of ordinary material. It poses a need to have an accurate method to characterise the absorption performance of these fabrics and determine whether it should be commercialised. Through this work, a sensitive, reliable and accurate measurement system will be developed under relatively low cost, with a wide range of distinguished features of which various types of fabric could be tested.

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