Vapour moisture transmission behaviour of individual component and multi-layered fabric with sweat and pure water

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Abstract

Multi-layered clothing has allowed humanity to expand its habitat around the world even at lower temperatures ranges. Moisture transport through multilayer clothing system is one of the most important aspect governing the comfort and performance of multi-layered clothing system as inefficient transmission of moisture from clothing can be fatal to one's life. There is constant search for apparel with better moisture vapour permeability at the same time maintaining body heat. Moisture can be transported either in form of vapour and liquid. Hence the present study is focussed on properties critical to functioning of outdoor apparels were tested using sweat and pure water for both multi-layered and single layer components. Behaviour of actual sweat can be different from test water used while evaluating the performance of multi-layer clothing system. vapour transmission properties were studied using sweat and pure water. In addition to that the behaviour of different fabric components has been studied individually and as layered arrangement. It was observed that water vapour transmission rate of fabrics when tested with sweat solution was significantly lower as compared to water. Sweat also showed lower drying rate than water. In comparison to different types of fabric considered (viz polyester knitted, polyester fleece, polyester spacer and PU coated nylon) for testing, Polyester spacer fabric having higher porosity level showed better water vapour permeability, drying rate with water and sweat. Individual fabrics performed better as compared to multi-layered structure. Lowest values of testing results were reported in case of multi-layered structure. The results of multi-layered ensemble were dominated by impact of PU coated layer. There are evidence which show that moisture transmission occur between skin layer to middle layer but after that its flow was restricted by the presence of PU coated nylon layer at the bottom .Layered structure with fleece as middle layer showed better vapour transmission as compared to multi-layered spacer fabric at the inner layer.

Key words: sweat, air permeability, moisture vapour transmission, protective clothing

Introduction

A standard outdoor jacket contains three layers i.e. inner layer, middle layer and outer layer; where inner layer is generally a underwear which helps in sweat absorption, direct cooling of skin and transmission of sweat to other layers; middle layer provides thermal insulation and outer layer is shell layer to protect the wearer from physical hazards and penetration of water and cold air while allowing transmission of water vapours from body (Kasturiya et al,1999).Layering of the fabric which are likely to be used as garments worn together has major effect on properties such as permeability to air and water vapour, thermal resistance and nominal thermal conductance(Liang et al.,2011). Heat and moisture transfer properties of layered clothing are of considerable practical significance as they play a major role in determining the thermal comfort. They are of primary concern when considering performance of outdoor apparels in cold and moist environmental conditions. It becomes more challenging if sweat generated in the body gets condensed within the clothing system particularly in cold weather apparels(Gordon,2003).As the accumulated moisture may freeze on reaching threshold limit and can remain trapped within the clothing system, causing a reduction in heat resistance and user discomfort(Hepburn 1998, Das et al,200). Hence proper regulation of sweat from the layered clothing component and their microclimate to the external environment is an issue of great concern. Sweat may be in form of vapour or liquid.. Since most often clothing is made of materials that impede the flow of heat and moisture from the skin to the environment. It is thus important to quantify the thermal comfort of clothing materials in terms of their sweat transfer and absorption behaviour and to consider this when selecting particular material for different end use requirement according to climatic condition (Mathur et al., 1997). Material constitution and structure of each layer in multilayer clothing system plays an important role in influencing the transmission of moisture from the fabric. The differences in the components of layered structure may alter thermoregulatory responses, thermal strain, and thermal comfort during work and rest periods. In order to improve the comfort of clothing, there is a need to investigate the liquid and moisture management properties of different layering component of outdoor apparels. An equally important aspect is composition of moisture as moisture stored by garment as a result of absorption of sweat or as result of absorption of moisture from humid environment, is not pure water but also contains other ingredients. Sweat is a clear colorless liquid secreted by the eccrine sweat glands which lie in dermal layer of the skin. It consists primarily of water (~99%) in addition to salts, fats, urea, lactic acid, carbohydrates and minerals such as potassium, calcium, magnesium, iron (Baczek and Hes,2014).

Earlier studies (Boguslawska et al., 2014), reported the impact of salty water on thermal conductivity and resistance of nomex fabric. It was found that thermal insulation of nomex decreased with increasing moisture content. As with increasing percentages of aqueous solution, amount of sodium chloride content also increases which in turn causes the increase of thermal conductivity of wetted fabric and reduce its thermal resistance. However the study was restricted to particular type of textile material. Further response of various components of multilayer system towards sweat solution is yet unknown. Each component has significant role in overall performance of clothing. Present study mainly concerned with the evaluation of thermo-physiological comfort of protective clothing by analysing the moisture transmission and drying behaviour of multi-layered/individual fabric using simulated sweat solution and distilled water.

3. Experimental

3.1 Materials

Four different fabrics (Polyester knitted, Polyester spacer, Polyester fleece and Polyurethane Coated nylon) generally used in outdoor apparel have been selected for the present study. The specifications of the fabric are shown in Table 1. Before conducting the test all the fabric samples were first conditioned at tropical atmosphere of 27°C ±2°C and 65% ± 2% R.H. For each test fifteen samples were tested to minimise the error below 2%. Further statistical analysis was conducted for data interpretation at level of 5% significance.

Table 1: Specifications of fabrics used

Fabric type	Polyester knit	Polyester fleece	Polyester spacer	PU Coated Nylon
Construction	Knitted(Double jersey/interlock)	Knitted with fleece on one side (fibres raised on inner side)	Knitted 3D structure(Single jersey on both sides with spacer yarn in between)	Woven Fabric (Nylon filament) with PU coating
GSM (g/m^2)	80	320	450	75
Filament /spun type	Multifilament (150D/144F)	Spun Polyester	(Outer) Multifilament (Inner)Monofilament	Multifilament (70D/24 F)
Porosity (%)	79.4	74	82.5	45.6

Where 'D' and 'F' represents denier and number of filaments in yarn cross-section respectively.

Preparation of simulated Sweat solution

For testing purpose, simulated sweat solution was prepared according to the ISO standard 3160/2. The surface tension and density of sweat solution and water were measured using pendant drop method and densimeter DMA 5000 (Table 2).

Table2: Surface tension and density of water and sweat solution

Solution	**Surface tension (dyne/cm)**	**Density (g/cc)**
Water	72	0.99
Sweat solution	62	1.04

3.2 Methods

Measurement of surface tension and contact angle

Pendant drop method (Arashiro and Demarquette, 1999) was used for the measurement of surface tension of both the distilled water and sweat solution. Contact angle was also measured using drop shape analysis. DSA is an image analysis method (ASTM 5725) from the shadow image of a sessile drop(Figure 2).

Measurements of water vapour permeability

Water vapour permeability was measured as per BS 7209 using evaporative dish method. Sample of dimension of 8 cm in diameter was cut for the test. The specimen under test was sealed over the open mouth of a dish containing water placed in the standard atmospheric condition for testing. Weight of dish with sample mounted on it was noted down. After 1 hour the system will be stabilised; i.e. equilibrium would be maintained, to record the initial weight. After this, test was allowed to run for 4 hours. At the completion of test, the weight of the dish was recorded again. It was termed as final weight. The rate of water vapour transfer through the fabric were measured and water vapour permeability (WVP) was calculated using the Equation 1

$$WVP = \frac{24xM}{A.t} g/m^2/day \qquad \ldots\ldots\ldots\ldots\ldots.. (1)$$

Where M is the loss in mass of water in grams through the fabric, A is internal area of fabric in square cm and t is the time of testing in hour. This test was performed with both distilled water and sweat solution maintained at pH of 4.6.

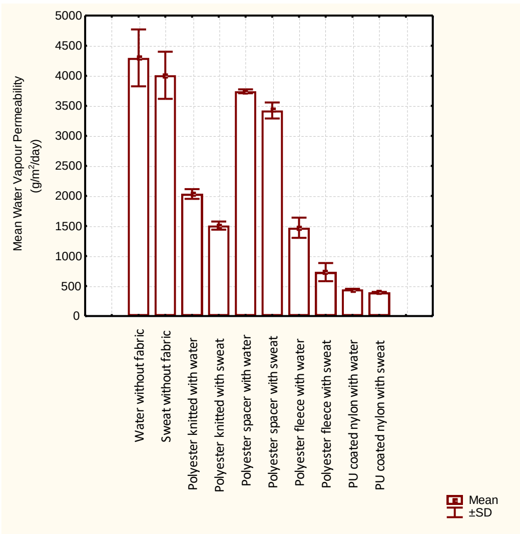
4. Results and discussion

Protection from cold in protective clothing is function of all the layer component of multi-layered system design. In order to assess its overall performance, individual layer were tested for their water vapour permeability, moisture management properties and drying rate properties. These arediscussed in detail in following section. Behaviour of sweat and water was found different. The liquid moisture transmission through a fabric, besides the factors related to the structure of material also depends considerably on the surface tension of liquid and contact angle it makes with the fabric. So for analysis purpose surface tension and contact angle were also measured.

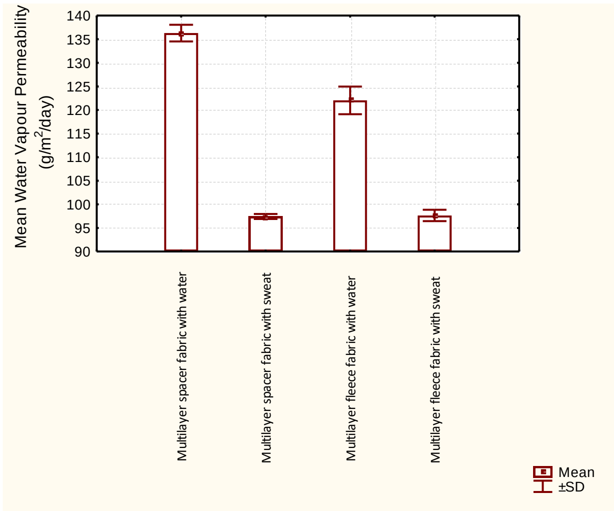
4.1. Water vapour transmission behaviour

The influence of water and sweat on the WVP of individual fabric and their multilayer assemblies are shown in Figure 5. Results showed that vapour permeability of pure water and sweat were not statistically different but in presence of fabrics, vapour permeability of sweat solution is always lower than pure water. This can be explained on the basis of the difference in pressure gradient build up by both water and sweat across the fabric. Addition of salt lowered the vapour pressure and resulted in less pressure gradient to be built across the fabric.
The above phenomena can be explained on the basis of Raoult's law {Raoult's law: $P_{solution} = (\chi_{solvent}) (P°_{solvent})$}; which states that the vapour pressure of a solvent above a solution is equal to the vapour pressure of the pure solvent at the same temperature scaled by the mole fraction of the solvent present.Thus, samples with sweat solution showed lower water vapour permeability (Figure 5 (a)). As expected there was overall reduction of vapour permeability in presence of fabric.In case of PU coated fabric there was no significant difference as its outer surface was coatedwhichrestricts the flow of vapours to the outside atmosphere. Further it can be also noted that variability in the data of vapour permeability of pure water and sweat solution was quite large but in presence of fabrics, it reduces. This is due to the impact of boundary layer above the evaporative dish which is susceptible to be affected by wind speed and other environmental factors in the absence of fabric.
It has been observed that vapour permeability both in form of pure water and sweat solution was found maximum in case of spacer fabric followed by knitted fabric and then fleece fabric. PU coated nylon exhibits lowest level of permeability. This can be explained as polyester spacer exhibits highest porosity of 82.5% (Table1) which assist in better water vapour transmission through the fabric. On the other hand lower vapour permeability exhibited by PU coated nylon fabric is due to its less porosity and coating on the outer side of fabric. Further among polyester knit and polyester fleece, polyester knit provides higher vapour permeability. This can be ascribed due to its higher porosity and lower thickness as compared to polyester fleece fabric (Table 1).Usually higher porosity in the material leads to higher water vapour transmission rate governed by Fick's law (Brewer et al., 2012).
In case of multi-layered ensemble, difference between vapour permeability of pure water and sweat solution reduces substantially (Fig 5b). Here in addition to porosity and pore size, barrier properties of the multi-layered ensemble particularly PU coated fabric plays an important role. Further pressure gradient at each layer reduces due to its increased overall thickness and the air gaps created within the layers which in turn impede the flow of moisture

to the outer atmosphere. It has been seen that multi-layered ensemble with spacer fabric shows higher vapour permeability (using pure water) as compared to multi-layered fabric with fleece. Interestingly no such difference is observed in case of sweat. Further multilayer fabric with fleece shows higher variability than spacer fabric. It may be added that in case of single layer also, fleece fabric was showing higher variability (Figure 5a and 5b).This can be due to the uneven arrangement of fibres on the inner surface of fleece structure thereby leading to variation in water vapour transmission rate.



a)



b)

Figure 5: Water Vapour Permeability of different fabric using water and sweat a) single layer b) multi-layered system

Conclusions

This study showed the vapour and liquid transmission behaviour of fabric components individually and as layered ensemble with sweat and water. It was observed that constituents of sweat and its density played a major role . Fabric structure were found to behave differently when tested individually and as layered component. The act of forming the layered ensemble has major influence on the water vapour permeability. The results of multi-layered ensembles were dominated by the impact of the base layer consisting PU coated layer which restrict the easy transmission of moisture both in vapour and liquid form through the fabric. Moisture management properties of water and sweat were found to differ significantly. It is attributed to variation in contact angle, surface tension and density of both water and sweat.Further in case of multi-layered ensemble, in addition to porosity and pore size, barrier properties of the multi-layered ensemble play an important role.Itmay be noted that accumulation of sweat inside the structure can have significant role in moisture vapour transmission which can be studied in future.

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