Parameters related to clothing comfort—A new approach for measuring moisture transport through fabrics

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A new experimental set-up to measure water vapour transmission through fabrics under ambient temperature has been designed and fabricated. The moisture transfer through fabrics has been characterized in terms of the time required to reach a certain RH in a dry chamber on passing moisture. The results of the new test method are compared with that of the standard control dish method. Fabrics having widely different constructions and fibre types were analyzed. In cotton fabrics, the moisture transfer time strongly depended on fabric thickness and fabric weight whereas in polyester fabrics, the cover factor seemed more important. It is observed that if the combined influence of fabric parameters on moisture transfer time can be kept constant, moisture transfer would be adversely affected by the polyester content in blended fabrics.

Keywords: Apparel fabrics, Fabric parameters, Moisture transfer

1 Introduction

It is well known that clothing acts as a moderator between human body and environment in so far as the heat and water vapour dissipation mechanisms are concerned. Also, it has been recognized that the movement of water vapour through fabrics is of paramount importance under all climatic conditions. Several methods for the measurement of this property are in vogue. An accepted standard method, viz. control dish method, depends on the measurement of the weight loss caused by the movement of water vapour to atmosphere through fabric over a specified time. Several mathematical models have also been developed based on fabric geometry to explain the moisture transfer through fabrics. Slater and coworkers, in their studies on water vapour diffusion, have evaluated the standard method and its demerits. They have also proposed new test methods based on the establishment of certain humidity gradients through the fabric. An alternative method for measuring the water vapour resistance has been proposed by Farnworth and Dolhan. The method is based on monitoring the dynamic weight loss of a dish of water covered by the fabric.

The environmental conditions and the clothing requirements in a tropical country like India are different from those in countries like UK in the sense that the ambient temperature in the many parts of the tropical country is normally higher than that of the human body. Also, there is a wide variation in humidity over different regions of the country. In this context, water vapour transmission properties of clothing gain added significance for maintaining the body temperature and skin moisture. Under a CTRL programme on the evaluation of comfort properties of apparel fabrics, we have developed a test method for the measurement of moisture transfer through fabrics. The newly developed method has been compared with the standard control dish method. The effects of fabric parameters, such as weight per unit area, thickness and cloth cover, on moisture transfer mechanisms have also been evaluated and the results are reported in this paper.

2 Materials and Methods

2.1 New Apparatus

The water vapour diffusion apparatus, designed and fabricated at CTRL (Fig. 1) consists of two chambers, one made of transparent acrylic sheets and the other of aluminium. The chambers, joined together by nut-bolts, are maintained airtight by the use of ‘O’ rings. A circular opening (diam, 6 in) in the acrylic chamber holds the fabric piece mounted with a nominal tension. The hole can be closed airtight or opened, whenever necessary, by a shutter made of 12 mm thick acrylic sheet using the shutter drive screw attached to the one end of acrylic chamber. The acrylic chamber is always maintained at 100% RH by allowing the moisture to flow inwards through a small duct from an ‘aerosol’ apparatus. The air in the aluminium chamber, referred to as dry chamber in Fig. 1, can be brought to a pre-determined lower RH
by passing dry air through it before starting the actual experiment.

2.1.1 Measurement

After the pre-determined RH was achieved in the aluminium chamber, the shutter was opened and the moisture allowed to pass through the fabric by diffusion into the dry chamber, which could be indirectly monitored by using a sensitive hygrometer placed close to the fabric. The increase in humidity in the dry chamber was noted every minute. From the plot of time (T) vs. RH in the dry chamber it was observed that the dry chamber reached 100% RH within 1 to 2 h depending upon the moisture diffusion through the fabric, which, in turn, was influenced by the fibre type, thickness, weave and other parameters of the fabric. From the time dependent moisture transfer plot, the time $T$, taken to reach mean RH i.e. $[\text{Initial RH} + 100 \times \text{final RH}] / 2$ was computed. Two test pieces of the same fabric were tested in this apparatus and an average value was obtained.

2.2 Control Dish Apparatus

The control dish apparatus, with all the improvisations incorporated by earlier workers, was assembled and used with slight modifications wherever necessary. Six dishes were prepared, three as controls and three containing fabric specimens. Very thin and highly porous nylon fabric was used as control fabric. The specimen dishes were assembled in an identical way with the specimen fabric at the top of the dish filled with distilled water, separated by a spacer ring below which the control fabric is mounted. The three control dishes covered with control fabrics, along with the specimen dishes, were carefully placed on a turning table.

2.2.1 Measurement

As a standardization experiment, the rate of evaporation was measured using control dishes with air layer thickness ranging from 1 to 6 cm. It was found that the reciprocal of the rate of evaporation was not linearly proportional to the air layer thickness for the whole range, the linearity being maintained only for 1.5-2.5 cm thickness. Hence, in the actual experiments, the control dishes always had air layers of 1.5-2.5 cm thickness.

The rotating table was allowed to rotate at a slow constant speed and the amount of water lost from the dishes after 20 h was determined. A relationship was established between the reciprocal of the amount of water lost and the air layer thickness. Using the water loss from the specimen dishes and the above relationship, the resistance offered by the fabric, equivalent to air layer resistance, was computed taking into account the total length of the air layers within the specimen dishes, as suggested by Weiner. In all the measurements, the total air layer thickness in the specimen dish (including the fabric thickness) was maintained within 1.5-2.5 cm. The average of two sets of measurements was taken as resistance $R$ of fabric.

2.3 Measurement of Fabric Properties

2.3.1 Fabric Weight and Thickness

The weight per unit area of the fabric was measured using the standard procedure employed in CTRL, except that the dimensions of the fabric used were the same as those used for moisture transfer. From the weight per unit area, the weight/m$^2$ was computed. Fabric thickness was measured using a compressometer.

2.3.2 Fabric Cover Factor

The counts and ends/in of the warp threads and the counts and picks/in of the weft threads were determined using the standard procedures. The cover factor $k$ was calculated using the method suggested by Booth, employing the following relationship:

$$k = k_1 + k_2 - k_1 k_2 / 28$$

where $k_1$ is the fabric cover factor; and $k_1$ and $k_2$, the warp and weft covers respectively.

3 Results and Discussion

The relationship between moisture transfer time $T$ (the inverse of which could be taken as an index of clothing comfort) measured on fabrics of widely different construction and fibre types and their resistance $R$ to moisture transfer, measured using control dish, is schematically shown in Fig. 2. The figure shows that a fairly good agreement ($r = 0.83$) exists between the two measurements and the gradation of the fabrics remains the same in both the methods. This shows that the present method has the
potential to be developed into a highly accurate and fast analytical technique.

Table 1 shows the moisture transfer time data for all the fabrics used in the study. Also included in this table are the fabric parameters. In case of cotton fabrics, the time $T$ depended strongly on the fabric thickness $t$ ($r = 0.97$) and fabric weight $w$ ($r = 0.96$). However, its dependence on cover $k$ was less ($r = 0.84$). This is because a hydrophilic fibre, like cotton, takes part in moisture transfer and the quantity and packing of the fibres have a pronounced influence in such a process.

The dependence of moisture transfer time $T$ on fabric parameters $t$ and $w$ was very poor in polyester fabrics, the correlations $r_{Tt}$ and $r_{Tw}$ being 0.36 and 0.42 respectively. However, a significant high positive correlation ($r_{Tk} = 0.73$) exists with cover factor, suggesting that the non-fibre space in

![Graph](image)

Fig. 2—Relationship between time taken to reach mean RH and resistance of fabrics to moisture transfer [(●) cotton fabrics; (○) cotton/polynosic fabric; (x) blended fabrics with polyester as component; and (▲) polyester fabrics]

<table>
<thead>
<tr>
<th>Fabric details</th>
<th>Moisture transfer time ($T$) min</th>
<th>Fabric parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Thickness ($t$) mm</td>
</tr>
<tr>
<td><strong>Cotton fabrics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long cloth, unbleached poplin</td>
<td>15.4</td>
<td>0.20</td>
</tr>
<tr>
<td>Bleached poplin</td>
<td>15.6</td>
<td>0.21</td>
</tr>
<tr>
<td>Plain poplin</td>
<td>15.4</td>
<td>0.19</td>
</tr>
<tr>
<td>Twill drill cloth</td>
<td>18.4</td>
<td>0.57</td>
</tr>
<tr>
<td>Plain semi voile</td>
<td>15.4</td>
<td>0.15</td>
</tr>
<tr>
<td>Plain semi voile</td>
<td>15.8</td>
<td>0.16</td>
</tr>
<tr>
<td>Plain casement</td>
<td>16.6</td>
<td>0.37</td>
</tr>
<tr>
<td><strong>Polyester fabrics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Texturized</td>
<td>15.5</td>
<td>0.10</td>
</tr>
<tr>
<td>Texturized</td>
<td>15.2</td>
<td>0.16</td>
</tr>
<tr>
<td>Texturized bosky</td>
<td>15.6</td>
<td>0.09</td>
</tr>
<tr>
<td>Texturized shirtsing</td>
<td>14.7</td>
<td>0.09</td>
</tr>
<tr>
<td>Texturized bosky</td>
<td>16.9</td>
<td>0.10</td>
</tr>
<tr>
<td>Texturized suiting</td>
<td>16.4</td>
<td>0.31</td>
</tr>
<tr>
<td><strong>Blended fabrics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25C/30V/30P/15PET</td>
<td>15.8</td>
<td>0.20</td>
</tr>
<tr>
<td>35C/25V/25P/15PET</td>
<td>16.9</td>
<td>0.21</td>
</tr>
<tr>
<td>15C/20V/20P/45PET</td>
<td>15.5</td>
<td>0.19</td>
</tr>
<tr>
<td>54C/46PET</td>
<td>16.0</td>
<td>0.16</td>
</tr>
<tr>
<td>28C/24V/48PET</td>
<td>14.9</td>
<td>0.18</td>
</tr>
<tr>
<td>33C/67PET</td>
<td>15.8</td>
<td>0.21</td>
</tr>
<tr>
<td>20C/11V/69PET</td>
<td>17.1</td>
<td>0.18</td>
</tr>
<tr>
<td>20C/80PET</td>
<td>15.7</td>
<td>0.15</td>
</tr>
</tbody>
</table>

C—Cotton; V—Viscose; P—Polynosic; PET—Polyester.
polyester fabrics has a deciding influence on moisture transmission. A multiple correlation analysis revealed that although the moisture transfer time primarily depends on cover k, the influence of fabric parameters (t and w) cannot be overlooked.

The blended fabrics used in this investigation had polyester as one of its components, the cellulosic component being either cotton, viscose, polynosic or a suitable combination of one or more of these fibres. The simple linear correlations between \( T \) and \( t \), \( T \) and \( w \), \( T \) and \( k \), and \( T \) and polyester content \( p \) were not significant. However, a partial regression analysis indicated that the moisture transfer time \( T \) depends almost equally on both the fabric weight and polyester content, if all other fabric parameters are kept constant. The above result can be easily understood from the various correlation coefficients given below.

The simple correlation \( r_{T,1} \) was 0.20 and did not improve further even when a partial regression was attempted \( (r_{T,t,w,k} = -0.28) \). Similarly, \( r_{T,k} = 0.13 \) became \( r_{T,k,w} = -0.36 \) only. However, the simple correlations \( r_{T,w} = 0.24 \) increased to \( r_{T,w,t,k} = 0.61 \) and \( r_{T,p} = -0.11 \) to \( r_{T,p,t,w} = 0.57 \) after the respective partial regression analysis. This result shows the greater influence of fabric weight and polyester content on the moisture transfer time for blended fabrics.

The above analysis indicates that if the combined influence of \( t \), \( w \) and \( k \) on moisture transfer time \( T \) could be kept identical for all blended fabrics by suitable choice of fabric parameters, then the moisture transfer time would increase with the increase in the amount of polyester fibres, thereby making the fabric less comfortable. This inference may also be arrived at in a different way as discussed below.

Analysis of the dependence of moisture transfer time \( T \) on fabric parameters \( t \), \( w \) and \( k \), carried out in the present work, for 100% cotton and 100% polyester fabrics shows that the moisture transfer directly depends on \( t \), \( w \) and \( k \), but to different extents. Hence, it is reasonable to assume the same type of functional dependence of \( t \), \( w \) and \( k \) on \( T \) for blended fabrics as well, in addition to their dependence on the polyester content. As a first approximation, all the blended fabrics were made to have the same combined influence of \( t \), \( w \) and \( k \) on time \( T \), by dividing \( T \) by the product \( t \times w \times k \). This function \( T/t_{wk} \), although empirical, was plotted against polyester content \( p \) for all the blended fabrics (Fig. 3). For the sake of completeness, the points corresponding to 0% \( p \) (100% cotton fabrics) and 100% \( p \) are also included.

These are obtained by taking the mean values of all the fabrics of cotton or polyester, as the case may be, used in this study. A close examination of the graph shows that the function \( T/t_{wk} \) increases with the increase in polyester content (\( r = 0.84 \)). The scatter in the points, especially for fabrics having \( p \geq 45\% \), in addition to other things might be due to the following reasons. Firstly, the different and yet changing influence of the fabric parameters \( t \), \( w \) and \( k \) on \( T \), as the polyester content in the fabric increases, could lead to some scatter in this relationship. In addition, the heterogeneous nature of the blend, having only polyester on the weft, might also be responsible for this effect. However, the above result does indicate that the moisture transfer slows down considerably as the polyester content in the fabric increases, thereby affecting its comfortability to wear.

The sensitivity of the hygrometer sensing element and its hysteresis effects are the deciding factors in hygrometer's response to change in humidity. The accuracy of the measurement can be improved by the proper selection of highly sensitive sensor elements. The fabrication of the instrument mentioned here is fairly simple and the measurement, based on simple principles, can be carried out quickly within 30 min. It has an added advantage that it is not necessary to achieve any equilibrium conditions before the actual measurements are carried out. In this respect, there is a certain novelty in this method.

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