CHAPTER 7

WICKING BEHAVIOUR OF
AIR JET ROTOR SPUN YARNS

7.1 INTRODUCTION

The problem of moisture transport through yarns is crucial for many applications like bed sheets and towels. During the last five years, a number of papers were published on wicking of yarns obviously to study the potential of various spinning technologies from which they have been produced. Wicking behaviour of yarns was studied by Nyoni and Brook (2006) to highlight their use in many applications. Wicking is easy to measure and very simple equipment is needed. Various techniques such as image analysis and electrical resistance method (Zhuang, Harlock and Brook 2002), Ansari (2000), Mazlampour, Ansari and Hemmatinejad (2007) have been used. In fact it can be unequivocally stated that wicking experiments are carried out on various types of yarn with vigour to obtain valuable information on comfort properties of fabrics.

Capillary action, or capillary, can be defined as macroscopic motion or flow of a liquid under the influence its own surface and interfacial forces of narrow tube, cracks and voids. The surface tension is based on the intermolecular forces of cohesion and adhesion.

When the forces of adhesion between the liquid and the tube are greater than the forces of cohesion between the molecules of the liquid, then
capillary motion occurs. Flow ceases when the pressure difference becomes zero. The primary driving forces responsible for the movement of moisture along the yarn are the forces of capillarity. The interaction of liquids with textile materials may involve several fundamental physical phenomena, wetting of fibre surface transport of liquid into assembly of fibres, absorption on the fibre surface or diffusion of the liquid into the interior of the fibres (Kissa 1996).

Wetting and wicking are not different processes. Wetting is a prerequisite for wicking. A liquid which does not wet fibres cannot wick into a yarn. When the fibres in assemble are wetted by a liquid, the resulting capillary forces drive the liquid into the capillaries created by the spaces between fibres in wicking process. In general, wicking takes place when liquid travels along the surface of the fibres but is not absorbed by the fibre. This type of flow is governed by the properties of the liquid – solid surface interactions, and geometric configurations of the pores structure (Hsieh 1995, Marchal 2001).

7.1.1 Equation of Lucas/ Washburn

The capillary flow in yarns was studied in an extensive way. To describe theoretically the capillary flow in a fibrous assembly is usually considered as composed of a certain number of parallel capillaries. The theory of the liquid movement was developed independently by Lucas (1918) and Washburn (1921). The description of the ascension of the liquid in fibrous material was reduced to wicking of a liquid in a linear pore which can be represented by a capillary. Lucas and Washburn established traditional equation (Minor et al 1959) describing the speed of liquid which move up or down in a capillary perpendicular to the free space of the liquid in the absence of a gravitational field.
In many common capillary systems which involve wicking in porous materials, the capillary pressure is much greater than the gravitational force in the earlier stage (Hollies et al 1957, Hollies et al 1956, Chen et al 2001, Kamath 1994). So the flow under capillary pressure can be modeled by the Lucas – Washburn equation which is

\[ h = \sqrt{\frac{r_c \gamma \cos \theta \cdot t}{2 \eta}} \equiv W_c . t^{1/2} \]  

(7.1) which gives when complete wetting (\( \cos \theta = 1 \))

\[ h^2 = \frac{r_c \gamma}{2 \eta} \cdot t \]  

(7.2)

where

- \( h \) is the liquid front position or wicking length
- \( \gamma \) is the surface tension of the liquid – vapour interface
- \( \eta \) is the viscosity of the liquid
- \( \theta \) is the apparent contact angle of the moving front
- \( r_c \) is the effective hydraulic radius of the capillaries
- \( t \) is the time

The capillary rise \( h \) of the liquid in a porous media is proportional to the square root of time as long as the effect of gravity is neglected. That is no more the case when the capillary rise becomes rather large. When the equilibrium between the capillary forces and gravity is reached, the rise will cease.
Other conditions postulated should also hold. These are

1) The physical properties of the liquid and the solid remain constant throughout the system.

2) The driving forces are forces of capillary

3) The radius of the tube or the equivalent radius of the non-tubular system is substantially constant; and

4) The supply of liquid to the system remains adequate.

In spite of these limitations, the equation of Lucas/Washburn was employed successfully for wicking (Ghali et al 1994).

The slope of the plot $h$ versus $t^{1/2}$ is called the wicking coefficient, $WC$ (Kamath et al 1994) and is given by

$$W_c = \frac{r \gamma \cos \theta}{2n}$$

(7.3)

In a very recent paper on yarn wicking, Nyoni and Brook (2006) have discussed the effect of tension and twist on yarn wicking which are novel features. It was Srinivasan and Shankaranarayana (1961) who first demonstrated that twist and tension were the factors which affected yarn characteristics.

7.2 MATERIALS AND METHODS

7.2.1 Materials

These are given in Chapter 3.
7.2.2 Methods

All the yarns are scoured, bleached and mercerized and studied for wicking as cotton yarns without these treatments will not wick at all due to the wax present. After drying and before measuring wicking characteristics, yarns were stored for 72 hours at a relative humidity of 65 ± 2 % RH and at a temperature of 25 ± 2 °C.

Measurements were carried out by ordinary capillary rise method on samples of yarn with distilled water.

Wicking property was studied by taking a sample length of 75cm of yarn and knotted into a loop of 70cm in circumference. While taking the yarn, care was taken to discard the outer layer, so that the yarn in the loop was not a sample that suffered twist loss. The loops were conditioned for 24 hours and then each one was fitted in a special frame for the wicking test. This frame consist of a plastic frame which supports four pegs that form the corners of rectangle 30cm × 5cm. the yarn was stretched over the pegs. On the vertical support, two scales were engraved; these have the least count of a millimeter. The slope of the frame was such that each long arm of the yarn loop was superimposed on a scale. This is shown in Figure 7.1. 250ml beakers were taken each filled with 100ml of distilled water. The frames were picked up 1/1 and placed in the beakers, as the first frame was placed in the beaker, the stopwatch was started. The other frames were immersed at 10 seconds intervals. After 10 seconds, the yarns in the beakers were examined, and the heights wicked on both yarns were recorded. The second wicking heights were recorded 10 seconds later and so on. This continued for 24 hours. In each sample, the height reached by the water at 0, 2, 4, 5, 10, 15, 30, 60, 120, 1440 min were recorded. Then the water level in beaker was read off the plastic scales on the frame. The height according to both the scales was
recorded. For each yarn, eight tests were done and the mean was considered. The CV % was less than 8%.

The experiments were allowed to continue. A plastic bag was lapped over the beakers, and 5 beakers were set aside. All the height readings were corrected by subtracting the height the liquid surface in the beakers from the recorded height.

The mass of the lower grip which maintained the yarn under tension during the test was 5 gms. Ten tests were conducted on each sample. The CV% was less than 10%.

**Figure 7.1 Installation of vertical wicking**

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The mass of the lower grip which maintained the yarn under tension during the test was 5 gms. Ten tests were conducted on each sample. The CV% was less than 10%.
7.3 RESULTS AND DISCUSSION

Two types of analyses were made. Wicking height was plotted against of square root of time and the slopes were computed. In the other method, logarithm of the height of rise was plotted against the logarithm of the duration of time.

The results are illustrated in Figures 7.2 to 7.12. It is apparent that jet rotor spun yarns are characterized by lower values of wickability in comparison with rotor yarns. Tables 7.1 and 7.2 give the regression equations and correlation coefficients obtained by linear regression analysis of the yarns by plotting log h vs log t. It is clear from the Figures 7.1 and 7.2 that the relationship is linear which demonstrates that the rise is controlled by the equation given by Lucas/Washburn. The slopes are characteristics of yarns.

That the jet rotor spun yarns are very sensitive to wicking as compared to regular rotor yarns is evident. The process of mercerization, as expected, has led to a significant increase in slope indicating that wickability for these yarns is good. Mercerization treatment swells the cotton fibres and increases the water absorption and dyeability.

Another type of analysis was also carried out on the data in that they are represented as $h^2=f(t)$ (Figure 7.8 to 7.10). This also demonstrates that the rise is controlled by the equation of Lucas/Washburn. The curve only considers the unsaturated region of wicking.
Figure 7.2  Saturated and unsaturated zones of 16\(^{\text{th}}\) Ne (36.91 tex) scoured, bleached and mercerised rotor and air jet yarns

Figure 7.3  Saturated and unsaturated zones of 20\(^{\text{th}}\) Ne (29.53 tex) scoured, bleached and mercerised rotor and air jet yarns
Figure 7.4  Saturated and unsaturated zones of 24° Ne (24.60 tex) scoured, bleached and mercerised rotor and air jet yarns

Figure 7.5  Logarithm of wicking time and wicking height (16° Ne (36.91 tex) Rotor and air jet rotor for scoured yarn)
Figure 7.6 Logarithm of wicking time and wicking height (20° Ne (29.53 tex) Rotor and air jet rotor for scoured yarn)

Figure 7.7 Logarithm of wicking time and wicking height (24° Ne (24.60 tex) Rotor and air jet rotor for scoured yarn)
Figure 7.8  Time in seconds Vs Height in cm² for 16° Ne (36.91 tex) (Scoured, Bleached and Mercerised - Rotor and air jet rotor yarn)

Figure 7.9  Time in seconds Vs Height in cm² for 20° Ne (29.53 tex) (Scoured, Bleached and Mercerised - Rotor and air jet rotor yarn)
\[ y = 0.0032x + 0.0309 \quad R^2 = 0.9772 \]
\[ y = 0.0026x + 0.013 \quad R^2 = 0.9781 \]
\[ y = 0.0015x + 0.1054 \quad R^2 = 0.9618 \]
\[ y = 0.0012x + 0.0793 \quad R^2 = 0.9638 \]
\[ y = 0.001x + 0.0502 \quad R^2 = 0.9681 \]

Figure 7.10  Time in seconds Vs Height in cm$^2$ for 24° Ne (24.60 tex)  
(Scoured, Bleached and Mercerised - Rotor and air jet rotor yarn)

Figure 7.11  Relationship between (Rotor and air jet yarns) scoured, bleached and mercerised yarns and log-slope of wicking
Figure 7.12  Relationship between (Rotor and air jet yarns) scoured, bleached and mercerised yarns and square root-slope of wicking

Table 7.1  Regression equation of the form \( \log(H) = k \log t + \text{constant} \)

<table>
<thead>
<tr>
<th>Correlation coefficient</th>
<th>16s 16 Ne (36.91 tex)</th>
<th>20s Ne (29.53 tex)</th>
<th>24s Ne (24.60 tex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log(H) = 0.1857 \log t - 0.055</td>
<td>Log(H) = 0.1827 \log t - 0.0567</td>
<td>Log(H) = 0.188 \log t - 0.1304</td>
<td></td>
</tr>
<tr>
<td>Log(H) = 0.1313 \log t - 0.0705</td>
<td>Log(H) = 0.1565 \log t - 0.2436</td>
<td>Log(H) = 0.1359 \log t - 0.1603</td>
<td></td>
</tr>
<tr>
<td>Log(H) = 0.208 \log t - 0.0186</td>
<td>Log(H) = 0.2013 \log t - 0.0424</td>
<td>Log(H) = 0.2155 \log t - 0.1796</td>
<td></td>
</tr>
<tr>
<td>Log(H) = 0.1697 \log t - 0.1398</td>
<td>Log(H) = 0.1602 \log t - 0.1383</td>
<td>Log(H) = 0.1431 \log t - 0.0815</td>
<td></td>
</tr>
<tr>
<td>Log(H) = 0.2088 \log t + 0.1023</td>
<td>Log(H) = 0.2027 \log t + 0.0615</td>
<td>Log(H) = 0.2016 \log t - 0.0605</td>
<td></td>
</tr>
<tr>
<td>Log(H) = 0.1778 \log t - 0.1126</td>
<td>Log(H) = 0.1887 \log t - 0.1866</td>
<td>Log(H) = 0.1566 \log t - 0.0809</td>
<td></td>
</tr>
</tbody>
</table>
Table 7.2 Regression equation of the form $H=kt^{\frac{1}{2}} + \text{constant}$ and correlation coefficient of various yarns

<table>
<thead>
<tr>
<th>Yarn Type</th>
<th>Regression equation</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>16's Ne (36.91 tex)</td>
<td>$H=0.0686t+1.0072$</td>
<td>0.7606</td>
</tr>
<tr>
<td>20's Ne (29.53 tex)</td>
<td>$H=0.0698t+0.9341$</td>
<td>0.7797</td>
</tr>
<tr>
<td>24's Ne (24.60 tex)</td>
<td>$H=0.0715t+0.8107$</td>
<td>0.8088</td>
</tr>
<tr>
<td>Sc Rotor</td>
<td>$H=0.0489t+0.7446$</td>
<td>0.7797</td>
</tr>
<tr>
<td>Sc Airjet rotor</td>
<td>$H=0.0507t+0.6549$</td>
<td>0.7792</td>
</tr>
<tr>
<td>Bl Rotor</td>
<td>$H=0.0812t+1.1523$</td>
<td>0.7901</td>
</tr>
<tr>
<td>Bl Airjet rotor</td>
<td>$H=0.0804t+1.012$</td>
<td>0.7954</td>
</tr>
<tr>
<td>Mc Rotor</td>
<td>$H=0.0927t+1.299$</td>
<td>0.7950</td>
</tr>
<tr>
<td>Mc Airjet rotor</td>
<td>$H=0.0927t+1.1373$</td>
<td>0.7975</td>
</tr>
</tbody>
</table>

Mercerised yarns have shown higher wickability either compared to scoured or bleached yarns although the trend maintained by rotor spun yarns vis-à-vis regular rotor yarn is similar.

7.4 CONCLUSION

Jet rotor spun yarns show that their wickability is lower than those of regular rotor yarns: Mercerised yarns represented as $h^2 = f(t)$ have higher wickability either compared to scoured or bleached yarns although the trend maintained by jet rotor spun yarns vis-a-vis regular rotor yarn is similar.