CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is concerned with the literature review on wicking of fibres, yarns and fabrics. A considerable amount of work has been carried out on wicking of manmade cellulosic fibres, yarns differing in linear densities, twist levels and tensions and woven cotton, grey and silk fabrics. This literature survey is based upon the intensive search of journals published in textile technology. Articles from other sources are also included and the subject is reviewed under different captions.

2.2 MOISTURE MANAGEMENT

The wearing comfort properties of clothing are closely related to the moisture transport properties of fibres opine Mizutani, Tsujii and Bertoniere (1999). Moisture transported through textile material may be conveniently divided into those involving the diffusion of water vapor and those involving the transport of liquid water remark Hollies, Kaessinger and Bogaty (1956). Clothes made out of any material should provide comfort to the wearer. However, physical action leads to perspiration, which wets out the garment has to be transported to its outer surface through wicking. The evaporation should be fast in order to keep the wearer’s body dry and cool. This entire phenomena is known as moisture management suggests Ghosh (2004). Moisture management often refers to the transport of both water vapour and liquid away from the body. Moisture management can be defined as: “the controlled movement of water vapour and
liquid water (perspiration) from the surface of the skin to the atmosphere through the fabric”.

2.2.1 Need for moisture management

When a person is engaged in routine indoor activity, the energy expended is 50/watt/square meter/hour. The metabolic heat generated is readily dissipated through the clothing as sweat. When at rest, a body will give out a quarter of a cup (2 ounces, about 60ml) of water vapour per hour at ambient conditions. Moderate exertion like walking will increase the amount to one point (16ounces, about 450ml) per hour. During sporting activities, for eg, tennis or cycling, the metabolic heat increases six times and perspiration 14times. During such strenuous body activity the wearer perspires and his clothes get wet with sweat. Sports and leisure wear exerts a barrier for efficient transfer of excess heat, resulting in a rise in body temperature and skin temperature greater than 37°C, which increase sweating. The excess heat moistens the fabric, which then reduces the body heat and makes the wearer tired. So the fabric should have two important properties. The initial and foremost property is to evaporate the perspiration from the skin surface, and the second is to transfer the moisture to the atmosphere and make the wearer feel comfortable. For comfort purposes, the rate of evaporation should be as close to the wicking rate possible.

2.2.2 Factors affecting moisture management

In moisture management fabric thickness plays the most significant role. The drying time also depends on the fabric thickness. This ability of the fabric depends on the surface properties of the constituent fibres and their total surface area. The size and number of capillary paths through the fabric are also important but these are governed by factors such as the fibre size, the yarn structure and the fabric structure. Consequently, the drying time and the energy required to
evaporate water from a wet garment depends on the amount of water absorbed and not on the fibre type. Fabrics which contain yarn with more inter-fibre space give wider diameter capillary. This will result in poor wicking action.

The capillary network of the fabric depends on the direction under consideration. So that the wicking properties through the thickness of the fabric may be different from those in the plane of the fabric. The rate of wicking may also be different along the warp (wale) direction than along the weft (course) direction remarks Ram (2007).

2.3 WETTING

The term “wetting” is usually used to describe the displacement of a solid-air interface with a solid-liquid interface. When a small liquid droplet is put in contact with a flat solid surface, two distinct equilibrium regimes may be found: partial wetting with a finite contact angle $\theta$, or complete wetting with a zero contact angle opines Gennes (1985).

The forces in equilibrium at a solid-liquid boundary are commonly described by the Young’s equation:

$$\gamma_{SV} - \gamma_{SL} - \gamma_{LV} \cos \theta = 0$$  \hspace{1cm} (2.1)

where $\gamma_{SV}$, $\gamma_{SL}$, and $\gamma_{LV}$ denotes interfacial tensions between solid/vapor, solid/liquid and liquid/vapor, respectively, and $\theta$ is the equilibrium contact angle.

The parameter that distinguishes partial wetting and complete wetting is the so called spreading parameter $S$, which measures the difference between the surface energy (per unit area) of the substrate when dry and wet:

$$S = [E_{\text{substrate}}]_{\text{dry}} - [E_{\text{substrate}}]_{\text{wet}}$$  \hspace{1cm} (2.2)
Or \[ S = \gamma_{SV} - \left( \gamma_{SL} + \gamma_{LV} \right) \] (2.3)

If the parameter \( S \) is positive, the liquid spreads completely in order to lower its surface energy (\( \theta = 0 \)). The final outcome is a film of nano-scopic thickness resulting from competition between molecular and capillary forces. If the parameter \( S \) is negative, the drop does not spread out, but forms at equilibrium a spherical cap resting on the substrate with a contact angle \( \theta \). A liquid is said to be “mostly wetting” when \( \theta \leq \pi/2 \), and “mostly non-wetting” when \( \theta > \pi/2 \) says Gennes, Wyart, and Quere (2004). When contacted with water, a surface is usually called “hydrophilic” when \( \theta \leq \pi/2 \), and “hydrophobic” when \( \theta > \pi/2 \).

### 2.3.1 Wicking

Wicking is the spontaneous flow of a liquid in a porous substrate, driven by capillary forces. As capillary forces are caused by wetting, wicking is a result of spontaneous wetting in a capillary system reports Kissa (1996). In the simplest case of wicking in a single capillary tube, a meniscus is formed. The surface tension of the liquid causes a pressure difference across the curved liquid/vapor interface. The value for the pressure difference of a spherical surface was deduced in 1805 independently by Thomas Young (1773-1829) and Pierre Simon de Laplace (1749-1827), and is represented with the so called Young-Laplace equation suggest Adamson and Gast (1997)

\[
\Delta P = \gamma_{LV} \left( \frac{1}{R_1} + \frac{1}{R_2} \right) 
\] (2.4)

For a capillary with a circular cross section, the radii of the curved interface \( R_1 \) and \( R_2 \) are equal. Thus:

\[
\Delta P = 2\gamma_{LV} / R 
\] (2.5)
where \( R = \frac{r}{\cos \theta} \) \hspace{1cm} (2.6)

and \( r \) is the capillary radius. As the capillary spaces in a fibrous assembly are not uniform, usually an indirectly determined parameter, effective capillary radius \( r_e \) is used instead.

### 2.3.2 Capillary Theory

Capillary action is governed by the properties of the liquid, the fiber surface wetting characteristics, and the geometric configurations of the porous medium. In a capillary, liquid rise due to the net positive force (\( \Delta P \)) across the liquid-solid interface.

\[
\Delta P = P - \delta gh,
\]

where, \( \delta = \) liquid density in g/cc, \( g = \) gravitational acceleration of 980.7 cm/s\(^2\), height of liquid rise in cm \( = h \), the capillary pressure (\( P \)) is described by the initial wetting force (\( F_{wi} \)) in the capillary area (\( \pi r_i^2 \)):

\[
P = \frac{F_{wi}}{\pi r_i^2} = 2 \pi r_i \gamma \cos \theta / \pi r_i^2 = 2 \gamma \cos \theta \]

where \( \gamma = \) liquid surface tension in dyne/cm

\( r_i = \) radius inside the capillary in cm and

\( \theta = \) liquid–solid contact angle

Where capillary pressure (\( P \)) is greater than the weight of the liquid (\( \delta gh \)), the positive forces drives the liquid upward. Upon reaching equilibrium where \( P - \delta gh \), the net driving force \( \Delta P \) becomes zero. The liquid stop rising at the equilibrium height (\( h \)) says Hsieh (1995).
2.3.3 Liquid transport in a porous media

When a dry porous medium, such as a brick or a wick, is brought into contact with a liquid, it will start absorbing the liquid at a rate which decreases over time. For a bar of material with cross-sectional area $A$ that is wetted on one end, the cumulative volume $V$ of absorbed liquid after a time $t$ is

$$V = AS\sqrt{t},$$

(2.9)

where $S$ is the sorptivity of the medium, with dimensions m/s$^{1/2}$ or mm/min$^{1/2}$. The quantity

$$i = \frac{V}{A}$$

(2.10)

is called the cumulative liquid intake, with the dimension of length. The wetted length of the bar, that is the distance between the wetted end of the bar and the so-called wet front, is dependent on the fraction $f$ of the volume occupied by liquid. This number $f$ is the porosity of the medium; the wetted length is then

$$x = \frac{i}{f} = \frac{S}{f} \sqrt{t},$$

(2.11)

Some authors use the quantity $S/f$ as the sorptivity. The above description is for the case where gravity and evaporation do not play a role. Sorptivity is a relevant property of building materials, because it affects the amount of rising dampness (http://en.wikipedia.org/wiki/File:capillary_action.jpg).
2.4 TYPES OF WICKING

2.4.1 Longitudinal or In–plane Wicking

It is common practice to use in-plane wicking measurements to evaluate the absorbing power or liquid transport capabilities of fibrous sheet materials. One end of a strip (25mm wide X 170 mm long) was clamped vertically with the hanging end immersed to about 3 mm in distilled water at 21°C. The height to which the water was transported along the strip is measured at 1, 5 and 10 minute intervals and reported in centimeters (cm). Higher wicking values show greater liquid water transport ability (www.tx.ncsu.edu).

2.4.2 Transplanar or Transverse wicking

Transverse wicking is the transmission of water through the thickness of a fabric, i.e. perpendicular to the plane of the fabric opines Kissa (1996) and Saville (1999). It is also termed ‘demand wetting’ Lichstein (1974) or spontaneous transplanar liquid uptake suggest Miller and Tyomkin (1984). It is perhaps of more importance than longitudinal wicking because the mechanism of removal of liquid perspiration from the skin involves its movement through the fabric thickness. Transverse wicking is more difficult to measure than longitudinal wicking as the distances involved are very small and hence the time taken by a liquid to transverse the thickness of fabric is short remarks Saville (1999). Sorption of water in a towel is one practical example.

Base on the extent of interactions with fibres, wicking processes can be divided into four categories

- Wicking of a liquid, no significant diffusion into the fibre surface, e.g. hydrocarbon oil wicking into a polyester fabric at ambient temperature; capillary penetration is the only process operating;
Wicking accompanied by diffusion of the liquid into fibres or into a finish on the fibre, e.g. water wicking in a cotton fabric and diffusing into fibres, water wicking into a soil release treated polyester fabric, and diffusing into the finish. Two simultaneous processes are operating – capillary penetration and diffusion of the liquid into the fibres;

Wicking accompanied by adsorption on fibres, e.g. an aqueous surfactant solution wicking into a polyester fabric. Several processes are operating simultaneously – capillary penetration of the liquid, diffusion of the surfactant in the liquid, and adsorption of the surfactant on fibres; and

Wicking involving adsorption and diffusion into fibres, e.g. an aqueous surfactant solution wicking into a cotton fabric. Several processes are operating simultaneously – capillary penetration, diffusion of the liquid into the fibres, diffusion of the surfactant in the liquid and adsorption of the surfactant on fibres remarks Kissa (1996).

2.5 DISTILLED WATER

The water which is almost completely pure and does not contain any impurities can be roughly defined as distilled water. Boiling water and condensing the steam formed as a result of it, is known as distillation. Most of the impurities present in water are removed by the process of distillation. Distilled water is often defined as bottled water that has been produced by a process of distillation and has an electrical conductivity of not more than 10 μS/cm and total dissolved solids of less than 10 mg/L. Distillation involves boiling the water and then condensing the steam into a clean container, leaving most solid contaminants behind. Distilled water is safe to drink, but it is used more often for research purposes where water purity is essential or industrial uses where mineral deposits can cause damage over time. The pH value of the distilled water falls in the neutral range (pH 7). Nevertheless, in most cases, the pH of distilled water is slightly acidic (around
pH 5.8). Some sources even report the distilled water pH level to be as low as 5.5. Generally speaking, the pH of distilled water is below 7 or neutral value (www.wisegeek.com).

2.5.1 pH Value

In chemistry, pH is a measure of the acidity or basicity of a solution. Pure water is said to be neutral, with a pH close to 7.0 at 25 °C (77 °F). Solutions with a pH less than 7 are said to be acidic and solutions with a pH greater than 7 are said to be basic or alkaline. A low pH indicates a high concentration of hydronium ions, while a high pH indicates a low concentration. Pure water is neutral, and can be considered either a very weak acid or a very weak base (center of the 0 to 14 pH scale), giving it a pH of 7 (at 25 °C (77 °F)), or 0.0000001 $M$ $H^+$. For an aqueous solution to have a higher pH, a base must be dissolved in it, which binds away many of these rare hydrogen ions. Hydrogen ions in water can be written simply as H$^+$ or as hydronium (H$_3$O$^+$) or higher species (e.g. H$_9$O$_4^+$) to account for solvation, but all describe the same entity(http://en. wikipedia.org/wiki/ph).

2.5.2 Surface tension of water

Surface tension is also related to the intermolecular forces in the liquid. The molecules in liquids are held closely and hence attract each other. A molecule in the bulk of the liquid is attracted equally on all sides so that the net attractive pull on the molecule is zero. However, a molecule at the surface is subjected only to the attractive forces of the molecules below it, as there are no molecules above it. Therefore, surface molecules experience a resultant downward attractive force from within the liquid, which tends to make the surface area of the liquid as small as possible. This causes the molecules at the surface to be pulled inwards and so there is always some residual imbalance force acting on the surface of the liquids. This is called surface tension.
When the temperature is raised, surface tension of the water decreases linearly. The decrease of surface tension with increase in temperature results because the kinetic energy of the molecules increases. Thus the strength of intermolecular forces decreases resulting in the decrease of surface tension also. For example, clothes washed more efficiently in hot water than in cold water due to decreased surface tension of hot water (http://en.wikipedia.org/wiki/surface-tension).

Hsieh et al., (1991) and Hsieh and Yu (1992) carried out dynamic measurements of liquid wetting and retention between the lower edge of a vertically hung single fibre filament or woven fabric respectively and a liquid. The combined findings of these authors were used to demonstrate that the wetting characteristics of a fabric are identical to those of their constituent single fibre filaments. It was suggested by the latter authors that wetting characteristics of a fabric could be obtained more conveniently from fabrics than from single fibre filaments since handling of fabrics is much easier and simpler.

### 2.5.3 Summary of previous research work on wicking

Wicking has been investigated by many researchers. Most of them have focused on vertical wicking behaviour in yarns and fabrics. The subject matter has been discussed in many seminars and conferences. Recently many papers have been published and mathematical models have been developed to predict the vertical wicking behaviour in yarns and fabrics.

However, it is noticed that many interesting papers have been published on woven fabrics and upward, horizontal and downward wicking behaviour was examined. A great deal of work has also been carried out by research workers in India, United Kingdom, USA, Australia, France, Iran, Hong Kong, Turkey, Czech Republic and Saudi Arabia. Table 2.1 shows the research work which has been carried out on wicking.
<table>
<thead>
<tr>
<th>S.No</th>
<th>Research Worker(S)</th>
<th>Year</th>
<th>Experimental Materials</th>
<th>Yarn/Fabric Produced</th>
<th>System Used</th>
<th>Highlights of Research</th>
<th>Journal</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Azita Asayesh and Mohammad Maroufi</td>
<td>2007</td>
<td>Cotton yarn with different twist levels</td>
<td>Weft knitted interlock structures with two loop lengths</td>
<td>Weft knitting</td>
<td>Weft knitted fabrics with low twist level showed better wickability. By increasing the amount of twist, wickability decreases.</td>
<td>Indian Journal of Fibre and Textile Research, Vol 32, Sep 2007, pp 373-376</td>
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<tr>
<td>2</td>
<td>A.B.Nyoni and D.Brook</td>
<td>2006</td>
<td>Nylon 6,6 continuous textured filament yarns</td>
<td>Yarns with linear density R67.1 dtex f 68, R100.58 dtex f 102 and R 134.5 dtex f 136</td>
<td>Not specified</td>
<td>Yarn wicking performance reduced when the twist inserted increases</td>
<td>The Textile Institute, 2006, vol 97, No. 2, pp 119-128</td>
</tr>
<tr>
<td>4</td>
<td>T.Sharabaty, F.Biguenet, D.Dupuis and P.Vialliar</td>
<td>2008</td>
<td>Polyester and cotton</td>
<td>Double faced fabrics (150 den, 48 filaments) and cotton or cotton / polyester weft yarns with different weaves</td>
<td>Not specified</td>
<td>Wickability in weft direction is faster than in warp direction</td>
<td>Indian Journal of Fibre and Textile Research, Vol 33, Dec, pp 419-425</td>
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<td>S.No</td>
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<td>5.</td>
<td>S.Mhetre and R. Paracharu</td>
<td>2010</td>
<td>Cotton and polyester</td>
<td>Cotton –warp 280denier ring yarn twisted (20TPI) diameter $\approx 270\mu m$ and weft -660 denier ring yarn twisted (10TPI) diameter $\approx 500\mu m$ And 296 denier, ring yarn twisted 13TPI,diameter $\approx 300\mu m$</td>
<td>Not specified</td>
<td>Fabrics with lower thread densities show better wicking behaviour than denser fabrics</td>
<td>The Journal of the Textile Institute, Vol 101, No 7, July 2010 pp621-626</td>
</tr>
<tr>
<td>6.</td>
<td>S.N.Subramaniam, A.Venkatachalam and V.Subramaniam</td>
<td>2007</td>
<td>Cotton regular ring, jet ring and compact yarns</td>
<td>Yarns with linear densities 19.68tex(30Ne), 14.76tex(40Ne) and 11.81tex(50Ne)</td>
<td>Rocos and Elite systems</td>
<td>Wicking height shows a reduction as the count becomes finer which is due to variation in thickness</td>
<td>Indian Journal Of Fibre And Textile Research, Vol 32, pp 158-162</td>
</tr>
<tr>
<td>7.</td>
<td>Rajashree Phukon and Dr. Avarani Phukon</td>
<td>1997</td>
<td>Cotton, acrylic and polyester</td>
<td>100%acrylic, viscose and polyester and 65:35 cotton polyester, viscose polyester and Eri polyester</td>
<td>Not specified</td>
<td>Acrylic fabrics showed maximum wicking behaviour and polyester minimum wicking behaviour</td>
<td>The Indian Textile Journal, October, pp40-43</td>
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<td>S.No</td>
<td>Research Worker(S)</td>
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<td>9.</td>
<td>M. Mazloompur, F Rahmani, N. Ansari, H. Nosrati and A. H. Rezaei</td>
<td>2011</td>
<td>Cotton and polyester</td>
<td>Cotton samples with different weft yarn counts 10, 20, 30 and density 18.1, 20.8 and 23.1 picks per cm, warp yarn with PET filament 80Den, 800tpm and density of 3000 per minute</td>
<td>Projectile Machine</td>
<td>Wicking rise of water along the weft direction decreases as the weft yarn density increases from 18.1 to 23.1</td>
<td>The Journal of the Textile Institute Vol 102, No 7, pp 559-567</td>
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<td>11.</td>
<td>Wiah Wardiningsih and Olga Troynikov</td>
<td>2011</td>
<td>100% bamboo</td>
<td>Single jersey fabrics with 13 different cover factors</td>
<td>Not Specified</td>
<td>It was observed that as the cover factor of the fabric increased, wetting time increased</td>
<td>The Journal of Textile Institute, 16th March</td>
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<td>S.No</td>
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<td>12.</td>
<td>Merve Kucukali, Banu Nergis and Candan</td>
<td>2011</td>
<td>Acrylic and Cotton</td>
<td>100% acrylic, 50/50 cotton acryl, 100% cotton, 85/15 cotton acrylic yarns with 20s and 30s counts</td>
<td>Mayer and Cie Relanit 1.2 circular knitting machine 30 inch diameter and 96 feeders</td>
<td>Wicking heights of coarser yarns with lesser counts are higher compared to finer counts</td>
<td>Textile Research Journal 81(3)pp324-328</td>
</tr>
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<td>13.</td>
<td>U.J.Patil, C.D. Kane and P.Ramesh</td>
<td>2009</td>
<td>30s count combed Cotton ring yarn</td>
<td>Single jersey, double and single pique and honeycomb structures with structural cell stitch length 2.5 and 3</td>
<td>Mayer and Cie knitting machine</td>
<td>More height of wicking was found in hot liquids compared to normal temperature. This is due to the surface tension of the water</td>
<td>The Journal of Textile Institute, Vol 100, No 5, July 2009, pp457-465</td>
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<td>15.</td>
<td>G.KTyagi, G.Krishna, S.Bhattacharya and P.Kumar</td>
<td>2009</td>
<td>Polyester, viscose and cotton</td>
<td>Ring and MJS yarns with blending ratios 48/52p/c,65/35p/c with circular and trilobal fibres</td>
<td>MMC carding machine. Lakshmi Reiters Draw frame, Murata air jet spinners and Lakshmi Reiters ring spinning</td>
<td>wickability remains higher for polyester viscose compared to polyester cotton fabrics and wicking increase as the polyester content decreases from 65% to 48%</td>
<td>Indian Journal of Fibre and Textile Research, Vol 34,June 2009, pp137-143</td>
</tr>
<tr>
<td>17.</td>
<td>Norman R. S. Hollies, Martha M. Kaessinger and Herman Bogaty</td>
<td>1956</td>
<td>cotton, nylon, wool and wool blended yarns and polyester,</td>
<td>cotton, nylon, wool and wool blended and polyester fabrics</td>
<td>not specified</td>
<td>Increase in yarn roughness due to random arrangement of its fibres gives rise to a decrease in the rate of water transport</td>
<td>Textile Research Journal Nov, 1956, pp829-835</td>
</tr>
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<td>S.No</td>
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<td>18.</td>
<td>Anne Perwuelz, Pascal Mondon and Claude Caze</td>
<td>2000</td>
<td>Polyester, polyamide yarns and glass fibres</td>
<td>Polyester (88 multifilaments and 10 µm) and polyamide yarns (25 multifilaments and 12 µm) glass (800 multifilament and 14 µm)</td>
<td>Not specified</td>
<td>Kinetics of capillary rise always follows the Lucas-Washburn equation, but the great dispersion of the experimental results along the yarns is attributed to the yarn heterogeneity of the interfilament space.</td>
<td>Textile Research Journal, 70(4), pp 333-339</td>
</tr>
<tr>
<td>19.</td>
<td>P.R. Harnett and P. N. Mehta</td>
<td>1984</td>
<td>Polypropylene, acrylic, polyacrylic, wool, polyvinyl chloride, porous acrylic</td>
<td>Polypropylene, acrylic, polyacrylic, wool, polyvinyl chloride, porous acrylic knitted fabrics</td>
<td>Not specified</td>
<td>Wicking properties of various fibres shows that wicking is often not inherent to the fibre, but is in part due to surfactants such as spin finishes which can be removed by washing</td>
<td>Textile Research Journal, July 1984, pp 471-478</td>
</tr>
<tr>
<td>20.</td>
<td>A.B. Nyoni and D. Brook</td>
<td>2010</td>
<td>Textured yarn 195 dtex f170, continuous filament yarn 160 dtex f80</td>
<td>Textured yarn 195 dtex f170, continuous filament yarn 160 dtex f80 yarns and fabrics with same warp and weft density</td>
<td>Not specified</td>
<td>Wicking behaviour was dependant on the structure of the constituent yarns, their orientation in the fabric, fabric structure, the pretension and the force applied.</td>
<td>Textile Research Journal, Vol.80(8), pp 720-725</td>
</tr>
</tbody>
</table>
2.6 **REGENERATED CELLULOSIC FIBRES**

Rayon can be defined as a general term for manufactured fibers or yarns produced chemically from cellulose, or with a cellulose base and for threads, strands, or fabrics made there from, regardless of the process used in the manufacture of such fibers, yarns and goods express Gopalakrishnan and Murugan (2006).

2.6.1 **Viscose Fibres**

Viscose rayon is a regenerated cellulose fiber, cellulose is the base for producing this manmade fibres. The raw material is obtained from a special variety of wood (spruce). It is a very versatile fiber and has same comfort properties like natural fiber. It imitates the feel and texture of silk, wool, cotton and linen. It has the characteristics like soft, smooth, cool, low elastic recovery and highly absorbent, but do not insulate body heat opines Cook (2005).

2.6.2 **Properties**

Viscose absorbs more moisture than cotton. Moisture content of cotton is 6% at 70°F and 65% RH, and for viscose rayon it is 13% under the same conditions. The tenacity of viscose fibre is 2-2.6 g/den at dry and 1-1.5 g/den in wet condition and its elasticity is less than 2-3%. This is very important in handling viscose yarns during weaving, stentering etc when sudden tensions are applied, opines Kothari (2000). Ordinary viscose rayon has 15-30% elongation at break, while high tenacity rayon has only 9-17% elongation at break (www.mytextilenotes.com). The density of viscose rayon is 1.53 g/cc and are available in three densities: 1.5, 3.0 and 4.5, explains Shenai (1996). As regenerated fibres are made from bleached pulp and are bleached by the producers, it is not necessary to use bleaching agents to restore their whiteness. Peroxide solution can weaken this at 6.5°C, remarks Rattan (2001).
2.6.3 Modal Fibres

Modal is a regenerated cellulose fiber made out of pure wooden chips from beech tree. It is the second generation viscose fibre. It has a appearance of silk, soft feel, excellent drape, high tenacity in wet condition, good hydroscopic properties, smooth feeling, good dimensions, good moisture regain and air permeability, eco friendly, bio degradable and absorbs 50% more water than cotton (www.swicofil.com).

2.6.4 Properties

The tensile strength of the fibre is less when the fibre is wet than when dry. It is 3.4-5.5 g/d in the dry state and 2.7-4.0 g/d in the wet state. The elastic recovery of modal fibre is high, while the viscose fibre is 82% elastic recovery but modal fibre has 95% (www.freepatentsonline.com). Elongation of a modal fibre is low when compared as regular rayon. In dry state has 6.5-18% and in wet state 7-33%, remarks Cook (2005). The most outstanding property of Lenzing Modal has to be its superior softness. The fiber remains wonderfully soft even after repeated washing without losing its brilliant colors or sheen. In addition, it also makes other fibers softer (www.birlacellulose.com). Unlike cotton, modal fabrics show more resistance to shrinkage, has good moisture regain and air permeability, thus considered best for exercising clothing and health suit. Reduced growth of bacteria when compared to cotton, if both stored for the same long period of time, and doesn’t age like cotton. Modal has an advantage that it is less likely to fade or to form pills as a result of friction. Modal achieves rich colors, and also retains its appearance after several washes (www.fibre2fashion.com).
2.6.5 Lyocell Fibres

Lyocell made from wood pulp cellulose offers desirable properties of manmade and natural fibres. Soft like silk, strong like polyester, cool as linen, warm as wool, and absorbent as cotton, narrates Sahu (2006). It is praised as "the natural, green and eco friendly new-type textile material of 21st century" (www.swicofil.com). It has properties like soft hand, good hygroscopicity, cool, bright, lustre, good wearability, natural antibiotic and bacteriostasis for colon bacillus and golden staphylococcus, easy to absorb and evaporate moisture and feels cool (www.shocksheaven.com).

2.6.6 Properties

In dry condition tencel is 30% stronger than cotton. Wet tencel retains no less than 85% of its strength. Lyocell performs more like cotton than rayon. Its breaking tenacity is 4.8 - 5.0 g/d (grams per denier) dry and 4.2 - 4.6 g/d wet. This is only a 12 % loss in strength. It is the strongest of the cellulosic fibers. Its breaking elongation is 14-16 % and its wet elongation is 16-18% (www.desleeclama.com). It absorbs excess liquid and quickly releases it into the atmosphere. Compared to other fibres like viscose and modal, lyocell fibres is easy to dye to deep vibrant colors. Controlled and regular arrangements of nanofibrils are the key elements behind the performance possibilities like natural cooling, outstanding moisture management, remarks Borbély (2008). The nanofibrils are hydrophilic in nature and optimize absorption of moisture with excellent cooling properties. The tencel fiber has a smoother surface than wool or cotton. Because of this reason it is suitable for sensitive skin (www.tencel.com/fibres/en/textiles).
2.6.7 Pore Structure of Lyocell

Lyocell fibre is composed of structural subunits (fibrils) in micro and nanometer range. An approximate calculation of the number of fibrillar sub-units within a lyocell fibre cross-section is given below:

<table>
<thead>
<tr>
<th>Structure Element</th>
<th>Size</th>
<th>Approximate number of fibrils per fibre cross-section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nano fibril</td>
<td>10 nm</td>
<td>1,330,000</td>
</tr>
<tr>
<td>Micro fibril</td>
<td>0.15 μm</td>
<td>5902</td>
</tr>
<tr>
<td>Macro fibril</td>
<td>0.75 μm</td>
<td>236</td>
</tr>
<tr>
<td>Complete fibre</td>
<td>13 μm</td>
<td>(1)</td>
</tr>
</tbody>
</table>

Rous et al., (2006)

2.6.8 Bamboo Fibres

Bamboo fibre is a regenerated cellulose fiber, which is produced from raw materials of bamboo pulp. Firstly, bamboo pulp is refined from bamboo through a process of hydrolysis-alkalization and multi-phase bleaching. Bamboo pulp is then processed into bamboo fiber. The raw material bamboo is well-selected from non-polluted region (www.bambootextiles.com).

2.6.9 Properties

Bamboo fiber can be softer even than silk fiber when spun into yarn. It has a basic round surface which makes it very smooth and to sit perfectly next to the skin. It has natural sheen like silk or cashmere. It drapes like silk or satin. It’s organic and natural smooth properties are non-irritating to the skin, making ideal for people with skin sensitive’s or other allergies, (www.fibre2fashion.com). Bamboo fiber absorbs and evaporates sweat very quickly. Its ultimate breathability keeps the wearer comfortable and dry for a very longer period. It is 3-4 times more...
absorbent than cotton. Bamboo fibre has natural UV resistant properties. It is best suitable in summer clothing, opine Rathod and Kolhatkar (2010). The cross-section of the bamboo fiber is filled with various micro-gaps and micro-holes leading to much better moisture absorption and ventilation. It is also very warm in cold weather; because of the same micro structure as the warm air gets trapped next to the skin (www.philexport.ph). Bamboo is naturally antibacterial, antifungal and anti-static. Bamboo has a unique anti-bacteria and bacteriostasis bio-agent named "bamboo kun" which bonds tightly with bamboo cellulose molecules during the normal process of bamboo fiber growth. This feature gets retained in bamboo fabrics too. Many tests have been conducted whose results show over 70% death rate after bacteria was incubated on bamboo fiber fabric. It makes bamboo fabrics healthier, germ free and odour free.

2.6.10 Related studies on wicking of fibres

Rous, Ingolic and Schuster (2006) have reported the visualization of the nano structure of tencel and other cellulosics as an approach to explaining functional and wellness properties in textiles. The pore distribution in all the fibres was studied by transmission electron microscopy (TEM) and fluorescence microscopy. The results from fluorescence microscopy show the higher accessibility of lyocell fibres, which correlates with the water and vapour sorption results. The obtained TEM images visualize for the first time by a non destructive method the internal pore structure of lyocell and modal cellulosic fibres and the fibril and pore structure of lyocell. They concluded that the tencel fibres are composed of structural fibrils in micro and nanometer range. This nano fibrillar-nano porous structure of tencel has a strong impact on the kinetics and thermodynamics of water binding into the structure. Ito and Muraoka (1993) studied the water transport behaviour along a fibre bundle using electrical capacitance technique similar to that previously constructed by Tagaya et al.,
(1987). When the end of a fibre bundle comes in contact with the liquid water, the water starts to travel along the fibre bundles by displacing air.

Perssin, Kleinschek and Kreze (2002) studied the hydrophilic and hydrophobic characteristics of different cellulose fibres monitored by tensiometry. Alkaline purification has the biggest influence on viscose fibres. In the case of lyocell and modal fibres, influence of alkaline purification is smaller in comparison with viscose fibres and no essential reduction in contact angles can be seen. In the case of viscose fibres, after washing, the alkaline solution of the washing agent easily penetrates into less oriented amorphous regions and breaks down the interactions between the cellulose macromolecules. The diameter of the fibres increases and the structure becomes loose leading to better accessibility of fibre interfaces to liquid. The result is a smaller contact angle and wettability and sorptivity improvement of the viscose fibres. In comparison with viscose fibres, modal and lyocell fibres have a higher degree of crystallinity and higher molecular orientation which means that only a small quantity of washing agent can penetrate into less ordered amorphous regions of the fibres. This result also implies a smaller pre-treatment effect on the hydrophilic character of the fibres. The improvement of sorption characteristics due to washing in an alkaline medium can be explained by the increase of voids.

2.7 SPINNING

According to Barker (1998) spinning may be defined as the art of throwing a number of more or less short fibres together in such a way that, being drawn out to form a comparatively fine filament, they grip one another and thus form a comparatively firm, strong thread. Thus spinning primarily consists of two operations of drawing out or “drafting” and twisting. In 1779, Samuel Crompton invented a yarn spinning machine. In 1830, Richard Robert invented fully automatic spinning mule says Klooster (2009). The open end spinning, rotor
spinning and friction spinning were introduced in the early 1970s. This was followed by air-jet spinning and wraps spinning describes Gillham (1995).

Standard staple fibre spinning procedures involves,

a) Picking (opening, sorting cleaning, blending)

b) Carding and combing (separating and aligning)

c) Drawing (re-blending)

d) Drafting (drawing into a long strand) and


The spinning industry in India is capital intensive and its activities range from production of raw materials for providing the consumers high value –added products such as fabrics and garments. It plays a significant role in the country’s economy with its notable contribution to the Gross Domestic Product (GDP), employment generation and earning valuable exchange views Balamuralikrishna (2011).

2.7.1 Ring Spinning

The ring spinning will continue to be the most widely used form of spinning machine in near future, because ring spinning still offers the greatest flexibility in application and supplies yarns of a quality that cannot be equalled by the new technologies owning to technological reasons quote Derry and William (1993). Initially developed in America in the 1830s, its popularity has survived the emergence of much faster spinning technologies. Ring spinning is extremely versatile. It is capable of producing yarn with wide ranges of linear density and twist from a great variety of fibre materials. Ring spun yarns have regular twist structure; fibres in the yarn are well straightened and aligned and therefore have excellent tensile properties reveal Horrocks and Anand (2000). The ring spinning
machine is used in the textile industry to simultaneously twist staple fibres into yarn and then to wind it onto bobbins for storage. The yarn loop rotating rapidly about a fixed axis generates a surface referred to as “balloon”. Ring frame settings are chosen to reduce yarn hairiness and the risk of glazing or melting the fibre suggest Fraser and Stump (1998).

2.7.2 Objectives of Spinning

1. To draft the roving fed to the ring spinning frame i.e. to convert roving into fine strand called yarn.
2. To impart strength to the yarn by inserting the necessary amount of twist.
3. To collect twisted strand called yarn into handy and transportable package by winding the twisted thread on a cylindrical bobbin or tube explain Sinha, Sharma and Sharma (2003).

2.7.3 Basic principles of ring spinning

- Drafting mechanism: To attenuate roving until the desired fineness is reached.
- Consolidation strength mechanism: To impart strength to the fibre by twisting it.
- Winding and package mechanism: To wind up resulting yarn in package suitable for storage, transportation and further processing express Hargrave (2008).

2.7.4 Ring Spinning Process

- Roving bobbins are creeled in appropriate holders.
- Guide rods leave the roving into the drafting arrangements.
- Drafting arrangements attenuate the roving into the final count.
➢ The drafting arrangements are inclined at an angle of 45 degrees to 60 degrees.
➢ Upon leaving the front rollers the fibre strand is twisted to impart strength.
➢ Each rotation of the spindle imparts one twist to the strand.
➢ Twist is generated by the spindle which is rotating at high speed.
➢ The direction of the twist is either "S" or "Z"
➢ This completes the spinning of the yarn.
➢ The amount of twist inserted in the yarn is controlled by the front roll or the delivery speed and traveler rational speed.
➢ In practice spindle speed is used instead of traveler speed in the above equation; the spindle speed is slightly higher than traveler speed.
➢ Yarn winding is performed simultaneously with twisting.
➢ The difference in the speed between traveler and spindle causes the yarn to wind on the package.
➢ The size of the yarn package is limited by the ring diameter, which has to be small to increase the spindle rotation at the same traveler speed (www.textile school.com).

Ring spun yarns produce high quality yarns and are mainly produced in the fine (60Ne, 10tex) to medium count (30Ne, 30tex) range, with a small amount produced in the coarse count (10 Ne, 60 tex) range. The fibres in the ring yarn are highly parallel and helical in nature and the fibre arrangement is uniform along the thickness of the yarn (www.natureworksllc.com).

2.7.5 Blending of fibres

Blending of different fibres is done to enhance the performance and improves the aesthetic qualities of fabric. Fibres are selected and blended in certain proportions so that the fabric will retain the best characteristics of each
fibre(www.fabriclink.com). According to Lacasse and Baumann (2004) fibre blends can be produced according to three different methods:

- Fibres of different type in the form of staple fibres are mixed at the yarn manufacturing stage, during spinning;
- Fibers of different types are separately spun and the resulting yarns are wound together to give a mixed yarn;
- Fibres of different types are separately spun and combined together only at the weaving stage where one or more fibre yarns are used as warp and the other one as weft.

2.7.6 Related Studies on Wicking of Yarns

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. Various parameters such as yarn structure, yarn tension, twist, fibre shape, number of fibres in yarns, fibre configuration, finish, and surfactants influence wicking of yarns. Chattopadhyay and Chauhan (2004) studied the wicking behaviour of ring and compact yarns and reported that coarser yarns wicked faster than fine yarns. Subramaniam et al., (2007) discussed the wicking behaviour of regular ring, jet ring-spun and compact yarns. Asayesh and Maroufi (2007) studied the effect of yarn twist on the wicking behaviour of knitted fabrics. Senguptha and Murthy (1985) found that wicking was highly sensitive to the twist and structure of ring and open-end spun yarns. For the ring yarns, the wicking time increases steeply as the twist increases. Nyoni and Brook (2010) reported a paper on effect of cyclic loading on the wicking performance of nylon 6.6 yarns and woven fabrics used for outdoor performance clothing. Results showed that the straining forces generated between filaments of the yarns result in spasmodic pumping of the liquid which
was dependant on the yarn and fabric construction, contact between the yarns, volume of liquid in yarns and duration of the force applied.

Ansari and Kish (2000) investigated the wicking behaviour of polyester spun yarns by electrical resistance technique produced with different twist levels. It was observed that the wicking rate decreases with the increase of twist factor from 22 to 49 tex $^0.5$ x turns per cm, due to reduction of capillary size. Twists in the yarns influence the size of inter-fibre capillaries as a result of the helical path of the fibres in the yarns. Minor et al., (1959) observed similar findings on nylon filament yarns of different twists. Fabrics produced from viscose are breathable and moisture absorbent and have high dimensional stability and results in outstanding wear comfort. Since viscose is extremely hydrophilic fibre, it readily imbibes large quantities of water.

Doakhan, Ravandi, Gharehaghaji and Mortazavi (2010) investigated a paper on capillary rise in core spun yarns. Nylon /cotton core spun yarns have been chosen for the study. These yarns have a sheath of cotton with the same count (20Ne) and a core of nylon multifilament with different counts (20 and 100denier, 3.3 denier per filament, circular cross section and without crimp). These yarn samples were produced under conditions of different pretensions of core component (0,30 and 60gf) and different twists of core spun yarn (600,670 and 760 T.P.M).In addition 18 yarn samples were produced with different construction features and the vertical wicking behaviour was examined. The capillary rise was observed through a camera and the images were recorded on a video tape. The video signal is transmitted from the video camera to the computer with the help of fast forward, a digital graphic adapter. The effect of yarn twist and pretension of core component shows that with increasing the former, the capillary rate decreased, while with latter increasing, the capillary rate increased.
Wang, Zha and Wang (2008) have carried out a study on wicking property of polyester filament yarns by capillary rise method. Effect of yarn twist, monofil cross sectional shapes and texturing on the wicking height were discussed. The results indicated that with the increase of twist levels, the wicking height ascends until reaching the maximum height and then descends. Liu, Chao and Li (2008) in their study wicking in twisted yarns reported that when a high twist is introduced into the yarn, fibres near the yarn center may buckle due to twist retraction. This can harm the pore structures between fibres and affect wicking behaviour of liquid.

Das, Jain and Pant (2008) studied the liquid flow behaviour of cotton wick. This paper reports the interaction effect of yarn twist, yarn count and number of plies on wicking behaviour of plied cotton yarn. Vertical experiments were carried out with liquids of varying surface tensions like distilled water, saline water and petrol. They have concluded that rate of vertical wicking for saline water was found to be significantly lower than that of distilled water. The rate of longitudinal wicking for distilled water was less than that of vertical wicking of distilled water.

Dasaradan, Murugan and Kannan (2005) have discussed the wicking behaviour of modified ring-spun yarns and various other modified ring-spun yarns like siro yarn and compact yarn with respect to wicking height and wicking time. An instrument has been fabricated for this study and the results were correlated with the yarn tenacity. They have reported that the warp yarn with 19.6tex showed maximum wicking behaviour compared to other yarns.

In a very interesting paper on wicking kinetics of liquid droplets into yarns using a computerized imaging system Chen et al., (2001) studied the time needed for droplet disappearance as a function of droplet volume for various yarns and comparative analysis was made. The absorption of two liquids namely hexadecane
and spin Lurol PP-912 into yarns of finish free nylon and polypropylene fibres of 200 denier were used. Results showed that for wetting liquids, the capillary pressure at the liquid front dominates the Laplacian pressure caused by the droplet curvature. As a result the droplet is sucked into the yarn in accordance with the Lucas Washburn equation. The time of the droplet absorption $T_w$ is a linear function of the initial droplet volume squared $V_o^2$. For the liquid – yarn pair, the slope provides the important information about the yarn properties. For non-wetting liquids, the model predicts that droplet wicking can still occur even if $\theta_a$ is greater than $90^0$ and the relation between $T_w$ and $V_o^2$ becomes nonlinear.

Das, Das, Kothari and Fanguiero (2011) have developed a mathematical model to predict vertical wicking behaviour in yarns and fabrics. The yarn model has been developed based on the Laplace equation and the Hagen – Poiseuille’s equation on fluid flow; pore geometry has been determined as per the yarn structure. Factors such as fibre contact angle number of filaments in a yarn, fibre denier, fibre cross sectional shape, yarn denier and twist level in the yarn have been taken into account for development of the model. They have concluded that yarn having linear density but made of more number of fibres (i.e. with smaller denier fibres) will provide higher wicking. The model also predicts that with the increase in twist in the yarn, its wickability reduces and with the increase in fibre shape factor, the wickability of the yarn increases.

2.8 SILK

Silk is a natural fibre of animal origin widely used for apparel purpose and it is one of the strongest textile fibre says Murphy (2000). It is the only natural filament that man does not have to spin before it can be used for textile fabrics and has remained the “Queen of fibres” for its elegant textile qualities, wear, comfort and aesthetic look.
Silk is so special because,

<table>
<thead>
<tr>
<th>Silk</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silk shines</td>
<td>The colour radiate and assume a luminant character.</td>
</tr>
<tr>
<td>Silk caresses</td>
<td>It flows in a supple and soft way.</td>
</tr>
<tr>
<td>Silk insulates</td>
<td>It cools and warms simultaneously.</td>
</tr>
<tr>
<td>Silk wears</td>
<td>It is wrinkle resistant and tear resistant and dries quickly.</td>
</tr>
<tr>
<td>Silk is safe</td>
<td>It is the most hypo allergenic, because of its protein structure.</td>
</tr>
<tr>
<td>Silk flatters</td>
<td>It has been celebrated in throughout history princesses are in silken robes and noblemen in silken capes (<a href="http://www.innervision.com/silks">www.innervision.com/silks</a>).</td>
</tr>
</tbody>
</table>

### 2.8.1 Types of silk

Silk is a natural protein fibre extruded by the larvae of the silkworm in the form of filaments and in the shape of a cocoon it is wound by the larvae or moth. Before the larvae turn into moths by breaking cocoons, the same is put in boiling water and the filaments are reeled out. There are mainly two types of silk. *Bombyx Mori* – Biological name of the silkworm. This is called cultivated silk. The silkworms are fed in special trays kept under roofs under mild temperature conditions and fed continuously with mulberry leaves in shredded forms. The essential nature of this type of silk filaments is fine, almost white when degummed, soft and lustrous. 85% of all cultivated silk belongs to this category. Wild silk or “Tussah silk” produced by silkworms called *Antheraca*. The tassah silkworms produce this wild silk called Tassar or tussores silk. By rearing these silkworms under controlled conditions of feeding etc. a more regular yarn can be produced. The characteristic of this silk are coarser, more irregular, rougher and brownish in color, in natural shade and never as white as cultivated silk. About 15-20% of all silk production is of this type remarks Iyer (2004).
2.8.2 Degumming of silk

Removal of gum or sericin is termed as degumming and removal of natural pigmentation is known as bleaching.

The different methods of degumming include;

A. Soap and soda ash method
B. Enzymatic method

Degumming with soap in the presence of alkali is in practice from a very long tome. In this method of degumming, silk is boiled in a solution of soap and an alkali like soda ash for about one hour.

Good degumming should involve the following factors:
- Good soft water, less than 50 PPM hardness
- Right type and quality of soap
- Right quality of alkali
- Prevention of vigorous boiling of liquid
- Right duration of degumming
- Right style of handling material
- Proper washing after degumming

2.8.3 Dyeing of silk with acid dyes

Though silk has an affinity for acid dyes, the dyed shades tend to be less fast than on wool. However, silk exerts its affinity for acid dyes at lower temperatures. The dyeing is usually started at 40°C and the temperature is allowed to rise to about 85°C views Sonwalkar(1993).
2.8.4 Photodegradation

Photodegradation is degradation of a photodegradable molecule caused by the absorption of photons, particularly those wavelengths found in sunlight, such as infrared radiation, visible light, and ultraviolet light. However, other forms of electromagnetic radiation can cause photo degradation. Photo degradation includes photo dissociation, the breakup of molecules into smaller pieces by photons. It also includes the change of a molecule's shape to make it irreversibly altered, such as the denaturing of proteins, and the addition of other atoms or molecules. A common photo degradation reaction is oxidation (http://en.wikipedia.org/wiki/photodegradation). The action of light on protein fibres results in loss in tensile strength of the fibres, change in the dyeing properties, handle and yellowing of fibres. During exposure, the fibres undergo photo – oxidation and photo – sensitized degradation. The source of radiation and the duration of exposure, the surrounding atmosphere, humidity, nature of the fibre substance, light absorption characteristics of the dyes and chemicals present on the fibre during the exposure, temperature etc. influence the degradation of the fibre taking place during the exposure opinion Shenai and Sahai (1978).

2.8.5 Related studies on wicking of fabrics

Mhetre and Paracharu (2010) investigated the effect of fabric structure and yarn-to-yarn liquid migration on liquid transport in fabrics. Results showed that the wicking in fabrics is determined by the thread spacing and rate at which liquid migrated from longitudinal to transverse threads and vice versa. Fabrics with lower thread densities show better wicking properties provided that inter-yarn spaces are completely filled. Larger inter-yarn spaces can trap more liquid, which could become available for migration. Du and Li (2010) investigated the dynamic moisture absorption behaviour of polyester cotton fabrics of different warp and weft densities. The density of the fabric only determines additional hindering
when the water molecules enter into the fabrics. Fabrics of lesser density reaches balance status in a shorter time while a fabric with greater density takes more time to reach the balance status.

Wardiningsih and Troynikov (2013) studied the influence of cover factor on liquid moisture transport performance of bamboo knitted fabrics. The fabrics were produced from 100% bamboo yarns with 13 different fabric cover factors and the relationship between cover factor and moisture management properties were determined. They have observed that as the cover factor of the fabric increased, the wetting time increased, the maximum wetted radius decreased, rate of absorption decreased, spreading speed decreased and overall moisture management capacity decreased.

Hsieh et al., (1996) studied the water wetting and retention of cotton assemblies as affected by alkaline and bleaching treatments. Scouring improves water wettability and water retention even when the pore volume in the fabric is reduced. Bleaching on the other hand, improves surface wettability and water retention without affecting the fabric pore structure. Patil et al., (2009) studied the wicking behaviour of single knit structures. In this study the most widely used structures such as single jersey, single pique, double pique and honeycomb with two structural-cell stitch lengths have been considered and effect of different liquids like distilled water, artificial perspiration, tap water and hot water was also tested. The distilled water and hot water showed better wicking behaviour followed by perspiration solution and tap water which is due to the change in properties of liquids.

El-Hady and El-Baky (2011) have recently reported on enhancing the functional properties of sportswear fabric based carbon fibre. Six samples were produced out of which three samples with satin weave (4/1) and another three samples with twill weave (2/1). The difference between each three samples
depends on the ratio of carbon fibre and fabric composition. The yarn count in warp is the same ie 36/2 whereas in the weft 24/1and 36/2 were selected. The ends and picks per inch were 109 and 60, 93 and 53 respectively. The fabric compositions were cotton 65%, polyester 17.5%, 28.5% and 35% and carbon 17.5% and 6.5% respectively. Fabric thickness, strength and elongation, air permeability, water resistance, thermal insulation were studied. They have concluded that as the carbon fibre ratio increases, warp breaking load values increased. Similarly water absorption time, air permeability and thermal insulation were also increased. Combination of cotton, polyester and carbon fibre gave sportswear fabrics better functional properties rather than a single fibre type with greatest performance properties.

In a very recent study Nassif (2012) examined the effect of weave structure on the physical and mechanical properties of micropolyester woven fabrics. Three different structures namely plain, twill and satin with five different weft densities were produced. Weft yarns were spun from drawn textured polyester yarn (DTY) with count 150 denier and 288 filaments. Micropolyester fibres with fineness of 0.52 denier per filament were used. Warp yarns were produced from DTY whose fineness is 150 denier with 208 filaments i.e. denier per filament is 0.72. The warp density is 110 ends /inch whereas weft densities like 61,65,71,75 and 80 picks/inch was selected. The weave structures were 1/1 plain, 2/2 twill and 4-satin weaves. The findings of the study revealed that increasing weft density leads to an increase in fabric breaking load, stiffness and crease recovery. On the contrary, the increase in weft density decreased air permeability and tearing strength. The effect of weft density on fabric breaking load, breaking elongation and abrasion resistance are similar to each other. Plain weave fabrics were superior to other structures in fabric breaking load, elongation and fabric stiffness; satin weave fabrics had higher air permeability whereas twill weave fabrics showed higher crease recovery.
Crow and Dewar (1993) investigated the vertical and horizontal wicking of water along a strip of textile material, a common method of evaluating the wicking behaviour of fabrics. Seven fabrics of varying fibre content and physical properties were examined. The majority of the fabrics wicked similarly to theoretical capillaries, with the water moving quickly along the fabric and then slowing up with time. This was the case whether gravity was involved or not, i.e. whether the sample was vertical or horizontal. However, only in two tests did the fabrics wick according to the classical equation for liquid movement in capillaries. It was concluded that textile fabrics contain imperfect capillaries, with no one property, other than gross surface characteristics such as "troughs" on the surface, universally contributing to their wicking behaviour. Therefore, the wicking behaviour of each fabric must be determined individually, rather than being predicted from the classical wicking equation.

The pioneering work of Owens, Leisen, Beckham and Breedveld (2010) involves the quantitative evaluation of wicking in fabrics. The goal of this work is to evaluate an upward, horizontal and downward (UHD) wicking test method to determine the permeability (k) and capillary pressure (Pc) of a fabric as a function of its saturation (S). The validity of UHD technique was determined by testing it on various fluids like homologous series of alkanes and on an alcohol. Then the results were studied to define the effect that changes in fluid characteristics has on wicking. Results showed that the UHD technique was validated.

Singh, Chatterjee and Das (2010) have reported a paper on physiological comfort of fabrics made up of structurally modified friction spun yarns. Polyester filament fibre was used as a core, viscose staple fibre as a secondary core and PVA as a sheath and DREF spinning machine was employed to produce the series of yarns at constant speed of 200m/min and spinning drum speed of 3500rpm. The yarn is then treated with hot water to wash out PVA in the sheath, leaving the
twistless viscose staple fibre on the surface. Effect of sheath fibre proportion, fibre fineness, and yarn fineness on physiological comfort properties affecting liquid transmission such as wicking and absorbency was studied. They have concluded that with the increase in coarseness of fibre, fabric wicking and absorbency increase.

Varshney, Kothari and Dhamija (2010) investigated a study on thermophysiological comfort properties of fabrics in relation to constituent fibre fineness and cross sectional shapes. Four different polyester fibre fineness along with microdenier and four cross sectional shapes were selected to produce 2 sets of 2/1 twill fabrics, one composed of 100% polyester and other 67:33 p/v blends. Results showed that moisture absorption of viscose is an important factor influencing the moisture transport characteristics including both wickability and moisture vapour transmission rate of 100% viscose and p/v blended fabrics.

Fangueiro, Filgueiras, Soutinho and Meidi (2010) have recently reported on the wicking behaviour and drying capability of functional knitted fabrics. In this study platted knitted fabrics produced with functional fibre yarns in the back of the knit (close to the body), combined with polypropylene or polyester in the face (outer surface) were analysed in terms of wickability. The wicking behaviour of fabrics is mainly determined by the effective capillary pore distribution and pathways as well as surface tension. The drying capability is related to the macromolecular structure of the fibre. Viscose Outlast ® demonstrated the best wickability in horizontal and vertical wicking, but its drying capability is low. Coolmax ® showed a good wicking ability and the best drying capability. PBT showed better wickability and drying capability than EL. The functional knitted fabrics with PP face yarn are worse in wicking ability and better in drying capability than that of fabrics using a face PES yarn.
Cimilli, Nergis, Ozdemir and Candan (2010) compared the comfort related properties of socks made from different fibre types like modal, micromodal, bamboo, soyabean and chitosan. In order to compare their properties with conventional fibres, cotton and viscose were also included. Water vapour transfer, air permeability, wicking, wetting and heat transfer were evaluated. In order to conduct thermal conductivity measurements, a special experimental setup was designed according to the hot plate method (ISO 8302). The results suggested that the fibre type, together with regain and properties such as thickness, appears to affect some comfort related properties of the fabric. Moreover, they have concluded that chitosan, modal and viscose fabrics performed better than the other fabrics so far as all the properties studied were concerned.

Das et al., (2009) studied the moisture flow through blended fabrics in order to study the effect of hydrophilicity of polyester viscose blended fabrics. Gokarnesan (2009) discussed the wicking behaviour of polyester viscose blended single jersey fabrics and reported that increase of polyester component in the blend decreases the wicking behaviour. Tyagi et al., (2009) investigated the comfort aspects of finished polyester cotton and polyester viscose ring and MJS yarn and fabrics. They have concluded that wickability always remains faster for polyester-viscose fabrics as compared to polyester-cotton fabrics and it increases slightly as the polyester content is decreased from 65% to 48%. The higher hydrophilicity of the viscose component of fibre mix, which governs liquid transport through capillary interstices in yarns, is obviously the contributing factor for higher wickability.

Cay, Atav and Duran (2007) have investigated effect of warp weft density variation and fabric porosity of the cotton fabrics on their color in reactive dyeing. Plain woven bleached cotton fabrics with different warp and weft densities and porosities were dyed with reactive dyes and the color measurements were carried
out with a spectral photometer. The linear yarn densities of warp and weft yarns were 12tex (Ne 50) and 15tex (Ne 40) respectively. They have reported that warp and weft density variation do not affect the color shades independent of dye concentration. However, the L*values of the sample increase by increasing the warp and weft density. When the warp and weft densities are increased, the colors of the dyed fabrics become lighter. In parallel with L*, the color yield (k/s) of the fabrics decreases by increasing fabric tightness, especially for dark shade dyeing. It is obvious that fabric tightness and porosity directly affect the color yield.

Rebenfield and Miller (1995) discussed the pore structure of fibrous materials using liquid flow. They have reported that fluid flow through textiles is a complex physical phenomenon, because of the fibrous and highly non uniform organization of the structure and deformation. Nevertheless, fluid flow through a fabric is important inorder to understand many of its physical and mechanical properties. Since textiles are discontinuous materials which are produced from macroscopic sub-elements such as fibres and filaments, they have void spaces or pores and therefore finite porosities. Critical fabric functionalities such as the performance of parachute and sailcloth, efficiency of filtration, transportation of the moisture from body to environment, apparel comfort, thermal insulation properties, the rate of liquid penetration during wet processing and liquid removal during drying of fabrics etc. depend on the porosity of textiles.

Bhattacharjee, Ray and Kothari (2004) in the study air and water permeability characteristics of nonwoven fabrics concluded that knowledge of porosity makes it possible to determine both the air and water flow through fabrics. Dubrovski (2009) reported that in a fabric, pores are situated in the fibres, between fibres in the yarns, and between yarns in the fabric. Cay, Vassiliadis, Rangoussi, and Tarakcioglu (2004) have reported that the yarn diameter, surface formation techniques and number of yarn threads per unit area are the main factors
affecting the porosity of textiles. Dimensions of the pores are smaller when the fabrics are processed in a wet medium due to the swelling of fibres (especially for hydrophilic natural fibres). It is obvious that porosity is a function of fabric geometry.

Das, Das, Kothari, Fanguiero and Araujo (2009) in a paper on moisture flow through blended fabrics and the effect of hydrophilicity discussed how the water vapour permeability and absorbency of the material increase with the increase in number of hydrophilic group in the material. Eight sets of plain woven fabrics have been developed using polyester/viscose blended spun yarns with different blend proportion. Scoured and bleached woven fabrics were subjected to air permeability, water vapour permeability, absorptive capacity and time, moisture regain and vertical and horizontal wicking. They have concluded that the vertical and horizontal wicking of the material decrease with the increase in viscose proportion in the polyester/viscose blended fabrics. So higher is the hydrophilic proportion in the blended material; it will offer quick absorption of the sweat from the skin, leaving it dry.

In a very interesting paper Mazloompour, Rahmani, Ansari, Nosrati and Rezaei (2007) have used the electrical resistance method to study the rate of horizontal wicking of different fluids into untreated and finished cotton fabrics by estimating the critical surface tension of both fabrics and equivalent capillary spaces of fabric samples from the experimental work based on Washburn derivation. The finishing agents namely Perlit based on modified fatty acid derivative and Baygard 430 AFF with a fluorochemical base has been used. It was observed that the penetration rate and wicking distance of finish treated samples reduced when compared to those of untreated samples. The results confirmed different solid-vapour surface tension of two types of samples due to changes in surface characteristics of fabrics after finishing treatment. The radii of
open channels which acts as capillary tubes tend to decrease, leading to blockage of the tube during water-repellant finishing treatments.

Fangueiro, Goncalves, Soutinho and Freitas (2009) investigated the moisture management performance of functional yarns based on wool fibres. Blends of wool and moisture management fibres such as Coolmax and Finecool were prepared to produce innovative yarns with specific functionalities. These yarns were used to produce knitted fabrics and their performance was evaluated including vertical and horizontal wicking. The drying capability of the fabrics was assessed by drying rate testing under two different conditions namely standard conditions (20±2°C and 65±3% RH) and in an oven at 33±2°C to simulate the body skin temperature. The influence of wool fibre proportion on the performance of each blend was analysed and it was observed that the Coolmax based fabrics showed the best capillary performance and the wool based fabrics showed low water absorption performance with good drying rate.

Haque (2009) discusses the effect of weft parameters on weaving performance and fabric properties. Experimental studies were conducted by weaving fabrics with three different picks per inch (PPI) and weft counts. The study shows that weaving performance is affected by too high cover factor. It was also observed that when the threads per inch increase the fabric strength also increases but at higher threads per inch the gain in strength is relatively more.

Meeran, Cocqu, Flores, Demeyere and Declercq (2002) have outlined the effect of fabric conditioners on the wetting and wicking characteristics of cotton terry. The active ingredients of fabric conditioners are cationic fatty acid based surfactants, and their action can basically be explained as covering fibres with a fatty coating. As a consequence of this mechanism, the treated fabric surface may become hydrophobic which may negatively affect water uptake properties. Comparing nonsoftened fabrics to fabrics treated with two different fabric
conditioners, n-octane wicking experiments showed that the fabric conditioners do not influence the absorption capacity of the fabric, indicating that the physical parameters of the fabric such as porosity and pore size are not changed by the use of a fabric conditioner. There is a large reduction in the wicking rate when using a liposomal fabric conditioner.

Wong, Tao, Yuen and Yeung (2001) reported on the wetting and wicking properties of linen treated with low temperature oxygen and argon plasma. Wetting and wicking are investigated using contact angles and upward and downward water wicking methods. The scoured and bleached linen was exposed to oxygen and argon plasma at a pressure of 15 pa and discharge powers of 100 and 200W for various times of 2.5 to 60 minutes. The results showed that the contact angle between the liquid and low temperature plasma treated fabric surface decreases. The oxygen plasma treatment can increase the downward wicking rate under all treatment conditions. However prolonged exposure of linen to 100W argon plasma and 200W discharge power leads to reduction in water uptake may even degrade the fabric causing adverse effects on its performance. Hence plasma treatment greatly improves the wicking properties of linen making it more absorbent.

Simile (2004) has reported that saturation levels decreased as the vertical distance traveled by moisture increased. This phenomenon occurs as a result of capillary pressure within the voids dropping below the functional range needed to support flow in those voids at increasing heights. As the height is increased, the capillary pressure also needs to increase; therefore only smaller radii pores will fill. Once saturation levels are known at specific heights capillary pressure and permeability calculations were made using Darcys Law and the Lucas Washburn equation. Although this phenomenon is well known in civil engineering, it has not
been widely addressed in textile sciences, especially in its implications for wicking tests.

In a very recent paper Simile and Beckham (2012) investigated the permeability, saturation and capillary pressure relations in textile fabrics from an integrated upward, horizontal and downward wicking test. A new wicking test was developed that provided intrinsic quantitative descriptors of fabrics that can be used to predict wicking behaviour. These descriptors are permeability (k) and capillary pressure (P_c) as functions of saturation (S). A single fabric strip is positioned to allow sequential upward, horizontal and downward wicking of fluid from an infinite reservoir. The upward section governs saturation, the horizontal section is analysed to determine capillary pressure, and the downward segment is analysed to determine permeability. The test and its application is demonstrated on a plain stitch knit fabric manufactured for performance athletic apparel. Results are provided in the form of characteristic k-S-P_c relations for water.

Recently Owens, Leisen, Breedveld and Beckham (2012) studied the UHD wicking test for providing intensive properties of textile fabrics on a polyester knit fabric using three different test fluids characterized by different surface tensions, densities and viscosities: dodecane, tetradecane and hexadecane. All the fluids fall on the same k vs S and k vs R_c curves, providing these curves are intrinsic characteristics of the fabric. Then k-S-R_c properties were used to predict the inplane horizontal and downward wicking rates of two different fluids, octanol and water in the fabric. These results validate the UHD wicking test as a method for providing intensive properties of textile fabrics which can then be used for predicting wicking tests.

Tera, Elnagar and Elamoudy (2012) investigated the photodegradation of the Holly Kaaba cover fabric by the environmental conditions in Mecca city. Samples of the Holly Kaaba jacquard silk cover fabric were exposed directly to
the prevailing conditions at Mecca city in the kingdom of Saudi Arabia through whole one year and at different successive periods. The incident solar energy values and the accompanied amount of UV radiation were evaluated for the whole, together with average maximum temperature and relative humidity values and also the total amount of sunny hours. The produced photo fading was assessed by following the changes in the physical and mechanical properties. The losses in tensile strength and elongation percent together with the change in drape, stiffness, weight and the thickness were assessed and discussed. Moreover, the changes in the colour parameters : brightness (L), red green component (a), yellow-blue component (b) and the allover colour difference (ΔE) changes, in addition to the colour strength expressed as (k/s) values, besides the light fastness ratings were also examined. It was concluded that the prevailing severe environmental conditions together with the air pollution at that urban site had contributed greatly to the observed degradation of all examined properties of the holly Kaaba silk cover fabric. Maximum losses were observed at summer time and during the pilgrim period.

Yatagai, Magoshi, Becker, Sano, Ikuno, Kohara and Saito (2000) have reported on the degradation and colour fading of silk fabrics dyed with natural dyes and mordants. Photo degradation of fibre was assessed by measuring yarn strength loss and photo fading was expressed as the difference in colour before and after light exposure. The dyed fabrics mordanted with iron showed light fading and a large decrease in tensile strength regardless of the dye upon exposure to light. The dyed fabrics mordanted with aluminium, on the other hand showed considerable fading and the degree of degradation was dependant on dye. The degummed fabrics showed a greater loss in tensile strength and colour change than the raw fabrics, whether treated or not, which suggests some protective effect of sericin present in raw silk against light damage to the fabrics.
In a series of papers on Indian silk, Sen and Babu (2004) have looked at the macro characterization and analysis of amino acid composition. Different varieties of Indian silk for their macro structural parameters such as filament length, degumming loss, denier, cross section, moisture regain and intrinsic viscosity were characterized for the results of amino acid analysis using reverse-phase techniques.

Five Indian silk varieties – two mulberry (bivoltine and crossbreed) and three non mulberry (tasar, muga and eri) were investigated. The differences existing between the different varieties and the extent of lengthwise variations within a cocoon in the dimensional and macrostructural parameters were discussed. It was observed that the denier of the filament decreased considerably from the outer layer to the inner layers whereas the density showed an increasing trend in all the varieties. Both the mulberry silk demonstrated lower moisture regains. Electron micrographs of all the non mulberry varieties showed micro voids in their cross section. Fraction studied showed that the development of mushroom structure on the tips. In both the types of mulberry silks, glycine, alanine and serine constitute about 82% of the amino acids present. On the other hand, in non mulberry silks, these constitute about 73% with a high proportion of alanine. The non mulberry varieties showed a substantial proportion of amino acids with bulky side groups. Similarly the higher hydrophilic to hydrophobic amino acid ratio (9.06-9.85) for non mulberry silks compared against that of the mulberry varieties (5.26-6.22) was shown responsible for the higher moisture content of non mulberry silks. Cystine and methionine were present in all the varieties. The higher intrinsic viscosity of non mulberry varieties suggested their higher molecular weight.

Sen and Babu (2004) have studied the effect of dyeing behaviour of silk. The results of the dyeing tests carried out were discussed in relation to the physical
and chemical structure of the silk fibres. Noticeable differences in the dye uptake were observed among the different varieties of silk. Mulberry varieties showed higher dye uptake compared to that of all three non mulberry varieties. Among the non mulberry varieties, tasar shows higher uptake followed by eri and muga. Interestingly, dye uptake reduces significantly within a variety from the outer layer to the inner layers. The reduction within a variety was found to correlate well with the morphological parameters. Determination of morphology of fibres confirmed significant differences in structural parameters such as crystallinity, orientation, density and birefringence, for example, between and within varieties. An increase in all these parameters was observed as one moves from outer to the inner layers within a variety. The differences in the dye uptake of different varieties of silk correlated well with the physical as well as chemical structure of silk fibres. Dye uptake differences between the varieties were found to correlate with the end amino groups.

Shenai and Sahai (1978) studied the photochemical degradation of tasar silk in the presence of acid dyes and an optical brightner. Tasar silk yarn and fabrics were degummed, bleached, dyed with acid dyes and exposed to sunlight for different periods. The results have showed that exposure to sunlight has brought photochemical degradation of the fibre as assessed in terms of cuprammonium fluidity and breaking strength. Acid dyes enhance the degradation of fibre and they fade linearly with the duration of exposure. Shenai and Singhi (1981) investigated the photochemical degradation of dyed tasar. Tasar silk fabric was degummed, bleached and dyed with acid dyed and then treated with an optical brightner and exposed to sunlight for various periods. The degradation of the fibre was assessed in terms of zinc chloride fluidity and the fading of the dye in terms of characteristic fading time determined from fading rate curves. They have concluded that the fluorescent brightner had a protective effect on the fading of acid dyes during exposure to sunlight.
Dadashian and Wilding (2001) investigated the photodegradation of lyocell fibres through exposure to simulated sunlight. FTIR microspectroscopy was used in combination with measurements of tensile properties, fluidity, moisture regain, yellowness, weight loss and birefringence. X-ray diffraction and SEM was used to determine the crystallinity and fibre surface changes. The results indicated that after prolonged exposure, open pores appear on the surface, probably due to the release of gaseous products, accompanied by an increase in moisture regain. Sultanov (1974) found that the photodegradation of cotton fibres was accompanied by decreased degree of crystallinity of the cellulose. The moisture regain values also reveal an initial slow period followed by a more rapid rate of change with exposure. Daruwalla, D'Silva and Mehta (1967) noticed a similar increase in the moisture regain of irradiated cotton. Harris (1934) studied the photochemical decomposition of silk and reported that the decrease in strength is caused by the action of oxygen in the air in the presence of light. Horsfall (1982) examined the factors influencing the daylight photodegradation of Nylon66, Nylon 6 and polyester in commercial fabrics. These fabrics together with dyed ones were exposed under glass and by direct weather to determine the relative contribution of the various factors to reduced performance on exposure to light.

Koussoulou (1999) examined the photodegradation of historic silks in the museum environment. He explained the mechanisms of deterioration of the silk fibres and dyes used to make historic textiles displayed in museums and introduce a new method of protection of historic silks by the application of materials as light stabilizers directly to the objects. Also the suitability of these stabilizers using silk fabrics dyed with traditional dyestuffs resembling the original historic objects was described. He had concluded that the prospects of using light – stabilizing agents in textile conservation are promising. The materials do not affect the fibres or the dyes or the appearance or texture of the silk after application. Some of them proved to increase the light fastness of the samples after exposure to
electromagnetic radiation with two different dyes, one sensitive and one resistant. It should be noted however that the stabilizer D, which shows the better performance on madder dyed silks, also had the most negative results on brazilwood. This raises the possibility that different stabilizers would have to be used on differently dyed silks.

2.9 CONCLUSION

From the foregoing, it is clear that considerable amount of research work was carried out on wicking behaviour of fibres, yarns and fabrics. However work on the wickability of fibres is scant. What appears to be less emphasized are the effect of weathering on wickability of silk fabrics, effect of finishes on wickability of grey cotton fabrics and effect of weave structures and sett on wickability of woven cotton fabrics. Also the effects of adding tensions, blends, counts and twist levels on wickability of yarns were not investigated. This thesis addresses these aspects in depth and provides information on them.