CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This review includes the general introduction, definition, importance of wicking, findings of work done by other researchers with regard to wetting, wicking, transverse wicking and review of laboratory test methods. The necessity of further development on transverse wicking is discussed. Research related to transverse wicking and theoretical background related to instrument are also discussed.

2.2 GENERAL

Textiles and clothing should fulfill the functional, comfort, aesthetic safety and ecological requirement. These characteristics, by and large, define the serviceability of the textile products. Of all the parameters, comfort is a quality parameter that is yet to get its expected importance. Clothing comfort is an extremely complex phenomenon resulting from the interaction of variation of various physical and non physical stimuli.

Thermo physiological comfort properties such as air permeability, water vapour permeability, thermal resistances, wickability, absorbency, drying rate, water resistance and so on, can be altered by fabric construction. The quickness with which a fabric absorbs moisture and gives it up again in evaporation has an important bearing on health and comfort. The comfort has
been an inherent feature of the woven and knitted textiles as it is mostly used for inner and outer garment and the wears of delicate use such as ladies and infant dress materials.

Comfort properties of textiles are extremely important than the aesthetic properties when the garments are worn next to skin. Among all the comfort properties, good absorption and easy drying are the major requirements. Garment next to the skin should absorb the sweat quickly and transport it to the outer surface of the garment. From the outer surface, sweat should be evaporated quickly to keep the body dry or cool. All these desired phenomena come under one technical term called "Moisture management", explained by Ghosh (2004).

Jinlian Hu (2008) says that moisture has a big impact on thermal comfort, but also on sensory comfort. This sensory comfort may change with different activity rates and environmental conditions, along with different garment designs. Capillary action or capillarity can be defined as the macroscopic motion or flow of a liquid under the influence of its own surface (Sharabaty et al 2008).

Brojeswari Das et al (2007) have stated that in sweating conditions, wicking is the most effective process to maintain a feel of comfort. In the case of clothing with high wicking properties, moisture coming from the skin is spread throughout the fabric which may offer a dry feeling and the spreading of the liquid enables the moisture to evaporate easily.

2.3 DEFINITION

A spontaneous transport of a liquid driven into a porous system by capillary forces is termed “wicking”. Mahadevan (2004) defines it is the ability of a fabric to take in moisture. Absorbency is a very important
property which affects many other characteristics such as skin comfort, static build-up, shrinkage, stain removal, water repellency and wrinkle recovery.

The ability of a fibre or a fabric is to disperse moisture and allow it to pass through the surface of the fabric, enabling evaporation to take place (Brown 2004). Wickability is the ability to sustain capillary flow whereas wettability describes the initial behaviour of a fabric, yam or fibre when brought into contact with water (Sharabaty et al 2008).

Wickability is the time taken by a strip of fabric sample to absorb water for a distance of 1 cm. This strip is suspended vertically with its lower edge in a reservoir of distilled water. The spaces between fibres act as capillaries. The capillary network within a fibre will vary in different direction within the fabric.

Wettability is the ability of the fabric to become wet. It is calculated by the weight of water absorbed by a fabric sample in a given direction when immersed in water (Thayumanavan et al 2006).

According to Pandey et al (2010), wicking ability was determined by the method suggested by Booth. Following formula (2.1) was used in this test.

\[
\text{Wicking percent} = \frac{\text{Wet weight of sample} - \text{Dry weight of sample}}{\text{Dry weight of sample}} \times 100
\]  

(2.1)

2.4 WETTING AND WICKING

Wetting and wicking are important phenomena in the processing applications of fibrous materials. Various aspects of liquid-fibre interactions such as wetting, transport and retention have received much attention both in terms of fundamental research and for product and process development.
Wetting of a fibrous assembly affects many manufacturing processes, as well as the end-use performance of materials. Wetting is a complex process complicated further by structure of the fibrous assembly e.g. yarns, woven/ nonwoven/ knitted fabrics and pre- forms for composites. The transport of a liquid into a fibrous assembly, such as a yarn or fabric, may be caused by external forces or by capillary forces. Wicking can only occur when a liquid wets fibres assembled with capillary spaces between them. The resulting capillary forces drive the liquid into the capillary spaces (Patnaik et al 2006).

According to Pan and Zhong (2006), 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.

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. Both wicking and wetting behaviours are determined by surface tensions (of solid and liquid) and liquid/solid interfacial tensions.

Wicking depends on a series of factors, for example those which influence interfacial tensions (temperature, pressure, impurities, polarity...), the other properties of liquid (viscosity, liquid evaporation...) and fibre properties (surface articulation, fibre fineness...), Wiener and Dejlova (2003).

Wetting, wicking and moisture vapour transmission properties are critical aspects for assessing the comfort performance of textile products. There are certain difference between wetting and wicking. Wickability can be defined as the ability to sustain capillary flow and wettability can be defined
as interaction between, liquid and the substrate before wicking takes place. So wetting is a prerequisite of wicking (Ramachandran et al 2009).

The surface wetting characteristics of textiles affect their processability in finished products and their performance when the fibres contact fluids. Wettability can be valuable for characterizing fibre surfaces, liquid transport and interaction of fibres with liquids, surfactants and adhesion with polymers (Mazloompour et al 2007).

Raul (2005) says, the ability of fabric to absorb water, especially by wicking or capillary action may be observed by timing the rate at which water climates up a narrow strip of fabric suspended vertically with its lower end dipping into the water.

Wetting is the displacement of a fibre- air interface with a fibre - liquid interface. Wicking is the spontaneous flow of a liquid in a porous substrate, driven by capillary forces. Because capillary forces are caused by wetting, wicking is a result of spontaneous wetting in a capillary system. Wicking processes can be divided into two groups; wicking from an infinite liquid reservoir (immersion, transplanar wicking and longitudinal wicking), wicking from a finite liquid reservoir (a single drop wicking into a fabric).

According to Samajpati and Sengupta (2006), the phenomenon of wetting or non-wetting of a solid by a liquid is better understood by studying the contact angle. It describes the shape of a liquid drop resting on a solid surface by drawing a tangent line from the drop shape to the touch of the solid surface.

For wicking to take place, the fibre has first to be wet by the liquid. In fact it is the balance of forces involved in wetting the fibre surface that drives the wicking process. When a fibre is wetted by a liquid, the existing
fibre-air interface is displaced by a new fibre-liquid interface. The forces involved in the equilibrium that exists when a liquid is in contact with a solid and a vapour at the same time are given by the following Equation (2.2):

\[ A_{SV} - A_{SL} = A_{LV} \cos \theta \]  

(2.2)

where \( A \) represents the interfacial tensions that exist between the various combinations of solid, liquid and vapour; the subscripts \( S, L \) and \( V \) standing for solid, liquid and vapour, \( \theta = \) equilibrium contact angle, \( A_{LV} = \) the surface tension of the liquid. The contact angle is defined as the angle between the solid surface and the tangent to the water surface as it approaches the solid; the angle is shown as \( \theta \) (Saville 2000).

The fiber length, width, shape and alignment influence the quality of capillary channels in the inter-fiber spaces and sizes of the pores present. Moreover, the density and the structure of yarns influence the dimensions and the structure of inter-yarn, intra-yarn pores, pore sizes and their distribution along the fabrics (Nyoni 2011).

2.5 CAPILLARITY

The term wicking has taken on many definitions and has been the subject of many research papers. In general, wicking takes place when a liquid travels along the surface of the fiber but is not absorbed into the fibre. Physically, wicking is the spontaneous flow of a liquid in a porous substrate driven by capillary forces. This type of flow in any porous medium, caused by capillary action, is governed by the properties of the liquid, liquid-medium surface interactions, and geometric configurations of the pore structure in the medium (Hsieh 1995).
Liquid properties such as surface tension, viscosity, and density, as well as the surface wetting forces of the fibers are known or can be experimentally determined, but the pore structure of a fibrous medium is complicated and much more difficult to quantify. The complexity of a fabric structure makes it impossible to measure an accurate pore structure. Furthermore, movement and interaction of a liquid through pores can cause both shifting of fibers and changing the pore structure (Marchal 2001).

Changes in fiber properties caused by wetting can significantly alter liquid movement. Figure 2.1 below shows the movement of liquid perspiration into a fabric from the skin. The wicked moisture spreads throughout the fabric allowing the moisture to easily evaporate.

![Figure 2.1 Illustration of wicking in a fabric](image)

Wicking in fabrics may occur in a range of conditions and situations. Ghali et al (1994b) believe that “to define this range of conditions, researchers attempt to distinguish between two phenomena related to liquid transport in fabrics – wettability and wickability.” Qualitative definitions of these terms can be found in the literature but parameters which quantify these properties are not available.
According to Harnett and Mehta (1984), “wickability is the ability to sustain capillary flow,” whereas wettability “describes the initial behaviour of a fabric, yarn, or fiber when brought into contact with water.” While wetting and wicking are still argued to be separate phenomena, they can be described by a single process liquid flow in response to capillary pressure (Ghali et al 1994b).

More completely, in the absence of external forces, the transport of liquids in a porous media is driven by capillary forces that arise from the wetting of the fabric surface. Because capillary forces are caused by wetting, wicking is a result of spontaneous wetting in a capillary system (Kissa 1996). Hence, they are coupled and one cannot occur in the absence of the other.

The spontaneous flow of moisture or wicking occurs due to a pressure differential or capillary action. Capillary action, or capillarity, can be defined as the macroscopic motion or flow of a liquid under the influence of its own surface and interfacial forces. The primary driving forces responsible for the movement of moisture along the fabric are the forces of capillarity.

Capillarity describes the phenomenon when liquids in narrow tubes, cracks, and voids take on motion caused by the surface tension of the liquid. Capillarity is based on the intermolecular forces of cohesion and adhesion. If the forces of adhesion between the liquid and the tube wall are greater than the forces of cohesion between the molecules of the liquid, then capillary motion occurs. This flow is similar to other types of hydraulic flow in that it is caused by a pressure difference between two hydraulically connected regions of the liquid mass.

The direction of flow is such as to decrease the pressure difference. Flow would cease when the pressure difference became zero. According to the laws of capillarity, fluid flow would be faster in a void with a large
capillary radius than that in one with a small radius. Though that may be true, the smaller radius capillary can transport moisture to a greater height as illustrated in Figure 2.2 below.

![Figure 2.2 Illustration of capillary rise in different size pores](image)

**Figure 2.2 Illustration of capillary rise in different size pores**

Unlike a capillary of a given dimension, the capillaries that constitute the flow boundary in a yarn are made up of a distribution of pore radii. Due to the mechanisms of capillarity, the moisture front moves from the larger pores to the smaller pores as height increases. This would indicate that the moisture flows from a region of low capillary pressure to a region of high capillary pressure.

In general, the moisture begins in all the pores, but can travel only to certain heights in the larger pores where it then migrates to the smaller pores. So as the height increases, moisture held in the yarns of a fabric decreases because all pores are not filling. If the pores or capillaries do not fill, they do not contribute to the transport of wicking of the moisture.
2.6 TRANSVERSE WICKING

Horizontal or transverse wicking is the ability of horizontally aligned fabric specimens to transport liquid along and/or through them by capillary action. According to Saville (2000) transverse wicking is the transmission of water through the thickness of the fabric i.e. perpendicular to the plane of the fabric.

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 to traverse the thickness of the fabric is short.

Liquid transfer mechanism consists of water diffusion and capillary wicking and they are determined by effective capillary pore distribution, pathways and surface tension (Fangueiro et al 2010). Transverse wicking increases the spreading of the liquid or vapor throughout the fabric by increasing the evaporation of the moisture leaving a drying feeling in the end (Supuren et al 2011).

2.7 REVIEW OF LABORATORY TEST METHODS

The measurement of wicking in fabrics is of topical interest, as the transport of perspiration in liquid form is claimed by some writers but disputed by others. Holcombe and Fourt (1981) consider as an important contributor to the thermal comfort of fabrics worn next to the skin.

Attempts to obtain meaningful laboratory measurements of wicking have given rise to a multiplicity of test methods, and the diversity of the
results has led to some confusion in their interpretation, especially as some of
the methods do not adequately distinguish between wickability (i.e., the
ability to sustain capillary flow), and wettability which describes the initial
behaviour of a fabric, yam, or fiber when brought into contact with liquid
(i.e., prior to any wicking taking place). Various laboratory test methods are
discussed below.

2.7.1 Longitudinal Wicking ‘Strip’ Test

Published Standards

Two standards are listed for this test: BS3424 Method 21 (1973),
Determination of Resistance to Wicking, and DIN 53924 (1978),
Determination of the Rate of Absorption of Water by Textile Materials
(Height of Rise Method).

Procedure

A strip of the test fabric, preconditioned at 20°C, 65% RH, is
suspended vertically with its lower end immersed in a reservoir of distilled
water, to which may be added a dye (of a type known not to affect the
wicking behaviour) for tracking the movement of water (Figure 2.3.a). After a
fixed time has elapsed, the height reached by the water in the fabric above the
water level in the reservoir is measured.

Calculation of Results

In the standards mentioned above, the measured height of rise is
taken as a direct indication of the wickability of the test fabric.
2.7.2 Transverse wicking ‘plate’ test

Published Standards

No published standards exist; the method has been used by Buras et al (1950) on cotton and Korner et al (1981) on porous acrylic and fabrics produced from other fiber types.

Procedure

The apparatus consists of a horizontal sintered glass plate fed from below with water from a horizontal capillary tube, the level of which can be set so that the upper surface of the plate is kept damp, as a simulation of a sweating skin surface (Figure 2.3.b). A disk of the test fabric is placed on the plate and held in contact with it under a defined pressure applied by placing
weights on top of it. The position of the meniscus along the capillary tube is recorded at various time intervals as water is wicked through the fabric layer.

**Calculation of Results**

Given the diameter of the capillary tube, the recorded data is used to calculate the mass transfer rate of water into the fabric.

2.7.3 **Areal wicking ‘spot’ test**

**Published Standards**


**Procedure**

In the standard tests, a drop of liquid (either distilled water or, for highly wettable fabrics, 50% sugar solution) is delivered from a height of approximately 6 mm onto a horizontal specimen of the test fabric (preconditioned at 20°C, 65% RH) (Figure 2.3.c). The region of the fabric on which the drop falls is illuminated by a beam of light to create a bright reflection from the liquid surface and the elapsed time between the drop reaching the fabric surface and the disappearance of the reflection from the liquid surface is measured.

**Calculation of Results**

The disappearance of the reflection is assumed to indicate that the liquid has spread over and wetted the fabric surface. The elapsed time
recorded is taken as a direct measure of the fabric wettability, the shorter the time, the more wettable the fabric.

2.7.4 Siphon Test

Published Standards

No published standards exist. Use of the method has been reported by Lennox-Kerr (1981) on acrylic and porous acrylic; by Tanner (1979) on cotton, polyester/cotton, and polyester/acrylic blends; and by Hardman (1987) on polypropylene, wool, polyvinyl-chloride, and blends.

Procedure

A rectangular strip of the test fabric is used as a siphon, by immersing one end in a reservoir of water or saline solution and allowing the liquid to drain from the other end, placed at a lower level, into a collecting beaker (Figure 2.3.d). The amount of liquid transferred at successive time intervals can be determined by weighing the collecting beaker.

Calculation of Results

Some authors have taken the rate of mass transfer of liquid when a constant flow through the siphon has been attained as an indicator of wickability.

Hardman (1987) distinguished this as a “rate of drainage”. However, since the flow is aided by gravity and occurs through an already saturated fabric with a lower resistance to flow than an initially dry fabric, this is uncertain.
Miller and Clark (1978) used the elapsed time between the initial moment of contact between the fabric strip and liquid and the moment when dripping from the lower fabric end commences as a measure of wicking.

### 2.7.5 Summary of the Review

The strip test and spot test (continuous supply) appear to be equally suitable for measuring wickability parallel to the fabric plane. The relevance of this aspect of wicking behaviour to clothing comfort studies appears to reside in the notion that fabrics in which liquid can spread quickly can aid comfort by distributing perspiration (from individual droplets of sweat on the skin surface or from localized regions of high sweat gland population density or restricted evaporation, e.g., underarms) over a large surface area, thus increasing evaporative moisture loss and helping to keep the skin dry.

Several interesting points are illustrated by these results. From the above survey, there is a good correlation between height and mass in the strip test.

The magnitude of a fabric’s wickability parallel to the fabric plane may be only loosely related to that of its wickability perpendicular to the fabric plane; hence separate test methods are required to evaluate these properties. The strip test (continuous supply) or spot tests are equally appropriate for the former, while the plate test is suitable for the latter.

The reliability of the test methods is likely to be diminished for very weakly wetting or wicking fabrics, but this may be mitigated by taking extra measurements over an extended test duration (spot or strip tests) or by ensuring a high degree of uniformity in the distribution of contact pressure (plate test).
Results obtained using distilled water at 20°C as the wicked liquid appear to be accurately indicative of wicking behaviour using human perspiration at normal skin temperature. So the former may be regarded as an acceptable substitute in studies of the perspiration transport properties of fabrics.

2.8 THEORETICAL BACKGROUND RELATED TO TRANSVERSE WICKING INSTRUMENT

The idea of studying the spreading of drops on materials dates back to 1950s when Gillespie (1958) developed a method to measure the radius of drops on filter paper at fixed time intervals. The studies showed that the spreading process could be divided into two phases.

(Figure 2.4.): phase I, where the liquid is still above the substrate, and phase II, when the drop is completely contained by the substrate. In this second phase the liquid wicks through the fabric horizontally under the influence of capillary forces.

![Figure 2.4](image)

**Figure 2.4** Schematic illustration of the two phases spreading
a) represents the first phase where part of the drop is still above the substrate, b) represents the second phase where all the drop is contained within the substrate
Gillespie developed the following Equation (2.3) to describe the spreading process:

\[
R_t^2 \left[ R_t^4 - R_0^4 \right] = \frac{3\beta}{2} \left( \frac{3V}{2\pi h} \right) t
\]  

(2.3)

In which \( R_t \) denotes the radius of the stain at time \( t \), \( R_0 \) the radius of the stain at time zero, \( V \) the volume of the liquid, and \( h \) the thickness of the substrate. The value of \( \beta \) is given by the term: Equation (2.4).

\[
\beta = \frac{b q s \gamma \cos \theta}{C^3_s \eta}
\]  

(2.4)

In which \( b \) is a constant characteristic of the substrate, \( q_s \) the permeability of the substrate, \( \gamma \) the surface tension of the liquid, \( \eta \) the viscosity of the liquid, \( \theta \) the advancing contact angle, and \( C^3_s \) the saturation concentration of the liquid in the substrate.

Unlike filter paper, textile fabrics are not isotropic, and hence the area formed by a liquid spreading on a textile fabric is seldom a perfect circle. It is therefore more meaningful to measure the area covered by the spreading liquid. Another difficulty with measuring the spreading of the liquids on porous substrates is the speed with which the liquid front moves, in particular during the first phase.

Transverse wicking (Harnett et al 1984) and (Saville 2000) has been defined as the term used when the transmission of a liquid is through the thickness of the fabric, that is, perpendicular to the plane of the fabric. Several techniques, but no standards, have been developed to measure transplanar liquid transport into fabrics.
Hollies et al (1957) evaluated the rate of water transport along a fabric by placing a strip 1 in. wide, 3½ in. long, horizontally over an electrical contacting device and by following the motion of water along the fabric with time.

In the horizontal water transport apparatus, the fabric is held on pairs of contact pins, and one end dips into a small beaker of water. The water level in the beaker is measured with the attached manometer so the volume of water transferred to the fabric can be obtained. The contact pins were placed at 2 cm, 1 cm, ½ cm, starting from the end nearest the beaker. Movement of water along the fabric to each set of contacts triggered a buzzer. And so the distance of water travel as a function of time could also be determined. A method was devised for determining the water-holding capacity of the fabric strips used in the water transport apparatus. The convention of allowing one minute of drainage from the strips held in a horizontal position was found to duplicate most closely the wetness achieved in the rate experiments. The resulting water-holding capacity values were calculated on the basis of the conditioned weights of the fabric samples, i.e., in an atmosphere of 70° F. and 65% relative humidity.

To assess absorption behaviour in the presence of evaporation, Yoo and Barker (2004) modified the gravimetric absorbency test system to incorporate a special specimen cell and cover. In this arrangement, they used a sintered glass with fine pores instead of a single hole to supply fluid to the system, which simulates sweat-wetted skin more precisely. The test sample was mounted at the end of the cover pins with the inner side of the fabric facing downward. An electronic balance continuously monitored changes in the weight of the reservoir discharging fluid to the sample mounted on the test plate. The absorption test was terminated when 0.01 g absorption by a test sample took place in less than 10 seconds. For the evaporation test with air
flow, each test was run for 1000 seconds. Each sample was weighed before and after the evaporation test to determine the amount of moisture that evaporated. The amount of fluid lost from the reservoir during the test was logged by a computer by means of an RS 232 interface as a function of the test duration, and the rate of absorption and the evaporation properties were calculated from the data.

A gravimetric absorbency testing system (GATS) was used to measure the moisture accumulation associated with the wicking of liquid moisture from sweating skin by Yoo and Barker (2005). This test method indicated the lateral wicking ability of the fabric, which provides a more realistic simulation of sweat uptake by garments than a vertical type test does. To assess not only absorption but also the evaporation profiles of the test materials, the GATS was modified to assess absorption behaviour in the presence of evaporation. The absorption capacity, rate of absorption and water retention were measured.

Fangueiro et al (2010) described another apparatus used to evaluate the horizontal wicking rate. In the horizontal wicking apparatus, the specimen (size 200 mm × 200 mm) is placed horizontally, a tiny drop of water is placed on the fabric and the water absorption takes place by wicking and wetting through the pores. The water is supplied continuously from a reservoir by siphoning. The reservoir is kept on an electronic balance, which enables the recording of the water mass absorbed by the fabric. Because the mass absorbed by the sample is related to the sample thickness, water absorption per unit of thickness is used to evaluate the horizontal wicking ability.

Rengasamy et al (2011) tested the water absorbency and spreading rate with gravimetric absorption tester. He reported that the thickness of the nonwoven, fibre diameter and porosity played a vital role in transporting liquid.
Different studies have analyzed the (transplanar) water transport between the layers of a multi-layer fabric using gravimetric methods (Keiser et al 2008, Adler et al 1984, Crow et al 1998, Rossi et al 2004, Spencer-Smith 1977, Yoo et al 2008). Zhuang et al (2002) analyzed the water transport between knitted fabrics subjected to an external pressure. With increasing pressure, the liquid water transfer rose because of the higher contact area between the two layers. Above a critical pressure, however, the water transport decreased due to the lack of void space in the dry fabric. All these gravimetric methods have the common disadvantage that for every measurement, the system has to be separated into its single components, which might lead to additional evaporation of moisture during the manipulation of the samples and to subsequent weight measurement inaccuracies.

In the case of in-plane wicking, the fabric surface stays in contact with the wetting liquid at a point from where liquid flows through the capillaries along the fibre axis. An instrument has been developed by Chattopadhyay et al (2004) IIT Delhi in order to measure in-plane wicking of fabrics. The instrument works on the siphonic principle and the water uptake by the fabric sample with time is recorded. The fabric sample is placed on a horizontal base plate which is connected to a liquid reservoir by means of a siphon tube. The fabric is covered by a glass top plate, so as to ensure intimate contact between the base plate and the fabric.

A similar instrument has been developed by Adams et al (1987) to measure the in plane flow of fluids in a fibrous network. They have used an image analysis technique to obtain the shape and position of a radially advancing fluid front, which can define the directional permeabilities in the plane.
Using this type of in-plane wicking apparatus Håkanson et al (2005) have determined three principal permeabilities of a fibrous layer by a parallel saturated flow method using two flow cells, one for in-plane and the other for out-of-plane or transplanar measurements. From their experiment using card webs; it is observed that the out-of-plane permeability is almost an order of magnitude lower and it contains more scatter than the in-plane permeability.

There is a limitation with the above type of instrument due to the use of the upper plate. A possibility may arise in which air bubbles might be trapped in the fabric or between the plates and the fabric, as there is no other pathway for the air to escape other than the edges of the fabric. This could introduce an uncontrollable error. Another source of error with this type of method is as both top and bottom plates stay in contact of the fabric, two extra capillaries are formed; one between the bottom plate and the fabric and the other between the fabric and the top plate.

Miller and Tyomkin (1984) have introduced alterations to reduce the error that may be caused by air entrapment when using the above instrument. They have replaced the non-porous solid top plate with an alternative kind of top plate, which consists of a set of 25 metal pins (1 mm diameter), evenly spaced, mounted in the same kind of plastic cover plate as before; the sample is attached to the pin tip where contact with the fabric occurs. A comparative study has shown that no significant difference has been obtained in the uptake rate or other kinetic parameters, but the total capacity of the fabric seems to be somewhat lower when the pins are used. They have used this type of top plate in a transplaner wicking tester.

Konopka and Pourdeyhimi (2002) have developed an in-plane wicking tester which overcome the entire above mentioned
problems. This instrument works on a gravimetric principle and has a camera mounted above the plate to record the spreading of the liquid. The instrument is placed on a compression load cell, and is connected to the bottom of a plate using a plastic tube. This instrument replaces the electronic controls with an Analog to digital interface card and appropriate software, which automatically maintains the platform height at the same level, maintaining a constant pressure head for testing. They have developed new types of plates to eliminate the extra capillaries and determine the intrinsic wicking ability of the fabric. In the middle of the plate, there is a cylinder where the liquid enters the system and that is the initial point of absorption/wicking coinciding with the only point at which the fabric touches the plate. The liquid spreading distribution is determined by analysing the image captured by the attached camera.

D’Silva et al (2000) have developed a test method which provides information on both absorption and in plane wicking simultaneously. The absorption-wicking curve obtained from this typical instrument is given in Figures 2.5 and 2.6.

![Figure 2.5 Typical combined bulk absorption and wicking curve of fabric](image-url)
Vertical wicking can be measured by several techniques. In the visual observation method, the movement of the liquid along the sample is observed. The sample is hung from a glass rod that is attached horizontally to a ring stand and lowered vertically into a reservoir. The sample comes into contact with the contents of the reservoir in a perpendicular direction. A little amount of dye is added in the water, which can enhance the clear observation of the liquid. The movement of the liquid, in terms of height wicked by the water is measured as a function of time (Chattopadhyay et al 2004). Microscopic observation has also been used by some researchers Sengupta et al (1985), Nyoni et al (2006) and Perwuelz et al (2000). A load should be hung at the lower end of the sample so as to keep it straight.

Ansari and Kish (2000) have developed an apparatus to study the water transport behaviour along a yarn, using electrical resistance technique. This technique is based on the difference in electrical conductivity between air and water. The electrical conductivity of water is 18 times higher than that of air; so, as the liquid wicks along the sample, the electrical resistance is reduced. The rise of the liquid water in the sample triggers an electrical circuit which is coupled with a personal computer, so that the rise of the liquid as a
function of time may be recorded. The technique based on the measurement of the electrical resistance of fabrics was also used by other authors Hollies et al (1957) and Kamath et al (1994).

Junyan Hu et al (2005) have developed a moisture management tester to characterise fabric liquid moisture management properties, based on the same principle; measuring the electrical resistance of a fabric by this tester has been correlated with the fabric moisture content. This method is also used to measure the liquid water transfer of a fabric in one step, in a multidirection way, as the liquid moisture spreads on both surface of the fabric and transfers from one surface to the opposite one.

The method of measurement is based on the change of the electrical resistance of the fabric with its water content (Yi Li et al 2000). Six concentric rings (sensors) of different sizes are then placed on both surfaces of the fabric. The distance between two consecutive rings is 5 mm except the first one which is at 1.5 mm from the centre. They allow us to measure the spreading and the transfer of water along the 2 faces. More specifically they allow to determine the water content at different ring locations (local) and consequently on the overall (global) surface.

The considered fabric is held fixed by top and bottom sensors with a certain pressure. A liquid solution is prepared and put into the sweat gland, and then introduced on to the top surface of the fabric with a fixed flow rate (0.01g/s). A computer is used to record the temporal resistance changes between each couple of metal rings at the top and bottom fabric surfaces. The experiment duration is 120 s.
After its introduction on the top fabric top surface, the liquid solution will move in the three space directions according to the following steps:

- spreading outward on the top surface of the fabric,
- transferring through the fabric from the top surface to the bottom surface,
- spreading outward on the bottom surface of the fabric.

Ten indexes have been introduced to characterize liquid moisture transmission in moisture management tester.

The method described above able to measure the liquid spreading behaviour of single weave structure fabric. Measuring liquid spreading behaviour of different woven structures in a single fabric (multi structure weave fabric) was quite difficult.

Bao-guo Yao et al (2006) introduced an improved method to measure the changes of water/liquid moisture content on the two surfaces of fabrics. The fabric tested was placed between the two moisture sensors of a moisture management tester. A predefined amount of test solution (synthetic sweat) was introduced onto the top side of the fabric which transferred it in three directions of the fabric. Using the measuring head with six rings, determination of water content and the liquid moisture transfer behaviour in a fabric at both surfaces (top surface and bottom surface), as well as the transport between these two surfaces was done. A set of indexes were calculated and converted from value to grade based on a five grade scale (1–5). The five grades of indices represent: 1—poor, 2—fair, 3—good, 4—very good, 5—excellent. The test results for the liquid moisture management properties of the tested fabrics was expressed by means of the water content
chart with index table, the fingerprint with the classification result, the multi-
measurement profile and the map of water location.

Water transport along textile fibres has also been studied by various
scientists using the electrical capacitance technique. Ito and Muraoka (1993)
have developed an apparatus based on the electrical capacitance technique. A
similar apparatus was also developed by Tagaya et al (1987). The dielectric
constant of water is 80 times higher than that of air, and so, the water
transport can be sensitively detected by measuring the change in electrical
capacitance between the condensers. The electric current generated by the
change in electric capacitance, which is caused by the transport of water, is
converted into voltage by a current to voltage converter circuit. Adler et al
(1984) developed a technique to study the moisture transport and to determine
the mechanism by which moisture is transported between layers of fabric
under transient conditions.

Kissa (1981) has measured the spreading area of a drop on textile
fabric as a function of time. The area of a spreading liquid was photographed
at uniform time intervals with an instant-picture camera. The area depicting
the spreading liquid was cut out from the dried photograph and weighed.
Kissa found that assuming that the fabric was impermeable to the liquid, the
spreading rate could be represented by Equation (2.5):

\[ A = K \left( \frac{\gamma}{\eta} \right)^{m} V^{n} t^{n} \]  (2.5)

where
\[ A \] - area of the liquid drop at time \( t \),
\[ V \] - volume of the drop,
\[ \gamma \] - surface tension,
\[ \eta \] - viscosity, and
\[ K \] - capillary sorption coefficient.
In this study, the equations developed by Kissa are applied to a more rigorous measurement of spreading behaviour using the image analysis of frames captured at fast rates, especially in the initial stages. Measurements of the dynamic change of shape of the spreading area of the liquid are also made.

Kawase et al (1986) developed new test method and apparatus for measuring spreading behaviour. The apparatus used in the spreading studies was a desicato with a 200 mm diameter. The cover had a sealable orifice for inserting a micropipette. The liquid used in the spreading measurement was placed on the bottom of the desicato to minimize volatilization of the liquid spreading in the fabrics. The fabric was mounted on a 12.0 cm wooden ring (embroidery hoop) and placed into the desicato along with a stopwatch. The cell was covered and the fabric was left for at least 2 hours. A measured amount (0.05 to 0.20 ml) of liquid was introduced onto the fabric by a micropipette. The area of the spreading liquid and the stopwatch were recording simultaneously on a videotape. The temperature of the apparatus was maintained at 25°C throughout the experiment. The spreading area was copied on the film, cut out, and weighed. The calibration curve was determined by recording the areas of several known sizes and weighing the copied film in every experiment in order to determine the actual spreading area. The correlation coefficients of the calibration curves were higher than 0.999. The precision of the method was determined by recording the known area 10 times.

Lee et al (2004) conducted horizontal wicking with a spectrophotometer in order to avoid using balances. They determined the liquid weight wicked into the fabric by measuring the difference in color depth between wet fabric and dry fabric. Various researchers, e.g. Morent et al (2006) and Perwuelz et al (2000) have proposed image analysis instead
of an analytical balance to determine the extent of horizontal wicking. In the study by Morent, the progression of the liquid front during wicking was recorded with a digital camera and an algorithm was used to calculate the area of the fabric wetted by fluid.

Petrulyte et al (2009, 2010 and 2008) developed another instrument to measure the in-plane flow of fluids in woven structure. They have used an image analysis technique to obtain the shape and position of a radially advancing fluid front, which can define the directional permeability in the plane for testing terry woven fabrics. They established the absorption speed of terry woven fabrics, the influence of pile height with respect to liquid retention capacity and the impact of macerating process on the absorption process.

In the above method automatic area calculation was not performed. So total time consumed for finding the area with respect to time is more and also accuracy of finding the area is also depends on method of measuring the spreading area.

Wardman et al (2010) developed another instrument based on image analysis technique to study the effect of oxygen plasma treatment on two polyester fibre types, polylactic acid and standard polyester, and its influence on their respective wetting characteristics. He reported that the effect of oxygen plasma treatment on PLA fabric was one of topographical modification. The surface roughness of the fibres increased, which had the effect of increasing the time taken for the drop to penetrate the fabric. The area of water spread on plasma treated fabric was measured through the tool “Free Hand” of the software measurement tools package.
Due to manual method of finding area using free hand tool, this method took more time to find the spreading area and accuracy also depends on persons experience in that software.

Sampath et al (2011) developed new manual method to measure spreading area with respect to time. Application of this method is to measure the transverse wicking behaviour of moisture management finished fabrics. He described spreading of water by one drop method and saturation method.

Each fabric sample of 10 cm diameter was mounted on an embroidery frame. A burette is placed 6mm above the surface of the fabric. One mL of water was allowed to fall from the burette and the area spread on the fabric was measured. This was done by placing a graph sheet beneath the fabric surface and tracing the boundary of the water spread area by using a pin.

The method described above was of static type and hence it took more time to insert pin in the boundary of liquid spread area in each test thus it was more time consuming process.

Nyoni et al (2010) developed another test method and instrument to measure effect of cyclic loading on wicking performance of nylon 6.6 yarns and woven fabrics. The basic principle of this apparatus was to measure the effect of yarn and fabric displacement on the wicking rate as the samples were subjected to different ranges of cyclic loads. He reported that results of this work showed that the stretching and relaxation of yarn filaments and yarns during fabric deformation resulted in spasmodic pumping of the liquid and led to its distribution over a wide region of the fabric, thus improving the rate of evaporation. The fabric wicking behaviour was dependent on the structure of the constituent yarns, their orientation in the fabric, the fabric structure, the pretension, and the force applied.
In the present work, following techniques have been used to determine the transverse wicking behaviour of liquid with respect to time.

1. Technique based on embedded image analysis system
2. Technique based on image analysis using Photoshop method
3. Technique based on cyclic stress action on elastic knitted fabric
4. Technique based on electrical conductivity method.

These techniques help us to do an in-depth study of the transverse wicking behaviour of the fabrics.

2.9 CONCLUSION

It is clear from the foregoing that, although a considerable amount of work has been done on wickability, spreading and sweating and their measurement, still there are many gaps existing in the literature, in particular, on spreading. No systematic way of determining these parameters by proper instrumentation was attempted. Also, no proper statistical design of experiments was followed for determining the wickability under cyclic stress. Previous authors (Nyoni et al. 2010) determined the effect of cyclic loading on the wicking performance of nylon 6.6 yarns and woven fabrics on wicking only by using a complicated instrumentation. In this work, the effect of cyclic stress on wicking, spreading and sweating has been determined.

Li et al. (2000) has carried out work on the moisture management of fabrics using MMT tester and has not considered the effect of multi weave structure in his work. Also, the measurement of sweating in multi weave fabrics was not accomplished in a systemic way and this thesis addresses these aspects in depth.