CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

This chapter deals with the literature review on general principles associated with knitting, weft-knitting machine, weft-knitted fabric structures, derivative knit stitches, geometry of weft knitted fabrics and air permeability of fabrics. Ample amount of literature is available on geometry of weft knitted fabrics from the research works carried out by various workers for past many decades. But, the literatures available in connection with the specific area air permeability of knitted fabrics are comparatively lesser one that too with the study of air permeability of the fabrics under stretched condition. This review is an outcome of thorough search of various journals and books published on textile technology.

2.2 GENERAL FACTS ABOUT KNITTING

2.2.1 Principles of Knitting

Knitting is one of the major fabric manufacturing methods in which intermeshing or interlooping of yarn loops is the principle adopted to produce textile structures. Knitting is formed by a series of loops, intermeshing in rows, and each hanging from the last. Each intermeshed pair of loops is called as a stitch; a vertical column of stitches is a wale and a horizontal row of stitches is a course in a knitted fabric.

In knitting, the yarns are initially formed into loops, and then these loops are interconnected to produce a textile structure. The term interlooping is
used to describe this technique of forming fabrics. Based on this principle, a textile fabric is produced using only one set of yarn.

Spencer (2001) stated that knitting is one of the fabric forming methods in which the series of yarn loops are intermeshed to produce the fabric. The principles of knitting is classified into two based on the direction of loop formation or knitting namely weft knitting and warp knitting. If the direction of knitting is horizontal one that is called weft knitting and vertical one that is called warp knitting.

![Figure 2.1 Weft Knitting](image1.png) ![Figure 2.2 Warp Knitting](image2.png)

Fabrics essentially consist of a series of interlined loops of yarn, thereby, a horizontal set of yarn (weft) could be interlooped to produce a weft knitted fabric as shown in Figure 2.1 and a vertical set of yarn (warp) could be used to produce a warp knitted fabric as shown in Figure 2.2.

### 2.2.2 Weft Knitting Machines

Chandrasekhar et al (1995) stated that weft knitting is the more diverse, widely spread and larger of two sectors, and accounts for approximately one quarter of the total production of apparel fabric compared with about one
sixth for warp knitting. A major part of the weft knitting industry is directly involved in the assembly of garments using operations, such as over locking, cup-seaming and linking that have been specifically developed to produce seams with compatible properties to those of weft knitted structures. Weft knitting machines are classified into two as; flat knitting machine and circular knitting machine.

The first flat bar machine was demonstrated in 1862 and patented in 1865 by Rev. Isaac Wixom Lamb, an American clergyman. He later changed the arrangement to inverted V-bed shape patented by Eisentuck.

There are two types of flat machines evolved. The widely used one is V-bed rib machine and the slower, more specialized one is flat bed purl or links-links machine. V-bed machine has two rib gated, diagonally approaching needle beds, set between 90° and 104° to each other, giving an inverted V-shape appearance. Flat bed purl (links-links) machines have horizontal needle beds. They have been employed mainly in knitting that simulated hand-knitted constructions of a specialty type, such as cable stitch, basket purl, and lace patterning. They use double-headed latch needles that are transferred to knit in either of two directly opposed needle beds.

The term circular knitting covers all weft knitting machines have needle beds which are arranged in circular cylinders and or dials. Among global fabric production, circular knitting accounts for nearly 15%. Revolving cylinder latch needle machines produce most of the weft knitted fabrics and are of two main types, single cylinder machines and cylinder and dial machines.

2.2.3 Weft Knit Structural Elements

Majority of weft knitted structures are similar in four major structural units of construction, i.e. face loop, back loop, tuck stitch and float or
miss stitch. The most studied structure is plain-knit structure. It has proved, however, to be a difficult structure to analyze, mainly because of the experimental difficulty of measuring this highly extensible and easily deformable structure and also, it now appears, because its relaxed shape is not as simple to define as first thought.

It is not possible to discuss the geometric and other properties of knitted fabrics without describing the elements of a knitted structure. Ajgaonkar (1998) explained that the smallest element of a knitted fabric is the *loop*. The constituent loop of a weft knitted fabric has the general shape shown in Figure 2.3. During knitting the loop is extended due to take down force applied to the fabric. The fabric is removed from the knitting machine and left free from strain, and then the loop takes its original form similar to that shown in Figure 2.3. The top part of the loop (a), which is held by the needle, is called “needle loop”, while the lower part of the loop (b), which connects the adjacent loops, is held by the sinker and hence it is called “sinker loop”.

![Diagram of knitted fabric elements](image)

**Figure 2.3 Elements of knitted structure**
Doyle (1953) suggested that the knitted loop and the length of yarn knitted into the stitch in particular, is an important parameter for the measurement of knitted fabric quality. The loop formed is a three-dimensional unit, because to produce a flat knitted structure, the yarn is bent both in the plane of the fabric and in the plane at right angles to the fabric. The loop has a constant length ($\ell$) which is equal to yarn length needed to form a loop (Figure 2.2). This is the most important dimension within a construction and in fact decides the area covered by the loop together with loop height and width. The loop can vary in size, that is, its length ($\ell$) can be altered. It is rather obvious that as the loop length increases the area occupied by the loop gets larger.

The loops can be related to one another and can be intermeshed with one another to form fabrics. In a vertical direction loops can be joined together by intermeshing, forming a vertical row of loops known as “wale” and in a horizontal direction the relationship of the loops is a simple one where a series of loops is formed by the same thread called “course”.

In a knitted structure the *stitch density of fabric* can be defined as the number of stitches per unit area of fabric as depicted in Figure 2.4 and the mass per unit area of fabric is known as areal density. Usually, stitch density is measured in number of stitches present in square inch or square centimetre of weft knitted fabric. In the same way areal density of weft knitted structure is estimated in number of grams per square metre of fabric (GSM). It has been found that the total number of stitches per square inch of fabric, is dependent primarily on the length of yarn per unit cell and is independent of yarn material, yarn structure, and the system used to form the stitches.
2.2.4 Plain Knit Structures

Anbumani (2006) described that plain is a simplest fabric construction all units are of the same sort, i.e. each loop is in the same shape and is pulled through the previously knitted loop in the same manner or direction. The fabric has a different appearance on each side. The technical face is characterized by smoothness with the side limbs of the loops having the appearance of columns of “V” shape in wales direction. On the technical back, the heads of the needle loops and the bases of the sinker loops form columns of interlocking semi-circles as shown in Figure 2.5.
2.2.5 Derivative Sitches and Structures

Ajgaonkar (1998) stated that in a knitted structure, apart from the plain stitch, other types of stitches may also be produced by varying the timing of the intermeshing sequence of the old and new loops. The most commonly produced stitches are the tuck stitch and miss stitch as shown in Figure 2.6. Two or more miss stitches in sequence is called float.

A tuck stitch is composed of a held loop, one or more tuck loops, and knitted loops. It is produced when a needle holding its loop (b) also receives yarn to form a new loop which becomes a tuck loop (a) because it is not intermeshed through the old loop, but is tucked in behind it on the reverse side of the stitch.

![Tuck stitch and Miss stitch](image)

**Figure 2.6 Derivative weft knit stitches**

A miss stitch is also composed of a held loop, one or more miss loops and knitted loops. It is produced when a needle holding its old loop (d) fails to receive the new yarn which passes, as a miss loop (c), to the back of the needle and to reverse side of the fabric. The miss stitch shows the missed yarn floating freely on the reverse side of the held loop which is seen on the
technical back of single jersey structure, but in rib and interlock structures miss or float stitch is seen inside. Single jersey derivative structures such as pique, double pique, popcorn, lacoste and cross tuck are better examples for knit and tuck stitch combination, cross miss is for knit and miss stitch combination, twill is for knit, tuck and miss stitch combination are the interesting outcome of these two fundamental derivative stitches of weft knitting.

2.2.6 Tightness Factor

The most convenient means of assessing the knitting performance of a spun yarn is by the use of the “tightness factor” concept. Munden (1962) first expressed the use of a constant factor to indicate the relative tightness or looseness of a plain knit structure.

Knapton et al (1968) suggested that most spun yarn single knit fabric is commercially knitted between the range of $9 < K < 19$. It is essentially impossible on any machine gauge or with any yarn count to knit fabric over a wider $K$ range. A more usual knitting range, from loose to tight fabric is $12 < K < 18$ with a mean value of 15. He also found that at approximately $K = 15$, the dynamic forces required to pull a wide range of yarn counts into a knitting loop are at a low and equivalent value.

Baird and Foulds (1968) used the above equation on a factorial analysis of two shrink-resist treatments with fabric tightness factors 13.2 to 17.5. Using Smirfitt’s (1965) definition of the geometry of the 1X1 rib structure, the tightness factor formula is identical to that of the plain knit structure. Criteria for suitable combinations of machine gauge and yarn tex could be the extent and evenness of the dispersion of possible tightness factor values around 14.5.
2.3 GEOMETRY OF SINGLE JERSEY WEFT KNITTED FABRICS

The chiefly examined structure is the fundamental plain-knit structure. Peirce (1947) tried to generalize a loop model for a plain knit structure. Peirce created a three-dimensional model of a plain-stitch loop by laying it on the surface of a circular cylinder whose generators were parallel to the lines of courses. Peirce’s model also took into account changes introduced by changes in loop length for a given yarn diameter by adding extra straight portions across the top and bottom of the loops and in the diagonal straight portions.

An attempt was made by Chamberlain (1949) to create a model for the plain-knitted structure, who established a theoretically balanced loop depicted in Figure 2.7 is composed of an upper curved circular portion, two lower curved, also circular, portions and two diagonal straight portions that link the upper and lower curved portions, one on either side. In Chamberlain’s model, the loops of adjacent courses and wales are in contact, and the position of the maximum width of the interlocking loop.

![Figure 2.7 Chamberlain’s plain stitch model](image)

Figure 2.7 Chamberlain’s plain stitch model
It is concluded from Chamberlain’s model that any change in loop length will involve a change in length of the fabric. The width of the fabric will not change, as it is governed by yarn diameter (d) only.

Chamberlain considered only the case of a two-dimensional model of a knitted fabric of maximum cover. In fact, however, a plain stitch loop is a three-dimensional structure, and fabrics with different covers can be obtained.

Shinn (1955) considered a two-dimensional plain-stitch loop model which led to the same loop-characteristic values as those of Chamberlain’s model, the basic principles of his considerations being the same.

Leaf and Glaskin (1955) criticized Peirce’s (1947) model. They showed that, in reality, Peirce’s (1947) model could not represent a stable fabric. There were discontinuities of torsion at certain locations in Peirce’s model that would cause the loop to change its shape after relaxation as per their calculation. This criticism holds for another loop models. There are no physical reasons for some parts of the yarn in a loop to remain straight. The curvature of the yarn would therefore change and consequently, the shape of the loop would also change.

Doyle (1952, 1953) had observed, when investigating the dimensional properties of plain-knitted fabrics, that for a wide range of fabrics, the product of the number of courses and wales in unit area is dependent solely upon loop length, the relationship being of the form

\[ S = \frac{Ks}{\ell^2} \quad (2.1) \]

Where \( S \) = stitch density, \( \ell \) = length of yarn knitted in to a stitch
A further study by Munden et al (1961) showed that the dimensions of plain knitted wool fabrics, in a state of minimum energy, were dependent only upon the length of yarn knitted into each loop. His experimental studies indicated that courses per unit length, wales per unit length and loop length must be related to each other by constants and have the following relations:

\[ K_c = c \times \ell \quad \text{(2.2)} \]

\[ K_w = w \times \ell \quad \text{(2.3)} \]

\[ K_r \text{ or } R = \frac{K_c}{K_w} = \frac{c}{w} \quad \text{(2.4)} \]

Stitch density \( = \text{cpi} \times \text{wpi} = \frac{K_c}{\ell} \times \frac{K_w}{\ell} = \frac{K_s}{\ell^2} \quad \text{(2.5)} \]

In the above equations \( c \) and \( w \) define the courses per inch and the wales per inch respectively and \( K_c, K_w, K_s \) and \( K_r \) are constants called “K-constants or fabric dimensional parameters”.

These formulae are considered as the basic laws of knitted fabric structure, in that they indicate the dimensions towards which any plain-knitted structure tends in order to reach the state of equilibrium or minimum internal energy when knitted and removed from the machine. Moreover, they showed that there is only one factor which governs the dimensions of a knitted fabric known as loop length or stitch length. It means the length of the yarn knitted in to a loop. These experimental relationships have been realized and agreed by the succeeding researchers in the field of knitting and used as benchmark for further studies.

Munden’s investigations on knitted fabrics and their tendency to reach a characteristic state of energy equilibrium have led to the realization that there are two basic equilibrium states for the knitted fabric, depending upon the
treatment of the fabrics after knitting. These two states are known as the dry-relaxed state and the wet-relaxed state. If, after knitting, a fabric has been allowed to lie freely for a sufficient length of time, it may reach a stable state of equilibrium. This state is called a “dry relaxed state”. The state of equilibrium reached by a fabric after static relaxation in water and subsequent drying is called a “wet-relaxed state”.

Munden et al (1963) expressed that the wet-relaxed $K$-values of non-hygroscopic yarns were essentially the same as the dry-relaxed values, though a 13-15% difference in $K_s$ value between the same relaxed states for fabrics knitted from hygroscopic yarns such as wool, cotton etc., was obvious. The cause of this intrinsic shrinkage in hygroscopic yarns is attributed to the chemical action of water on hydrogen bonding within the fibre. On immersion in water, breakage of the hydrogen bonds between adjacent long-chain fibre molecules occurs as the water molecules penetrate between them. These bonds, formed when the yarn was straight, are strained when the fibres are bent into the configuration of the knitted loop. It is this internal cross-linking strain which causes the yarn to straighten again when unravelled from the dry fabric. On drying from the wet state, these bonds are reformed, but now, the yarn can no longer return to its original straight configuration. It remains temporarily set into the “crimped” configuration of the knitted loop. Wet-relaxation fabric shrinkage, Munden theorised, is therefore caused by the release of fibre constraints and is irreversible. Experimental studies by Munden (1959) on wool plain knit fabric indicated the values presented on Table 2.1 for the two relaxed states.
Table 2.1 K-constants for plain knit fabric (Munden)

<table>
<thead>
<tr>
<th>Fabric state</th>
<th>Parameters</th>
<th>Kc</th>
<th>Kw</th>
<th>Ks</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry-relaxed</td>
<td></td>
<td>5</td>
<td>3.8</td>
<td>19</td>
<td>1.31</td>
</tr>
<tr>
<td>Wet-relaxed</td>
<td></td>
<td>5.3</td>
<td>4.1</td>
<td>21.6</td>
<td>1.29</td>
</tr>
</tbody>
</table>

Subsequently, Munden (1959) has given the values of Ks and Kr for plain-knit fabrics in three states as shown in Table 2.2. From these values it is clear that the cpi /wpi ratio or Kc / Kw ratio is 1.3 for both dry and wet-relaxed fabrics. This K-value may be looked upon as a loop-shape factor.

Table 2.2 Munden’s estimated Ks and Kr values for plain knitted fabric

<table>
<thead>
<tr>
<th>K-values</th>
<th>Dry relax</th>
<th>Wet relax</th>
<th>Full relax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ks</td>
<td>19</td>
<td>21.6</td>
<td>23.6</td>
</tr>
<tr>
<td>Kr</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Leaf (1960) suggested a different geometrical loop shape for the plain-knit loop structure. The knitted loop in the fabric plane was considered to be composed of two joined, identical elasticas. He adopted the elastica because its shape is mathematically arrived and because its configuration is similar to that of a knitted loop.
Figure 2.8  Leaf’s plain stitch model(a)Original elastic(b)Loop model in plane (c,d)Its projections

The model was made three-dimensional by causing the elastics to be bent out of the plane of the fabric into two different surfaces. In the first model, the elastics were placed on the surface of a cylinder, as Peirce did. It was found that this model could be fitted to Munden’s experimental results for wet-relaxed fabrics and not for the dry-relaxed fabrics.

In his search for another model that would fit both the wet and dry-relaxed states, Leaf proposed a second model. The third dimension was assumed to be a sine wave. The second model is more complicated mathematically, but it provided a model that would fit the experimental relationship between cpi, wpi and stitch length for both the wet and dry-relaxed states. However, both of Leaf’s models are physically unrealistic, because the proposed elastics would only be produced if external forces acted on the yarn at those places on the knitted loop where there are no external forces. In addition, these models take no account of the effect of a given loop on its adjacent interlocking loops. It is to be noted that the loop shape of these models is determined by the experimental values obtained by Munden. They can be considered as possible models that fit the observed experimental results.
Nutting and Leaf, (1964) shown experimentally that the geometry (i.e., the loop shape) of weft knitted fabrics is controlled by loop length, fibre type and properties, and method of relaxation. A theoretical study indicates that, for given end conditions, the shape taken up by a deformed elastic rod depends on the ratio of its flexural and torsional rigidities. The result is used to provide a tentative explanation of the experimental results.

Postle (1965, 1968) found that an account is given of a study of the dimensional changes of plain-knitted fabrics brought about by various relaxation treatments. A wide range of natural and synthetic-polymer fibres was encompassed. It was found that, for synthetic-fibre fabrics, dry tumbling at elevated temperatures causes higher levels of relaxation shrinkage and larger changes in shape than static wet-relaxation treatments, whereas the opposite is true of fabrics produced from hydrophilic fibres. A wet treatment at an elevated temperature is proposed that brings about complete relaxation of all the fabrics investigated. It is only in this completely relaxed state that the loop shape is similar for all the fabrics investigated.

Knapton et al (1968) examined the dimensional properties of knitted wool fabrics and claimed that only in the fully relaxed state the plain knitted structure is a reasonably stable structure; and in any other state, the nature of the knitted loop is dependent on the yarn’s physical properties, mechanical processing and knitting variables. Possibly the significant contribution of Knapton et al, lies in the fact that a fully relaxed state is found to occur when the fabrics are thoroughly wetted out, briefly hydro extracted and tumble-dried. A further major point is that investigators proposed a new matter \( K_S \) which is equal to the ratio of ‘t’ and ‘d’. Here tis fabric thickness and d is yarn diameter. With respect to fabric dimensions, Knapton and Fong (1971) stressed that it is dependent on the loop length, but a small effect of fiber quality of wool on the completely-relaxed mean values of \( K \) has been found.
Song and Turner (1968) displayed the value of Ks varies with the tightness factor for dry relaxed fabrics, however, as progressively more severe wet-relaxation treatments were applied, Ks became independent of the tightness of construction. This finding differs with some results obtained by Knapton and Munden (1966) who used lubricated viscose staple yarn and concluded that Ks was constant in the dry-relaxed condition, but varied with tightness for certain wet-relaxation treatments carried out at unspecified temperatures.

Knapton and Fong (1970) observed that about ten cycles of laundering and tumble-drying brought the fabric to a state beyond which Ks values do not change on further relaxation. The Ks values at such dimensionally stable states show an appreciable spread and it was concluded that some factors, so far unidentified, must have influenced the stable state. Kc and Kw values were found to depend on tightness factor such that, with increasing tightness factor, Kc increased, and Kw decreased slightly; these views contradict the theoretical deductions for non-jammed structures but agree with the jammed ones. Yarn count and fiber quality affect Kc but yarn twist was observed to be of no effect at stable state. Thickness and bulk densities were observed to be affected by fabric tightness.

Postle (1971) developed a general geometrical model, based on the assumption of a constant unit-cell configuration for particular knitted construction such as plain, interlock, and various rib knit constructions to enable simple relations to be derived for the effective diameter and specific volume of the yarn as it exists within the fabric, the fabric thickness, and the bulk density of the structure. The relations between these parameters and the fabric tightness factor are evaluated quantitatively for fabrics knitted from wool yarns. The knitted fabric parameters evaluated in this work are difficult to measure experimentally. The geometrical approach used gives an assessment
that is independent of the problems encountered during experimental measurements of such parameters as fabric thickness and yarn diameter.

Lord et al (1974) carried out experiments with a view to finding out the performance of open-end, twistless and ring yarns in weft-knitted fabrics. They considered polyester cotton blended yarns of 18’s Ne having blend compositions of 75/25, 50/50 and 25/75 spun on ring and rotor spinning systems in their work. These authors studied only the air-permeability and bursting strength for the fabrics knitted from blended yarns. It was noticed that the fabric dimensional parameters were significantly affected by the twist factor used.

Kurbak (1998) carried out experiments of arbitrary shape fitting for plain knitted loop. This geometric model was suggested for visualizing the change of a parameter or same parameters with relaxation and tightness. The geometric model also showed the changes of radius of loop curvatures when the take-down tension was altered. Kurbak and Amreeva (2006) studied the geometric models of single jersey pique knitted fabrics. Elliptical shapes for the head of loops (tuck and plain) and general helices for the rest of the parts including the arms of the loops were used. He found the co-ordinates of the points on the fitting curves and used these points in the simulation of the front and back views of the single jersey pique knitted fabrics. Kurbak and Alpyildiz (2008) studied the double lacoste knits and established new coordinating points on the fitting curve.

Efthymios (2005, 2006) developed a software named “ProKNIT” for the prediction of knitted fabric weight per unit area. The software was able to determine the weight of knitted fabric in different relaxed conditions by entering process and material variables, such as the type of fabric and fibre, knitting machine gauge, yarn count, fabric loop length and tightness factor. The prediction of the fabric weight was dependent upon the dimensional
parameters of $K_c$, $K_w$, $K_s$ and $R$, which were entered in the system. The software was applicable for single-and double-knitted structures made with cotton and its blends.

2.4 ROLE OF ELASTOMER IN KNITTING

Schulze (1993) investigated the dimensional properties of single jersey, lacoste and fleecy fabrics knitted with cotton - spandex yarns and reported that the weight and loop densities of cotton/spandex fabrics were higher than cotton fabrics; also the extension, both width wise and lengthwise, increased as the relaxation progressed.

Tasmaci (1996) found that variations are higher both in width wise and in weight for the spandex containing fabrics.

In SITRA Focus (2003) it is indicated that in present scenario, fashion designers are much conscious than ever and have up-to-date information about the latest fashion trends. The present day consumer demands fashionable garments, which offer comfort and style, stretch and flexibility, freedom and figure enhancement, as it as the tool of expressing personality. As far as comfort is concerned, cotton blends are more popular than pure cotton. All cotton garments may be comfortable but have wrinkle problems. Spandex comes here to help in offering wrinkle resistance and garment integrity while offering extra comfort. The wearer of spandex containing garment feels less fatigued and less muscle strain than the one wearing garment without spandex. This value of spandex is well recognized by the fabric and apparel manufacturers as well as the consumers. The ongoing influence of casual clothing of life style is boosting the popularity of spandex containing garment. As casual work attire becomes more popular, spandex allows these types of garments more comfortable. Additionally, spandex provides a greater degree of
wear ability, wrinkle recovery and crease retention, making it the perfect complement to the most garments.

Thangamani and Natarajan (2003) stated that durability and comfort are the two-yard sticks, which determine the sale ability of fabrics. Spandex is known for having elongation up to 700%. So, an ideal blend of cotton and spandex will help the fabric to have the advantages of both of them. In the air covering (intermingling) process, spandex is combined with cotton yarn, which is used for producing casual wear and aerobic wear. The garments made out of the fabrics consisting of spandex core spun (with spandex filament as core and other natural / man-made fibres as sheath), provide consistent shape, fit and comfort. These properties also help to develop the garments for “ready to wear”. Because of the above properties, spandex fibres are found in light weight and uses especially in swim wear, sportswear, light weight support garments, ladies inner wear etc.,

Prakash and Thangamani (2010) observed that the dimension of fabrics containing spandex showed considerable change during their wet relaxation.

Sadek et al (2012) studied the effect of extension increase percent of bare lycra yarns during loop formation on the geometrical, physical and mechanical properties of plain jersey fabrics. Results showed a sharp increase in the courses density rather than the wales density.

Cuden et al (2013) mentioned that the development of knitted fabrics with incorporated elastane has increased in recent decades. Knitting with these elasticized yarns usually results in a very compact structure. Loop length is considered to be the primary parameter for knitted structures. Consequently, knowledge of all factors influencing loop length is vital for planning yarn consumption, comfort fit, quality, performance and aesthetic properties of knitted fabrics made from elasticized yarns. The objective of this
research was to study the impact of material, knitted structure and relaxation process parameters on loop length. In addition, the objective was to examine the differences in loop length of single weft knitted fabrics, produced from different types of elasticized and non-elasticized yarns. For both groups of knitted fabrics, elasticized and non-elasticized, knitted fabric density and relaxation process influence the loop length most of all. Loop length decreases during the process of consolidation, but this decrease is not substantial. Addition of elastane does not significantly influence the loop length.

2.5 AIR PERMEABILITY OF FABRICS

2.5.1 Definitions for Air Permeability

Saville (1999) stated that the air permeability of a fabric is a measure of how well it allows the passage of air through it. The ease or otherwise of passage of air is of importance for a number of fabric end uses such as industrial filters, tents, sail cloths, parachutes, raincoat materials, shirting, down proof fabrics and airbags. Air permeability is defined as the volume of air in millilitres which is passed in one second through 100 mm$^2$ of the fabric at a pressure difference of 10 mm head of water.

Air permeability of a fabric is defined as the volume of air in litres which is passed through 100 cm$^2$ of the fabric in one minute at a pressure difference of 10 mm head of water according to Turkish Standards Institution (1998) under its test procedure TS 391 EN ISO 9237 and Air Permeability Test Method & Explanatory Notes (2008).

Wilbik-Halgas et al (2006) found that the air permeability of a fabric is the amount of air passed through a surface under certain pressure difference in unit time. The value has significance with respect to the usage area. Air permeability is a function of the thickness and surface porosity of the knitted fabrics.
Ertekin et al (2011) expressed that air permeability is the rate of air flow passing perpendicularly through a known area under a prescribed air pressure differential between the two surfaces of a material. The fabrics get finer, the amount of air passed through the fabric increases.

2.5.2 Earlier Works on Air Permeability

Greyson (1983) specified that the heat and water vapour resistance increased with the increase of material thickness and air entrapped in the fabric.

Yoon and Buckley (1984) concluded that both the fabric construction and the constituent fibre properties affect thermal transport. In general, thermal insulation, air permeability, and water vapour transmission rate are dependent mainly on the fabric geometrical parameters, namely, thickness and porosity.

There is general agreement that the transfer of heat, moisture and air through the fabric are the major factors for the comfort. Many authors such as Holcombe and Hoschke (1983) and Obendorf and Smith (1986) pointed out that the major factors influencing heat transfer through a fabric are the thickness and enclosed air. A decrease in thickness of fabric, together with a corresponding decrease of fabric volume, is generally followed by decrease of air entrapped in fabric structure changing the thermal properties of the fabric.

Oinuma (1990) showed that as the stitch length increased, the porosity and the air permeability increased and the thermal retaining property decreased for dry relaxed cotton 1 × 1 rib knitted fabrics. When the results are examined, the fabric with the lowest courses per centimeter and yarn number (tex) has the highest air permeability values. Therefore, raising loop length caused looser surface in fabric which increased the air permeability.
Milenkovic et al (1999) stated that the term comfort is a subjective concept which is only recognized by the person experiencing. In recent years attempts have been made by several workers to connect comfort with clothing. The type of clothing used by defence forces is having a wide range at end – uses starting from parade garments suitable for summer and winter combat uniforms, fatigue for exercises, protective clothing like overalls, flying clothing, clothing for high altitude areas and extreme cold climates suits for protection against nuclear, biological and chemical warfare. Although the functional requirements for clothing items are paramount interest comfort, aspects of the same cannot be ignored while selecting the basic materials for such clothing or while designing the same for a particular end – use. Because it must be understood that the combat efficiency of the troops will much depend on the comfort and ease of donning a particular garment. The investigators demonstrated that fabric thickness, enclosed air still within the fabric and external air movement are the major factors that affect the heat transfer through the fabric.

Hes (2000) mentioned that to achieve the ideal clothing comfort, it is quite necessary to consider the end use of garment and suggested cotton yarns for hot days for a cool feeling.

Havenith (2002) mentioned that the heat and water vapour resistance increased with the increase of material thickness and air entrapped in the fabric.

Marmarali (2003) investigated the dimensional and physical properties of cotton/spandex single jersey fabrics and compared the results with fabrics knitted from cotton alone and found that the loop length and amount of spandex are used to determine the dimensions and properties of the knits. It is apparent that as the amount of spandex increases the loop length values remain nearly the same and the course and wale spacing values
decrease. Furthermore, spandex containing fabrics tend to be tighter, the weight and thickness of the fabric are higher but, air permeability, pilling grade and spirality are lower. She stated that the air permeability values of 100% cotton fabrics were higher than those of cotton / spandex fabrics. Moreover, 100% cotton loose fabrics are more air permeable than 100% cotton tight fabrics.

Marmarali (2003) confirms that the relationship between air permeability and loop length is strong one. It was found that as the loop length increased, the air permeability also increased. It was concluded that when the loop length increased, tightness factor decreased correspondingly and the trend was the same for ring and compact yarns.

Dubrovski (2004) concluded that a lot of thermo physiological comfort properties, such as air permeability, water vapour permeability, thermal resistance, wick ability, absorbency, drying rate, water resistance and so on, can be altered by fabric construction.

Ucar and Yilmaz (2004) studied the natural and forced convective heat transfer characteristics of rib knit fabrics. This result also indicated that as the fabric gets tighter, so the heat loss lessens, due to reduced air permeability, i.e., reduced air circulation within the fabric. However, when the fabric density for each fabric design is taken into consideration, the heat loss due to air circulation (convective heat loss) becomes more important than the conductive heat loss due to fibres and air gaps.

Karaguzel (2004) observed that knit fabrics are open and porous structures while comparing with other structures, such as woven or braided. A large proportion of the total volume occupied by a knitted fabric is usually air space. It is because of the way the yarns and fabric have been constructed. The distribution of this air space influences a number of fabric properties such as warmth and protection against wind and rain in clothing, and the efficiency of
filtration in industrial cloths. Air permeability is an important factor in the comfort of a fabric as it plays a role in transporting moisture vapour from the skin to the outside atmosphere. The assumption is that vapour travels mainly through fabric spaces by diffusion in air from one side of the fabric to the other. The air permeability of fabric depends on the shape and value of the pores and the inter-thread channels, which are dependent on the structural parameters of the fabric.

Kane et al (2007) focused on the effect of single jersey, single pique, double pique and honeycomb structures and structural cell stitch length (SCSL) on ring and compact yarn single jersey fabric properties. Compact yarn fabrics showed better performance in all the structures and their respective SCSL. With increased SCSL, the dimensional properties like CPI, WPI, SD, grams per square meter, thickness and tightness factor decreased for all the structures, while comfort properties like air permeability and water absorbency increased. The tensile, bending and compression properties of weft knitted fabrics improved and compression resilience and surface properties generally decreased. Total hand values improved with SCSL. Other properties, such as abrasion resistance, bursting strength and pilling resistance improved with decreased SCSL. Combination order of knit-tuck stitches played an important role in all the properties. Double pique fabric showed better performance for the summer outer wear and single jersey fabric showed better performance for summer inner wear.

Dias and Delkumburewatte (2008) discussed a geometrical model of plain knitted structures in depth to understand the yarn path in a knitted loop. They created a theoretical model to predict the porosity of a knitted structure depending on the geometrical parameters, such as course spacing, wale spacing, stitch length, fabric thickness, count of yarn and fibre density. Polyester and nylon plain knitted fabrics were produced to different tightness,
and porosity was determined by measuring the weight. The validity of the model was confirmed by experimental results, using different plain knit fabrics. They found that porosity of a knitted structure can be changed by reducing the yarn thickness and the stitch length; however, this would influence the courses and wales per unit length in the structure.

Chen et al. (2008) investigated the dynamic heat-moisture comfort property of textiles based on static and dynamic experiments. The results indicated that under comfortable conditions, fabrics with lower weight per square metre, higher thickness and air permeability will be more heat-comfortable, while fabrics with higher air permeability, moisture regain and vertical wicking height will be more moisture-comfortable. Under uncomfortable conditions, fabrics with lower thickness and weight per square meter as well as higher air permeability will be more heat-comfortable, while fabrics with lower moisture regain, higher air permeability and vertical wicking height will be more moisture-comfortable.

Vigneswaran et al. (2008) results show that the thermal conductivity, thermal diffusion and thermal resistance of the knitted fabrics depend on the percentage of the core/sheath components, fabric properties, such as, thickness, tightness factor, density and air permeability.

Vigneswaran et al. (2009) studied the relationship between fabric properties and thermal conductivity of jute/cotton blended knitted fabrics. The thermal conductivity reduces with increasing fabric thickness. Their values of thermal conductivity are erroneous usually, thermal conductivity values are expressed in two digits while they quote single digit. It also reveals that fabric air permeability and tightness factor values influence the thermal conductivity of knitted fabrics. The thermal insulation values are noticed to be higher with higher fabric tightness factor and lower air permeability.
Marmarali et al (2009 a) observed that the parameters of thermal conductivity, thermal resistance, thermal absorptivity and air permeability are affected by tightness factor significantly. The looser fabrics possess high insulation and high air permeability values, and give warmer feelings.

Marmarali et al (2009 b) observed that the parameters of thermal conductivity, thermal resistance, thermal absorptivity and air permeability are affected by tightness factor significantly. The looser fabrics possess high insulation and high air permeability values, also give warmth feel. They also investigated that the thermal comfort parameters of the knitted fabrics made from blended yarns. They observed that the parameters of air permeability, thermal resistance and thermal absorption are quite sensitive to blend ratios of fibres significantly. On the other hand, blend ratios do not have any effect on relative water vapour permeability and thermal conductivity.

Sampath and Senthilkumar (2009) studied the effect of stitch length and knit structure on the wicking, wetting, water absorbency, moisture vapour transmission and air permeability of moisture management finished micro denier polyester knitted fabrics.

Mezarcioz and Ogulata (2010) stated after their research that since, knitted fabrics have a loop structure, they have more pores than woven fabrics; therefore, in general the air permeability of knitted fabrics is higher than that of the woven fabrics of the same weight. An experiment to determine the air permeability is very important as it defines the properties of keeping warm, protection against the wind, breathability etc., of knitted fabrics used as clothing. They found that the air permeability and the porosity of a knitted structure will influence its physical properties such as the bulk density, the moisture absorbency, the mass transfer and the thermal conductivity.

Cimilli et al (2010) suggested that the fibre type, together with regain and fabric properties such as thickness, appears to affect some comfort-
related properties of the fabrics. It is suggested that for certain end uses, various combinations of fibre blends can be used.

Ramachandran et al (2010) studied the relationship between thermal behaviour and physical characteristics of knitted fabrics. The results show that the thermal conductivity, thermal diffusion and thermal resistance of the knitted fabrics depend on the fabric properties such as thickness, tightness factor, areal density and air permeability.

Bedek et al (2011) analysed and determined the relationship between the textile properties and the thermal comfort. The results suggested that the fibre type, together with moisture regain and knitted structure characteristics appeared to affect some comfort-related properties of the fabrics.

Onofrei et al (2011) found that thermal properties, diffusion ability, air and water vapour permeability were affected by raw material and fabric structure.

Gupta, et al (2011) stated that pressure garments are used to exert pressure on human limbs for scar management, venous and lymphatic problems, bone and muscle injury, sportswear, post cosmetic surgery, etc.. The amounts of pressure required for each medical condition are different. Pressure garments are produced from knitted elastic fabrics, which on wearing get extended and remain in the extended state, thereby exerting a positive pressure on the body. Since they are worn next to skin and are in intimate contact with the body, their comfort properties are of immense importance. In their research work, an attempt has been made to study the air permeability, water vapour transmission rate and thermal behavior of elastic fabrics in extended condition to simulate the conditions during wear. Results show that the comfort properties change significantly when the fabric is held in an extended state. As an outcome of their research they specified that air permeability increases with
fabric extension and this can be attributed to the opening up of the fabric loop structure during extended state.

Troynikov and Wardiningsih (2011) found that the water vapour permeability and air permeability of knitted fabrics increase with an increase of bamboo fibre in bamboo blended fabrics.

Jordeva et al (2012) investigated the influence of structural properties and characteristics of the fibre on the air and water vapour permeability, thermal properties (thermo-physiological comfort), of single jersey knitted fabrics. The results indicate that the structural characteristics of the knitted fabric have dominant influence on thermo-physiological comfort, as opposed from the raw material content. The density, mass per unit area and tightness factor of the knitted fabrics determine the air and water vapour permeability and thermal characteristics. The final assessment of the thermo-physiological comfort depends on the wearing conditions.

Bivainyte et al (2012) found that the dimensional characteristics of knitted fabrics, i.e. loop length, structure compactness and structure type, have an important influence on the air permeability of a knitted fabric.

Mukhopadhyay and Ishtiaque (2013) found that three basic parameters i.e. yarns packing density, inter-yarn porosity and fabric thickness have been found to be related strongly to fabric thermo physiological properties except water vapour permeability.

Oner and Okur (2013) observed that different knitting combinations and tightness used in the fabric structure caused important differences in the comfort properties. For the sake of providing optimum wetness comfort, it is necessary that the effects of different raw material combinations and suitable knitted fabric structures should be considered together.
2.6 SUMMARY

From the literatures surveyed for this research work certain things are obvious. The research work carried out on knitted fabric geometry and dimension was intense one for nearly three decades between 1950 to 1980. After that, the research direction is mostly diversified towards the study of elastomeric knitted fabrics and the study of comfort properties of knitted fabrics. The next three decades from 1980 to 2010 is certainly a golden era of research pertaining to the comfort properties of knitted goods and it still continues. It is a well-known fact from the available papers of various workers that the research contributions are voluminous for weft knit fabric geometry, contribution of spandex to stretch knit fabrics, factors influencing air permeability of fabrics in general and weft knitted fabrics in particular and last but not least, the effect of air permeability on thermal properties. But, of the earlier weft knitted fabric - air permeability related works; only in one work the impact of incremental stretch on air permeability of weft knit structures was investigated. Most of the times, certain degree of stretch prominently and incrementally occurs in intimate wear, leisure wear, sportswear, medical textiles etc., during their action. The changes in stretch gradient would definitely cause changes in the air permeability of the knitted fabrics. An initiative is required to investigate and to fill the gap in this area of research. Hence, in this dissertation the changes in air permeability of cotton jersey and pique samples without and with elastomer are investigated and reported by keeping the samples in static and up to an incremental stretch of 40% at the rate of 10% stretch gradient at their DRS, WRS and FRS. Moreover, the effect of number of process and product variables on air permeability of these single knit structures is discussed elaborately in this research work.