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Investigation of Air Permeability of Cotton & Modal Knitted Fabrics

S.S.Bhattacharya[1], J.R.Ajmeri[2]
[1]Textile Engineering Department, Faculty of Engineering and Technology M.S.University, Baroda, India
[2]Textile Technology Department, Sarvajanik College of Engineering and Technology, Surat, India;

Abstract:- In this study, it was aimed to investigate the porosity / compactness of the knitted structures made from cotton and modal yarns and to evaluate the air permeability property for sportswear. In the experimental section, cotton and modal yarns spun in different counts (Ne 30, Ne 40) with the same twist coefficient of α_e = 3.53 and 3.3 respectively were knitted as single jersey fabrics in the same production conditions with four tightness factors and air permeabililty property of fabrics were measured. The result showed that air permeability is a function of the thickness, tightness factor and porosity of the knitted fabrics and modal single jersey fabrics are considered preferred candidates for warmer climate sportswear, due to their higher air permeability.

Keywords:- Knitted fabric, Air permeability, Cotton, Modal, Porosity, Tightness factor.

I. INTRODUCTION

In the earlier days due to non-awareness about knitwears and their poor quality, its use was very much limited to inner wears only, but modern technology has enabled high quality knitted constructions in shaped and unshaped fabric form to expand into a wide range of apparel and clothing. In the recent decades, knitted fabrics have achieved remarkable success in sports and leisure wear. (e.g.[1]). Like other types of rayon, originally marketed as "artificial silk," modal is soft, smooth and breathes well. Its texture is similar to that of cotton or silk. It is cool to the touch and very absorbent due to the largest contact angle compared with viscose and excel. Many sports are performed in warm environments. The most important features of clothing to be worn in warm environment are; minimizing any negative effects on heat loss and maximizing any positive effects on heat loss. Clothing will normally reduce heat loss due to its resistance to heat and to water vapour transfer. This negative effect can be reduced by selection of appropriate materials with low resistances, but mainly by the design, e.g. one important design feature is the introduction of air flows (ventilation) into the clothing. A positive effect of clothing on heat loss can be achieved by increasing the effect of evaporation efficiency. This again is related to ventilation. (e.g.[2]).

A.Porosity

Knitted fabrics are the preferred structures in athletic wear in which demand for comfort is a key requirement. Heat and liquid sweat generation during athletic activities must be transported out and dissipated to the atmosphere. A key property influencing such behaviors is porosity. The yarn diameter, knitting structure, course and wale density, yarn linear density, pore size and pore volume are the main factors affecting the porosity of knitted fabrics (e.g.[3]). It was determined that the loop length of a knitted jersey has more influence on porosity than the stitch density and the thickness (e.g.[4]). Dias and Delkumburewatte, (e.g.[5]) created a theoretical model to predict the porosity of a knitted structure and determined that porosity depended on fabric parameters and relaxation progression (e.g. [6]). The most commonly used methods to evaluate the porosity of textile fabrics are: air permeability; geometrical modelling and image processing (e.g.[7]).

B. Air Permeability

Air permeability is defined as the volume of air in millilitres which is passed in one second through 100mm^2 of the fabric at a pressure difference of 10mm head of water. The air permeability of a fabric is a measure of how well it allows the passage of air through it (e.g.[8], [9]). The ease or otherwise of passage of air is of importance for a number of fabric end uses such as industrial filters, tents, sailcloths, parachutes, raincoats, shirtings, downproof fabrics and airbags. In outdoor clothing it is important to have air permeability as low as possible for achieving better wind protection (e.g.[10], [11]).

Generally, the air permeability of a fabric can influence its comfort behaviours in several ways. In the first case, a material that is permeable to air is, in general, likely to be permeable to water in either the vapour or the liquid phase. Thus, the moisture-vapour permeability and the liquid-moisture transmission are normally related to air permeability. In the second case, the thermal resistance of a fabric is strongly dependent on the enclosed still air, and this factor is in turn influenced by the fabric structure.

It was noted that the stitch length, porosity and air permeability increase and the thermal retaining property decreases for dry relaxed cotton 1 x 1 rib knitted fabrics. Thermal properties and thermal behavior of cellulosic textile fabrics, air permeability, porosity were investigated previously and found that air permeability and heat transfer through fabrics is closely related to both the capillary structure and surface characteristics of yarns (e.g.[12]). The effect of fibre composition and yarn type on the wickability, air permeability and thermal insulation of knitted fabrics was studied previously and found that the air permeability of fabrics decreases with the increase in cotton content. The air permeability of a fabric is affected by the fabrics material such as fibre fineness, structural properties such as shape and value of pores of the fabric ad the yarn and fabric thickness. (e.g. [13], [14], [15]).

Most of the previous studies investigated the relationship between the air permeability and structural characteristics of plain knitted fabrics. The effect of the some of parameters on air permeability of cotton and modal knitted structures has not been researched systematically yet. In the present study, the effect of fabric tightness factor, fabric weight, fabric thickness and porosity on the air permeability of cotton and modal knitted fabric is determined and an attempt is been made to explore whether the natural hydrophilic properties of cotton and modal fibre could be used to enhance the comfort properties of sportswear fabrics improving the aesthetics.

II. MATERIALS AND METHODS

For the research, cotton and modal fibres made from a natural polymer – cellulose were selected as the basic material and the yarns were produced in two different yarn counts (Ne 30, Ne 40) with a twist coefficient of α_e = 3.53 and 3.3.

A.Knitting

A 24-gauge Single Jersey Circular Knitting Machine of 30-inch diameter of Mayer & Cie, Model : S4-3.2, Germany was used for manufacturing the samples. By adjusting the stitch cams the rate of yarn feeding to knitting needles was adjusted. The amount of yarn feeding in one revolution was varied in order to produce fabrics with different loop length values (ℓ) : 2.7, 2.9, 3.1 and 3.3 mm to knit samples in four different tightness factor. Combining two fibres, two yarn counts, and four tightness levels, sixteen different samples of single jersey fabric were prepared in all.

B.Fabric Relaxation

Full relaxation was carried out of the samples by wet relaxing them in an automatic front loading machine followed by rinsing, spinning and tumble drying and finally conditioning for 24 hours in standard atmospheric condition as per Standard wash procedure - IS 1299:1984.

C.Fabric Testing

1) Fabric weight per unit area : Standard procedure for measuring GSM as per ASTM – D 3776-1996, IS:1964-2001 was followed using Mettler make measuring balance, model PB 602-5 capable of weighing to an accuracy of 0.1 gm.
2) Fabric thickness : The thickness of fabric samples was measured as the distance between the reference plate and parallel presser foot of the thickness tester under a load of 20 gm / cm^2. Standard procedure using Baker make J02 thickness tester as per ASTM – D 1777:197, IS:7702:1975 was used.
3) Air permeability : Air permeability was tested according to ASTM standard D737-1996 on the Air Permeability Tester Model : MO21A (SDL Atlas). The measurements were performed at a constant pressure drop of 196 Pa (20 cm^2 test area). Measurements of the fabrics were carried out 10 times, and the average expressed as cm^3/cm^2/s and standard deviations were calculated.
4) Porosity :The porosity was determined using construction parameters of the knit fabric (Benltoufa et al. 2007) using ‘Eq. (1)’

$$\varepsilon = 1 - \frac{\Pi d^2 \ell c w}{2t} \quad (1)$$

Where:
t : sample’s thickness (cm) ;
ℓ : elementary loop length (cm) ;
d : yarn diameter (cm) ;
c : number of Courses per cm ;
w: number of Wales per cm.

5) Fabric tightness factor : The tightness factor of the knitted fabrics was determined by the equation (2):

$$K = \sqrt{T} / \ell \quad (2)$$

Where T is the yarn count in tex and ℓ is loop length in cm or mm.

To determine the statistical importance of the variations, correlation tests were applied.

III. RESULTS AND DISCUSSION

All tests were performed under standard atmospheric conditions (20^{o}C, 65% RH).The basic dimensional properties of both types of knitted fabrics are enumerated in (Table 1 and 2). Results showed that thickness increases with the fabric tightness for both structures, but not linearly in the case of cotton.

A.Porosity

Porosity is one of the key properties influencing thermo-physiological comfort of the wearer. The thickness and mass per square meter of the fabrics reduces as the yarn becomes finer, which is quite obvious. For single jersey cotton knitted fabrics the mass per square meter of the fabrics reduced from 162.60 g/m^2 to 104.93 g/m^2 i.e. by 35.47% (Table 1),

Table 1. Dimensional Properties of Cotton Single Jersey Fabric

Fabric Code	Tightness factor, K	Thickness, cm	Weight, g/m^2
$C1JT_1$	1.64	0.633	162.60
$C1JT_2$	1.53	0.626	155.50
$C1JT_3$	1.43	0.6694	149.63
$C1JT_4$	1.34	0.673	138.38
$C2JT_1$	1.42	0.609	127.38
$C2JT_2$	1.33	0.622	116.82
$C2JT_3$	1.24	0.590	115.53
$C2JT_4$	1.16	0.587	104.93

(C: Cotton; 1:Ne 30s; 2:Ne 40s; J:Single Jersey structure; T: Tightness factor)

Table 2. Dimensional Properties of Modal Single Jersey Fabric

Fabric Code	Tightness factor, K	Thickness, cm	Weight, g/m^2
$M1JT_1$	1.64	0.47	141.95
$M1JT_2$	1.53	0.45	129.87
$M1JT_3$	1.43	0.436	118.34
$M1JT_4$	1.34	0.432	103.54
$M2JT_1$	1.42	0.424	104.71
$M2JT_2$	1.33	0.412	95.09
$M2JT_3$	1.24	0.414	85.9
$M2JT_4$	1.16	0.389	78.74

(M: Modal; 1:Ne 30s; 2:Ne 40s; J:Single Jersey structure; T: Tightness factor)

However, the corresponding reduction in terms of fabric thickness was from 0.633 mm to 0.587 mm, i.e., by 7.27% for single jersey knitted fabrics. For Modal single jersey knitted fabrics the mass per square meter of the fabrics reduced from 141.95 g/m^2 to 78.74 g/m^2 i.e. by 44.53%, however, the corresponding reduction in terms of fabric thickness was from 0.47 mm to 0.389 mm, i.e., by17.23%. This analysis bolsters the fact that when yarn is becoming finer, mass per square meter is reducing at a faster rate as compared to that of fabric thickness. Therefore, the porosity of the fabric increases. (Figure 1) shows the porosity of cotton and modal single jersey fabrics.

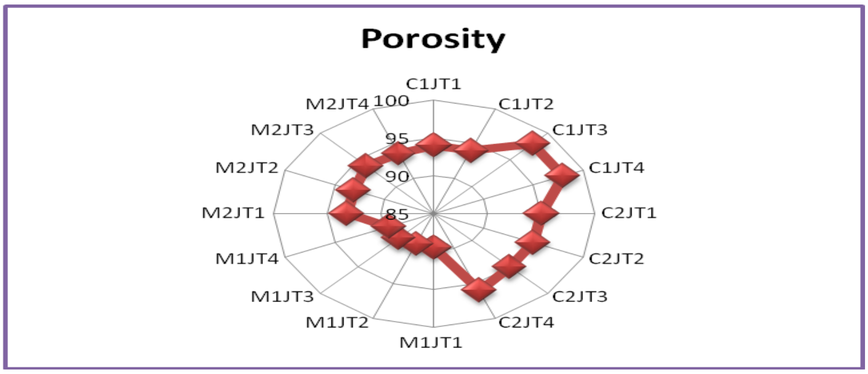

Figure1: The values of porosity for different variants of cotton and modal fabrics

B.Air permeability:

(Table 3) present the research results of air permeability. The cotton is thin, the fibres are confined to a thin plate, the volume occupied by the fibres is small, there is little air space between the fibres and the air permeability is consequently low compared to modal fibres. The range of values obtained is significant, ranging from 83.3 to 283.1 cm^3/cm^2/s, for cotton and from 408.8 to 805.3 cm^3/cm^2/s for modal. The porosity determines the variation of air permeability. Fabrics having low porosity values shows the lowest value for air permeability. Increasing fabric tightness by machine setting decreased the air permeability in both fabrics. Coarser yarn produce fabrics with more intra-yarn air spaces but with fewer inter-yarn air spaces resulting in lower air permeability in the single jersey knitted fabrics. Air permeability increases for the fabrics made from finer yarns as expected. The lower thickness and mass per square meter also facilitate the passage of air through the fabric. The lower hairiness of the finer yarn may be another contributing factor towards the better air permeability. As the loop length increases, the air permeability value also increases.

Table 3. Air permeability results

Fabric Code	Air permeability $cm^3/cm^2/s$	
	Average	Standard Deviation (S)
$C1JT_1$	83.3	5.22
$C1JT_2$	94.31	7.76
$C1JT_3$	123.8	18.58
$C1JT_4$	164.8	19.35
$C2JT_1$	171.2	15.98
$C2JT_2$	191.3	17.25
$C2JT_3$	218.1	13.33
$C2JT_4$	283.1	29.42
$M1JT_1$	408.8	17.54
$M1JT_2$	458	26.88
$M1JT_3$	524.6	36
$M1JT_4$	653.2	21.12
$M2JT_1$	529.2	20.23
$M2JT_2$	606	35.16
$M2JT_3$	704.3	48.79
$M2JT_4$	805.3	35.05

((C: Cotton; M: Modal; 1:Ne 30s; 2:Ne 40s; J:Single Jersey structure; T: Tightness factor)

From the (Tables 1 and 2), it reveals that as for the same yarn linear density the thickness was increased by increasing the fabric tightness. Thicker yarns increased thickness in both fabrics. The barrierability of knitted fabrics to the air as fabrics thickness function, is presented in (Figure 2 and 3). It shows that in both cotton and modal yarns single jersey knitted with Ne 30s (R= 0.89 and 0.88) and Ne 40s (R= 0.76 and 0.90) gives good correlation between air permeability and thickness.

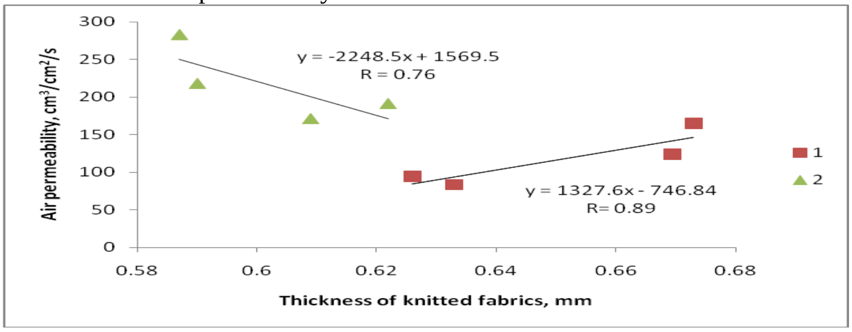

Figure 2: Air permeability in function of thickness of cotton single jersey knitted fabrics.

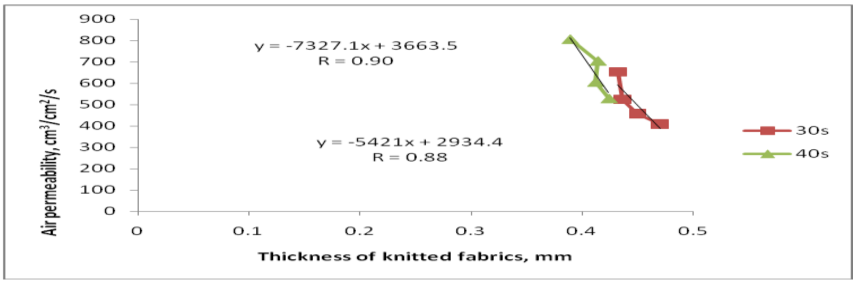

Figure 3: Air permeability in function of thickness of modal single jersey knitted fabrics.

Air permeability is inversely related with fabric tightness; it decreased with increase of compactness and decrease of air space. It must be emphasized that tightness factor correlates more with air permeability than knitted fabric thickness. This is documented by the test results and statistical analysis presented in (Figure 4 and 5), where the estimated value of correlation index between air permeability and the tightness factor of knitted fabric is R = 0.95 for Ne 40s and 0.96 for Ne 30s for cotton single jersey knitted fabrics and R = 0.996 for Ne 40s and 0.96 for Ne 30s for modal single jersey knitted fabrics which demonstrate that the dependence between those parameters exists and is extremely strong. The tightness factor can be changed through alteration of the loop length or linear density or through alteration of both these parameters. The correlation between the characteristics presented allows to maintain that when the tightness factor of the knit is known, it is possible to predict the potential air permeability of such a construction.

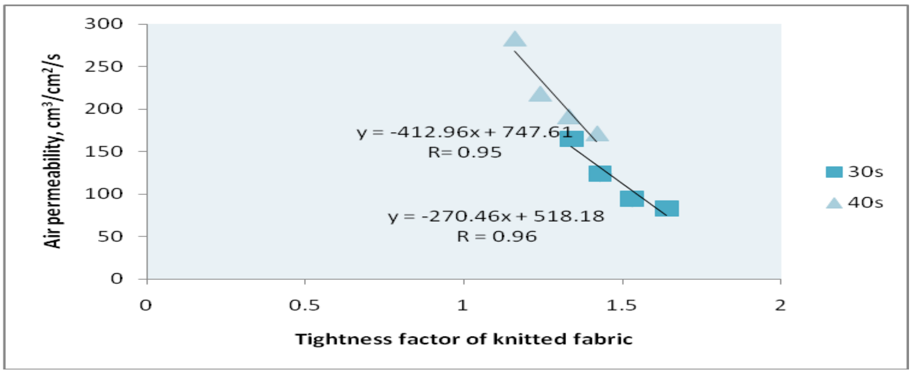

Figure 4: Air permeability in function of tightness factor of cotton single jersey knitted fabrics.

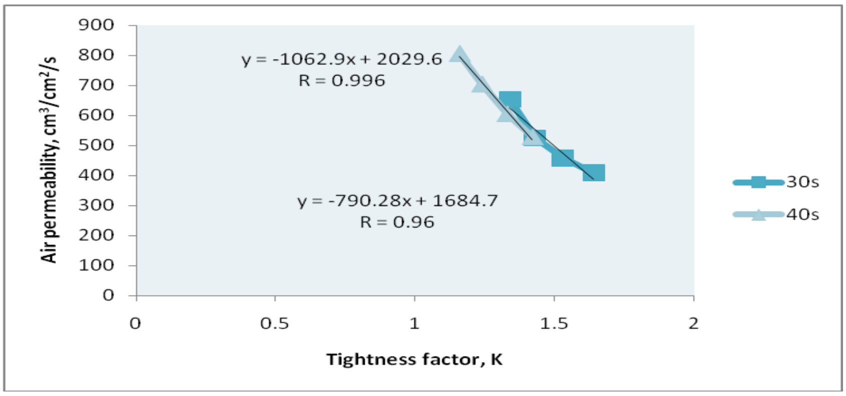

Figure 5: Air permeability in function of tightness factor of modal single jersey knitted fabrics.

(Figure 6 and 7) shows the influence of the fabric porosity on air permeability. Better correlation observed in case of cotton single jersey fabrics compared to modal single jersey fabrics. Previous research also showed that air permeability of fabrics was mainly affected by the porosity of the fabrics.

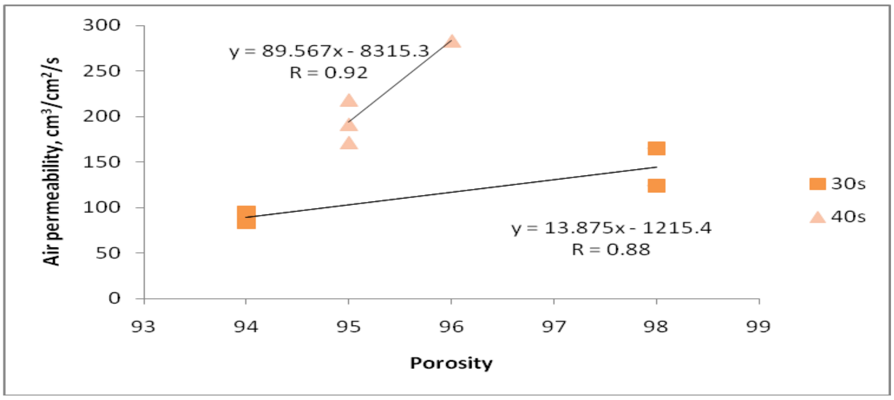

Figure 6: The relation between air permeability and surface porosity for cotton single jersey knitted fabrics.

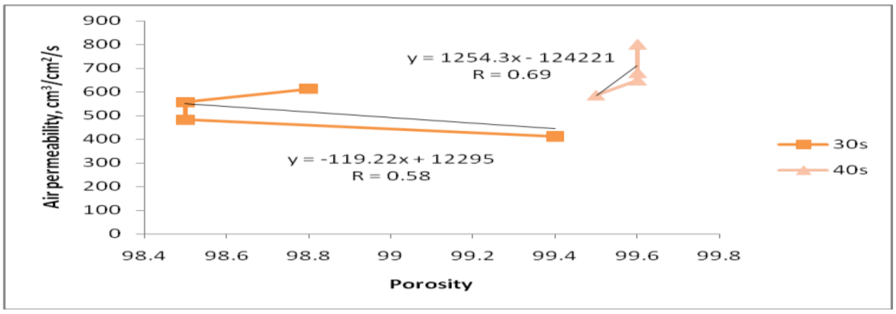

Figure 7: The relation between air permeability and surface porosity for modal single jersey knitted fabrics.

IV. CONCLUSION

We may see from the above test results that the air permeability of fabric knitted with Ne 40s is determined higher. Air permeability has a direct relationship with the count of the yarn. Increase in yarn fineness and more open structure of the knitted fabric improved air permeability. Air permeability, is a function of knitted fabric thickness, tightness factor and porosity. Air permeability showed a negative correlation with fabric thickness and tightness factor. Tightness factor can be used for fabric air permeability forecasting. The high correlation between the permeability to air and tightness factor confirms that. Porosity is affected by yarn number or yarn count number. The effect of the loop length has more influence on porosity than the stitch density and the thickness. Increasing loop length, looser the structure and so the values of air permeability increases. Air permeability is an important factor in comfort of a fabric as it plays a role in transporting moisture vapours from the skin to the outside atmosphere. Sports clothing can be worn for different reasons. Modal single jersey fabrics are considered preferred candidates for warmer climate sportswear, due to their higher air permeability.

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