3. EXPERIMENTAL

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3.1 Materials

For this work Combed Cotton Ring, Regular Viscose, Modal and Excel yarns having linear densities 15Tex, and 20Tex were produced. In all the cases, the twist coefficient (α_e) was tried to maintain same, but a little difference was observed. In case of cotton yarns it was observed to be 3.53 and for viscose, modal and excel yarns it was 3. 3. The produced yarn characteristics are shown in table 3.1. The machinery and technical parameters are given in Appendix.

In this work plain knitted fabrics which are commonly used in many apparel applications were considered. The two structures important for reference are the plain jersey fabric which is single layer fabric in which the same yarn was being knit on the front and back of the fabric and a variation of the plain jersey called pique.

The fabric samples were knitted on Single Jersey Circular Knitting Machine of Mayer & Cie, Model : S4-3.2, Germany. 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 in mm): as 2.7, 2.9, 3.1 and 3.3 and hence four different tightness factor. Combining all, sixty four different samples of fabric were prepared (see table 3.8, 3.9, 3.10 and 3.11).

Table 3.12, 3.13, 3.14 and 3.15 depicts the knitting parameter for the single jersey fabric with cotton, viscose, modal and excel yarns respectively. Table 3.16, 3.17, 3.18 and 3.19 depicts the knitting parameter for the pique fabric with cotton, viscose, modal and excel yarns respectively.

The knitting process was completed with constant machine settings and the samples were kept under the standard atmospheric conditions for 24 hours for the 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. The surface appearance of selective fabrics before and after 3 washing cycles are shown in figure 3.1.

Washing machine details:

Make – IFB

Rpm – 600

Water intake – 10 liters

Material ratio – 1:10

Water hardness 155 parts per million

Tumble drying period – 20 minutes; temperature - 60 ^{o}C.

3.2 Method

Prior to testing all fabrics samples were conditioned and tested in a standard atmosphere.

3.2.1 Fibre testing

3.2.1.1 Cotton fibre testing

Cotton fibre testing was carried out on Premier ART 2. Trash measurement was carried out with Shirley Analyser. Table 3.20 depicts the properties of Cotton fibres used to spin yarn.

Table 3.20.:Properties of Cotton fibre used in yarn production

Micronaire value (ug/inch)	3.48
Maturity coefficient	0.73
Maturity percent	70.33
Fineness	136.67
Rd (%)	70.8
+b(%)	11.7
C.G	33-3
Tg (%)	2.06
Trash weight (gm)	0.21
UHML (mm)	31.76
ML (mm)	26.89
UI (%)	84.7
Strength (g/tex)	35.1
Elongation (%)	6.7

3.2.2.2 Viscose, Modal and Excel fibre testing

Denier of Viscose, Modal and Excel fibre was measured using Vibroskop 400 (Lenzing Technik Instruments) and Tenacity and Elongation using Vibrodyn 400 dynamometer

(Lenzing Technik Instruments) with a length between the clamps of 20 mm according to ISO 2062. Whiteness percentage was determined using Vibrochrom 400 (Lenzing Technik Instruments) tristimulus colorimeter with dual beam principle, which measures according to ISO 2469 and DIN 5033. The OPU% was determined by using ALFA 300 Automatic Finish Analyzer (Lenzing Instruments). Table 3.21, Table 3.22 and Table 3.23 depicts the properties of Viscose, Modal and Excel fibres used to spin yarns respectively.

Table 3.21: Properties of Viscose fibre used in yarn production

Property		CV%
Fineness (Denier)	1.08	11.3
(Conditioned) Tenacity (gpd)	2.79	6.6
(Conditioned) Elongation (mm)	20.6	14.5
OPU %	0.31	
Whiteness %	73.4	

Table 3.22: Properties of Modal fibre used in yarn production

Property	
Fineness (Denier)	1.2
Cut length (mm)	38
OPU (%)	
Tenacity (Conditioned) (gpd)	
Elongation (Conditioned) (mm)	
Whiteness (%)	

Table 3.23: Properties of Excel fibre used in yarn production

Property		CV%
Fineness (Denier)	1.12	10.6
Tenacity (conditioned) (gpd)	4.27	6.9
Elongation (conditioned) (mm)	15	11.7
OPU (%)	0.24	
Whiteness (Berger) (%)	83.06	
Brightness (Z axis) (%)	94.07	
Yellowness (%)	-2.58	

3.2.2 Yarn testing

Imperfections were measured by Uster Tester 4-SX-R20 AT 400m/min for 1 min for 100 km length. Elongation at break, tenacity and breaking force were tested on USTER Tensorapid 4.8 at speed of 5000m/min. Yarn twist was measured using Automatic Twist Tester. Yarn diameter was measured using ERMASCOPE 808 T with the magnification of 100 X. Strength and Elongation properties of yarn were measured using Lloyd Strength Tester version 5.0.

3.2.3 Physical and dimensional properties of knitted fabrics:

Fabric Weight per unit area as per ASTM – D 3776-1996, IS:1964-2001 using Mettler make measuring balance, model PB 602-5 capable of weighing to an accuracy of 0.1 gm; Fabric thickness as per ASTM – D 1777:197, IS:7702:1975 using Baker make J02 thickness tester; Wales per cm; Courses per cm (ASTM 2001.2.6-2001, Method of test for textile: Method 2.6); Stitch Density.

The porosity was determined using construction parameters of the knit fabric using *Eq*[160]:

$$\varepsilon = 1 - \pi \frac{d^2 \ell\, cw}{2t}$$

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.

3.2.4.Fabric Comfort properties

3.2.4.1 Air Permeability

Air permeability of the samples was investigated according to ASTM standard D737-1996 using SDL Atlas make Air Permeability Tester Model: MO21A. The measurements were performed at a constant pressure drop of 196 Pa (20 cm^2 test area). Ten samples were tested in each group and expressed as $cm^3/cm^2/s$. To address a mathematical relationship between the thickness of fabric, tightness factor, porosity of the knitted samples and air permeability, a linear regression equation was used and applied on the air permeability values.

3.2.4.2 Thermal properties

Thermal resistance

Thermal resistance is an indication of how well a material insulates. It is based on the equation:

$R = h / \lambda$

Where R is the thermal resistance, h is the thickness (m) and λ is the thermal conductivity[70, 168] (W/Mk).

Since λ is roughly constant for different fabrics, thermal resistance is approximately proportional to fabric thickness. It is therefore the thickness of the garment that determines its thermal resistance and gives the wearer protection against cold.

Thermal conductivity

It is based on equation: $\lambda\ [W/Mk] = Qh / A\Delta Tt$

Where Q is the amount of conducted heat (J); A is the area through which the heat is conducted (m^2); t is the time of conductivity (s); ΔT is the drop of temperature (k); h is the fabric thickness (m).

It is considered to be dominant in determining the heat transfer through fabrics and garments. SDL Atlas make Laser Comp. model Fox 314 was used to measure thermal conductivity and thermal resistance values as per ASTM 1518-2003. It utilizes two isothermal plates that can have their temperature adjusted to desired set points. The heat flow caused by the temperature gradient is measured via heat flow (or flux) transducers. Using the measured material thickness, the thermal conductivity can be determined. The results of the measurement have accuracy of 1%, repeatability of 0.2% and reproducibility of 0.5%. The sample size was 12x12 inch. Five readings were noted for each sample.

To address a mathematical relationship between the fabric thickness, fabric weight on thermal properties, a linear regression equation was used and applied on the thermal properties. Multiple Regression analyses were made between thermal properties and fabric parameters. Thermal properties are defined as dependent variables (Y), loop length, tightness factor, fabric thickness and porosity are defined as independent variables (X). Multiple linear regression analysis have been applied to the measured values and obtained the best fit equations using MINITAB 16. To deduce whether the parameters were significant or not, p values were examined. Ergun emphasized that if p value of a parameter is greater than 0.05 ($p>0.05$), the parameter will not be important and should be ignored.

3.2.4.3Moisture management properties

The liquid water transport and distribution in the fabrics was tested according to AATCC 195-2009 using a moisture management tester (MMT, a commercial testing product of SDL Atlas, figure 3.2 and figure 3.3).

Sample preparation

To reduce the influence of environmental factors on the obtained experimental results, five specimens were cut into samples of size 80 mm x 80 mm for each type of fabric.

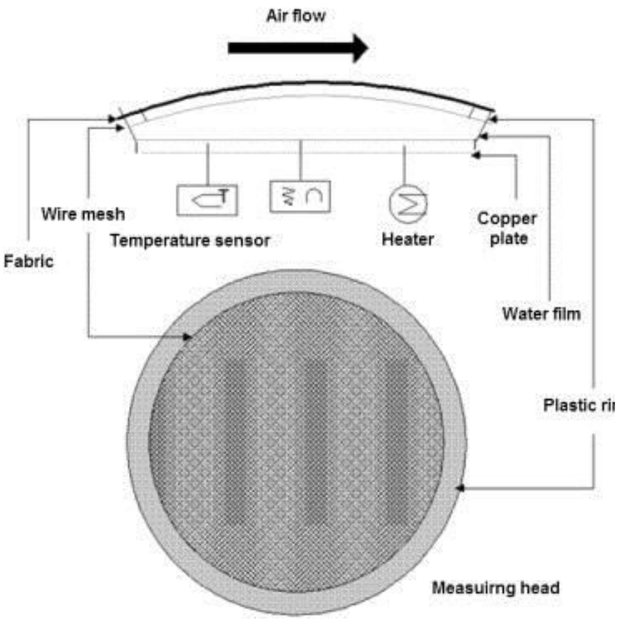

Figure 3.2: Schematic view of the tester sensors **Figure 3.3: Moisture Management Tester**

Procedure

The test solution was prepared by dissolving 9 g sodium chloride (USP Grade) in 1L of distilled water and adjust its electrical conductivity to 16$\pm$ 0.2 milli Siemens (Ms) at 25^{o}C (77^{o}F) by adding sodium chloride or distilled water as necessary[114]. The test solution was used in order to simulate sweating and provide a conductive medium for the instrument's sensors. Manufacturer's instructions were followed for starting the instrument, addition of the test solution, and the computer set up to collect test data. The upper sensor was raised to its locked position and a paper towel was placed on the lower sensor. The "pump" button was pressed for 1-2 minute until the amount (0.22 cc) of the test solution is drawn from the container and drips onto the paper towel and no air bubbles are present inside the tubing. Then the paper towel was removed. Then the conditioned test specimen was placed on the lower sensor with the specimen's technical back up (facing the top sensor) imitating the case where the technical back is in direct contact with the skin[51]. The upper sensor was released until it freely rests on the test specimen and the door of the tester was shut. It was confirmed that the "Pump-On Time" was set at 20 s to assure the predetermined amount (0.22 cc) of test solution was dispensed. For each specimen, the per cent (%) water content point on the graph should be 0.0 at the start of each test to avoid erroneous test results. The "Measure Time" was set for 120 s and the test was started. At the end of the 120 s test time, the software automatically stopped the test and calculated all of the indices. The upper sensor was raised and the tested specimen was removed. Before inserting the next specimen, the upper sensor was kept in its locked position. Between the rings of pins on both upper and lower sensors were dried using AATCC Blotting paper or a soft paper towel cut into narrow (0.5 cm) strips. Waited for 1 min, or longer, to ensure there is no residual test solution present on the sensors, otherwise any leftover moisture will cause an erroneous start. If slat deposits were observed on the sensors after drying, distilled water was used to remove. A new specimen was loaded on top of the lower sensor with the fabric back surface up and the above steps were repeated. When testing was been completed for the day, distilled water was used to clean and purge the pump and tubing. The test time presented by the horizontal axis (x) is composed of two stages. The first stage is the pump time period, during which liquid is injected onto the top layer automatically. The liquid received by a fabric begins wetting its surface gradually. Then liquid tends to be accumulated on the top, and it penetrates to the bottom layer simultaneously. However, the accumulating speed is much greater than that of the penetration, and thus moisture accumulating speed plays a key role in this stage until the pump time set is exhausted. Subsequently, the other stage (called a measure time period) starts, during which only the liquid accumulated in the former stage penetrates to the bottom layer. Both the pump time and measured time in these two stages have to be set on the control panel of the MMT before testing, and the test time displayed by the final measurement figure's horizontal axis is the sum of the two[110].

For the evaluation of the statistical importance of the tightness factor on the moisture management properties of the knitted fabrics, Pearson correlation was found. In order to decide the statistical significance of the variable on the related property, p value is also used. The results (expressed as means/standard deviation) of all assays were compared using ANOVA in order to investigate the effect of fibre type and fabric structure, on Wetting time top surface/ Wetting time bottom surface (WTt/WTb), Absorption rate top surface / Absorption rate bottom surface (ARt/ARb), Maximum Wetted radius top surface / Maximum Wetted radius bottom surface (MWRt/MWRb), Spreading speed top surface / Spreading speed bottom surface (SSt/SSb), Accumulative one-way transport capability (AOTI), Overall (liquid) moisture management capability (OMMC).