Experimental Procedure

3. EXPERIMENTAL PROCEDURE

The experimental procedure adopted for the study comprised of the following steps:

3.1 Industrial Survey

3.2 Experiment

3.3 Evaluation

3.4 Techno Economic Study

3.5 Statistical Analysis

3.1. INDUSTRIAL SURVEY

A survey is a widely used method for gathering scientific information. The purpose of a survey is to determine how people feel about a particular issue, explains McBurney (2002). An industrial survey was conducted to elicit information about the existing pretreatment methods used in the processing industries.

Surveys are concerned with conditions that exist, opinions that are held, processes that are going on, effects that are evident or trends that are developing, state Marshall and Rossman (1999). Hence they provide valuable information to form the basis for the selection of materials and pretreatment methods for the study. The survey consists of the following steps.

3.1.1. Selection of area

3.1.2. Selection of samples

3.1.3. Selection of the tool

3.1.4. Formulation of the tool

3.1.5. Collection of data and

3.1.6. Consolidation of data

3.1.1. Selection of area

The investigator selected two hundred textile processing units in Tirupur to study the commonly used fibres, yarns, fabric structures, the pretreatment methods, dyes used and the dyeing and finishing undertaken. Tirupur was selected since it was a major export centre for knitted materials and housed many processing centres where pretreatment was the first step for all types of value addition processes like dyeing, printing and finishing.

3.1.2. Selection of samples

According to Singh (2001), a sample is that part of the population which is selected for the purpose of investigation. When population elements are selected for inclusion in the sample based on ease of access, it is called convenience sampling. The samples for the industrial survey were selected on the basis of ease of access and the cooperation extended on the part of the owners.

3.1.3. Selection of the tool

The tool selected for the study was interview schedule. Bell (1999), records that an interview is one, where a number of questions or statements relating to the investigation is prepared; these questions are put forth to the selected group and their answers are recorded by the interviewer or enumerator.

3.1.4. Formulation of the tool

An interview schedule was framed. The schedule was used to find out the background information about the industries, the type of processing done, the pretreatment undertaken, the impact of the pretreatment, details regarding effluent parameters and the treatment undertaken to achieve zero discharge. A pilot study was conducted by the investigator in twenty five industries and based on these results, the necessary modifications were made to draft the final interview schedule. The finalised interview schedule used for the industrial survey is presented in Appendix I.

3.1.5. Collection of data

The investigator visited the selected industries at their convenient time, explained the purpose of the study and the necessary information was gathered using the interview schedule.

3.1.6. Consolidation of data

The data thus collected was consolidated and the results are presented in the chapter results and discussion. This information formed the basis for the selection of yarn, knitted structures, the pretreatment procedures, the types of dyes and the dyeing methods to be undertaken for the study.

3.1. EXPERIMENT

Flow Chart 1

EXPERIMENTAL DESIGN

SHANKAR 6 COTTON

↓

RING SPINNING

30 Ne Carded Yarn & 30 Ne Combed Yarn

↓

KNITTING

↓

100 % COTTON FABRIC

- 30 Ne Carded Yarn
  Single Jersey and Rib
- 30 Ne Combed Yarn
  Single Jersey and Rib

LYCRA COTTON FABRIC

- 30 Ne Carded Yarn + 40 Denier
  Lycra - Single Jersey and Rib
- 30 Ne Combed Yarn + 40 Denier
  Lycra - Single Jersey and Rib

↓

PROCESSING

PROCESSING SEQUENCE FOR BIO PRETREATMENT

*Bio Pretreatment,
Dyeing, Finishing

*Bio Pretreatment, Bio
Polishing, Dyeing, Finishing

PROCESSING SEQUENCE FOR CHEMICAL PRETREATMENT

*Chemical Pretreatment
Dyeing, Finishing

*Chemical Pretreatment, Bio
Polishing, Dyeing, Finishing

↓

CONVERSION TO APPAREL

↓

WEAR STUDY

↓

EVALUATION

↓

- **VISUAL ASSESSMENT**
- **LABORATORY TESTS**
- **TECHNO ECONOMIC STUDY**

The experiment consists of the following steps:

3.2.1. Selection of the Raw Material

India's target for cotton exports was 2.5 to 3 million bales in 2005-2006 of which 2.2 million bales of Shankar-6 cotton was exported, highlighting the leading role it plays in the export market. This trend seems to continue till today and is the most preferred cotton fibre - http://www.jalaramcotton.com/ product.htm Low neps, good dye absorption, relatively better price and good lustre are some of the merits of this variety. Hence Shankar 6 cotton was used for producing 30 Ne carded and combed yarns for the study.

3.2.2. Fibre Testing

The cotton fibres used for the study were tested for physical properties, trash content and moisture control. The properties of the cotton fibre are given in the Table I in comparison with the South Indian Textile Research Association (SITRA) Norms stated by Rajamanickam *et al.* (2004).

- **Physical Properties of the Cotton Fibre**

As recommended by ASTM (2007), D 5867-2005, the cotton fibres were conditioned in standard testing condition for 12 hours prior to testing. The Fineness Test method for micronaire reading describes the determination of the micronaire of loose cotton by measuring the resistance of a plug of cotton to air flow under prescribed conditions, by using a programmed microprocessor with memory for controlling all internal operations and performing calibration, all calculations, and data presentation.

The Fibre Length and Length Uniformity was determined by outputting a voltage directly proportional to the amount of fibre in the prepared specimen at a given distance from the base of the test beard. In this method a fibrograph type photo electrical instrument or a length analyzer pneumatic instrument may be used. The 2.5% and 50% span length, Uniformity Ratio and Short Fibre Index were directly read from the High Volume Instrument used.

The test method determines the Breaking Tenacity and Elongation at the breaking force of cotton fibres in a test specimen in which the fibres are placed randomly in a specimen comb or clamp and broken using a 1/8 inch clamp spacing. Elongation was measured directly from the displacement of clamps at maximum force on the fibres. The average Breaking Tenacity was given in grams per tex and the average Elongation at break in percentage.

Colour is the primary factor of the colour grade of cotton. A smooth representative surface of the cotton sample was placed over the colorimeter sample window and pressed flat. The instrument colorimeter was energized, and colour values were displayed on the visual monitor of the instrument in terms of the grayness and yellowness scale developed for cotton, the Rd and +b values and the United States Department of Agriculture colour grade code number.

- **Trash Content**

The test method describes the measurement of the amount of trash as seen by a video camera focused on the surface of the test specimen of cotton pressed against a glass window. The internal programmed microprocessor performs all the calculations and the values were read directly from the visual monitor of the trashmeter in the high volume instrument.

TABLE I

PROPERTIES OF THE COTTON FIBRE

S. No.	Fibre Properties	SITRA Standard	S6 variety
1.	**Physical properties of the cotton fibre by HVI ASTM D 5867:2005**		
	Mean Micronaire	4.1	4.1
	Maturity Index	0.85	0.86
	2.5 % span length (mm)	30	29.2
	50 % span length (mm)	15	13.2
	Uniformity Ratio (%)	50	48.00
	Short Fibre Index	8	7.8
	Breaking tenacity [g/tex]	21.7	24.7
	Elongation %	6.2	6.4
	Colour [Rd/+b]	80/10	79.0/10.1
2.	**Trash Content TC / LAB/TM03**		
	Lint %	96	96.48
	Trash %	2	1.60
	Cage loss %	1.3	1.42
3.	**Moisture Content IS :199:1989**		
	Average Moisture content %	7.8	7.1

- **Moisture Content**

The average moisture content percentage was determined by the IS (2000), TS 199-1989, method. The original mass of the test specimen and the oven dry mass of the specimen

was determined using an electronic balance and the percentage moisture content was calculated using the formula:

$$\text{Moisture content \%} = \{(a - b)/a\} \times 100$$

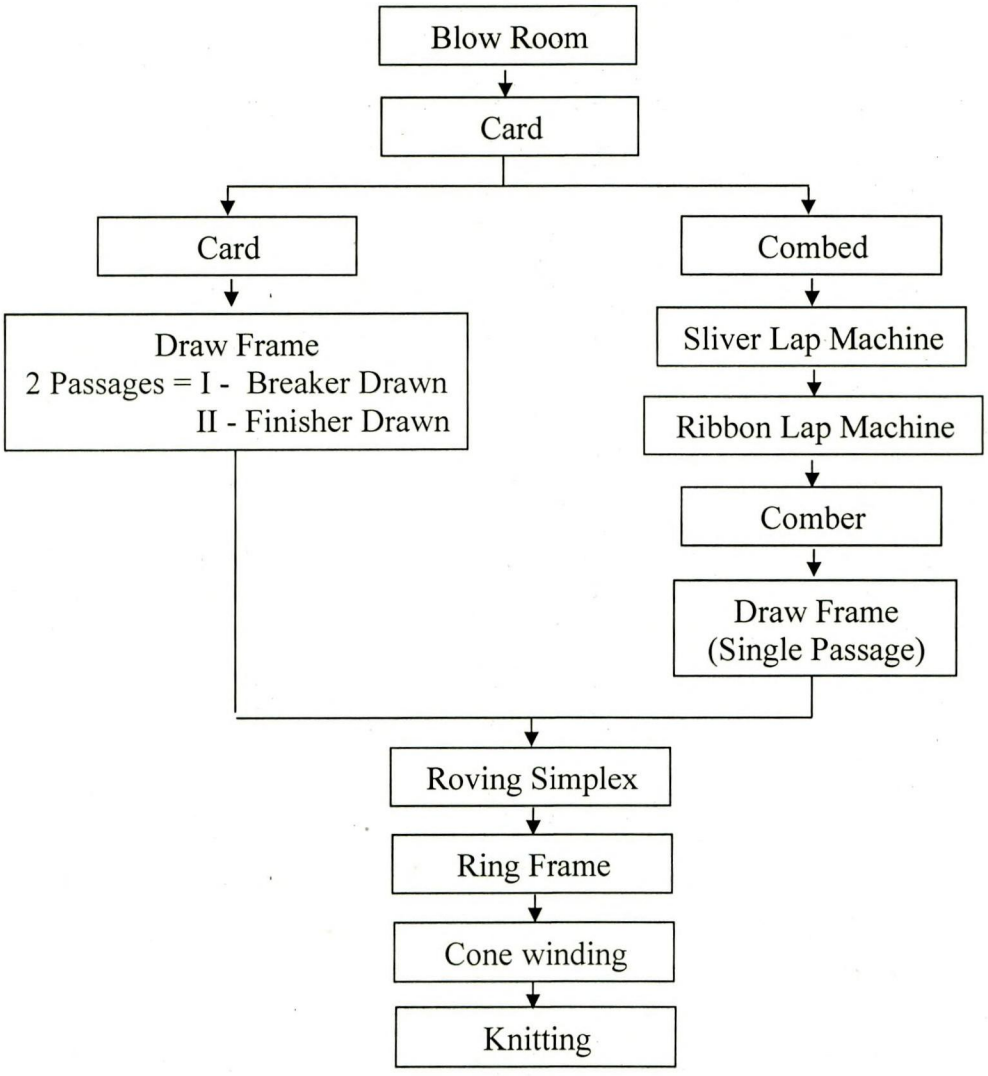
where a = original mass in grams of the specimen, b = oven–dry mass in grams of the specimen.

3.2.3 Production of 30 Ne Carded and Combed Yarns

The cotton fibres selected were converted into yarns by the ring spinning process. The ring spinning process for 30 Ne carded and combed yarns used for the study is given in Flow Chart 2. The machine particulars and process parameters for the ring spinning process are given in Appendix II.

FLOW CHART 2

RING SPINNING PROCESS



- **Opening and Cleaning :** The first level cleaning operation was done in the first process of spinning namely opening, blending, mixing and cleaning. The baled cotton was opened into small, light, fluffy tufts that would facilitate the removal of foreign matter.

- **Blow Room :** The opened and cleaned tufts of cotton were fed into the blow room where the cotton tufts collided with revolving pin cylinder against a grid bar. The cotton tufts were rotated, thrown against the spikes of the pin cylinder three or four times whereby the impurities were removed and fibres separated. The cotton emerged in the form of thin blanket called the 'lap'.

- **Carding** : The card is composed of a system of three wire-covered cylinders and a series of flat, wire-covered bars that further separates or opens the cotton fibres and removes a very high percentage of trash and other foreign matter. The second and final level cleaning functions were performed by the carding system and the fibres were collected into a rope-like form called the 'sliver'.

- **Draw Frame :** The draw frame straightened the fibres and removed curls by passing the slivers through different sets of rollers that were revolving at different speeds. The speed of the rollers were increased as the sliver moved from one stage to the next. The slivers were first passed through Breaker Drawing process to mix slivers from different laps to achieve homogeneity. The same process was repeated at the Finisher drawing stage.

- **Combing** : This process is usually required for the production of high value added yarns. In this step the short fibres are separated from the long fibres, followed by the alignment and straightening of the long fibres and removal of any foreign matter and neps (nep is a small knot of entangled fibres which in case of cotton usually comprises of dead or immature cotton hairs). The resulting product is a smoother, more uniform and stronger yarn. For combing, the sliver from the carding was passed through sliver lap machine and then through the Ribbon Lap machine to get smaller laps of cotton. These laps were fed to combers to get slivers which were free from 14% to 18% of the shorter staples.

- **Roving :** Slivers from the drawing stage were passed through the Roving Frame or Simplex. Here the yarn was stretched so that the weight per unit length decreased. The purpose of this operation was to reduce the size of the sliver and to impart a little twist to enable it to withstand the tension in the ring spinning frame. The product from this operation, called Roving, was spun around big sized bobbins.

- **Ring Frame :** The ring frame performed ring spinning in order to give the yarn its proper count and twist. By the drafting process the linear density of the roving was decreased by controlling the surface speeds of the input and output machine components. The twist was then inserted into the yarn and winding was the next operation. The product of ring spinning was the yarn of given count (Ne), twist type (S or Z), draft and (TPI) Twists per Inch -http://www.textiletechnology.co.cc/spinning/RINGFRAME.htm

- **Cone Winding :** Yarns from Ring Frame Machines was sent to the Cone Winding Machine where the yarn was wound on cones, which was the final product to be sold in the market. Conditioning was done by storing the cones in a controlled moisture environment for 24 hours. Now the yarns of definite count and twist were ready for knitting or weaving.

3.2.4. Yarn Testing

The ring spun 30 Ne carded and combed yarns were tested for the following properties : Count, Lea Breaking Strength, Count Strength Product, Tenacity and Elongation, Twist per Inch, Unevenness, Appearance and Imperfections (Table II).

- **Yarn Count :** As recommended by IS (2000), TS 1315-1977, the linear density or count of the cotton yarn is expressed as number of hanks (768.1 m) per 453.6 grams. The yarn count was determined using the Beesley Balance. The number of yarns, of specified length, which were hung on one side of the balance to equal a given weight, gave the linear density or count of the yarn.

- **Breaking Strength :** The mean value of the breaking strength of the lea was determined by the IS (2000), TS 1671-1977 method. The Lea Strength tester was used to record the lea breaking load in pounds and the count was determined by taking the weight in grams of the broken lea. The average breaking load and average count of all the observations were taken. The CSP was calculated by computing the product of average count and average breaking load of lea of 120 yards.

- **Yarn Tenacity :** Yarn Tenacity refers to the tensile force per unit linear density corresponding with the maximum force on a force extension curve. According to ASTM (2007), TM D2256-2002, single strand yarn specimens were broken on a tension testing machine at a predetermined elongation rate and the breaking force and the elongation at break was determined.

◊ **Yarn Twist :** The twist per inch was determined by the IS (2000), TS 832-1985, test method. The direction of twist was identified by suspending 100 mm of the yarn in a vertical position. If the shape of the yarn element confirm to the shape of central portion of the letters 'S' or 'Z', the direction of twist was noted as 'S' or 'Z' respectively. The direct counting type twist tester was used and the number of turns required to untwist the yarn specimen was noted. The number of turns noted gave the twist per inch.

TABLE II

PROPERTIES OF 30 Ne CARDED AND COMBED COTTON YARNS

S. No.	Yarn Particulars	Carded yarns		Combed yarns	
		SITRA Standard	30s	SITRA Standard	30s
1.	**Count [IS:1315:1977]**				
	Mean Count value	30	27.7	30	27.4
	CV % of Count	1.3	1.5	1.3	1.5
2.	**Lea Breaking Strength [lbs] IS:1671:1977**				
	Mean Lea breaking strength	78	86.6	83	91.6
	CV % of Lea breaking strength	4.5	4.7	3	4.5
3.	**Count Strength Product**				
	CSP	2350	2400	2500	2510
4.	**Single Yarn Strength [ASTM D 2256 : 2002]**				
	Tenacity (RKm)	16	15.5	17	17.5
	CV % of Tenacity	11	9	10	10.3
	Elongation (%)	5	5.1	5.5	5.7
	CV % of Elongation	6	6.3	6.5	6.8
5.	**Twist per Inch [IS:832:1985]**				
	Single twist (tpi)	19.4	19.0	19.4	19.4
	Direction of twist	'Z'	'Z'	'Z'	'Z'
6.	**Unevenness [ASTM D 1425:1996] withdrawn**				
	U%	11.5	9.62	10.5	10.6
7.	**Appearance [ASTM D 2255:2007]**				
	Average rating /Index	C+/100	A/130	C+/100	B+/123
8.	**Imperfections /km [TC/LAB-TM-01]**				
	Thin [-50%]	4	5	0	2
	Thick [+50%]	125	80	12	20
	Neps[+200%]	180	190	30	25
	Total	309	275	42	47

◊ **Yarn Evenness :** Yarn Evenness is the variation in mass, along the yarn, per unit length of the yarn. The ASTM (2007), TM D1425-1996 method, was followed for estimation of unevenness and imperfections (thick places, thin places and neps) based on capacitance principle. A fault length of approximately the fibre staple length, having a cross section of 50 per cent increase (+50%) over the average value is termed as thick place. A fault length of approximately the fibre staple length, having a cross section of 50 per cent less (-50%) than the average value is referred to as thin place. Neps are fault length of 1mm having a cross section 200 per cent (+200%) of the average value. The U% and the imperfections per kilometer were recorded from the evenness tester and the mean value of 8- 10 samples were calculated.

◊ **Yarn Appearance :** The standard test method followed for Grading Spun yarns for Appearance was ASTM (2007), TM D2255-2007. A series of photographic standards representing Grades A,B,C and D in six ranges of yarn numbers was used. On comparing the yarn with the standards in a yarn grading cabinet, a grade was assigned to the yarns based on the closeness to the standard. The yarn appearance grade of each specimen was converted to its yarn appearance index given in the ASTM standard and the average yarn appearance index was calculated.

From Table II, it may be noted that all the test results were close to the SITRA standards for 30 Ne carded and combed yarns in terms of Count, Lea Breaking Strength, Count Strength Product, Tenacity, Elongation, Twist per Inch, Unevenness, Appearance and Imperfections. Hence the yarns used for the study may be rated as slightly better than the SITRA standards for both carded and combed yarns.

3.2.5. Properties of Lycra Yarns

The value of lycra is well recognized by fabric and apparel manufacturers and customers. Lycra provides a greater degree of wearability, wrinkle recovery and crease retention, making it a perfect compliment to most garments. When lycra is knitted with the cotton yarns the cotton component offers comfort and aesthetic properties while lycra is known for its strength and elasticity - http://www.indiantextilejournal.com/articles/FAdetails.asp?id=855. Moreover the industrial survey also revealed that lycra yarns were commonly used in the manufacture of knitted garments. Hence lycra yarns were chosen to be knitted along with the cotton yarns.

The properties of Lycra yarn used along with the cotton yarns are given in the Table III. The standard tensile test was carried out using the Tex Techno Statimat 4 with guage length 200mm, speed 1800 mm/min and load cell 10N.

TABLE III

PROPERTIES OF LYCRA YARN

Yarn Particulars	Value
Linear Density	40.00 den
Elongation F Max 90%	185.36
Force	44.97 g
Work to rupture	579.42 g*cm
Tenacity	13.49 RKm
Time to rupture	13.46 sec.

From Table III, it may be noted that the linear density of lycra yarn was 40 denier and the elongation was 185.36 at a maximum of 90%. The tenacity was 13.49 RKm.

3.2.6. Conversion of Yarns to Knitted Fabric

Two types of weft knitted structures were selected namely Single Jersey and Rib for 100 per cent Cotton and for Lycra Cotton fabric, based on the results of the survey. The weft knit machine parameters for single jersey and rib are given in Table IV.

TABLE IV

WEFT KNIT MACHINE PARAMETERS

S. No.	Knitting Parameters	100 % Cotton Fabric		Lycra cotton Fabric	
		Single Jersey	Rib	Single Jersey	Rib
1.	Name and make of machine	Camber	Terrot	Camber	Terrot
2.	Guage	24	18	24	18
3.	Diameter – Carded Diameter - Combed	22 23	28 28	22 20	34 28
4.	Knitting Machine speed	22	19	18	16
5.	Take up tension	Normal	Normal	Normal	Normal
6.	Number of feeders	56 /58	100/ 85	56 /58	102/ 84
7.	Lycra arrangements	-	-	Alternate	Alternate

3.2.7. Optimization of Enzymes

The bio pretreatment process undertaken for the study consisted of utilization of three enzymes at different stages of the process. The enzyme Scourzyme L (pectate lyase) was used for scouring, enzyme Terminox Ultra 50L (calalase) for bleach clean up and enzyme Cellusoft L (acid cellulase) for bio polishing of 100% cotton weft knits and lycra cotton weft knits.

In order to ascertain optimum process conditions and to evaluate the effect of the enzyme on the properties of 100% cotton and lycra cotton weft knits, an experimental design was used. The response surface design, Box and Benkhen model, of three levels of the variables with 15 different conditions was chosen for the study. A multiple linear regression analysis was used to determine the relationship between these variables as represented by the response surface equation.

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4 X_1 X_1 + B_5 X_2 X_2 + B_6 X_3 X_3 + B_7 X_1 X_2 + B_8 X_1 X_3 + B_9 X_2 X_3$$

where Y is the response from each experiment. B_0 is a constant and B_1 to B_9 are coefficients of each monomial and X_1,X_2 and X_3 are the variables. Tyagi *et al.* (2003) state that a negative coefficient of a variable in the response surface equation indicates that the particular property or response decreases with an increase in that variable and a positive coefficient indicates that the same property increases with the increase of the variable analyzed.

Table V gives the enzymes used with the three levels of the variables chosen for the optimization of the bio pretreatment process of cotton and lycra cotton weft knits.

TABLE V

LEVELS OF VARIABLES FOR BIO PRETREATMENT AND BIO POLISHING

Variable	Scourzyme L (pectate lyase)			Terminox 50L (calalase)			Cellusoft L (acid cellulase)		
	Coded Level			Coded Level			Coded Level		
	-1	0	+1	-1	0	+1	-1	0	+1
pH	8	8.5	9	5.5	6	6.5	4	4.5	5
Enzyme conc.	0.3	0.4	0.5	0.05	0.1	0.15	0.5	1	1.5
Temperature	45	55	65	40	50	60	40	50	60
Time	45 minutes			15 minutes			45 minutes		
MLR	1:10			1:10			1:10		

The fifteen different combinations and their responses to different properties of the treated fabrics are discussed in the chapter Results and Discussion. The response surface design served the basis for the optimization of the three enzymes used for the bio pretreatment and bio polishing processes for both cotton and lycra cotton fabrics.

3.2.7. Selection of the Pretreatment Methods

Two types of pretreatment methods were selected namely the Chemical Pretreatment Method and the Bio Pretreatment Method. The chemical pretreatment method was the one commonly used by the industries. The chemicals used included Caustic Soda for scouring, Hydrogen Peroxide for bleaching, chemical peroxide killer with Sodium Silicate and Formic Acid for the neutralization of the alkali. The chemicals used for 100% cotton and Lycra Cotton weft knits were similar but the percentage of chemicals used differed in both cases.

The bio pretreatment was formulated with enzymes namely Pectate Lyase for scouring, Hydrogen Peroxide for bleaching as it was eco friendly and Catalase enzymes for removal of hydrogen peroxide before dyeing. The product sheet of the enzymes selected for the bio pretreatment, are given in Appendix III. The recipes for chemical pretreatment of 100% cotton and lycra cotton weft knits are given in Table VI. The chemical processing sequence for 100% cotton and lycra cotton weft knits given in the Flow Chart 3.

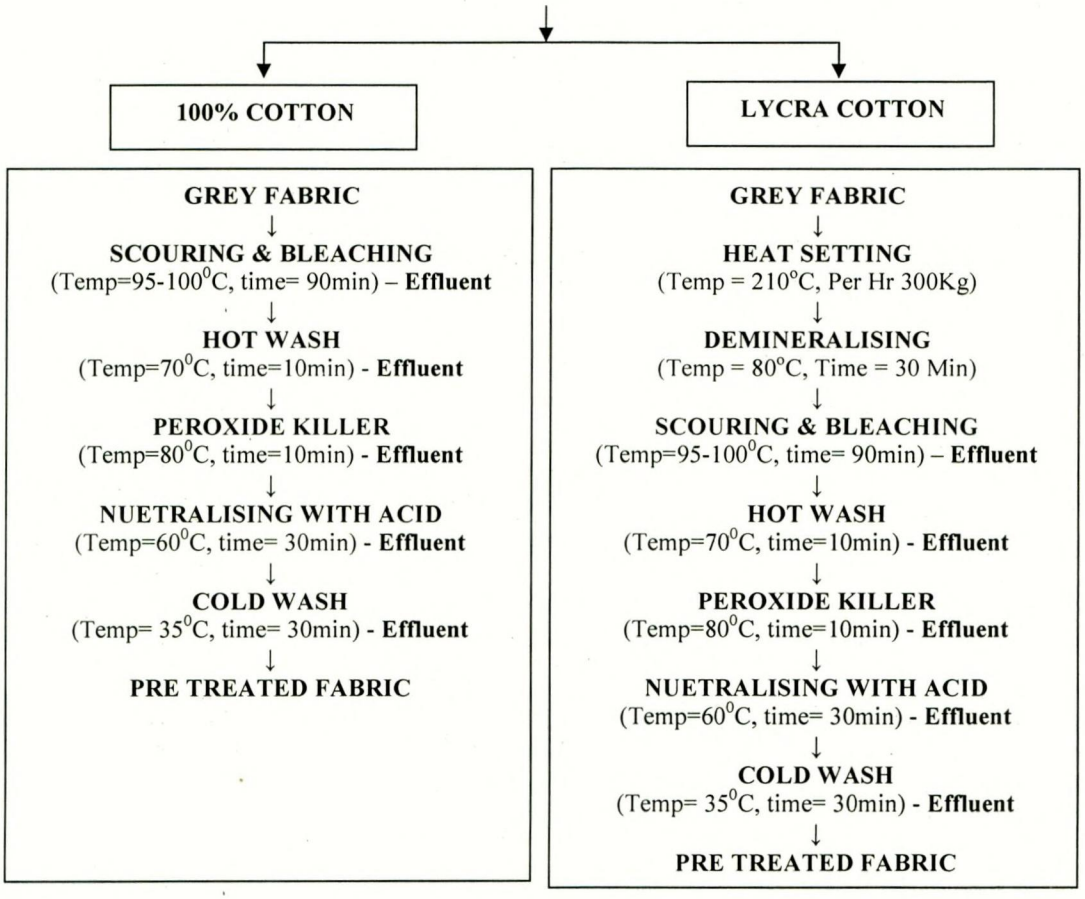
TABLE VI

RECIEPE FOR CHEMICAL PRETREATMENT

S.No.	Chemicals/ Auxiliaries	Quantity in GPL	
		100% Cotton	Lycra Cotton
1	Demineralising Agent	-	0.5
2	Wetting oil	0.5	0.66
3	Lubricant	0.5	0.55
4	Sequesterant	0.75	0.825
5	Caustic Soda	3	3.5
6	Peroxide	3	3.5
7	Stabiliser	0.5	0.55
8	Peroxide killer	0.8	0.88
9	Formic Acid	1	1.1
Material Liquor Ratio		1:8	1:8

FLOW CHART 3

PROCESS SEQUENCE FOR CHEMICAL PRETREATMENT



The grey fabric was first wetted with the required wetting oil and lubricant for 15 minutes in the soft flow machine. The caustic soda, sequesterant, hydrogen peroxide and stabilizer was added after the temperature was raised to 100° C. The fabric was worked for 90 minutes to ensure even penetration of the chemicals in the solution. The bath was drained followed by a hot wash for ten minutes in fresh water at 70° C. The bath liquor was drained and refilled to undertake a peroxide killing treatment for 10 minutes at 80°C. This is an important step to remove excess hydrogen peroxide, which would interfere with the reactive dyes and cause shade variation. The next step was neutralization with acid, to convert caustic soda to salt, and removed in the effluent. The last step was a cold wash with fresh water at 35°C for 30 minutes. The chemically pretreated fabric was ready for the next step which may be dyeing, printing or any finishing operation.

In the case of Lycra cotton the grey fabric was passed through a heat setting machine to set the lycra for the processing treatment. The fabric was then worked for 30 minutes at 80°C with a demineralising agent to remove the oils from the lycra and to make it suitable

for pretreatment. The remaining steps in pretreatment processes are similar to the 100% cotton pretreatment.

The reciepe for Bio pretreatment, based on the optimization of the selected enzymes, of 100% Cotton and Lycra Cotton Weft Knits are given in Table VII. The bio processing sequence is given in the Flow Chart 4.

TABLE VII

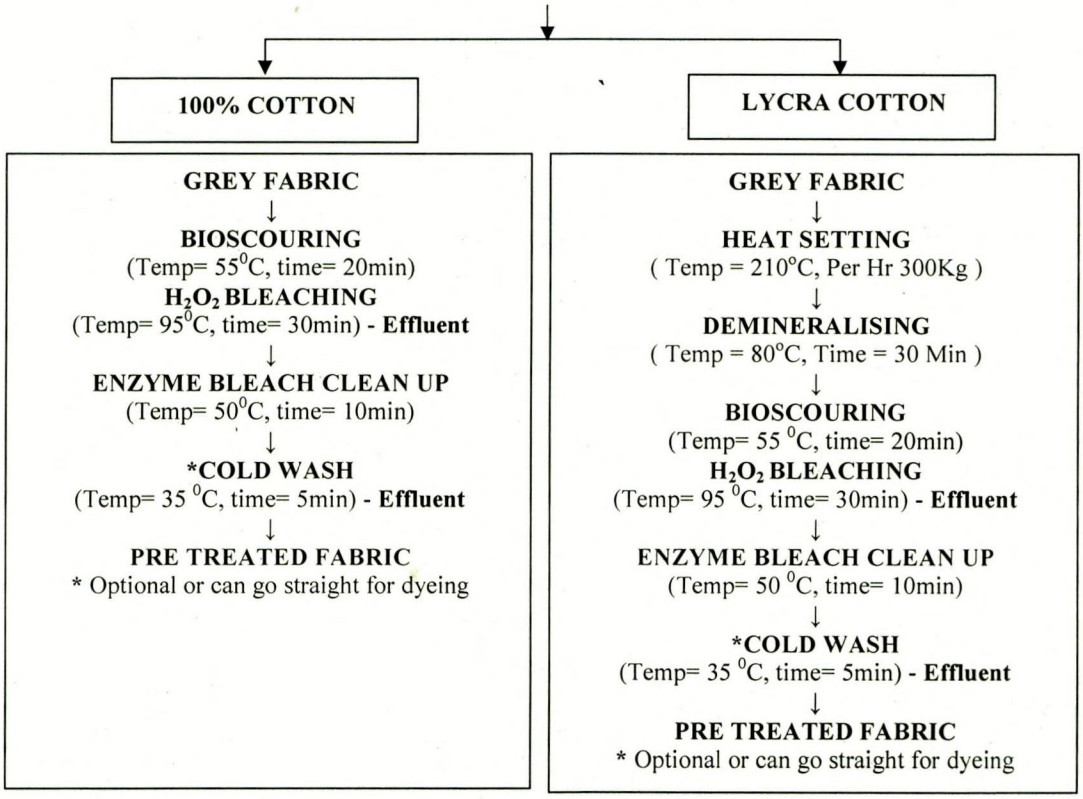
RECIEPE FOR BIO PRETREATMENT

S.No.	ENZYMES / AUXILLARIES	QUANTITY IN GPL	
		100% COTTON	LYCRA COTTON
1	Demineralising Agent	-	0.5
2	Wetting oil	0.5	0.5
3	Lubricant	0.5	0.5
4	Scourzyme L	0.4	0.4
5	Caustic Soda (optional)	1	1
6	Peroxide	3	3
7	Stabilizer	0.5	0.5
8	Terminox 50L	0.1	0.1
Material Liquor Ratio		1:8	1:8

The grey fabric was first wetted with the required wetting oil and lubricant for 15 minutes in the soft flow machine. The enzyme for scouring Scourzyme L was added, after the pH of the bath was adjusted to 8.5 to 9 with the help of soda ash and acetic acid. The temperature was raised to 55 °C and the fabric was rotated in the soft flow machine for 20 minutes. The recommended quantity of hydrogen peroxide and stabilizer was added to the same bath and the temperature was raised to 95 °C for 30minutes. The bath was drained and refilled for the enzymatic bleach cleanup with Terminox 50L keeping the pH at 6 and temperature at 50 °C for 10minutes. This process removed all traces of hydrogen peroxide in the bath which if left untreated would bring about variation in shade during the dyeing process. It has been suggested that dyeing could be undertaken in the same bath or can be drained and refilled for a cold wash at 35°C for 5minutes. The bio pretreated fabric was ready for the next step which may be dyeing, printing or any finishing operation. It must be noted that the correct pH, temperature, enzyme concentration and time duration are important factors in activating the enzyme to enable the reaction.

FLOW CHART 4

PROCESS SEQUENCE FOR BIO PRETREATMENT



In the case of Lycra cotton the grey fabric was passed through a heat setting machine to set the lycra for the processing treatment. The fabric was then worked for 30 minutes at 80°C with a Demineralising Agent to remove the oils from the lycra and to make it suitable for pretreatment. The pretreatment processes following demineralising are similar to the 100% cotton pretreatment.

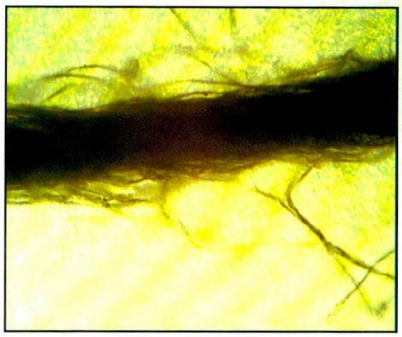
3.2.8 Bio Polishing Treatment

A portion of the chemically pretreated and bio pretreated fabrics were subjected to a bio polishing treatment using acid cellulase enzymes from Novozymes, Denmark to study the effect of bio polishing on the pretreated fabrics. The product sheet of the bio polishing enzyme is given in Appendix III. The recipe followed for the bio polishing of chemical pretreated and bio pretreated fabrics is given in the Table VIII. The bio polishing sequence is given in the Flow Chart 5. Images of the cotton, lycra yarns and fabrics in grey state and after bio polishing, using the Image Analyzer (40 magnification), are given in Plates 1, 2 and 3.

PLATE 1

IMAGES OF COTTON AND LYCRA YARNS

GREY YARNS -COTTON



Carded Yarn

Combed Yarn

BIO POLISHED YARNS -COTTON

Carded Yarn

Combed Yarn

LYCRA YARN

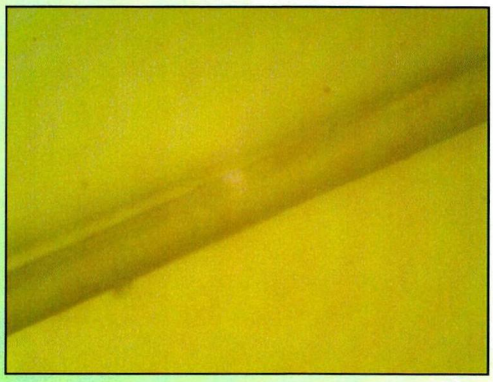
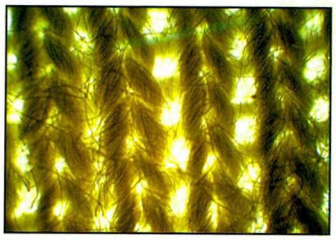


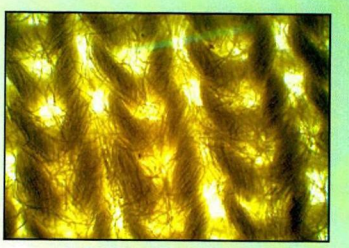
PLATE 2

IMAGES OF COTTON WEFT KNITS

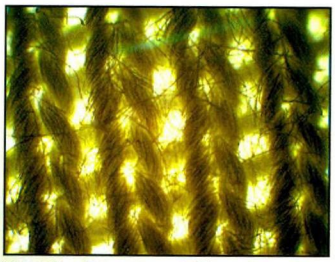
GREY FABRICS



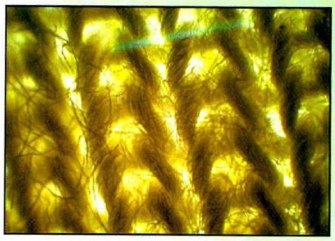
Single Jersey (Carded)



Rib (Carded)

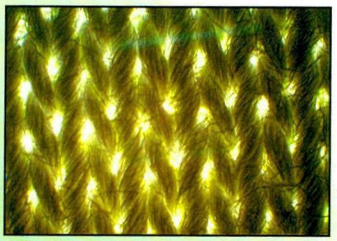


Single Jersey (Combed)

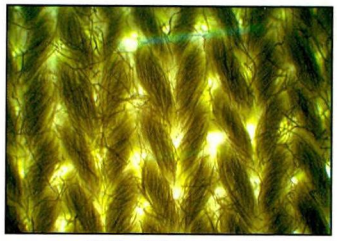


Rib (Combed)

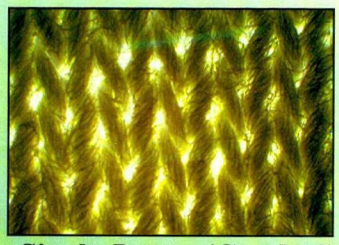
BIO PRETREATED BIO POLISHED FABRICS



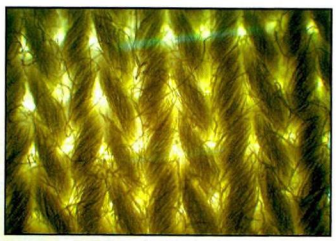
Single Jersey (Carded)



Rib (Carded)



Single Jersey (Combed)

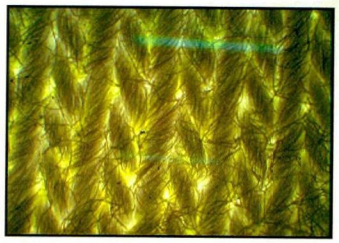


Rib (Combed)

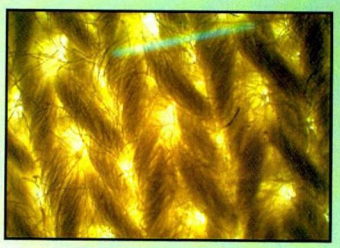
PLATE 3

IMAGES OF LYCRA COTTON WEFT KNITS

GREY FABRICS

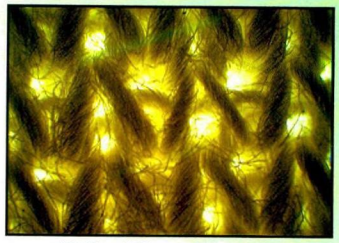


Single Jersey (Carded)



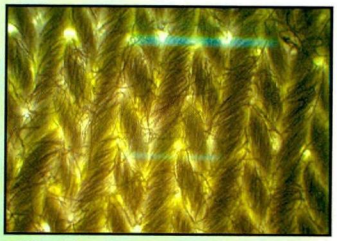
Rib (Carded)

Single Jersey (Combed)

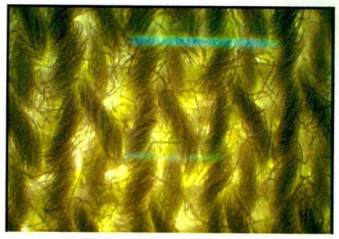


Rib (Combed)

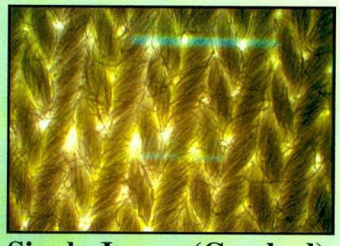
BIO PRETREATED BIO POLISHED FABRICS



Single Jersey (Carded)



Rib (Carded)



Single Jersey (Combed)

Rib (Combed)

TABLE VIII

RECIEPE FOR BIO POLISHING

S.No.	ENZYMES / AUXILLARIES	QUANTITY IN GPL
1.	Cellusoft L	1
2.	Sequesterant	0.5
MLR 1:8, pH 5		

FLOW CHART 5

PROCESS SEQUENCE FOR BIO POLISHING

PRETREATED FABRIC
↓
BIOPOLISHING
(Temp= 50 ^{0}C, time= 45min)
SEQUESTERANT
(Temp= 70 ^{0}C, time= 10min) - **Effluent**
↓
COLD WASH
(Temp= 35^{0}C, time=10min) - **Effluent**
↓
BIOPOLISHED FABRIC
↓
DYEING

The pH of the water was maintained at 5 by adjustment with acetic acid. The pretreated fabric was allowed to circulate in the soft flow machine for 15 minutes for thorough wetting of the fabric. The bio polishing enzyme was dozed and the temperature was raised to 50°C. After 45minutes the sequesterant was added into the same bath, the temperature was raised to 70°C and the fabric was worked for ten minutes. The water was drained and this process was followed by a cold wash at 35°C temperature for ten minutes. Care was taken in the after treatment process since a thorough removal of the short fibrils of cotton, which are disengaged from the fabric during the bio polishing process, thereby giving a clean smooth surface finish to fabric.

3.2.9 Selection of the Dyeing Procedure

The dye recipe for the reactive dyeing of the 100% Cotton and Lycra Cotton fabrics are given in Table IX. The characteristics of the chosen dyes are given in Appendix IV. The process sequence for reactive dyeing is given in Flow Chart 6.

TABLE IX

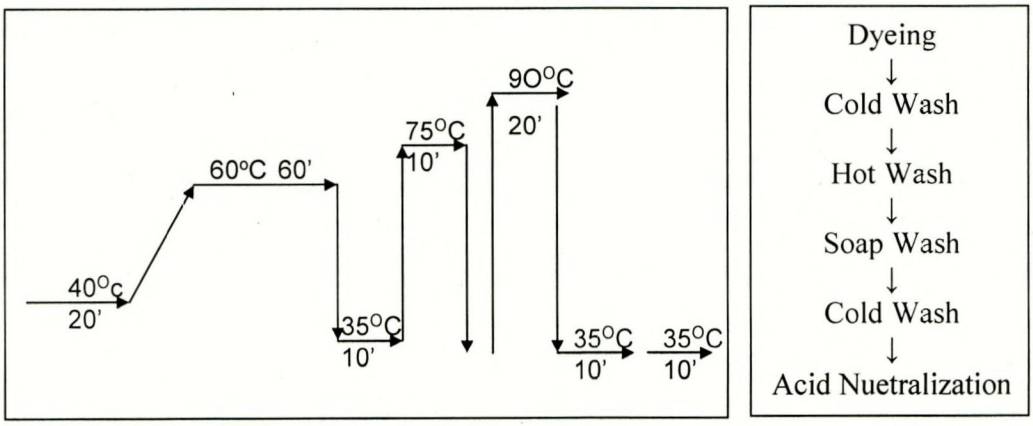
DYE RECIPE FOR COMBINATION SHADES

S.No.	Name of Dye stuff / Auxiliaries	Quantity used	
		Light Blue	Dark Blue
1.	Drimarene Blue HFRL	0.200%	
2.	Drimarene Red ClBl	0.02%	
3.	Drimarene Yellow Cl_2R	0.002%	
4.	Col. Black B		3%
5.	Drimarene Red Cl_5B		0.03%
6.	Drimarene Yellow F_3R		0.003%
7.	Shade Depth	0.222%	3.033 %
	Vacuum Salt	20 gpl	80 gpl
	FBSN - Sequesterant	1 gpl	1 gpl
	Primasol Jet - Lubricant	1 gpl	1 gpl
	Soda Ash	10 gpl	20 gpl
	MLR 1:8, water pH 6		

The chemical and bio pretreated samples (without bio polishing) and the bio polished, chemical and bio pretreated knitted fabrics were subjected to reactive dyeing (hot brand). In order to study the different parameters of the dyed fabrics, combination shade of a light blue colour and dark blue colour was chosen with the shade depth 0.222 % for light blue and 3.033% for dark blue respectively.

FLOW CHART 6

PROCESS SEQUENCE FOR REACTIVE DYEING (HOT BRAND)



The dye bath was prepared with the dye, FBSN, Primasol Jet, Vacuum Salt and water. The pretreated fabric was immersed in the dye bath and the dyeing machine was operated for 20 minutes at 40°C. The dyeing was continued for another 60 minutes after

adding soda ash (as per the recipe) to the bath and raising the temperature to 60°C. This was followed by cold wash at room temperature for 10 minutes, hot wash with acid for 10 minutes at 75°C, soap wash for 20 minutes at 95°C, cold wash at room temperature for 10 minutes and neutralization with acid for 10 minutes (pH 7). The dye bath was drained and the sample was dried.

3.2.10. Method of Finishing Treatment

After dyeing the fabric was subjected to a finishing treatment balloon padding followed by relaxation drying. Balloon padding is a preparatory process for drying and relax drying that will ensure shrinkage free fabrics The next step was compaction of fabric. Compacting is a key process that relaxes the knitted fabric to natural stage. Now the fabric was ready for conversion to apparel.

3.2.11. Nomenclature of the Samples

The nomenclature of the samples are given in Table X.

TABLE X
NOMENCLATURE OF THE SAMPLES

S. No.	Fabric Content		Yarn Type		Knit Structure		Dye Shade		Nomenclature
	100% cotton (C)	Lycra Cotton (LC)	Carded (1)	Combed (2)	Single Jersey (SJ)	Rib (RB)	Light Blue (B1)	Dark Blue (B2)	
1	/		/		/				C1SJ
2	/		/			/			C1RB
3	/			/	/				C2SJ
4	/			/		/			C2RB
5		/	/		/				LC1SJ
6		/	/			/			LC1RB
7		/		/	/				LC2SJ
8		/		/		/			LC2RB
9	/		/		/		/		C1SJB1
10	/		/			/	/		C1RBB1
11	/			/	/		/		C2SJB1
12	/			/		/	/		C2RBB1
13		/	/		/		/		LC1SJB1
14		/	/			/	/		LC1RBB1
15		/		/	/		/		LC2SJB1
16		/		/		/	/		LC2RBB1
17	/		/		/			/	C1SJB2
18	/		/			/		/	C1RBB2
19	/			/	/			/	C2SJB2
20	/			/		/		/	C2RBB2
21		/	/		/			/	LC1SJB2
22		/	/			/		/	LC1RBB2
23		/		/	/			/	LC2SJB2
24		/		/		/		/	LC2RBB2

3.2.12. Conversion of Fabric to Apparel

The fabrics ready for conversion to apparel were as follows:

- bio pretreated and dyed fabrics (in light blue and dark blue)
- chemical pretreated and dyed fabrics (in light blue and dark blue)
- bio pretreated, bio polished and dyed fabrics (in light blue and dark blue)
- chemical pretreated, bio polished and dyed fabrics (in light blue and dark blue)

The above mentioned fabrics were made into round neck, short sleeve, basic Tshirts for the wear study, 2 in each colour and each combination according to the size chart given in Appendix V. The pattern development and construction of T-Shirt is also given in Appendix VI. The ironed T-shirts were distributed to the subjects for wear study.

3.2.13. Wear Study

The investigator selected 36 subjects of age group 15-25 years, for the wear study, based on convenience sampling (Plate 4). The garment was worn from 8.30 AM to 6.30 PM (10 hours per day) for a period of one month. After each wear the T shirts were collected from the subjects and cleaned, ironed well and given for the next wear.

Synthetic detergents are those cleaners that remove soil by some colloidal chemical process, points out Shennai (2000). The synthetic detergents are not sensitive to hard water, acids or to salt. They are powerful degreasers and rapidly wet out greasy work. Surf Excelmatic with low foaming formula was selected as the detergent. Soft water was used as the solvent for wet cleaning. A front loading tumble wash system was used for the washing process.

The detergent solution for a garment, was prepared using 3 grams per 1000 ml (pH 9.8) of water. The detergent solution was then mixed with 7 litres of water. The sample was loaded into the fully automatic tumble washing machine which had a soak facility for thirty minutes. The time taken for a full wash and four rinse cycle was ninety minutes. The semi dry clothes were removed and dried on an indoor line. This process was repeated for 30 washes.

3.3. EVALUATION

Evaluation of the processed materials were done at different stages namely the grey stage, after chemical and bio pretreatment, after bio polishing, after dyeing and after wear study. The original and processed fabrics were evaluated by the following ways:

PLATE 4

WEAR STUDY – SUBJECTS WITH T-SHIRTS

3.3.1. Visual Assessment

3.3.2. Laboratory Tests

3.3.1. Visual Assessment

All the processed samples were evaluated by a panel of judges. The cotton and lycra cotton samples were displayed for evaluation. The panel, which consisted of twenty five post graduate students specializing in the field of Textiles and Clothing at the Avinashilingam University for Women, Coimbatore, evaluated the samples using a proforma given in Appendix VII. The proforma included details regarding general appearance, colour, lustre and texture of the samples.

3.3.2. Laboratory Tests

Weaver (1998) stresses that textile testing plays a crucial part in production processes, as a result of mechanical properties on fabrics, for undergoing evaluations. As a general rule, all the samples tested were conditioned, for the required hours to reach equilibrium, in a standard atmosphere for testing textiles, Relative Humidity 65%±2% at 20°C±2 °C. After conditioning, samples were evaluated by the following laboratory tests.

3.3.2.1 Geometrical Properties

3.3.2.2. Tests after Pretreatment and Bio polishing

3.3.2.3. Tests after Dyeing and Wear

3.3.2.1. Geometrical Properties

The geometrical properties studied are given below:

- **Wales and Courses per Unit Length**

In knit fabrics, a column of loops lying lengthwise in the fabric are wales and those lying widthwise are courses. The number of visible loops per unit length measured along a course gives the wales per unit length. The number of visible loops per unit length measured along a wale gives the courses per unit length - http://textile.texworld.com.

As recommended by BS 5441:1988, http://www.standardsdirect.org/, the test samples, conditioned for twenty four hours, were laid on a flat horizontal surface. The number of face courses and wales visible within a minimum measuring distance [2.5 centimeters] were counted using a pick glass. These values are divided by 2.5 to compute the wales and courses per centimeter. The result was expressed as courses or wales per

centimeter This procedure was repeated at ten different places on the sample and the mean was calculated.

- **Stitch Density**

Stitch Density refers to the total number of loops in a measured area of fabric. It is the total number of needle loops in a given area (such as one square inch or three square centimeters). The number of courses per three centimeters and the number of wales per three centimeters are counted using a pick glass and divided by three to get the number of wales and courses per centimeter. The product of the number of wales and number of courses per centimeter gives the stitch density, as stated in ASTM (2007), TM D 3887-1996.

- **Loop Length**

Loop length is also known as stitch length and is expressed in millimeters or centimeters. As per the Starfish Guide for Knitted Goods (1986), the Shirley stitch length tester was used to determine the loop length. This tester consists of a clamp, attached to a stand, and a graduated scale to note the length of the yarn. A 20 cms square sample was cut and a fine red marker was used to mark the distance between the specified number (100 loops) of wales. Two parallel cuts approximately 2 cms outside the marked wales was made to provide sufficient space for clamping the sample. One end of the partially extracted yarn was clamped to the stand taking care to see that the red mark coincided with the '0' of the scale. The other end of the yarn was attached to a 10gm weight to make it free of crimp. The distance between the two red marks were recorded. The mean value of ten such readings, from ten yarn samples, was divided by 100 to calculate the stitch length or loop length in centimeters. The loop length or stitch length is the length of yarn in a loop.

- **Fabric Thickness**

Fabric thickness is the distance between face and backside of the fabric measured under specific pressure. The instrument used to measure the thickness is called the fabric thickness gauge. Thickness gauge has a set of flat platforms: a stationary anvil and a vertically movable pressure foot. After conditioning for 24 hours, the fabric should be tested in a standard testing atmosphere avoiding selvedges and creased areas.

The pressure foot was raised and the sample to be measured placed on the anvil. The pressure foot was gently lowered on the fabric. The thickness of the fabric was read on the dial and recorded to the nearest 0.01mm. After ten seconds another measure of thickness was

recorded again. This operation is repeated on different parts of the sample. The mean value of ten readings gave the thickness value as explained in ASTM (1999), TM D1777-1975.

- **Count**

The test method recommended in ASTM (2007), TM D1059-01, was followed to determine the yarn number based on short length specimens taken from the fabric sample. The yarns were raveled from the fabric and 36 inches (1 yard) was weighed [W_1] using an electronic balance. The weight for 120 yards [lea weight] was calculated by multiplying W_1 *120 to get W_2. The count was determined by the formula,

$$\text{Count} = \text{Constant} / \text{lea weight} = 64.8 / W_2$$

Ten such readings were taken and the mean value gave the count of the fabric.

- **Mass per Unit Area**

Fabric weight is an important factor for international selling and buying highlights Saini (2004). The most widely used methods of expressing fabric weight for knitted fabrics is Grams per square meter (GSM).

The sample cutter, used to determine GSM, is a device to cut accurate circular specimens of 100 square centimeter of a fabric. It has four blades that cut the fabric when the hand wheel is rotated by applying slight pressure on it.

As per the recommendations of ASTM (2007), TM D 3776-1996, five test specimens were cut using the GSM cutter avoiding selvedges and centre creases. The samples were allowed to condition for one hour after which the weight was taken on a digital balance having a 0.01 gm sensitivity. The mass per unit area of the sample is calculated using the formula:

$$\text{Mua} = m \times 100$$

where Mua = mass per unit area in grams per square meter of fabric

m = mass in grams of the specimen.

The mean weight of the five samples was calculated to give the mass per unit area of the knitted fabric.

- **Geometrical Constants (Kw, Kc, Ks, R)**

The fundamental laws of knitting state that the stitch is taken as a basic unit in all knitted fabrics. The stitch has a specific length and diameter which are the factors that control a knitted fabric. Ajgaonkar (1998) states that the dimensional characteristics of

knitted fabrics are based on the loop length and the number of loops per unit length. The courses per unit length are inversely proportional to the stitch length. The wales per unit width are inversely proportional to the stitch length. Tompkin's Law states that the product of wales and courses with a given stitch length is equal to a constant. Loop Length is the fundamental unit of the weft knitted structure. Loop Shape determines the dimensions of the knitted fabric and this shape depends upon the yarns used and the treatment that the fabric has received. The relationship between the loop shape and loop length are expressed in the form of simple equations.

Length Constant = Kc = courses per cm x loop length

Width Constant = Kw = wales per cm x loop length

Area Constant = Ks = Kc x Kw

Loop Shape Factor = R or KLSF = Kc / Kw

The geometrical constants of the fabrics used for the study were determined based on the above mentioned equations -http://www.ft.tul.cz/science/conference/indoczech-conference/conference_proceedings/abstract/India07.pdf

3.3.2.2. Tests after Pretreatment and Bio polishing

The tests carried out after the chemical pretreatment, bio pretreatment and bio polishing of the fabrics included The pH of Fabric, Absorbency, Fabric Weight, Bursting Strength, Degree of Polymerization, Residual Alkali, Whiteness and Yellowness Index, Comfort Properties, Low Stress Mechanical Properties and Effluent Estimation.

- **The pH of Fabric**

The pH is the logarithm of the hydrogen ion activity expressed in gram equivalents per liter used in expressing both acidity and alkalinity on a scale whose values run from 0-14 with seven representing neutrality, numbers less than seven indicating acidity and numbers greater than seven indicating alkalinity.

As recommended by AATCC (2006), TM 81 -2001, 250 ml of distilled water was boiled at a moderate heat for ten minutes. The fabric sample weighing 10 grams was cut into small bits. The prepared sample was immersed into the beaker, covered with a watch glass. The beaker was boiled for another 10 minutes. The covered beaker with contents were allowed to cool to room temperature. The specimen was removed with tweezers and the filtrate checked for pH using a pH meter.

The pH of the water extract will depend on the treatment previously given to the fabric, the pH of the wash water and the efficiency of the washing operation. Textiles with high pH values may exhibit yellowing tendencies, create shade changes, alter the exhaustion and fixation of dyes.

- **Absorbency**

Absorbency is the propensity of a material to take in and retain a liquid, usually water, in the pores and interstices of the material. As one of the determinants that influence textile processing, this characteristic can influence the uniformity and completeness of bleaching and dyeing by the ability to take in water into the fibre, yarn or fabric construction.

As per the AATCC (2008), TM 79-2007, the conditioned fabric was spread over an embroidery hoop without wrinkles and kept 9.5 mm below a burette positioned to deliver 15-25 drops of water per milliliter. A drop of distilled or deionized water was allowed to fall on the cloth. The stopwatch was started immediately and the time required for the drop of water to loose its specular reflectance and appear as a dull wet spot, was noted. The average of five readings was taken and the shorter the average time the more absorbent the fabric.

- **Fabric Weight**

The weight of the fabric after each pretreatment process and bio polishing was determined according to the ASTM (1999) D 3776 small swatch option. The percentage weight gain or loss was calculated. After conditioning the samples for twenty four hours in standard testing atmosphere the mass of the sample was recorded using an electronic balance.

Degani *et al.* (2002) state that the extent of chemical and enzymatic hydrolysis can be measured by weight loss. Pretreatment removes the impurities, pectins and waxes resulting in loss in weight. Similarly cellulases catalyze the hydrolysis of cellulose, in the course of which soluble products form and the substrate mass is reduced after bio polishing.

Ten weight readings were taken and the mean weight was computed after each pretreatment process and bio polishing.

- **Bursting Strength**

As per ASTM (1999), TM D3787 -1989, bursting strength is the distending force which is applied at right angles to the plane of the fabric, under specific conditions, will

result in the rupture of a textile. This test method determines the ball bursting strength of the fabric and is used for the evaluation of the fabric after any manufacturing process.

The apparatus used for this test was the Hydraulic Bursting Tester. Booth (1996) describes that the tester consists of a reservoir of liquid which may be water or glycerine. In the upper face of the reservoir is a circular hole over which is clamped a thin flexible rubber diaphragm. The sample to be tested was clamped by a ring over this rubber diaphragm. The hydraulic pressure, controlled by valves or screw-driven piston, was indicated by the guage which is connected to the reservoir.

Cutting of the sample was not necessary but should be of 125mm square or a circle with 125mm diameter and conditioned to moisture equilibrium in standard atmosphere for testing. The conditioned test sample was clamped to the ring without tension. The hydraulic pressure was increased causing the diaphragm to distend, taking with it the specimen. This was continued till the fabric ruptured and the reading noted in the gauge. The mean value of ten such readings gave the bursting strength of the fabric.

- **Degree of Polymerization**

Viscosity of solutions of cotton in cuprammonium hydroxide has a close correlation to the tensile strength of the fibre. The fluidity of cuprammonium hydroxide solution containing 0.5 g of bone dry cotton per 100 ml solution at 20°C is the fluidity of the cotton.

According to the procedure stated in IS (2000), TS 244 -1984, a viscometer with a capillary tube of internal diameter of 10mm, length 300mm and volume 20ml was taken. Bone dry cotton necessary to make a 0.5 per cent solution of cotton in the volume of liquid [25ml] needed to fill the viscometer was weighed. The lower end of the viscometer was closed with a rubber stopper. Half the capacity of the viscometer was filled with cuprammonium hydroxide solution prepared as per the IS : 244-1969 standard. Dry mercury [0.7 ml] was poured into the viscometer. The weighed cotton material was added to the solution and stirred well. The remaining cuprammonium hydroxide solution was added to fill the viscometer and closed with a stopper so that the excess liquid displaces the air inside the tube. After covering the viscometer with a black cloth, it was rotated in a rotating device till a complete solution of the fabric was effected. The viscometer was placed in a wider tube and the temperature was maintained at 20°C. The time taken for the meniscus to fall from the upper fixed mark [vertical height of 242mm] to the lower fixed mark [122mm] in the viscometer was noted and the fluidity calculated using the following formula:

$$F = \frac{C1}{T - K / t}$$

where F = Fluidity in absolute units, C_1 = modified constant of viscometer, t = observed time in seconds, K = kinetic energy correction constant.

The Degree of Polymerization was calculated in order to express the amount of damage to the samples, after chemical and enzyme treatment, using the formula:

$$DP = 2032 \log_{10}\left[\frac{74.35 + F}{F} - 573\right]$$

where DP = Degree of Polymerization, F = Fluidity.

- **Residual Alkali**

The AATCC (2005), TM 144-2002, determines the total alkali content of wet processed textiles particularly after bleaching. It is used as a measure of the suitability of the prepared fabric for subsequent dyeing and finishing operations. Pretreated sample (5-10 grams) was placed in a beaker containing 450-500 ml of distilled water at room temperature and stirred for one minute. The beaker was covered and kept aside for 15 minutes. The pH meter electrode was immersed into the beaker avoiding contact with the specimen. 0.10 N H_2SO_4, the titrant used, was dropped steadily with gentle agitation, avoiding contact with the specimen, into the beaker till the end point pH 3.9 was reached. The titration was repeated with blank water without the specimen. The total alkali was then calculated using the following formula:

$$X = [(A - B)(0.04)(N)\ 100] / W$$

where X = % total alkali as sodium hydroxide, A = Volume of acid used for specimen (mL), B = Volume of acid used for blank (mL), N = Normality of sulphuric acid (0.10 N), W = weight of the specimen.

Total alkalinity quantifies the amount of residual alkali in a specimen per unit weight. Ten specimens were selected and the mean value was computed.

- **Whiteness Index and Yellowness Index**

Whiteness index is the attribute by which an object colour is judged to approach a preferred white. As recommended by AATCC (2000), TM 110-2005, the sample to be measured was conditioned for 12 hours in standard atmospheric conditions. The Konica Minolta Spectrophotometer CM 3600D in the wave length range of 400 to 700nm and Tree Point software was used to measure the whiteness and the yellowness Index. The

spectrophotometer was calibrated using the white tile once in 3 hours. The sample was folded to obtain the required degree of opacity. Four measurements was taken and the sample was rotated 90° between each measure. The reading (whiteness index / yellowness index) was displayed on the monitor screen and the average of these measures gave the whiteness index or yellowness index of the sample.

- **Comfort Properties**

Slater (1977) defines the term 'comfort' as 'the absence of displeasure or discomfort' or 'a neutral state compared to the more active state of pleasure'. Clothing comfort includes psychological, sensorial and thermo-physiological comfort. Thermo-physiological comfort entails both thermoregulation and moisture management - http:/textilepapers.tripod.com /smart.htm. Comfort properties include Air Permeability, $q_{max,}$ Thermal conductivity and Wicking.

♦ **Air Permeability :** Air permeability indicates the breathability of clothing fabric. It is the volume(cm^3) of air passing through 1 cm^2 of fabric per second at a pressure difference of 1 cm head of water. The apparatus consists of means for drawing or forcing air through the fabric of known area, circular orifice of definite known area, provision to hold the fabric without peripheral leakage of air, means for adjusting the pressure drop across the fabric to a known amount, means for measuring the rate of flow of air through the fabric and means for checking the calibration of air flow meter, records ASTM (2007), TM D 737-2004.

According to IS (2000), TS 11056 -1984, the test samples were conditioned to moisture equilibrium in the standard atmosphere. The conditioned sample was mounted between the clamp and circular orifice with sufficient tension to eliminate wrinkles. The vacuum cleaner suction fan was started to force the air through the fabric and adjust the rate of flow of air till pressure drop of one centimeter or 10mmWG of water head across the fabric. This was achieved by opening the air flow of the rotometers and adjusting the flow rates. The sum of all the rotometer values indicated the rate of flow of air in Litres per hour. The test was repeated at ten different places and the mean value was calculated. The air permeability was calculated using the following formula:

$$R = r / A$$

where Air permeability R = rate of flow of air/cm^2 of fabric in cm^3/s, r = mean rate of flow of air in cm^3/s and A = area $cm^2$of fabric under test in cm^2.

♦ **q_{max} :** The q_{max} value [watts/m^{2o}C] indicates the instantaneous warm/cool feeling sensed when there is initial contact of the fabric with the skin surface. A higher value of q_{max} denoted that there was more rapid movement of heat from the body to the fabric surface resulting in a cooler feeling of fabric, express Durai and Arun [2004].

Hes (2001) explains that the Alambeta Instrument is a computer controlled semi automatic instrument which evaluates the thermal contact feeling of textile fabrics. The sample was kept on the instrument base under the measuring head which contains a ultra thin heat flow sensor of a constant temperature, differing to the sample temperature. When the measurement starts, the measuring head with the heat flow sensor, moves down and touches the sample. The surface temperature of the sample suddenly changes and the instrument computer registers the heat flow course. A photoelectric sensor also records the sample thickness. To simulate the real warm –cool feeling evaluation, the measuring head was heated to 32° C which corresponds to the human skin and the sample was` kept at room temperature.The result evaluation lasts less than 3-5 minutes. The measurements were repeated ten times on randomly chosen parts of the fabrics and the average values were calculated.

♦ **Thermal Conductivity :** Oglakcioglu and Marmarali [2007], explain that thermal conductivity is an intensive property of a material that indicates the ability to conduct heat expressed as W/mK units. The transmission of heat through the fabric occurs both by conduction through the fibre and the entrapped air and by radiation. Thermal conductivity measures the total heat transmitted by both the methods, explains Saville (2000). The Holometrix, Rapid-K (computer controlled) instrument, used to measure the thermal conductivity of the fabrics, basically simulates the dry human skin and its principle depends in mathematical processing of the time course of heat flow passing through the tested fabric due to different temperatures of the bottom measuring plate [22°C]and the measuring head [32° C]. The measurements were repeated five times on randomly chosen parts of the fabrics and the average values were calculated, narrate Fournier *et al.* (2008).

♦ **Wicking :** The phenomena which transports water or any other liquid chemical, that comes into contact, through the fibrous structures is wetting and wicking. Wicking is the spontaneous flow of a liquid in a porous substrate driven by capillary forces, explain Pan and Zhong (2006). High and uniform absorbency of cotton fabric is a desirable quality in nearly every wet finishing operation and many finished fabrics. Absorbency of fabric is influenced by their wicking ability, express Patnaik *et al.* (2006).

Ram (2007) expressed that in the Longitudinal Wicking Test, the fabric strip was cut into a 1cm width x 12 cm length using a template. Seven lines were drawn one centimeter apart with the help of a graduated scale after leaving a gap of one centimeter at the bottom edge to facilitate vertical immersion into a reservoir of distilled water. A 20 gram weight was suspended from the bottom edge of the strip to keep the knitted fabric straight. The time taken for the water to rise every centimeter in the wale direction and the course direction, was noted in seconds till the seventh centimeter was reached. The difference in the time gave the wicking tendency of the treated fabrics.

- **Low Stress Mechanical Properties**

The Low Stress Mechanical properties of the fabrics were evaluated by the Kawabata Evaluation System. Table XI shows the low stress mechanical properties measured by the KES-FB system. Professor Kawabata developed the first series of Kawabata set of instruments KESF in collaboration with the Kato Tech. Company, Japan in 1982. The Kawabata Evaluation System includes four highly sensitive instruments that measure fabric bending, shearing, tensile and compressive stiffness along with the smoothness and frictional properties of the fabric surface. All Kawabata systems consist of an integrator and an automatic data processing system which records and computes the results with the computer software developed in the LSU School of Human Ecology. All measurements are directional except for compression and are made in both lengthwise and crosswise direction - www.atira-rnd-tex.org/fac_kawabata_des.htm.

♦ **Tensile :** The fabric sample of 20cm x 5 cm was extended up to a preset maximum load of 500 N/m and the stress/strain parameters were measured by the KES-FBI Tensile –Shear Tester. Four tensile properties namely Tensile Linearity LT, Tensile Energy WT, Tensile Resilience RT and Elongation EMT were determined. Tensile Resilience RT, per cent indicated the recovery of deformation from strain or the ability to recover from stretching, when the applied force is removed. Higher values indicate greater recovery from stretch. Elongation EMT is the extensibility or stretch per cent strain at maximum applied force. Higher percentage indicates higher stretch in the material tested.

♦ **Shear :** In Shear testing, the KES-FBI Tensile Shear Tester applies opposing, parallel forces to the fabric until a maximum offset angle of 8 was reached. A pretension load of 10gf/cm was applied to the specimen. The slope of the shear curve is a measure of shear rigidity. Three values were recorded namely Shear Rigidity G, Shear Hysteresis 2HG, Shear Hysteresis at 5 degree 2HG5. Shearing Rigidity is the ease with which the fibres slide

against each other resulting in soft/pliable to stiff/rigid structures. Lower values indicate less resistance to the shearing movement corresponding to the softer material having better drape.

TABLE XI

LOW STRESS MECHANICAL PROPERTIES MEASURED BY THE KES-FB SYSTEM

Properties	Parameters	Description	Units	Apparatus
Tensile	*LT*	Linearity of tensile curve	–	KES-FB1
	WT	Tensile energy	gf·cm/cm^2 N·m/m^2)	
	RT	Tensile resilience	%	
	EMT	Extensibility	%	
Shear	*G*	Shear modulus	gf/cm·° (N/m·°)	
	2HG	Shear hysteresis at 0,5°	gf/cm (N/m)	
	2HG5	Shear hysteresis at 5°	gf/cm (N/m)	
Bending	*B*	Bending rigidity	gf··cm^2/ c (N· m2/m)	KES-FB2
	2HB	Hysteresis of bending moment	gf··cm/ cm (N· m/m)	
Compression	*LC*	Linearity of compression curve	–	KES-FB3
	WC	Compressional energy	gf·cm/cm^2(N·m/m^2)	
	RC	Compressional resilience	%	
	T0	Thickness at pressure 0.5 gf/cm^2	mm	
	Tm	Thickness at pressure 50 gf/cm^2	mm	
Surface	*MIU*	Coefficient of friction	–	KES-FB4
	MMD	Mean deviation of MIU	–	
	SMD	Geometrical roughness	mm	

- **Bending test :** Bending Tester is a measure of force required to bend the fabric approximately 150^0. The fabric of 1cm length was subjected to pure bending at constant curvature of 5 x 10^{-3}m$^{-1/s}$. The slope of the curve gave the bending rigidity of the fabrics. Two values were determined namely B the bending rigidity per unit fabric width, gf cm^2/cm and 2HB Hysteresis of bending moment. Greater the B value greater the stiffness / resistance to bending motions.

- **Compression :** Compressional properties of a 2 cm^2 area, are measured with the KES-FB3 Compression Tester at 0 to 50 gf/cm^2 [10 gf/cm^2] in a constant velocity of 20ums.

Three different parameters Linearity of Compression LC, Compressional Energy WC, and Compressional Resilience RC were used to characterize the compressional properties. Compressional Resilience RC per cent, is the extent of recovery or the regain in thickness, when the force is removed. Higher RC values indicate a high per cent recovery from being compressed. Compressibility per cent is the initial thickness measurements compared to the thickness of the samples at the maximum applied force. A higher value indicates greater compressibility.

- **Fabric Weight and Thickness Test** : Fabric weight was measured to the nearest mg/cm^2 using the KES-FB3 tester. Two thickness values were taken by using a sample of 2 cm^2 area measured at a pressure of 0.5 gf/ cm^2 and 50 gf/ cm^2 and reported in millimeters. The KES-FB3 was used to measure the thickness of the fabric.

- **Surface Test :** The surface properties of friction [resistance/ drag] and surface contour [roughness] was determined using the KES-FB4 Surface Tester. The friction sensor, which consists of 10 parallel piano wires of 0.5mm in diameter and was used to measure the friction of fabrics at a tension load of 20gf/cm. Three surface properties Mean Co-efficient of Friction MIU, Mean Deviation of Friction MMD and Surface Roughness SMD were measured. MIU is Mean Co-efficient of Friction 0 to 1 value. Higher MIU value corresponds to greater friction or resistance and drag. SMD is geometric roughness in microns. Higher SMD corresponds to geometrically rough surface.

- **Effluent Estimation**

Textile industries are the leading consumers of water and industrial chemicals. These chemicals are non-biodegradable and their removal before discharging the water in river, ponds, lakes is essential. Some of the tests which are to be conducted to study the nature of the effluent are Measurement of Effluent pH, Colour, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD).

- **Measurement Of Effluent pH :** The effluent pH is the measure of intensity of acidity or alkalinity and the concentration of hydrogen ion can be measured in the water sample. It does not measure total acidity or alkalinity but measures the normality or gram equivalent weight of acid and alkali. If H^+ ions are more than the OH^- ions, then water sample will be acidic or alkaline when the OH^- ions are more than the H^+ ions.

pH is generally measured in log scale and equal to $-\log_{10}[H^+]$; pHl $= -\log_{10}[H^+]$

Measurement of effluent pH was performed as mentioned in www.astm.org/Standards/ D6569.htm, TM D6569–05. The pH meter was standardized using a standard buffer solutions of known pH before measuring the pH of water sample. The electrodes were washed thoroughly with distilled water and pH of the given water sample was measured. The mean value of ten such readings gave the pH of the effluent sample.

- **Colour :** The effluent sample was tested for colour in a spectrophotometer Spectroquant 118 from Merc, Germany. Distilled water was taken in a blank cuvette and the reading was noted. The effluent sample was taken in another cuvette and the readings displayed in the spectrophotometer was directly in hazens. A total of ten readings were taken and the mean value was calculated, explains Manivasagam (1995).

- **Total Suspended Solids (TSS) :** As per the method mentioned in www.db19.com/DASTM81.htm, TM D6050-2009,100 ml of well mixed effluent sample was filtered through a pre-weighted G4 – Gooch crucible (w1); the residue was washed with distilled water and dried at 103 ^{0}C to 105^{0}C. The weight of the crucible with residue (w2) was noted. The increase in weight represents the total suspended solids (w2 – w1).

$$\text{Total suspended solids (mg/l)} = \frac{\text{Increase in Weight (gms)} \times 10^6}{\text{ml of the sample taken}}$$

- **Total Dissolved Solids (TDS) :** As mentioned by Manivasagam (1995), a well mixed effluent sample was filtered through G4 sintered Gooch crucible. 100 ml of filtrate was taken in the previously weighed dish (w1) and kept in a water bath for evaporation. After evaporation, the dish was dried in a hot air oven at 180^{0}C for an hour and then cooled in a desiccator for an hour and weighed (w2). The difference in weight (w2 – w1) was noted.

$$\text{Total dissolved Solids (mg/l)} = \frac{\text{Difference in weight (gms)} \times 10^6}{\text{Volume of the sample in ml}}$$

- **Chemical Oxygen Demand :** The apparatus used for the chemical oxygen test was Digester model – Kjel plus – Kps 12. According to http://www.astm.org/Standards/ D1252.htm, TM D 1252- 06, about 50ml of the effluent sample was taken in a glass tube. A pinch of mercuric sulphate and 5ml of silver sulphate was added followed by 20ml of potassium dichromate and 75ml of concentrated sulphuric acid. The solution was refluxed for 2 hours. The contents were diluted with distilled water and titrated against ferrous ammonium sulphate using ferrion indicator. The end point was the appearance of

reddish brown colour. The chemical oxygen demand was estimated using the following calculation.

Chemical Oxygen Demand (mg/l) = (A – B) N x 8 x 1000 / C

where A – Blank titre value, B – Sample titre value, N – Normality of ferrous ammonium sulphate, C – ml of sample taken for testing.

- **Bio-Chemical Oxygen Demand :** Delzer and McKenzie (2003), state that the dissolved oxygen content of the effluent sample was determined before and after five days incubation at 27^0C. The amount of oxygen depleted was calculated as Bio chemical Oxygen Demand. The apparatus used was BOD incubator model Remi NO: CI-6A and Specific Ion Analyser Model – OP ion720.

  100 ml water sample was taken in BOD bottles and closed without any air bubbles. Immediately the initial dissolved oxygen was estimated by Ion selective electrode meter. After 5 days of incubation at 27^0C the final dissolved oxygen was estimated. A set of blank was included.

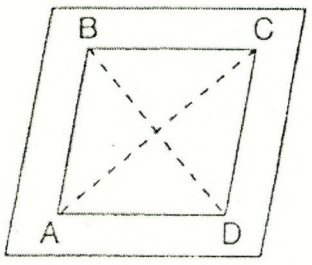
$$\text{Bio chemical oxygen demand (mg/l)} = \frac{(A - B) - BCx100}{\text{Percentage of sample in dilution}}$$

  where A = Dissolved oxygen before incubation, B = Dissolved oxygen after incubation and BC = Blank Correction.

3.3.2.3. Tests after Dyeing and Wear

The properties of the fabrics analysed after dyeing and wear study are Skewness, Bursting Strength, Abrasion Resistance, Flexural Rigidity, Drape, Pilling, Air Permeability, Wicking, Dimensional Stability, Colour Fastness and Instrumental Colour Measurement.

- **Skewness :** As reported in www.astm.org/Standards/D123.htm, skewness or spirality is a fabric condition resulting when the filling yarns or knitted courses are angularly displaced from the line perpendicular to the edge or side of the fabric. Change in skewness in fabric specimens resulting from procedures typical of home laundering practices is measured using benchmarks applied to the specimens before laundering.



  As recommended in AATCC (2005), TM 179-2004, three test specimens of dimensions 380mm x 380mm (15 inches x 15 inches) was taken and two pairs of

benchmarks 250mm (10 inches), one pair parallel to the length of the specimen and one pair perpendicular to the length of the specimen, was marked. The four points were marked as A,B,C, and D. The marked test specimens were tumble washed with the Standard reference detergent in an automatic washing machine with the specified water temperature (85°F). The partially dried samples were line dried. This procedure was repeated four times. The dried samples were conditioned in standard testing atmosphere and laid on a flat surface without any wrinkles. The diagonals AC and BD were measured to the nearest millimeter. The spirality or skewness percentage was calculated using the formula,

$$X = \frac{[2(AC - BD)]}{(AC + BD)} x100$$ where X = % change in skewness or spirality

A positive per cent change indicated skewness to the left and a negative per cent change indicated skewness to the right.

- **Bursting Strength :** Bursting Strength is the distending force which is applied at right angles to the plane of the fabric, under specific conditions, which will result in the rupture of a textile. The conditioned samples were tested for bursting strength as per the test method ASTM (1999), TM D3787 -1989.

- **Abrasion Resistance :** Abrasion is the wearing away of any part of a material by rubbing against another surface. Plane abrasion is the abrasion of the material from flat area, as explained in ASTM (2007), TM D 4966-2007.

Booth (1996) states that the plane abrasion tester, Martindale Abrasion Tester, has four cloth specimen holders into which the fabric to be abraded is mounted after standard conditioning. Four square abrasion tables, one for each specimen holder, is covered with zero emery polishing paper. The load on the cloth is adjusted to 125g/cm^2. The path taken by the cloth specimen holders on the surface of the abrading table is known as Lissajous figure. The resistance to abrasion is estimated by breakage of threads or by loss in mass of the specimens.

Four circular specimens of 38mm diameter was mounted in the specimen holder. The specimen was kept under tension by selecting a load of 125g/cm^2.The weight of the circular specimens, before abrasion, was taken using an electronic balance. The number of rubs to reach the end point was 25 for cotton samples and 50 for lycra cotton samples The abrasion tester was operated and the samples were weighed after the specified

number of rubs. According to the recommendations of IS (2000), TS 12673 -1989, abrasion resistance was expressed as the mass loss difference and reported as a percentage using the formula:

$$\text{Abrasion Resistance} = \frac{(A - B)x100}{A}$$

where A = Weight before abrasion and B = Weight after abrasion.

- **Flexural Rigidity :** ASTM (2007), D 5732-2001, records that fabric stiffness is a measure of resistance of fabric to bending. Bending length is a measure of the interaction between fabric weight and fabric stiffness as shown by the way in which a fabric bends under its own weight. It is also related to the manner in which fabric drapes.

  According to Booth (1996), three samples are cut in the wale way and course way with the help of the template which measures 25mm x 200mm. The cantilever bending tester has a flat horizontal platform having a smooth low friction surface of polished metal supported by two side pieces, two index lines inclined at an angle of 41.5^{o} below the plane of the platform surface, a movable slide metal bar with scale in centimeters, having a mass of 270 g, a mirror to view the contact point of the specimen with the index line and a pointer to measure the length of the overhang.

  The conditioned sample was placed below the metal scale such that the zero of the scale was in line with the pointer. The positioned specimen and scale were moved until the edge of the specimen touched the angle line. The reading on the metal scale was noted as the bending length of the sample. The average of four readings, at each end and again with the strip turned over, gave the bending length of the sample.

  As stated in IS (2000), TS 6490-1971, flexural rigidity is the ratio of the small change in the bending moment per unit width of the material to the corresponding small change in the curvature, expressed in milligram centimeters (mg-cm). Flexural rigidity was calculated using the formula,

$$G = 9.809 \times 10^{-6} Mc^{3} \mu N.m$$

  where G = Flexural rigidity, c = bending length (mm) and M = Fabric mass per unit area, g/m^2.

- **Drape :** Devarajulu (1982) defines fabric drape as the extent to which a fabric will deform, when it is allowed to hang under its own weight. It is a complete property involving bending and shearing deformations. Nakamura (2000) propounds that the main

elements which affect drape are fabric weight, stiffness, flexibility, surface smoothness, density of the fabric, condition of pattern and finishing.

The Eureka Drapemeter was used for characterizing the draping properties of fabrics. A brown paper of thirty one centimeter diameter was cut using a template and weighed (Warp). A circular sample of the same size was cut using the template and was draped over a disc of eighteen centimeter diameter. A light source and lens located below the disc projected an image of the draped sample on the brown paper, which was placed over the glass lid. The outline of the projected image was carefully traced out. The paper was cut along this outline and weighed (Wpa). The area of the supporting disc was cut away from the actual projected area and then weighed again (Wsda). The drape coefficient percentage was calculated using the formula:

$$F = \frac{Wpa - Wsda}{Warp} \times 100$$

where F = Drape Coefficient Percentage, Warp = Weight of the annular ring of paper, Wpa = Weight of the projected area of the paper and Wsda = Weight of the supporting disc area of the paper.

IS (2000), TS 8357-1977, defines Drape Co-efficient as the area covered by the shadow of the draped specimen expressed as a percentage of the area of the annular ring. Thus the drape coefficient of all the samples was calculated. The mean value was calculated for five readings and recorded.

- **Pilling :** Pilling is defined as fuzz and untangled fibre ends that protrude from the surface of a yarn or fabric and pills are bunches or balls of entangled fibres which are held to the surface of a fabric by one or more fibres, in ASTM (2007), TM D 3512-05. Pilling is formation of ugly looking small globules or balls of fibrous mass on the surface of the fabric, comment Sule and Gurudatt (2001). It is defined as the entangling of fibres during washing, dry cleaning, testing or wear, to form balls or pills that stand out of the surface of a fabric, explains Goktepe (2002).

The Eureka Pilling Box tester was used to assess the surface pilling of the samples. A sample was cut using a template thirteen centimeters by thirteen centimeters and sewn so as to be of firm fit when placed round a rubber tube sixteen centimeters long and three centimeters outside diameter and quarter centimeter thick. The sewn sample was wrapped around the rubber tube with the help of a jig. The cut ends of the fabric was covered by cellophane tape and four such tubes were placed in each box (23 cm x 23 cm

x 23 cm) lined with cork quarter centimeter thick. The machine was operated and the boxes rotated at the rate of sixty revolutions per minute for five hours continuously. After tumbling, the extent of pilling was assessed visually by comparing with the arbitrary standards 1, 2, 3, 4 and 5. Thus all the samples were tested and compared.

The pilling standards as recommended by IS (2000), TS 10971-1984, used for rating the samples are:

Standard 1 : No pill
Standard 2 : Slight but tolerable pilling
Standard 3 : Moderate pilling of borderline acceptability
Standard 4 : Unacceptable pilling
Standard 5 : Extremely high pilling

- **Air Permeability :** Air permeability is the volume(cm^3) of air passing through 1 cm^2 of fabric per second at a pressure difference of 1 cm head of water. The test standard used to determine the air permeability of the samples was IS (2000), TS 11056 -1984.

- **Wicking :** Wicking is the capillary movement of moisture along the pores in the fabric structure and is a major contributor to the comfort of the individual. The longitudinal wicking test that was performed, as per the method suggested by Ram (2007), was by partially immersing the sample in water with a weight of 20 grams to prevent curling of fabric.

- **Dimensional Stability :** The dimensional changes that occur to garments when subjected to repeated automatic laundering procedures commonly used at home are evaluated by this test procedure. Dimensional change may be defined in AATCC (2001), TM 135 - 2000, as the changes in length or width of a fabric specimen subjected to specified conditions. The change is expressed as a percentage of the initial dimension of the specimen. Two end results may occur namely growth or shrinkage. Growth is a dimensional change which results in an increase of length or width of the specimen. Shrinkage is a dimensional change which results in a decrease in the length or width of the specimen.

Three samples of fabric with dimensions 38 x 38 cm were conditioned in standard atmosphere. Three pairs of bench marks 25 cm long were marked with thread or indelible ink in the wale and course directions such that they were 12 cm apart and not less than 5 cms from the edge of the test sample. The marked samples were washed in an

automatic washing machine with washing temperature of 27°C using the standard detergent. The sample was removed after the final spin cycle and dried on a flat surface. This wash procedure was repeated four times. The sample was then laid without any tension on a horizontal surface and the distance between each pair of benchmarks on the wale and course directions were measured. The dimensional stability was calculated using the formula:

$$DC = \frac{(B - A) \times 100}{A}$$

where DC = Dimensional Change, A = Original dimension and B = Dimension after laundering.

- **Colour Fastness :** The important property of a dyed material is the fastness of the shade. According to the AATCC (2001), TM 15 – 1997, colour fastness is defined as the resistance of a material to change in any of its colour characteristics, to transfer of its colorant(s) to adjacent materials or both, as a result of the exposure of the material to any environment that might be encountered during the processing, testing, storage or use of the material. Bhattacharya and Raja (2000), commend that it has been possible to compare loss of colour or staining of any hue irrespective of depth. It is necessary to use two scales called the 'Grey Scales', one for assessing change in colour and the other for staining.

The colour fastness tests that were conducted to determine the fastness of colour of the test samples are Colour Fastness to Light, Colour Fastness to Dry and Wet Crocking, Colour Fastness to Dry and Wet Pressing, Colour Fastness to Perspiration and Colour Fastness to Washing

❋ Colour Fastness to Light

Textiles are exposed to light during use. Light tends to destroy colouring matters and the result is 'fading', whereby coloured materials change colour namely usually become paler and duller. Colour fastness to light is the resistance of a material to a change in its colour characteristics as a result of exposure of the material to sunlight or an artificial light source. Three swatches of size 7 cm x 12 cm of both the material to be tested and the standard with white card backing was secured on to the frames of the instrument and exposed to xenon arc light for a period of twenty hours. After exposure, the standard specimen was assessed either visually or instrumentally. As stated in AATCC (2008), EP7-2003, grey scale grade for colour change, has a numerical value that is assigned to the

change in colour of a test specimen as compared to the original or untreated specimen. The comparison was made using the colour matching cabinet with the light simulating day light (Day light B01)and incident upon the surface at an angle of 45° with the direction of viewing perpendicular to the plane of the surface.

❋ Colour Fastness to Dry and Wet Crocking

As stated in AATCC (2005), TM 8-2004, crocking is defined as a transfer of colourant from the surface of a coloured yarn or fabric to another surface or to an adjacent area of the same fabric principally by rubbing. This test is designed to determine the amount of colour transferred from the surface of coloured textile material to other surfaces by rubbing.

The Crockmeter was the standard device for this test. Each test sample was cut to a size of twenty six centimeter long and twenty one centimeter wide and mounted on the flat base of the crock meter. A square white material was wrapped around the rubbing finger and held in position with a ring. Each sample was given twenty rubs, after the number of rubs to be given was standardized. The white square cloth was removed from the rubbing finger and the colour transfer was assessed using a Grey Scale.

For wet crocking, a damp white material was wrapped around the rubbing finger. The rest of the procedure was the same as that of dry crocking. The above mentioned method was used to determine the colour fastness to both dry and wet crocking for all the samples.

❋ Colour Fastness to Dry and Wet Pressing

As suggested by Wingate (1984) two test samples of ten by ten centimeters size were sandwiched with a white material for both dry and wet pressing. A damp white material was used to sandwich the sample and ironed for 10 seconds at 350° F. The sample was then placed for half an hour in a dark room to regain its natural moisture. It was then assessed for colour change and staining using the Grey Scale in the colour matching cabinet.

A dry white material was used to sandwich the sample for dry pressing. The rest of the procedure was same as wet pressing. The colour fastness to dry and wet pressing was ascertained for all the dyed samples.

❋ Colour Fastness to Perspiration

As explained in www.aatcc.org/Technical/Test_Methods/scopes/ tm15.cfm, TM 15-2009, this test method is used to determine the fastness of coloured textiles to the effects of

perspiration. Perspiration may be acidic or alkaline in nature. The samples were therefore tested for colour change in both acidic and alkaline solution using the Perspirometer.

Two specimens measuring five by ten centimeters was cut from each of the original samples and sandwiched between desized white cotton material, stitched on three sides and numbered. The acid and alkaline solutions were prepared as per Table XII, the standards specified in ISO (2002), IS 105-C06-1994.

TABLE XII

RECIPE FOR ACID AND ALKALINE SOLUTIONS

Chemical	Acid solution	Alkaline solution
Sodium chloride	2.65 gm/lt	5 gm/lt
L-histidine monohydrochloride monohydrate	0.5 gm/lt	0.5 gm/lt
Sodium dihyrogen orthophosphate	2.2 gm/lt	-
pH	5.5	8

Acetic acid and sodium bicarbonate were added to get the required pH value in acidic and alkaline solutions respectively. The prepared test samples were saturated with the respective solutions and kept for thirty minutes. The samples were then removed from the respective solutions, squeezed and mounted on the instrument by placing each in between the plastic plate. The weight was then replaced on this set up and the entire instrument was kept in the oven at 60°C for four hours. The samples were removed and evaluated for colour change and staining using the Grey Scale. This procedure was followed for all the samples.

❋ Colour Fastness to Washing

Saville (2000), states that a composite specimen is agitated in a wash wheel using reference detergent for the specified time in a domestic front loading tumble washing machine. The sample is dried and assessed for colour loss and the adjacent fabric is assessed for staining.

The test method IS-105-C06-1994 as mentioned in www.iso.org/iso/catalogue_ detail.htm?csnum ber =21983, was followed. A stainless steel water bath, with electronic temperature controller, was provided with 8 stainless steel jars containing 4 g/l reference detergent and 1g/l sodium perborate solution, test specimen and 10 steel balls. After sealing the jars, the assembly was rotated at a speed of 40 $\pm$2 rpm for 30 minutes. The samples were removed, rinsed, squeezed and dried at room temperature and assessed for colour change and adjacent white fabric for staining using the grey scales.

- **Instrumental Colour Measurement**

Colour measurement is a numerical representation of the colour of an object obtained by the use of a colour measuring instrument. Colour measuring instrument is any device, such as calorimeter or spectrophotometer, used to measure the relative amounts of energy reflected from a specimen in the visible region of the energy spectrum comprising the wavelengths from 360nm to 780 nm. All the dyed samples were tested for colour difference value [Δ E], relative colour strength (WSUM) and K/S values, as recommended in AATCC (2008), EP 6-2003.

The dyed sample to be tested was conditioned for twenty four hours. It was folded many times to obtain the degree of opacity. Four measurements were taken and the sample was rotated 90^{o} between each measure. The average, of the four measures, were taken for illuminant D 65. The colour difference value [Δ E] between the chemical pretreated dyed samples and the enzyme pretreated dyed samples were estimated using the Gretag MacBeth spectrophotometer. The difference in measures served as guide lines to estimate the difference between the dyed fabrics and standard.

The colour yield of the chemical and enzyme pretreated and dyed samples were evaluated using the Gretag MacBeth spectrophotometer. The relative colour strength (WSUM) and the K/S value was directly read from the spectrophotometer. The mean value of four readings gave the values for relative colour strength (WSUM) and K/S value.

3.4. TECHNO ECONOMIC STUDY

The technical and economic aspects of any process or method relate to one another. The evaluation and analysis of the two aspects may assist in research guidance and planning in any industrial environment - www.intota.com/experts.asp?strSearchType=all&strQuery =technoeconomic+evaluation.

The requirement of chemicals, enzymes and auxiliaries, water, steam, energy and process time along with the quantity of effluent released were estimated for each type of pretreatment. Based on the above estimate the total cost was computed to analyze the feasibility of the enzymatic pretreatment process for the textile processors, in comparison with the chemical pretreatment method. The standard costs for bio polishing and dyeing are also given.

3.5. STATISTICAL ANALYSIS

The response surface design, Box and Benkhen model, of three levels of the variables with 15 different conditions was used for the optimization of the enzymes chosen for the study. A multiple linear regression analysis was used to determine the relationship between the variables represented by the response surface equation - http://www.Google.co.in/search?hl=en&q=box-behnken+design&meta=&aq=0&oq=box-behnken

In the case of the wicking test, linear regression analysis was applied and for the effluent estimation the statistical tool, 't' test was used.

Factorial analysis of variance is a very flexible, data analytic, statistical technique that allows us to analyze the effects of more than one independent variable - www.wadsworth.com/psychology_d/templates/student_resources/workshops/stat_workshp/fact_anova/fact_anova_02.html.

The statistical analysis, Factorial ANOVA was carried out separately for almost all laboratory test results to find out whether the quality of the selected fabrics was greatly affected by the type of yarns used, the knit structure, the type of pretreatment, the subsequent treatments given – bio polishing, dyeing and wear study undertaken.

Consolidation and analysis are important steps in problem solving and these procedures are required in any kind of research, to arrive at meaningful conclusions. Hence the collected information and data was consolidated and the statistically analysed results of the survey, experiment and wear study are presented and discussed under the chapter results and discussion.