CHAPTER – 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction:

The Indian textile and clothing industry is the mother industry of our country. It has a unique position in the Indian economy as, the largest manufacturing industry in terms of output, exports, and employment.

The industry currently accounts for about 16 percent of industrial production and about 4 percent of GDP. It employs close to 82 million people, 35 million and 47 million in the textile and allied sectors respectively. The total employment by 2012 will be close to 99 million people, 42 million and 57 million in the textile and allied sectors respectively [1].

Textile and clothing industry is one of the few sectors, which have the potential to emerge as a competitive global player. For Indian economy to achieve a growth rate of 8.5 percent, textile economy has to grow by 14 percent annually in value terms [1].

The Indian textile industry has the potential to reach a size of $90 billion from the current size of $46 billion and exports can touch $50 billion by 2012, from the current $17 billion. The annual average export growth will be 20 percent, raising India’s share in the global textile and clothing trade from current 3.2 percent to 6 percent.

The contribution of this industry to the world production of textile products is very significant. India contributes nearly 20 percent to the world spindleage and has the highest loomage in the world. We account for about 16 percent of world production in raw cotton, 12 percent each in cotton yarn and cellulosic fibres, 6 percent in synthetic fibres and 19 percent in cotton fabrics [1].
Today, cotton fibre is predominating in textile sector as an ecofriendly fibre. Medical textile sector, Home textile and Apparel fabrics sectors are increasingly using the cotton fibre for extremely good comfort and hygiene. Export of raw cotton, Cotton yarn, Woven fabrics, and Readymade garments from India to the World Market is progressively increasing every year [1]. Excellent export opportunities exist for Value addition of the cotton fabric export, which can be brought about by Mercerizing process

Table 1.1

Export of Cotton and Clothing from India

<table>
<thead>
<tr>
<th>Particulars</th>
<th>2004-05</th>
<th>2005-06</th>
<th>2006-07</th>
</tr>
</thead>
<tbody>
<tr>
<td>Export of Raw cotton in Million Kg.</td>
<td>179.85</td>
<td>605.47</td>
<td>1145.69</td>
</tr>
<tr>
<td>Export of yarn in Million Kg.</td>
<td>448.43</td>
<td>552.16</td>
<td>615.59</td>
</tr>
<tr>
<td>Fabrics export in Million m²</td>
<td>654.27</td>
<td>613.70</td>
<td>687.51</td>
</tr>
<tr>
<td>Export of Readymade Garments pieces in Millions</td>
<td>1374.00</td>
<td>1818.00</td>
<td>1834.80</td>
</tr>
</tbody>
</table>


Source: Ref. 3: www.textilecommittee.gov.in

It can be seen from Table 1.1 that export of raw cotton increased from 179.85 million kg in 2004-2005 to 1145.69 million kg in 2006-2007. Fabric exports have also increased from 654.27 square meters to 687.51square meters during the same period. The Readymade Garments export has also increased from 1734 to 1834.40 million pieces during the same period.
Table 1.2

Projections of Cloth Production

<table>
<thead>
<tr>
<th>Item</th>
<th>2007-08</th>
<th>2008-09</th>
<th>2009-10</th>
<th>2010-11</th>
<th>2011-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>28,810</td>
<td>33,026</td>
<td>37,069</td>
<td>43,313</td>
<td>49,629</td>
</tr>
<tr>
<td></td>
<td>(14.63%)</td>
<td>(14.66%)</td>
<td>(14.85%)</td>
<td>(14.58%)</td>
<td></td>
</tr>
<tr>
<td>Blended</td>
<td>7,347</td>
<td>7,861</td>
<td>8,411</td>
<td>9,000</td>
<td>9,630</td>
</tr>
<tr>
<td>100% Non Cotton</td>
<td>23,636</td>
<td>25,999</td>
<td>28,599</td>
<td>31,459</td>
<td>34,605</td>
</tr>
<tr>
<td>Khadi Wool</td>
<td>707</td>
<td>714</td>
<td>721</td>
<td>728</td>
<td>736</td>
</tr>
<tr>
<td>Silk</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>60,500</td>
<td>67,000</td>
<td>75,800</td>
<td>84,500</td>
<td>94,570</td>
</tr>
</tbody>
</table>

(Figures in bracket are percentage increase as compared to previous year)


The Table 1.2 shows projected growth of woven cloth production as estimated by Government of India from year 2007-2008 to 2011-2012 i.e. in 11th five Year planning period. Total cloth production is expected to increase from 60,500 million square meters in 2007-2008 to 94,600 million square meters in 2011-2012. Similarly production of cotton cloth is expected to increase by 28,810 million square meters in 2007-2008 to 49,629 million square meters during the same period.
Table 1.3
Projected Per Capita Cloth Availability
(Square Meters)

<table>
<thead>
<tr>
<th>Year</th>
<th>2007-08</th>
<th>2008-09</th>
<th>2009-10</th>
<th>2010-11</th>
<th>2011-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per Capita</td>
<td>42.84</td>
<td>46.99</td>
<td>51.60</td>
<td>56.62</td>
<td>62.23</td>
</tr>
<tr>
<td>Availability of Cloth in square meters.</td>
<td></td>
<td>(9.68%)</td>
<td>(9.81%)</td>
<td>(9.72%)</td>
<td>(9.90%)</td>
</tr>
</tbody>
</table>

(Figures in bracket are percentage increase as compared to previous year)


As can be seen from Table 1.3 that the projected per capita cloth availability is expected to increase from 42.84 square meters in 2007-2008 to 62.23 square meters in 2011-12.

Table 1.4
Projected Growth of Export of Textile (Cotton)

<table>
<thead>
<tr>
<th>Year</th>
<th>2006-07</th>
<th>2007-08</th>
<th>2008-09</th>
<th>2009-10</th>
<th>2010-11</th>
<th>2011-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth of Textile Export</td>
<td>5167</td>
<td>5645</td>
<td>7573</td>
<td>8185</td>
<td>10982</td>
<td>11328</td>
</tr>
</tbody>
</table>

(Figures in bracket are percentage increase as compared to previous year)

Table 1.4 shows the projected growth of textile export rising from 5167 Million US $ in 2006-2007 to 11328 Million US $ in 2011-2012.

**Uses of mercerization:**

The process of Mercerization can save the quantity of dye required for dyeing. It brings about 25% minimum saving in dye requirement and reduction in cost of processing the fabric.

The half-matured and immature fibres of cotton dye differently. It may give defective evenness of dye pick-up. This give specks appearance in the fabric. To avoid this defect, this mercerization process helps in bringing even dye pick-up, showing same level of the shade at all places of the fabric with reducing dye consumption.

Similarly, the lustre of the fabric is enhanced by Mercerization, which further increases fabric appearance by reflecting more light. This change is not temporary but permanent in nature due to permanent change in crystal orientation of fibre brought about by mercerization process.

**1.2 Historical background**

John Mercer [5] made a filter composed of six folds of strong, bleached and calendered fine cotton cloth and poured upon it a solution of caustic soda of 60°Tw. The filtration was very slow. He found filtering cloth had undergone an extraordinary change; it had become semi-transparent, contracted in both length and breadth, and thickened or fulled.

Lowe filed two specifications, B.P.20314 of 1989 and 4452 of 1890 [5]. The main feature of the first document was the recovery of the sodium hydroxide and the glossy appearance of the treated material. The second patent was about imparting lustre by mercerizing process, carried out under tension.
1.3 Cotton Morphology and Structure:

Cotton is a seed hair. The fibres grow in a tubular form, the lumen running down the centre. When the boll splits, the moisture inside it evaporates. The wall of the fibre shrinks, collapses, lumens become smaller, and the fibre develops convolutions. Different types of morphology observed in cotton fibre are shown in Figure 1.1.

![Figure 1.1-Different types of morphology observed in Cotton fibre](image)

Molecular Structure of Cellulose:

Cellulose is a high molecular weight linear polymer. Cellulose molecule decomposes to form glucose, when heated with strong acids. This indicates that the basic unit of cellulose is D-glucose, which is joined with the neighbouring D-glucose by \( \beta, 1, 4 \) – glucoside bonds to form a long chain molecule. [6]
The structure of cellobiose unit is shown in Figure 1.3. As shown in the figure, the cellobiose unit forms the same structure in two different directions. This leads to the formation of parallel chain and anti-parallel chain structure. In both, the chain conformations are identical, corresponding to minimum energy conformations. Therefore, the identity or repeat period has to be at least two or multiple of two glucose units. The molecule itself is stiff and straight because of its internal hydrogen bonds and $\beta$-linkage.
Intra-hydrogen bonding affects the physical properties as well as chemical reactivity of cellulose. Increased hydrogen bonding results in a more stable and lower energy structure.

**REACTIONS OF CELLULOSE**

All the reactions of cellulose are broadly classified into two groups.

1. Reactions involving hydroxyl group.
2. Reactions comprising degradation of the chain molecule.

**REACTION INVOLVING HYDROXYL GROUPS**

Cellulose is a trihydric alcohol. This means that, it has three-hydroxyl group per each anhydro-glucose unit. Out of these three hydroxyl groups, one is primary (C-6 hydroxyl group) and two are secondary (C-2 and C-3 hydroxyl group) as shown in figure 1.4.

![Figure 1.4 - Primary and secondary alcohol groups in cellulose](image)

The acidity of these hydroxyl groups increases in the order of OH -6 < OH-3< OH-2. When OH-2 is ionized or substituted, the acidity of OH-3 is lowered and the hydroxyl groups in OH-6 may be then more acidic [7].
ADDITION REACTIONS:

Sodium hydroxide, potassium hydroxide, lithium hydroxide, liquid ammonia react with cellulose forming soda cellulose, potassium cellulose, lithium cellulose and ammonia cellulose respectively. In general, the alkalis in solution are converted into their respective hydrated form with a diameter of 0.5 – 2.0 nm. The diameter depends upon the concentration of the alkalis in solution.[172]

These hydrates are able to penetrate inside both crystalline and amorphous region. Solvated dipole hydrate and hydrate ion pair can penetrate only in amorphous region. However, the dipoles hydrated are capable of penetrating into crystalline regions because of their smaller size.

1.3.1 Mercerization Process:

If cotton is dipped into a strong alkaline solution such as lithium hydroxide, caustic soda, or potassium hydroxide, the fibres swell and shrink. If the fibres are placed under tension, in this swollen state and then rinsed with water, then the alkali is removed and a permanent silk-like lustre results. After swelling, if the alkali is rinsed off when the fibre is in its shrunk state, good elasticity is obtained. Appearance is improved through increased lustre, deepening of the colour and the production of a transparent look, the feel of the fabric is improved through a resulting soft hand and improved smoothness, and strength and elongation are improved, along with the addition of good stretching ability.

1.3.2 Effect of Caustic Alkalis on Cotton:

Single Fibre:

Qualitative observations of the behaviour of cotton when exposed to caustic soda solutions of different concentrations were first conducted by Rebenfeld et al [8 & 9]. The results obtained with X-ray diffraction method showed that with 17°Bé NaOH solution cotton is 10% mercerized, with 18-19°Bé NaOH solution it is 40-45%
mercerized, with 19-20°BéNaOH solution it is 70% mercerized, with 20-21°Bé NaOH solution it is 80% mercerized, with 22°Bé NaOH solution it is 90-95% mercerized, with 23-24°Bé NaOH solution it is 95-100% mercerized, and in NaOH concentrations above 24-25°Bé it is 100% mercerized.

Yarn Mercerization:

Pillay [10] studied the influences of mercerization process under different conditions on the tensile properties of cotton. Mercerization in two stages rather than one (30% followed by 10% caustic soda solution) has been found to give the most satisfactory results. The extent of improvement in bundle strength for different cottons was found to be 49% for fibres and from 15% to 43% for yarns. The breaking elongation is reduced by 24% to 63% for fibres and by 46% to 63% for yarns.

1.3.3 Caustic Alkali and Yarn Structure:

Rotor yarn:

In the case of Rotor yarn, Hari [11] observed that maximum increase in yarn tenacity obtained by slack mercerization was 46%, at the lowest twist level. While, tension mercerization increases yarn tenacity primarily by improvement of fibre packing at lower twist levels, but at higher twist levels fibre orientation, fibre packing, and improvement in fibre tenacity all affect yarn tenacity after mercerization.

Polyester/cotton:

Barella and Manich [12] studied the effect of sodium hydroxide on polyester/cotton yarns, determined mechanical properties and reported that 14% improvement in tenacity of 100% cotton yarn, accompanied by 20% decrease in breaking extension was achieved.
Yarn Twist:

Chavan et al [13], observed that mercerization under both slack and tension conditions improve the tenacity of yarns. The maximum gain in strength is observed with yarns having lowest twist. An increase in twist density progressively reduces the gain in strength after mercerization.

Friction spun yarn:

Huh Y. et al [14], studied structural and physical properties of ring, rotor, and friction spun yarns. Results show that the ring spun yarns exhibit the highest fibre migration, followed by rotor spun yarns. Friction spun yarns show the least fibre migration. A higher migration factor corresponds with a higher yarn breaking tenacity. The ring spun yarn has a uniform distribution of fibre packing density. The experimental results on fibre arrangement near the yarn axis show that the friction spun yarn has the highest rupture elongation due to the skewed arrangement of fibres around the yarn axis. Yarn hairiness strongly depends on mean fibre position, with an inward shifting of the packing density leading to low yarn hairiness.

Double yarn:

Pillay et al [15], studied the effect of mercerization on yarn quality of cotton and synthetic cellulosic fibre blends (2/60 and 2/80). It is reported that Slack mercerization reduces tenacity and increases breaking elongations. However, stretching after mercerization increases the tenacity and lowers the breaking elongation of cotton-synthetic fibre blends.
1.3.4 **Lustre and Convolution:**

**Lustre:**

The lustre of a material is a property which depends on the reflection of light. The greater the proportion of specularly reflected light, the higher is the degree of lustre. It may be determined as the ratio of the light specularly reflected to that diffusely reflected. Lustre is a subjective phenomenon. Brightness, as perceived by the eye, is proportional to the logarithm of the intensity and not to the actual intensity of the light. The eye is not equally sensitive to light of all wavelengths. This influences the effect of lustre. The diffused light penetrates the fibres and suffers selective absorption whereas the specularly reflected light is of the same colour as the incident light. The degree of illumination affects the lustre of coloured materials. Instruments for measuring lustre are less influenced by colour, as the light increases in intensity. Many researchers have shown that from a parallel bundle of fibres the light emerges as an annular cone of rays. The maximum rays lying at an angle of specularly reflected cone of rays. The plane of reflection from fibres, the fibres appear lustrous.

Highly lustrous yarns are having parallel hairs and they are parallel in relation to the yarn axis. There is minimum diffusion of light and maximum reflection of the regularly reflected light from individual hairs.

The lustre of a fabric changes by the structure of yarn and the fabric. It can easily be measurable at the angle of specular reflection, as the plane of the fibres is the same as that of the cloth. The light reflected from a mercerized fibre in certain positions is concentrated within a small angle of incidence around 67.50°, but with an unmercerized fibre the reflected light is scattered or spread out in a wider angle.

A number of readings at different angles of illumination showed that the samples with the highest lustre by visual grading had the highest reflection at 45° and...
the least at 90°. The lustre number was defined as the ratio of the light reflected from
the sample illuminated at 45° to that when illuminated at 90°.

An important contribution to the knowledge of lustre in cotton is made by
Adderley [16]. Adderley correlates these lustre values with the various physical
properties of the cotton hair. There is no connection between such properties as
length, hair weight per centimeter, diameter, or convolutions, but a close connection is
found with the shape of the cross section of cotton hairs, which tend to be circular in
section having a higher lustre. Index is determined by means of the ratio of the two
axis the longest possible straight line through the section and a line intersecting this at
right angles and passing through the centre of the portion intercepted by the hair.
From the smoothness of the curve, it appears that the variation in lustre is intimately
associated with shape of the cross sections. The cotton hairs mercerized under tension
are nearly circular in section than hairs, mercerized without tension.

**Deconvolutions:**

Calvert and Clibbens, [17] have studied the deconvolutions of cotton hairs in
the mercerizing process. The method consists in cutting a large number of hair
fragments 0.2mm long, mounting them in liquid paraffin on a microscope slide, and
counting the proportion of fragments free from twist or convolution. The results are
expressed as a percentage, called as the Deconvolution count.

This method has its limitations, as the deconvolutions are greatly influenced
by the maturity of the cotton and by the structure of the material, i.e. the twist of the
yarn or the weave of the cloth. The test is only for purpose of comparison and it need
not be regarded as a measure of successful technical mercerizing.
1.3.5 Changes in Width:

Since the cotton hair swells in a strong caustic soda solution, changes in the cross-section occur; thereby bean shaped becoming oval-shaped, as shown in Figure 1.5, thereby enhancing the lustre.

![Figure 1.5 - Changes observed in the cross-section of a cotton hair during mercerization](image)

1. Cross section before mercerization
2. →5. Swelling process in 18% NaOH
6. Rinsing process after swelling
7. Final state

There are many possible reasons explained by Neal [18] for all the behaviour exhibited by the cellulose fibre in the alkaline solution.

Analysis of the transformations of the crystalline structure of the cellulose hair in the alkaline solution with the X-ray diffraction method has been carried out by Katz and Mark [19], Katz and Viewg [20], Suich and Walff [21] and, Hers and Trogus [22]. The X-ray diffraction studies indicate that in an alkaline solution of low concentration, the alkali cannot combine with the cellulose molecules inside the micelle. The outer skin of the micelles and the cellulose, that is, the material with low molecular weight, react with the alkali. As the concentration increases, the crystalline structure of the cellulose swells and relaxes. When it reaches its most swollen state, the alkali penetrates the inside of the micelle, and undergoes a complete reaction with the cellulose.

Flecken H. [23] reported that even for the same type of yarn, the behaviour of single, double, and triple yarns display differences. Due to the degree of constraint on
the swelling and shrinkage of single fibre there is a difference in shrinkage of fibre
and fabrics of different qualities. Changes occur in the numerical values related to
the swelling of cellulose fibres. It increases the degree of constraint and moves the
peaks of these values towards higher alkaline concentrations.

1.4 Types of Mercerization:

1.4.1 Liquid Ammonia Mercerization:

Research studies on this subject were initially conducted in the mid 1930. It is
observed that cotton fibres are swollen and plasticized in liquid ammonia, and
undergo a polymorphic change (currently denoted as Cellulose III). Cotton fibres
treated with liquid ammonia revert to the native Cellulose I lattice when the ammonia
is removed from the fibres by immersion in water.

The fundamental studies were conducted [24] on swelling, shrinkage, and
metastable structural changes produced by liquid ammonia on cellulosic fibres. These
were utilized by commercial processes for the treatment of yarns and fabric. The
treatment of yarn consists of immersion in liquid ammonia at its boiling point (-33°C
or -28°F) for less than a second, then subsequent immersion of the yarn under tension
in hot water for about 0.1 sec to produce a 40% increase in tensile strength which
improved lustre and heat resistance and greater affinity for dyes. Final traces of
ammonia are removed by subsequent steaming. The resultant fabric had improved
dimensional stability, tensile strength, smooth drying properties, and resistance to
abrasion [25]. Most subsequent patents and commercial practices are based on the
TEDECO process for treatment of fabrics. The influence of liquid ammonia treatment
on the supramolecular and morphological structure of cotton has been critically
reviewed and analyzed with respect to changes in pore structure, pore volume
distribution and specific fibre surface area [26-30]. Lee et al [31] have found that
liquid ammonia is effective at improving the strength, shrink resistance, and hand of cotton fabric. In this study, liquid ammonia (NH$_3$) treatment was given to three regenerated cellulosic fabrics. They investigated the effect of the processes on crystal form, crystallinity, moisture regain, water absorption, and dyeing properties. In addition, the mechanical properties of the NH$_3$ treated fabrics were measured in relation to fabric hand. Borsa et al [32] bleached cotton fabric and treated with an aqueous solution of tetramethylammonium hydroxide (TMAH) and with sodium hydroxide in various concentrations with or without tension. The "mercerizing" effect of TMAH is higher than that of NaOH, and all changes caused by swelling are significantly reduced by tension.

Nelson M.L. et al [33] studied mechanical properties of cotton yarns mercerized with Liquid Ammonia and Sodium Hydroxide. Both the swelling agents produced similar changes in mechanical properties (breaking strength, tenacity, elongation-at-break, and initial modulus) under comparable conditions. Mercerization under high tension increased breaking strength and tenacity and decreased elongation at break. Slack mercerization with Sodium Hydroxide resulted in substantially higher elongation-at-break than it is obtained in ammonia treatment. X-ray and infrared spectroscopic analysis were used to measure crystallinity of cotton fibres swollen in liquid ammonia and an aqueous solution of caustic soda. Results showed that mercerization treatments lead to a sharp decrease in cellulose crystallinity. A correlation between crystallinity ratio determined by infrared spectroscopy and accessibility is also determined by moisture sorption by Saafan A.A. et al [34].

**1.4.2 Hot Mercerization:**

Since the beginning of the sixties, mercerization with hot caustic soda, at temperature between 60°C to 70°C is known as hot mercerization [35 to 41]. The cold mercerizing takes place at temperatures of -15°C to -18°C with 31% to 35% caustic
soda solution with a dwelling period of about 50 seconds. At this range cotton swells best. The fast swelling increases the outer edge density of the fibre. The viscosity of the caustic solution is also such that the penetration into the grey fabric becomes even more difficult. These result in poor mercerizing of the core and lack of uniformity as the reaction is restricted mainly to the surface of the yarn or fabric. To increase the penetration into the fibre, alkali stable wetting agents are necessary but they are expensive. In addition, the effluent load is considerable. In hot mercerization process, with caustic soda at 60°C to 70°C, the cotton swells rather slowly. The outer edge density of the cotton fibre is not increased as fast as in cold mercerizing. At 60°C to 70°C, the viscosity is considerably low. Thus, the penetration of alkali is extremely rapid with improved core mercerization and consequently results in better uniformity of alkali treatment. Due to higher temperature and higher diffusion into the core the dwell time of the material in the mercerizing section can be reduced from 50 sec (cold) to 20 sec (hot). There are interrelations between the necessary dwell time and the temperature of the lye. Cold mercerizing takes about 55 sec. with a nominal concentration of caustic soda 300 g/L on the material. Hot mercerizing at 60°C to 70°C takes about 20 seconds for achieving the same effect.

The degree of swelling of individual fibre is slower at higher temperature as the process is an exothermic one. The crystalline structure from Cellulose I to Cellulose II at higher temperature reveals a skin-core appearance [42]. Mercerizing at elevated temperatures can lead to improvements in lustre and shrinkage, has no adverse effect on strength, and under certain recommended conditions, can result in a softer handle [43-46]. Temperature upto 45°C can be used without any deterioration of lustre [47], but on the other hand, no substantial improvement in lustre is found because of double mercerization [48].
The following advantages are detailed for the hot mercerizing process by Shenai [49].

i) Due to higher and rapid penetration of alkali, level and uniform mercerization can be obtained with lesser contact time resulting in greater productivity with more compact unit.

ii) At higher temperature (about 100° C), the shrinkage is nearly half as compared to conventional mercerization and the shrinkage does not vary with dwell time.

iii) The necessary and expensive alkali resistant wetting agents needed in cold mercerization are not necessary for the hot mercerizing process. Production costs are reduced and the environment load is lowered.

iv) Hot mercerization uses the free reactive heat to raise the temperature of the lye to about 40° C. The further increase in temperature to about 60° C to 70° C is achieved in a moderately priced heat exchanger.

v) The fibre and fabric structure become more pliable and less elastic.

vi) Tensile strength increases due to greater degree of stretch and modification of cellulose during saturation with hot caustic soda solution. These lead to a greater orientation of molecular structure and increased cohesion between fibres.

vii) Hot mercerized fabrics have better wet crease recovery than conventionally mercerized fabrics. It induces easy care finishing characteristics. Hot mercerized fabrics are flatter and less crumpled when drip-dried.

viii) Hot mercerized cotton fabric gives uniform application of dyes. However, the total uptake is better, but the colour yield is less pronounced than conventional mercerized cotton. The colour yield decreases as the temperature of mercerizing treatment increases [50, 51].

ix) The combined mercerizing and desizing, and mercerizing and scouring processes minimize the energy consumption and can lead to cost saving. In
combined processes, a steaming step is inserted between hot alkali saturation and stabilization. The steaming time is about 10 min at atmospheric pressure and about 5 seconds under pressure at 130°C to 140°C.

x) Hot mercerizing technique also reduces the inventory and pollution problem.

1.4.3 Comparison of Methods:

The properties and swelling process of cotton fibres after treatment with liquid ammonia are compared with conventional and hot mercerized cotton in Table 1.5. The nature of the improvement in properties resulting from the treatment of cotton with liquid ammonia depends on the conditions of its removal from the fibre. Dry removal of ammonia after treatment converts Cellulose I to Cellulose II and there is hardly any increase in dye diffusion. The ammonia-water system gives an improvement in colour yield in subsequent dyeing which is however lesser than that obtained by conventional mercerizing [52]. This has been attributed to the changes in internal volume after ammonia treatment [53].
Table 1.5
Comparison of Various Swelling Processes

<table>
<thead>
<tr>
<th></th>
<th>Conventional Mercerization</th>
<th>Hot Mercerization</th>
<th>Liquid Ammonia Wet Steam</th>
<th>Liquid Ammonia Dry Steam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>Slow</td>
<td>Medium</td>
<td>Fast</td>
<td>Fast</td>
</tr>
<tr>
<td>Degree of Swelling</td>
<td>High</td>
<td>Medium</td>
<td>Less</td>
<td>Less</td>
</tr>
<tr>
<td>Evenness</td>
<td>Uneven</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Shrinkage Force</td>
<td>Small</td>
<td>Small</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Luster</td>
<td>Large</td>
<td>Medium</td>
<td>Small</td>
<td>Small</td>
</tr>
<tr>
<td>Dye take-up</td>
<td>Strongly Increases</td>
<td>Higher</td>
<td>Medium</td>
<td>Less</td>
</tr>
<tr>
<td>Strength</td>
<td>Higher</td>
<td>Higher</td>
<td>Higher</td>
<td>Higher</td>
</tr>
<tr>
<td>Dimensional Stability</td>
<td>Higher</td>
<td>Higher</td>
<td>Higher</td>
<td>Higher</td>
</tr>
<tr>
<td>Resistance to Deformation</td>
<td>Stiff and Harsh</td>
<td>Soft</td>
<td>Soft</td>
<td>Soft</td>
</tr>
<tr>
<td>Dry Crease Recovery Angle</td>
<td>No Change</td>
<td>No Change</td>
<td>No Change</td>
<td>Considerably Increased</td>
</tr>
</tbody>
</table>


The moisture regain and water absorbency of fibres treated with liquid ammonia are much improved as compared to the untreated fibres. “Sanforest” process produces a shrinkproof material, which does not only shrink in domestic washing (as is the case with Sanforised material), but also not during drying in tumbler dryers (55). The treatment with liquid ammonia produces non-iron properties without loss of strength, so-called non-iron finishing processes. At the same time, the wearing properties of the material are improved; it acquires a smoother surface, better uncreasing angles and soft and pliable handle. The stretching of the fabric with 60-80% ammonia not only avoids shrinkage during the treatment but also compensates...
for shrinkage during scouring and bleaching. The shrinkage potential is reduced and fabrics treated in this manner are more resistant to shrinkage through repeated washings. Liquid ammonia treatment prior to resin application will improve the relationship between strength and crease recovery and increase resistance to tensile, tear strength and abrasion [56]. Liquid ammonia is found to reduce fibrillation in the laundering of resin-finished goods. A combination of slack mercerization and liquid ammonia treatment for the production of cotton stretch fabrics has been reported [57 to 59]. It is also possible to combine liquid ammonia treatment with dyeing into a single operation. Liquid ammonia treatment is found to have less pollution problem but comparatively an expensive process. The most important cost element is the recovery of ammonia. The liquid ammonia treatment can also be applied in the pre- and after-treatments with organic solvents, since no water is used and the liquid ammonia can be largely recovered. There is no danger of the personnel being troubled by smell, etc., since the machines are hermetically sealed and the process is carried out in a closed system, which is under slight vacuum.

1.4.4 Dry and Wet Mercerization:

Shah R. K., et al, [60], developed methods for wet-on-wet mercerization to eliminate drying and thereby reducing the consumption of energy and improve end-product quality. Uniform moisture levels in the fabric at both entry and exit were critical. Wet-on-wet mercerization was compared with conventional wet-on-dry mercerization.

DiCesare J. A., [61], reported a side-by-side comparison of the "wet" and "dry" mercerizing processes. It determines optimum levels of fabric properties using sodium hydroxide, sodium silicate, and Mercerol DM concentrations as the processing variables on a knitted fabric and on a woven fabric. Results have shown increased tensile strength, bursting strength, whiteness level, and absorption of alkali.
Studies In Mercerization

Structure analysis has shown that mercerization occurs at a lower level of sodium hydroxide than that of wet mercerization.

1.5 Processing Conditions:

1.5.1 Temperature:

The reaction between the cellulose fibre and the alkaline solution is an exothermic reaction, and any increase in the treatment temperature reduces the absorption of the alkali, thus reducing the effectiveness of the mercerization. Sisson [62] studied treatment of cotton yarn with a wide range of alkaline concentrations and processing temperatures. He divided the results into the three divisions viz, complete mercerization, partial mercerization and un-mercerized and demonstrated with the help of a chart showing the relationship between the alkaline concentration and the temperature.

Results indicate that, above 60°C, complete mercerization does not take place. Concentration of around 30°Bé at room temperature, gives complete mercerization, and this, interestingly, is consistent with stable conditions determined by all researchers.

The above results are consistent with the results of Beltzer [63], who investigated the relationship between shrinkage and the effects of temperature and alkaline concentration in the mercerization of cotton yarn, and the results show that the concentration of 20°Bé represents a line beyond which behaviour during mercerization changes.

Similarly, the results of Birtwell et al [64], show that temperature has greatest influence on the shrinkage of cotton yarn at concentrations of 3N NaOH, (approximately 16°Bé), and above 4N (approx. 20°Bé), that influence diminishes.
Flecken [23] measured the shrinkage of cotton yarn at concentrations of 30°Bé and 38°Bé for temperatures from 0°C to 40°C. He reported very small variations for temperatures in the range of 10-30°C at a concentration of 30°Bé, and this result can also be found in the center of Sisson's mercerization chart.

In order to carry out stable mercerization, appropriate conditions are those at which the influence of the alkali concentration and the temperature are minimal, that is, those conditions as displayed in the center of Sisson's mercerization chart.

In cold mercerizing, it involves processing with an alkaline solution at temperatures below 5°C, commonly in the range of minus [-10°C to -15°C]. In this processing, it gives the yarn or fabric a feeling of transparency and a harshness like that of linen, therefore, this processing is also called as ‘linen finishing’.

One reason why alkali processing at low temperatures such as these produces a harsher hand is that, it is not able to produce the same degree of swelling as processing at room temperature or higher. Another important factor is related to the lowering of the temperature at which the freedom of the cellulose's molecular structure is fixed in a restrained state.

In contrast to cold mercerization, processing at high temperatures gives soft hand, but at temperatures above 60°C, processing produces partial mercerization and complete mercerization is not taking place. Thus, in mercerization in order to produce a soft hand in addition to a good lustre and stability of form, adjustments should not be limited to the temperature conditions of the alkali.

Ahmad Niaz et al [65] studied the effect of temperature of alkali solution on mercerization under chain mercerizing conditions. He measured the degree of mercerization with x-ray diffraction and dye sorption techniques in addition to visual assessment of lustre. The x-ray method is based on the well-known effect of mercerization on the crystal lattice of cellulose, which converts it from cellulose I to cellulose II.
In order to calculate the intensities of the crystalline interference, he adopted Manjunath and Peacock's [66] the minima on the low angle side of the 101 interference and the high-angle side of the 002 interference. They were joined by a straight line that served as a base line for measuring the peak heights of the various crystalline interferences. Peak heights for 101 and 002 were measured, and their ratio gave the degree of mercerization.

As compared to the unmercerized material, there is a substantial increase in dye uptake after mercerization at all temperatures for both 60 and 180 seconds treatment times; average increase range being from 34% to 53%.

1.5.2 Tension:

In mercerization, there are two types of tensions. One produced by the constraining force in opposition to the swelling, caused by the twisting of the hair or the structural density of the fabric, when the single fibre which constitute the yarn or the fabric, absorb alkaline solution and swell. The other, tension is being intentionally exerted on the yarn or fabric during mercerization. The former type of tension occurs due to the relationship between the force of the swelling and the constraining force in opposition to it. This tension cannot be adjusted during mercerization itself. Therefore, measures must be taken during the design stage of the yarn or the fabric.

The latter tension is intentionally exerted during mercerization. It can be considered in three stages,

a) These being during the penetration of the alkaline solution and the swelling,

b) During the fixing of the dimensions and the enhancing of the lustre,

c) Tension applied during the removal of the alkali.

Along with the concentration of the alkaline solution and the temperature during the treatment, control of the tension during the different stages is important in the mercerizing process.
Tension and penetration of the Alkali:

In the initial penetration of the alkaline solution and swelling of the fibres, the surface tension of caustic soda solution increases with increase in concentration. At temperature of around 18°C, at a concentration of 24°Bé, surface tension is approximately 84 dyncm\(^{-1}\), and at 30°Bé it is 89 dyncm\(^{-1}\). The surface tension of water at the same temperature is 73.05dyncm\(^{-1}\).

It is clear that the wetting of the yarn or the fabric with the alkaline solution during mercerization is not easy to achieve. The cellulose fibres are exposed to the alkaline solution, the surface of the yarn or the fabric will swell. The spaces between individual fibres contract and the air inside the yarn or the fabric will be less likely to escape to the outside. Thus, making the alkaline solution more difficult, to penetrate in the fibres.

These factors raise the degree of wetting and the internal penetration of the alkali. The dipping time for yarn and material that has been processed adequately, is commonly set at around 40-50 seconds. Results of investigations into the effects of tension during this time show that when there is no tension, the shrinkage nears equilibrium after 60 seconds. Under high tension, the same processing time will be around 120 seconds. Penetrating agents used in mercerization enhance the wettability during the alkali processing by accelerating the penetration of the alkaline solution into the structure of the yarn or fabric. High temperature mercerization is a method for allowing the rapid penetration and diffusion of the alkali inside the fibre to allow complete mercerization as far as the inner layer of the micelle. In addition to lowering the surface tension of the alkaline solution by raising its temperature, the internal diffusion of the alkali itself is accelerated because the swelling decreases due to a drop in the cellulose’s absorption of alkali.

Thereafter, the temperature is lowered in order to increase the absorption of alkali and thus increase the rate of the mercerization reaction.
Kim Y.K. et al [67] investigated three techniques. Cotton fibres in roving form were mercerized and stretched to their original length and then neutralized in the stretched configuration. The effectiveness of the three stretching systems was evaluated by testing the processed fibres and yarns. The mechanical properties of the yarns made from stretch mercerized roving were compared with those of yarns made of untreated fibres and slack mercerized fibres. Their properties were also compared with the properties of yarns that were package mercerized and single strand stretch mercerized.

The results show that a series of closely set rollers, gradually increasing in diameter from back to front, provide a reasonable device for stretching the individual fibres during mercerization. The yarn produced from roving with this technique shows superior properties over those of other methods studied in this investigation. Yarns made of stretch mercerized roving will have higher strength retention after durable press treatment.

Researchers agree that slack mercerization of cotton followed by restretching in the mercerization alkali to about its original length results maximum improvement in tensile stress. It is further necessary to study the effect of stretch percentage during mercerization and improvements in tensile properties of fabrics.

1.5.3 Drying:

Fibres in their wet state, at the conclusion of mercerization, have a very high degree of swelling, and have large internal air gaps. When the fibres are dried, these gaps contract as the water evaporates. The final fixed sizes of the gaps inside the fibres are altered by different temperature and tension conditions during the drying.

Researchers have shown that these changes can be determined by considering the changes in dye absorption rates and in moisture absorption rates. Using Benzopurpurin B4, the changes in the degree of absorption as relating to the alkaline
concentration was studied for the degree of tension and the type of drying after mercerization.

According to these investigations, a relationship exist between variations in the cellulose micelle's degree of swelling and the amount of dyestuff absorbed as determined by alkaline concentration. However, the air gaps in the fibre can vary in size up to 20% according to the level of tension that is applied. That is, in comparison to untreated fibre, absorption of dyestuff is twice as high after mercerization, and 2.4 times as high after tensionless mercerization. Furthermore, the absorption of dyestuff is reduced by one third after natural drying in air. It is reduced by nearly one half after drying at 110°C in comparison with non-dried fibre. This suggests the contraction of the air gaps inside the fibre.

According to Hessler L.E.[68], the level of crystallization of cotton before mercerization was 89%, while after mercerization, it was 64%. Coward and Spencer [69], measured changes in water absorbed due to conditions of washing and drying following mercerization using a centrifuge.

The size of the air gaps in the cellulose's micelles that is, the fibres internal volumetric capacity, is altered by the tension and temperature conditions during the rinsing and drying at the conclusion of the mercerization process. This alters the hygroscopic characteristics and producing variations in the absorption and reactivity of the dye. It also influences significantly, the hand of the fabric.

A significant difference exists between the slack and tension drying of mercerized samples and their temperature of drying. This affects moisture absorption and rate of dyestuff absorption, which is different at different tension and temperature of drying. For obtaining consistent results, tension and temperature must be kept same.
1.5.4 Heat Generation:

In mercerization, the heat produced is due to the behaviour of the cellulose fibre and the alkaline solution. During the reaction between the cellulose and the alkali, heat is generated through the dilution of a strong alkali with either the water content of the cellulose, which has been absorbed from the air, or the water present during mercerization in a wet state, as in wet mercerization.

The reaction heat of the cellulose fibre and the alkali:

Heat is generated by the cellulose, while bonding with the alkali. Heat is also believed to be produced by the deformation of the molecular structure caused by the hydration and swelling of the alkali cellulose.

However, all the results show that heat generation due to the reaction between the cellulose and the alkali varies according to the concentration of the alkali.

The results of Neal [18] shows that from a concentration of around 120g /L NaOH, or about 15-16°Bé, the reaction heat increases sharply, and from 240 g/L, or 26°Bé, the reaction heat increases in more or less constant proportion with further increase in concentration. These results are similar to the results of untwisting and swelling of the cotton hair and those measured for the relationship between the formation of alkali cellulose I and the concentration of the alkali as observed with X-rays. There is even a very slight generation of heat when cellulose fibres swell in water. While different researchers recorded different results for this heat generation, it is in the range of 2.6-4 Cal/g of cotton.

Heat generation through dilution of the alkali solution:

It is well known that if a strong caustic soda solution is diluted with water, a large amount of heat will be generated. During mercerization of cellulose fibres, heat
generation also occurs due to the dilution of the alkali solution by water that has been absorbed by the cellulose from the air.

Tschilikin [70] reported that the addition of 15cc of water to a 491 gm/L solution of NaOH to obtain 500 cc of solution yields 788 Cal/gm of heat.

While the concentration of the alkaline solution used for feeding in wet mercerization is presently 49-50°Bé, if the concentration of the caustic soda solution is reduced to 28-29°Bé, the dilution heat becomes 2.13 Kcal/mol, thus allowing the problem to be ignored.

**Behaviour in changing alkaline solutions:**

Willows, Barratt, and Parker, [71] observed the behaviour of hairs involving gradual changes of concentration and conducted, quantitative measurements of the changes of a cotton hair undergoing such alkaline treatments. This behaviour is conjectured to be because the diffusion of the caustic soda inside the cellulose fibre in its swollen state is extremely slow.

However, it is very difficult to measure the diffusion of the caustic soda inside the alkali-swollen cellulose. The wet mercerization involves application of a strong uniform squeezing and exposure in that state to a strong caustic alkali for mercerization. Because the water content of the cloth before mercerization (usually around 50%) steadily dilutes the caustic soda, in order to ensure the practical effectiveness of wet mercerization, the concentration of the alkaline solution must be preserved through the steady addition of a correspondingly high-concentration alkaline solution. Furthermore, to avoid a rise in temperature due to the dilution heat of the alkali and the heat generation that accompanies the absorption of the alkali, the alkaline solution must be cooled, thus allowing the preservation of a constant temperature. However, trends have returned to the previously used dry mercerization.
The major reason is regarding the quality, and the problems concerning to the efficiency and uniformity of the process and product.

In dry mercerization, the alkaline solution for the first dipping must have a concentration sufficient for mercerization. If it sufficiently penetrates the inside of the fibre with only the usual degrees of temperature and tension control, then no major considerations are required with regard to the change in concentration of the alkaline solution.

1.5.5 Concentration:

The sodium hydroxide concentration of the mercerizing bath plays an important role. The tenacity and the Young’s modulus increase with sodium hydroxide concentration. It reaches a maximum value at concentration of 300 grams/litre. It corresponds to the presence of the hydrate NaOH – 7H₂O in maximum proportion, imparting a better mercerization effect. On the other hand, the elongation at break decreases to a minimum at the same alkali concentration and then increases again slightly. Above a sodium hydroxide concentration of 200 grams/litre, the changes in the mechanical properties and in the tenacity are not much different.

1.5.6 Tensile Properties:

Mercerization tends to increase the tenacity of cotton fibres. It has been suggested by De Boer that the increase in fibre strength is related to the spiral angle and the orientation factor [72]. The orientation alone does not account for the difference in strength. In fact, the increase in tenacity can also be attributed to a strengthening of the weak points along the fibre for effectiveness weak points are consolidated. Other important factors of strengthening are the crystalline length, crystal size and degree of crystallinity as well as the removal of fractions of cellulose
of very low degree of polymerization [73]. Increase in tenacity depends on the state of the material. Experiments on fibre bundles resulted in significantly higher strength values [74to76]. The elongation at break and the elastic modulus (Young’s modulus) are also altered by the mercerization treatment [30].

The tension applied to the cellulosic material has a great influence on the mechanical properties. The results obtained in the case of mercerization of yarns for 60 seconds, at 20°C, with 300 grams/litre sodium hydroxide solution at several values of length. The tenacity and the elastic modulus increase significantly when the mercerization tension increases. It is in connection with the degree of orientation of the fibres. The extension at break, however, decreases when the tension increases and seems to be related to the variations of the degree of orientation. If the mercerization is carried-out without any tension (slack mercerization with shrinkage of about 15% - 20%), the value of elongation at break is three times the value of the unmercerized material, thus conferring elastic properties to cotton fibres. This elasticity is the basis of the preparation of stretch materials with ability to extend and recover their initial length. [77-78].

1.5.7 Dyeing Properties:

Mercerization induces a decrease in the volume of crystalline region. This treatment modifies principally their accessibility in an aqueous medium. Consequently, mercerized fibres have greater moisture absorption capacity. They are more reactive to aqueous chemical reagents, and are more accessible to dye molecules. Mercerization increases the, dye absorption (dye pickup), the rate of dyeing, and the visual colour yield. The mercerized material show darker shade than the unmercerized material when dyed with dye baths of same composition, under the same conditions [79 to 94]. The improvement of the dyeing properties is especially marked when the mercerization treatment is carried out under decreasing tension .The
dyeing properties vary only slightly with the treatment temperature and largely with the sodium hydroxide concentration. The variations of the dye absorption at equilibrium and the changes in colour yield as a function of sodium hydroxide concentration for yarns mercerized at constant length for 60 sec at 20°C. In fact, the dyeing properties are optimal at sodium hydroxide concentrations of about 260-300 grams per liter.

Slack mercerization with 150-190 grams per litre sodium hydroxide solution is capable of decreasing dyeing unevenness resulting from differences in cotton maturity. Particular attention must be given to the drying of the mercerized goods because higher temperature induces some decrease in the accessibility of fibres.

The increase in colour yield is such that it can allow for a saving of dyestuff about 15%-50%.

The colour yield has been defined by Kubelka and Munk as a function of the reflectance\(R\) of dyed material in terms of the ratio between a light absorption factor \(K\) and a light-scattering factor\(S\), the factor \(C\) being in linear connection with the amount of absorbed dye.

\[
\frac{K}{S} = \frac{(1 - R)^2}{2R} = \frac{C}{S}
\]

An increase in colour yield is especially connected to a decrease in the light-scattering factor. This is related to the change in cotton morphology. More rounded form of the mercerized fibres is accompanied by a lower amount of internal scattering of the incident light [81 & 82]. The fibres on the surface of the yarns swell very quickly and give rise to a jamming effect at the periphery of each yarn. This phenomenon hinders the further penetration of the sodium hydroxide solution into the interior of the yarns, especially when the treatment is carried out under tension. There is a preferential fixation of dyes on the fibres at the periphery of yarn. The penetration of the dyeing bath is also decreased because the internal fibres of the yarn are compressed following the jamming effect caused by the swelling of the external
fibres. The result of this heterogeneous treatment is a difference in the depth of dyeing between the periphery and the core of the yarns. If two yarns, one mercerized and the other unmercerized, are dyed with an equal amount of dye and if the mercerized yarn shows a preferential fixation of dye at its periphery, the apparent dye concentration of the mercerized yarn will be higher than that of the unmercerized yarn and there will be a higher colour yield. If we wish to avoid the peripheral dyeing of mercerized goods, it may be desirable to carry out the mercerization treatment at a higher temperature than commonly used. The increase in temperature induces a decrease in the degree of swelling and better penetration of the sodium hydroxide solution. It gives better uniformity in mercerization and in subsequent dyeing.

1.6 Application Methods:

1.6.1 Yarn:
Cotton yarn is mercerized to increase the lustre. It is mercerized under tension. The effect of various amounts of tension has received a great deal of attention, and Herbig's results may be summarized as follows

1. Mercerization without tension gives no lustre, while even a small amount of tension gives some increase in lustre.
2. Maximum lustre is obtained when the tension is sufficient to bring the material back to its original length and any increase in tension above this does not increase the lustre further.
3. The lustre obtained by impregnating and washing under tension is the same as impregnating loose and washing under tension, but more force is required in the second case.
4. The lustre obtained by impregnating and washing loose and then stretching is inferior and the tension required is very great.
5. Yarn made of long-staple cotton produces the highest lustre.

The effect of tension has also been examined by Skinkle [95]. He established that the amount of tension exerts a considerable effect on the rate of absorption of the alkali and on the rate of its removal. It is necessary to restore the original length of the yarn as far as strength and absorptive properties are concerned.

Herbig also noticed that small force is required to stretch the shrunk yarn when the rinsing or washing is actually in progress. The restoration of the original length of the fully washed material requires twice the force. Midgley [96] examined 2/40s yarn before and after mercerizing. He found that the fibre diameter had increased by 4% but that the yarn diameter had decreased by 18%. It is agreed with an observation previously recorded by Lowe [97]. The increase in strength of mercerized yarn is due to an increase in strength of individual cotton hairs and increased cohesion between them. The closer embedding of the hairs in the yarn not only increases the strength of that yarn but makes it more uniform in strength and less in diameter.

The lowering of the temperature to 0°C has little effect on the lustre, the feel is harsh, and great shrinkage is obtained in the absence of tension, Birtwell [64] and Mecheels [98] have given some quantitative results on mercerizing at different temperatures with 30°Be NaOH solution.

The results depend on the construction of the yarn as well as on the mercerizing conditions. The highest increase was encountered in the case of 10’s count of low twist. Low twist appears to be essential for maximum increase in strength, the highest figures being obtained from yarns spun with twist factors of 2.2 to 3.0

1.6.2 Cone:

Mercerization of the yarn in cheese form can raise productivity and reduce costs. However, mercerization in cheese form achieves half-mercerization, and not the same degree of evenness as hank mercerization. One problem is that, the difference in
shrinkage exists between the yarn wound at the core and the yarn at the periphery of the cheese. Important factors are the adjustment of the twisting, the density of the wound package, the size of the take-up tube, the thickness of the layers during the winding, and the alkali concentration and temperature during the treatment.

A problem in this form of mercerization is in the relative difficulty of controlling the tension on the yarn. Differences in the level of tension between machines and between cheeses or cones can occur easily lead to patchy dyeing. Due to this, in addition to giving special attention to tension control, it is important to adopt centralized controls in order to ensure the same conditions for each machine, including those of alkali concentration and temperature.

Other problems are related to the yarn breakage, yarn overlap, and yarn skewing. The yarn count and quality of the yarn undergoing treatment also has a large influence on mercerized yarn quality.

1.6.3 Hank:

This is currently the most commonly used method of mercerization, and generally entails rolling a 54-inch long (the length of one loop) hank weighing about 500 grams. The yarn is moved by the turning the rollers, with penetration of the alkali, application of tension and rinsing occurring automatically. In this, one cycle takes about three to five minutes, and four to eight kilograms can be treated at one time. In the latest machines, all operations are automated, including control of the alkaline solution's concentration and temperature and the addition and recovery of the alkali, along with application of tension on the yarn and rinsing. The only manual operation is the loading and unloading of the yarn.

An advantage of hank mercerization is that, the impregnation treatment can be carried out without tension; hence, the alkali solution is able to penetrate inside of the yarn sufficiently. After the fibres have swelled sufficiently, any level of tension can
be applied and the yarn is rinsed to remove the alkali. This gives the satisfactory mercerization effects.

However, if the winding or the handling of the hank is inappropriate, disarrangement of the lengths of yarn in one loop can result in different tensions, leading to uneven mercerization, which can often result in serious patchy dyeing.

Uneven mercerizing due to uneven tension is an unavoidable problem in current methods of mercerization. For these reasons, using yarn that has been hank mercerized and then dyed for finishing into solid-colour fabrics can result in a barre effect, preventing the fabric's use in a product, and so hank mercerization of pre-dyed yarn is mainly used for products with narrow stripes or a check design where barre is not noticeable.

Another problem in hank mercerization is that conventional rinsing after mercerization is insufficient, and without neutralization through separate rinsing with hot water, the remaining alkali can cause problems. Finally, after drying, winding from the hank to a cone or cheese is necessary, and the effort and labour hours needed for this is a major disadvantage.

1.6.4 Fabric:

The fabric is passed through many rollers without the use of a clip Stenter, and then it is known as Roller mercerization. The machine has a number of stainless rollers, or stainless and rubber rollers, of large diameter. They are tiered zigzag in close contact to each other inside a long trough, with the lower tier designed to submerge in alkaline solution for mercerization.

The absorption of alkaline solution and fabric swelling take place as fabric sequentially glides through the surface of these rollers. However, this movement from roller to roller in close contact with them reduces the widthwise contraction to a
minimum, the resulting fabric expansion remains within a limited range. It displays the mechanism of mercerization at fixed length. Therefore, the machinery required is extremely concise and the cost is low, in comparison with the chain mercerization method. However, this method is subject to a considerable number of constraints due to inflexible widthwise control over fabric depending on the kind and use.

1.7 Evaluation Methods:

1.7.1 Deconvolution:

In this method, cotton hairs are cut in large number of hair fragments of 0.2 mm long. They are then mounted in liquid paraffin on microscope slide. They are counted and the proportion of fragments free from twist or convolution during mercerization is noted. The result is expressed as percentage. It is called as “Deconvolution Count.” The disadvantage of this method is that the extent of deconvolutions is influenced by the maturity of cotton and twist of the yarn or weave of cloth.

1.7.2 Axial Ratio:

The first quantitative examination of the mercerization of cotton hairs was made by Willows [71]. The changes in dimensions of yarns are due to the relative positions of the hairs in the yarn. Hence, measurements on single cotton hairs are more reliable index of dimensional change due to mercerization.

The lustre of cotton fibres is decided by the ratio between the long and short axis of the cross section of the cellulose hair, and it improves as the cross section becomes more circular.
While mercerization can greatly improve lustre, it cannot make up for deficiencies in the lustre of the raw cotton itself. To produce products of superior lustre, primary considerations relate to the choice of raw cotton, the twisting and manufacture of the cotton yarn and the structure of the fabric. Changes in the mercerization process influence the improvement of lustre.

### 1.7.3 Barium Activity Number:

Mercerized sample absorbs barium hydroxide (alkali) to a greater degree than unmercerized sample and from practical point of view; barium hydroxide is easier to estimate. The ratio of uptake for this reagent has been referred as Barium Activity Number.

Two grams mercerized and unmercerized samples are placed separately in two conical flasks containing 30 ml of N/4 barium hydroxide and left for 2 to 12 hours. 10 ml of clear solution is withdrawn and titrated against N/10 HCL using phenolphthalein as an indicator. A blank titration is also carried out on the measured barium hydroxide solution using Methyl Red as an indicator.

\[
\text{Barium activity number} = \frac{b-s}{b-u} \times 100
\]

- \(b\) = ml required for blank test,
- \(s\) = ml required for mercerized cotton,
- \(u\) = ml required for unmercerized cotton.

For exact estimation, correction should be made for the moisture regain of the sample. Barium Activity Number [BAN] of semi-mercerized cotton BAN ranges between 115 to 130 and that for completely mercerized cotton it is about 155.
1.7.4 Dyeing Behaviour:

Wakida et al [99] made research in liquid ammonia and caustic soda mercerized cotton fabrics. Cotton fabric has been treated with liquid ammonia and caustic soda by a two-step process (NaOH/NH₃ and NH₃/NaOH) to examine the influence of the treatment sequence. After Mercerization, dye uptake was measured with CI Direct Blue I and mechanical properties were measured by Kawabata Evaluation System. The dyeing rate increases when liquid ammonia mercerization is carried out first and caustic soda mercerization is carried out later. This two stage process provides both soft hand and dyeing improvements simultaneously. However, the caustic soda mercerization first and liquid ammonia mercerization later is most effective in improving hand values only.

Iyer V., et al [100] have studied the effect of Sodium Hydroxide causticization and mercerization on the dyeing behaviour of Rotor spun and Ring spun cotton yarns. Dyes included direct (Incomine Green BHLY, Sky Blue 6BS, and Fast Orange SE/H), Vat (Indonon Blue BC, Jade Green FFB/U, Yellow GCN HLY, Yellow 3RT PDR, Brilliant Violet RR/U, Olive R PDR, and Brown R PDR), and reactive (Amective Brilliant Blue R xH, Yellow 4G, Rose 3B, Red EB, Yellow IRX, and Orange RX) types. Parameters included absorbance values for dyebath exhaustion and dye uptake. For all the dyes studied, slack mercerized samples exhibited optimum values for dyebath exhaustion and dye uptake. When dyed together, rotor spun yarns showed higher rates of dye uptake than ring spun yarns.

1.7.5 Near Infra Red Spectroscopy:

Robert T. O’Connor et al [101 & 102], studied applications of infrared absorption spectroscopy on cotton and modified cottons. It can be used to understand changes in hydrogen bonding by observing the exact wavelengths of the OH
stretching vibrations. Conrad and co-workers have shown that values of crystallinity measured in this manner are directly proportional to data obtained from X-ray diffraction measurements. Appearance of a band at about 7.0µ and a distinct band at 11.0µ, are reasonably sensitive criteria of crystalline and decrystallized cotton cellulose, respectively.

Crystallinity index is defined as the ratio of the absorbance at the band maximum of 6.9µ to the absorbance at the band maximum of 11.0µ.

Under these definitions, the bands at 6.9µ and at 11.0µ in the spectrum of cellulose may be called "crystalline" and "amorphous" bands, respectively.

1.7.6 Infra-red:

Determination of crystallinity of cotton at different wavelengths (1429 cm\(^{-1}\)/893 cm\(^{-1}\)) can be carried out. This ratio will give crystallinity index. When [cellulose-II] mercerized samples are considered, the ratio of wave length (of 1372 cm\(^{-1}\)/2900 cm\(^{-1}\)) can be considered as more reliable index.

1.7.7 X-Ray Spectroscopy:

A diagram of this unit cell, as derived by Meyer and Misch [103], the cell is a monoclinic with three principal planes of reflection shown as (002), (101), and (101). Using x-ray diffraction, Sarna and Wlochwica [104] determined that the crystallinity index (CI) of raw cotton. A setup of a continuously recording X-ray diffractometer of the angular intensity of X-ray photons as a function of [2θ] has found three peaks for native cotton cellulose I as (101) at 2θ = 14.9°, (101) at 2θ=16.6° and (002) at 2θ =22.7°.

Hsieh et al [29] analyzed single fibre breaking forces and tenacities of the single fibre are positively related to both the overall crystallinity and crystallite sizes. X-ray diffraction studies for the determination of the fine structure of cellulose and
 Mercerized cellulose is carried out by Gulzari Lal et al [105-107]. The data obtained by the X-ray diffraction studies such as orientation angle, lattice conversion ratio, length of crystallites and the degree of crystallinity will certainly throw a great deal of light about the original structure as well as the changes occurring in the structure during the process of chemical modification at mercerization.

In spite of developments in other techniques, such as infrared spectroscopy, electron paramagnetic resonance, nuclear magnetic resonance, neutron diffraction, the data obtained by X-ray diffraction for the purposes of structural analysis is considered much more reliable. Effect of mercerization on the crystallite size and crystallinity index in cellulose from different sources, has been studied by Revol J. F. et al [107]. Native cellulose samples having a wide range of crystallinity and crystalline size were mercerized by treatment with sodium hydroxide. For the low-crystallinity samples, crystallinity and crystallite size actually increased on mercerization. Meredith R. [108 & 109], correlated the tensile strength of single fibres with the orientation of the crystallites as measured by X-rays and the magnitude of the correlation coefficient ranges from 0.77 to 0.84.

The tensile strength of raw cotton fibres is correlated with the degree of molecular orientation, as shown by optical measurements with polarized light. The molecular orientation can also be measured by X-rays. Sisson [110] found a correlation coefficient of 0.87 between bundle strength of 21 samples and that calculated from the X-ray angle. Berkely and Woodyard et al [111] found a coefficient of correlation between bundle strength and X-ray angle as high as -0.95, although more recently Hessler et al [112] have obtained a correlation coefficient of -0.75.

Some possibilities and limitations of the X-ray method for estimating the strength of raw cotton have been discussed by Conrad et al [113]. The advantages claimed for the X-ray method were speed, general applicability to all staple length and
all strengths. Pattern is little affected by atmospheric conditions and test specimen preservation. While no modification of the X-ray diagram by chemical degradation or attack by microorganisms. Hindeleh and Patil [114, 116] correlate crystallinity, crystallite size, and physical properties of native Egyptian cotton and structural parameters. X-ray crystallinity, crystallite size, orientation birefringence, and degree of polymerization in many fibres and polymers are related to the physical and chemical properties such as tensile strength, elongation, elastic modulus, yield point, abrasion resistance, and degree of swelling, moisture content, and chemical reactivity. The measurement of the crystallite size (thickness) normal to hkl planes by x-ray diffraction is usually based upon peak broadening and requires an estimate of peak width at half maximum height or the integral breadth of the peak.

Segal L. et al [115 & 118] correlated an empirical method for estimating the degree of crystallinity of native cellulose using the X-ray diffractometer. The intensity of the 002 interference and the amorphous scatter at $2\theta = 18^\circ$ was measured. The percent crystalline material in the total cellulose was expressed by an x-ray "crystallinity index." This was done for cotton cellulose decrystallized with aqueous solutions containing from 70% to 100% ethylamine. The X-ray "crystallinity index" was correlated with acid hydrolysis, crystallinity, moisture regain, density, leveling-offs, degree of polymerization values, and infrared absorbance values for each sample. The results indicate that the crystallinity index is a time saving empirical measure of relative crystallinity. The relation was found between crystallite orientation and mechanical properties of mercerized cotton. Other things remaining constant, the elastic moduli of fibres are expected to increase and creep to become less prominent with increasing degree of molecular orientation.

Irrespective of the cotton used, the correlation between the average single fibre static Young's modulus and the average X-ray orientation factor of mercerized cotton is as high as 0.96. The elastic modulus increases more than tenfold over a range of
X-ray orientation factor from 0.70 to 0.95, the coefficient of variation of elastic modulus of single fibres tends to decrease with increasing average orientation.

Segal et al. [115, 118 to 120] developed an empirical method for estimating the degree of crystallinity of cellulose.

The amount of crystalline cellulose in the total cellulose can be expressed by the X-ray "crystallinity index" (CI) defined by

$$ CI = 100 \times \left[ \frac{I_{002} - I_{am}}{I_{002}} \right] $$

Where \([ I_{002} ]\) is the intensity of the principal Cellulose I peak at \(2\theta = 22.7^\circ\) and \([ I_{am} ]\) is the intensity attributed to amorphous cellulose given at \(2\theta = 18^\circ\).

More detailed methods utilizing multipeak resolution method and profile fitting of X-ray diffraction data have been followed by Hsieh et al. Hsieh applied these to the determination of the crystallinity of developing cottons. Non-diffraction methods of measuring the crystallinity of cellulose include both infrared and solid-state nuclear magnetic resonance (NMR) spectroscopy. O'Connor et al demonstrated that, the ratio of peaks at 1427 cm\(^{-1}\) to 901 cm\(^{-1}\) is proportional to the crystallinity index. Newman and Hammingon [119] have shown that carbon-13 NMR spectroscopy could be utilized to measure the crystallinity of cellulose [54, 63, and 64].

Sreenivasan S. et al [120], have shown that in X-ray diffraction diagrams obtained after hydrolysis indicate that regenerated cellulose contain an extraneous lattice in addition to cellulose II. Sreenivasan S. et al [121] studied X-ray orientation of equatorial planes in swollen and stretched cellulosic fibres. Warwicker [122] used independent measurements on the orientation of (110), (110), and (200) planes for cotton fibres swollen slack in various concentrations of alkali to suggest that the orientation changes can be accurately measured by any one of these reflections.
1.8 Low Stress Fabric Properties (Kawabata Evaluation):

**Introduction:** In 1930, Peirce [123] described first, a way of measuring some fabric mechanical properties related to fabric drape and fabric hand. Lindberg and Dahlberg later established the relationship of properties and garment appearance in 1961. The KES-F system (Kawabata hand Evaluation System for Fabrics) was developed in Japan by the Hand Evaluation and Standardization Committee (HESC, established in 1972) organized by Professor Kawabata. In this, fabric objective measurement method, scientific principles are applied to the instrumental measurement and interpretation of fabric low stress mechanical and surface properties such as fabric extension, shear, bending, compression, surface friction, and roughness. The fabric handle is calculated from measurements of these properties. Postle conducted research on fabric handle and methods of linking the fabric objective measurements with the subjective assessments.

1.8.1 Kawabata System:

Fabric hand has traditionally been assessed by experts who arrive at an overall judgment on quality after manipulating the fabric with their hands. This system requires years of experience and can obviously be influenced by the personal preferences of the assessor. Professor Kawabata of Japan has carried out a great deal of work with the aim of replacing the subjective assessment of fabrics by experts with an objective machine-based system, which will give consistent and reproducible results. It is generally agreed that the stimuli leading to the psychological response of fabric handle are entirely determined by the physical and mechanical properties of fabrics. In particular, the properties of a fabric that affect its handle are dependent on its behaviour at low loads and extensions and not at the level of load and extension at which fabric failure occurs.
1.8.2 Fabric Hand:

Fabric hand refers to the total sensations experienced when a fabric is touched or manipulated by the fingers. The term 'fabric handle' or simply 'handle' or 'hand' is also used. It is a complex parameter and is related to the fabric properties such as flexibility, compressibility, elasticity, resilience, density, surface contour (roughness, smoothness), surface friction, and thermal character.

1.8.3 Subjective Assessment of Fabric Handle:

The first part of Kawabata’s work was to find agreement among experts on aspects of handle. Primary hand values were rated on a ten-point scale. Ten is the highest and one is the lowest value of that property. The properties that are regarded as primary hand values may differ among fabric categories such as men’s summer suiting, men’s winter suiting, and women’s dress fabrics. The primary hand values are combined to give an overall rating for the fabric in its category. This is known as the total hand value and it is rated on a five-point scale where five is the best rating. The primary hand values are converted to a total hand value using a translation equation for a particular fabric category, which has been determined empirically.

Samples for each of the primary hands were produced by the Hand Evaluation and Standardization Committee (HESC) together with standard of total hand in each of five categories:

1. **MEN’S WINTER/AUTUMN SUITING**
2. **MEN’S SUMMER SUITING FOR A TROPICAL CLIMATE**
3. **LADIES’ THIN DRESS FABRICS**
4. **MEN’S DRESS SHIRT FABRICS**
5. **KNITTED UNDERGARMENTS.**

The purpose of these standards is to act as a reference to help the experts to produce more uniform assessments of fabric handle.
Fabric that scored the maximum points for total hand value in a particular category would be universally regarded as the best fabric. It has been found that although this may be true within one country there are differences between countries in their perception of the mix of properties required for a particular end use.

1.8.4 Objective Evaluation of Fabric Handle:

Kawabata [124] has produced a set of instruments to measure the appropriate fabric properties and then to correlate these measurements with the subjective assessment of handle. The aim was to enable any operator to measure total hand value of a fabric.

The system is known as the KESF system. It consists of four specialized instruments.

FB1  TENSILE AND SHEARING  
FB2  BENDING  
FB3  COMPRESSION  
FB4  SURFACE FRICTION

These instruments measure the tensile, compression, shear, and bending properties of the fabric together with the surface roughness and friction. Sixteen parameters are measured, all at low levels of force, which are intended to mimic the actual fabric deformations found in use. The quantities measured are listed in Table 1.6.

The properties are measured in the following ways.
Table - 1.6: The 16 parameters measured by the Kawabata system describing fabric mechanical and surface properties

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tensile</strong></td>
<td>LT</td>
<td>Linearity of Load Extension Curve</td>
</tr>
<tr>
<td></td>
<td>WT</td>
<td>Tensile Energy</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>Tensile Resilience</td>
</tr>
<tr>
<td><strong>Shear</strong></td>
<td>G</td>
<td>Shear Rigidity</td>
</tr>
<tr>
<td></td>
<td>2HG</td>
<td>Hysteresis of Shear Force at 0.5°</td>
</tr>
<tr>
<td></td>
<td>2HG5</td>
<td>Hysteresis of Shear Force at 5°</td>
</tr>
<tr>
<td><strong>Bending</strong></td>
<td>B</td>
<td>Bending Rigidity</td>
</tr>
<tr>
<td></td>
<td>2HB</td>
<td>Hysteresis of Bending Moment</td>
</tr>
<tr>
<td><strong>Lateral Compression</strong></td>
<td>LC</td>
<td>Linearity of Compression Thickness Curve</td>
</tr>
<tr>
<td></td>
<td>WC</td>
<td>Compression Energy</td>
</tr>
<tr>
<td></td>
<td>RC</td>
<td>Compression Resilience</td>
</tr>
<tr>
<td><strong>Surface Characteristics</strong></td>
<td>MIU</td>
<td>Coefficient of Friction</td>
</tr>
<tr>
<td></td>
<td>MMD</td>
<td>Mean Deviation of MIU</td>
</tr>
<tr>
<td></td>
<td>SMD</td>
<td>Geometrical Roughness</td>
</tr>
<tr>
<td><strong>Fabric Construction</strong></td>
<td>W</td>
<td>Fabric Weight per Unit Area</td>
</tr>
<tr>
<td></td>
<td>T₀</td>
<td>Fabric Thickness</td>
</tr>
</tbody>
</table>

The tensile properties are measured by plotting the force extension curve between zero and a maximum force of 500 grams/cm (0.49 N/cm), the recovery curve as the sample is allowed to return to its original length is also plotted to give the pair of curves shown in Graph 1.1. From these curves, the following values are calculated:
Tensile Energy $W_t = \text{The Area Under The Load Strain Curve (Load Increasing)}$

Linearity $L_t = \frac{W_T}{A \Delta OAB}$

Resilience $R_t = \frac{\text{Area under load decreasing curve}}{W_T} \times 100\%$

Graph - 1.1 Load extension curves for KESF

The compression properties are measured by placing the sample between two plates and increasing the pressure while continuously monitoring the sample thickness up to a maximum pressure of 50 grams/cm$^2$ (0.049 N/cm$^2$). As in the case of the tensile properties, the recovery process is also measured. The quantities $L_C$, $W_C$, and $R_C$ are then calculated in the same manner as $L_T$, $W_T$, and $R_T$ above.
In order to measure the shear properties a sample of dimensions 5 cm x 20 cm is sheared parallel to its long axis keeping a constant tension 10 grams/cm on the clamp.

The following quantities are then measured from the Graph 1.2.

Graph - 1.2- Shear curve for KESF

Shear stiffness \( G \) = Slope of shear stress and shear strain curve

Force hysteresis at shear angle of 0.5° 2HG = hysteresis width of curve at 0.5°

Force hysteresis at shear angle of 5° 2HG5 = hysteresis width of curve at 5°

In order to measure the bending properties of the fabric the sample is bent between the curvatures – 2.5 and 2.5 cm\(^{-1}\) the radius of the bend being 1/curvature as shown in Figure 1.6. The bending moment required to give this curvature is continuously monitored to give the curve shown in Graph 1.3.
The following quantities are measured from this curve:

**Bending rigidity** \( B = \) slope of the bending moment – curvature curve

**Moment of hysteresis** \( 2HB = \) hysteresis width of the curve

The surface roughness is measured by pulling across the surface a steel wire 0.5 mm in diameter, which is bent into a U shape as shown in Figure 1.7.
The contact force that the wire makes with the surface is 10 grams (98.1 mN). A plot of the height variation against distance is shown in Graph 1.4.

The value that is measured in SMD = mean deviation of surface roughness.

The surface friction is measured in a similar way by using a CONTACTOR, which consists of ten pieces of the same wire as above as in shown in Figure 1.8. A contact force of 50 grams is used in this case and the force required to pull the fabric past the contactor is measured.

MIU = mean value of coefficient of friction
MMD = mean deviation of coefficient of friction

All these measurements are then converted into primary hand values by a set of translation equations and the total hand values are then calculated from these primary hand values by the use of a second translation equation.
Shanmugasundaram O L [125] has studied the Objective Measurement Techniques for few Fabrics.

1.8.5 Factors affecting fabric hand:

In textiles, the raw material, yarn structure, planar structure, and finishing treatments affect the fabric hand.

A psychological reaction from the sense of touch, as the tactile sensitivity of peoples’ varies according to age, skin hydration, cultural aspects, or gender of the test person.

1.8.6 Fabric properties related to handle:

The fabric properties related to handle, performance in garment manufacture, and garment appearance after manufacture and in use are: physical properties (thickness and weight); dimensional stability (relaxation shrinkage and hygral expansion); mechanical properties (extensibility, bending properties, shear properties and compression); surface properties (compression, friction and surface irregularity);
optical properties (lustre); performance properties (pilling, wrinkling and surface abrasion).

Tyagi G.K. et al [126, 127] studied low-stress properties of mercerized cotton ring and open-end rotor spun yarns and the effect of yarn linear density, yarn structure, twist factor and rotor speed on low-stress properties of mercerized cotton ring-and rotor-spun yarns. For both, ring and rotor-spun yarns, at 1% and 3% extension, packing density and hairiness change markedly after mercerization treatment. Flexural rigidity increases significantly, however it is considerably lower for ring-spun yarns. The abrasion resistance of both types of yarns decreases but yarn twist increases abrasion resistance.

1.9 Yarn and Fabric Geometry:

1.9.1 Yarn Diameter:

As textile yarns are easily compressible, their thickness is not usually specified as a given gauge or diameter but as a weight/length relationship. However, for calculating cloth cover, especially when dealing with new materials, new structures, or new modifications, it is necessary to find yarn diameter.

In the Tex system the yarn number, N Tex, indicates the weight in grams of 1000 meters of yarn. Therefore, assuming constant yarn density, it will be proportional to the area of yarn cross-section. If circular cross-section is assumed, the yarn can be imagined as a cylinder whose diameter can be obtained from the following relationship.

\[
\text{Area of cross section} = \frac{\text{Volume}}{\text{Length}}
\]

Or, \( \pi r^2 = \frac{\pi d^2}{4} = \frac{V}{l} \); \( d^2 = \frac{4V}{\pi l} \) and \( d = \sqrt{\frac{4V}{\pi l}} \)
The length is fixed at 1000 meters to find a numerical value for diameter. It is necessary to find the volume of the yarn and this could be obtained if the density or the specific volume of the yarn is known. Densities of the textile fibres are known and the specific volume of any fibre can be accurately determined, as it is a reciprocal of density. Yarn, however, is a composite of fibres and air, and the relative amounts of air and fibre within a yarn will vary depending on the density of the material (or materials, in blended yarns), fibre thickness, fibre alignment, degree of twist and the amount of tension applied. Peirce in his experimental work on cotton yarns estimated that the specific volume of such yarns under moderate pressures (such as can be expected to exist in a cloth) is 1.1 cm³/gm. As the density of cotton is 1.52 gm/cm³, and cotton specific volume 0.658 cm³/gm, the specific volume of yarn is 1.1 cm³/gm. Therefore, this represents a yarn is composed of approximately 60 per cent fibres and 40 per cent air space. In the Tex system the actual volume of yarn is equals to (Tex X Specific volume) and, therefore, assuming the specific volume 1.1 cm³/gm, the formula for yarn diameter may be given as:

\[
d = \sqrt{\frac{4 \times N \times 1.1}{1000\pi}}
\]

From this, it is possible to calculate a constant to simplify the formula:

\[
d = \frac{\sqrt{N}}{F}
\]

For yarns of specific volume of 1.1 cm³/gm would be:

\[
d \text{ (mm)} = \frac{\sqrt{N}}{26.7}
\]
In the above calculations, a circular yarn cross-section has been assumed. This would be true in respect of monofilament and very hard twisted yarns. Most of the other types of yarns tend to flatten to some extent and some workers have proposed an elliptical or a racetrack cross-section as being closer to the actual appearance of yarn in a cloth. Apart from the intrinsic yarn characteristics, the degree of flattening is dependent on the density of setting. It determines the amount of space available for spreading, and the tension exercised by the transverse yarns.

**Cloth Cover:**

The Figure 1.9 shows Interlacement diagram of two woven cloths of different construction. In the Figure 1.9, [A] warp and the weft threads cover the area of the cloth partly. In the Figure 1.9, [B] cloth area is covered completely with no spaces left between the adjacent warp yarns. It will be seen that the relative closeness of yarns in a woven cloth, is dependent upon the ratio of yarn diameter (d) to yarn spacing (p). This ratio is known as relative cover and it can be defined as the proportion of a projected view of a given area of cloth, which is covered by threads. It will have a scale from zero to one. It may also be expressed as percentage cover with a scale from zero to 100 per cent.

![Figure 1.9 Interlacement Diagram](image-url)
It is preferable to express warp and weft relative cover separately, as the cumulative value of cloth cover does not indicate the comparative importance of each set of yarns, which is essential for the determination of certain cloth characteristics.

From the relationship shown above it will be obvious that if \( d = p \), the value of relative cover is one, and this is regarded as the theoretical maximum cover. In practice, however, this value can be exceeded considerably in any one direction, either through yarn distortion, or, by forcing the threads into different planes, especially if the relative cover of the opposite set of threads is reduced correspondingly.

The relative cover for one thread system can be calculated as follows by considering an area of 100mm x 100 mm:

\[
\frac{d}{p} = \text{relative cover} \quad ; \quad \frac{d \times 100}{p} = \text{Percentage cover}
\]

\[
\text{Area per thread} = 100 \times d
\]

\[
\text{Area covered by n threads of one system} = n \times 100 \times d
\]

\[
\therefore \text{Relative cover} = \frac{n \times 100 \times d}{100 \times 100} = \frac{n \times d}{100}
\]

In most circumstances, the cumulative value for cloth cover is of little use, but in some special cases, such as considering air permeability or porosity of cloths it may be of considerable interest, and should be specified. Simple addition of the relative warp and weft covers do not give the correct result because in this way the areas where one set of threads crosses the other are counted twice.
This covered area (double counted) = \((n_1 \times n_2 \times d_1 \times d_2)\) ; hence

\[
\text{Relative cloth cover} = (\text{Relative warp cover} + \text{relative weft cover}) - (\text{Relative warp cover} \times \text{relative weft cover}).
\]

The calculations involving the degree of yarn cover in cloth can be simplified considerably if an index or cover factor is derived which will obviate the need for the cumbersome calculation of yarn diameter, which is necessary to establish the relative cover value. This can be achieved in the following manner:

\[
d (\text{mm}) = \frac{\sqrt{N}}{26.7} \quad \text{(For yarns of specific volume 1.1 cm}^3/\text{gm})
\]

\[
p (\text{mm}) = \frac{100}{n} \quad \text{(Where } n \text{ is the number of threads per 100 mm)}
\]

\[
\frac{d}{p} = \text{relative cover and this has a value of 1.00 when } d = p.
\]

From the above the following relationship can be established:

\[
\frac{d}{p} = \frac{\sqrt{N}}{26.7} \times \frac{n}{100} = \frac{n\sqrt{N}}{2670}
\]

If the numerical factor is now eliminated a cover factor, \(K\), can be expressed as \(K = n\sqrt{N}\), the value of \(K\) being 2670 when \(d = p\), i.e. when the maximum theoretical cover value is reached. In this way a direct relationship is established between the cover factor, \(K\), the number of threads per 100 mm, and the tex yarn
number, \( N \), to the exclusion of yarn diameter calculation provided that only yarns of specific volume of 1.1 cm\(^3\)/gm are considered.

It has been recommended that the value of 267 be accepted as the tex cover factor, which will be correct for the relationship derived above if \( n \) is taken to equal the number of threads per 10 mm.

Mecheels O. [128] found that the shrinkage of yarn in the alkali and the lustre of the mercerized cotton both decrease with increasing temperature of alkali. For a series of soft twist yarns, it was found that the shrinkage in the caustic soda solution diminished as the count became higher. It was also observed that a high tendency to shrink does not necessarily imply high luster. The yarns with the highest lustre after mercerization are those yarns where fibres have the highest initial lustre. If, however, two yarns have the same lustre before mercerizing, then that with the highest tendency to shrink shows the higher lustre after mercerizing.

Croser and Turner, Mecheel [129,128] have shown that yarns cannot be stretched by more than 5% and cotton loses strength if stretched more than 5% during mercerization.

Edelstein, [130] has published results which were confined to the treatment of 2/40\(^{s}\) yarn. Samples were mercerized in caustic soda solutions of varying concentration of the alkali up to 70°Tw. the lustre was also found to increase with the concentration. Properties such as tensile strength, moisture absorption, dyestuff absorption, barium activity number, etc., increased with the concentration of sodium hydroxide only up to 30°Tw.

These data confirm the general experience that it is not possible to obtain maximum dyestuff absorption and maximum lustre under the same conditions of mercerizing; the greatest lustre is obtained at the highest tension, which affects the dyeing power and the extension at break. In mercerizing for lustre it is advisable to use 50°Tw to 55°Tw. NaOH, but the maximum affinity for dyestuffs was obtained in
solutions of 25°Tw to 30°Tw. NaOH, where the stretching force was only half that required in the higher concentrations.

Solutions of sodium hydroxide of 30°Tw appear to be very critical, in that small variations in concentration and temperature cause considerable variations in the properties of the mercerized materials. On the other hand, solutions of 50°Tw. NaOH are not very sensitive and are, therefore, to be preferred for practical mercerizing.

1.9.2 Yarn Twist:

Influence of the twist of yarns:

The twist is put into yarns in order to bind the fibres together which affect the handle, strength, and wearing property of a cloth and has a considerable influence upon the appearance of a fabric in which any form of twill line is developed.

Corser and Turner [129] carried out an experiment with 2/60s yarn spun from fine Sakellandis cotton. A 60s single yarn was spun, twisted with three different twist constants (2, 3 and 4, respectively; S, M, H), and then each singles was doubled weft way with three doubling twist constants (3, 4.5 and 5.6 respectively; S, M, H). This gave nine types of two-fold yarn, which are marked as SS, being soft singles twist, soft two-fold twist and HH as hard singles twist, hard two-fold twist.

It was found that the most lustrous yarns were those, which were doubled with the softest doubling twist, indeed a doubling twist constant of three is often used in commercial practice. The most lustrous yarn of all was that with medium singles twist and soft doubling twist.

Twist and Lustre

At one time, it was common for tables of doubling twists to be compiled as a guide to the production of maximum lustre. Adderley [131] conducted a survey of a series of two-fold yarns ranging from 2/12s to 2/14s and established that maximum
lustre is obtained when the doubling twist is seven-tenths of the original twist of the component single yarn. Cotton hairs are parallel to the axis of the folded yarn.

1.9.3 Woven Fabric Mechanics:

Pierce [123] presented a geometrical and a mathematical model of the plain-weave structures. Considerable progress has been made over the last century in the development of the theory of geometrical structure and mathematical properties of fabrics.

Muniswami has observed that, the sum of cover factor can be expressed effectively by the three measure characteristics, namely: fabric weight [W], fabric cover [Kc] and fabric thickness [g]. He has redesigned the fabric thickness as fabric quality index; [FQI] analogous to yarn quality index and suggested its use as a measure for measurement of fabric quality.

Efforts have been made by many research workers to find the theoretical maximum cover factor that is useful in weaving.

1.10 Energy Saving:

1.10.1 Caustic Recovery:

Vacuum Extraction of Caustic Soda solution from cotton fabrics and its impact on mercerization has been studied on a laboratory scale. Since cotton preferentially absorbs NaOH, the extracted solution was always more diluting than that in the initial bath. Extraction increases the concentration of the solution retained by the material, and the extracted solution was more dilute. The water content of cotton fabrics after extraction increased by about 25% when they were mercerized, washed, neutralized, and then vacuumed again. This was a consequence of increased water absorption by the swollen fibres.
On a full-scale mercerization range, vacuum extractors may be used before and after caustic impregnation, at the end of the mercerization chain, during washing, and before final drying of the fabric. They reduce saturator overflow, increase recovery of Caustic Soda, improve washing efficiency, lower consumption of acetic acid in neutralization, and reduce steam consumption in drying on cylinders. Optimization of the process, using vacuum extraction of various positions along the mercerizing range, requires study of the mass balances to evaluate the conditions for minimal operating costs and the best return on investment in equipment.

1.10.2 Yarn and Fabric Mercerization:

Sivakumaran, et al, [132], found optimum-mercerizing conditions of yarns using a reduced caustic concentration. He further observed that modified impregnation sequence gives product with improved strength, elongation properties, and a higher Barium Activity Number. A stretch-cold wash-cold wash sequence, is the most effective impregnation sequence. Reduced caustic concentration results in reduced chemical costs, more effective wash liquor disposal, and better effluent treatment. Avoiding the hot wash will also reduce costs associated with heating water. To determine optimum mercerization concentration, 2/30\(^{\circ}\), 2/40\(^{\circ}\), 2/61\(^{\circ}\), 2/76\(^{\circ}\), and 2/96\(^{\circ}\) yarns were mercerized at concentrations of 182, 247, and 307 grams per litre. Mercerization at 247 grams per liter was sufficient to obtain quality-mercerized yarns.

Modi J. R., et al, [133] and Dixit M. D., et al, [134], revived the interest in hot mercerization in the context of shortages of heat and electrical energy and increased cost of manufacture. With this background, mill scale trials were carried out in different mills covering different machines for both yarn and fabrics. The results obtained show that hot mercerization is a useful practical proposition. Hot mercerization enables reduction in time of preparatory treatment by combining
scouring and mercerizing, with added benefits of conservation of heat energy, reduction in materials inventory, reduction in workers, etc.

1.10.3 Dry and Wet Mercerization:

Shah et al, [60], found methods for wet-on-wet mercerization. They have eliminated drying and thereby conserving energy and achieved improvement in end-product quality. Uniform moisture levels in the fabric at both entry and exit were critical. Wet-on-wet mercerization was compared with conventional wet-on-dry mercerization. DiCesare [61], carried out an investigation of dry mercerization and its application to cotton fabrics. This traditionally "wet" process necessitates the use of a dedicated single purpose mercerization range, which requires a large capital investment. Fabric properties were studied using sodium hydroxide, sodium silicate, and Mercerol DM concentrations as the processing variables on a knitted fabric and a woven fabric. Results have shown increased tensile strength, bursting strength, whiteness level, and absorption of alkali. Structure analysis has shown that mercerization occurs at a lower level of sodium hydroxide than that of wet mercerization.
1.11 Special Problems:

1.11.1 Temperature:

The lustre, hand, and dimensional stability are most commonly demanded fabric properties from mercerization process. The extents to which these three are achieved are determined by a combination of the changes relating to the absorption of alkali, the shrinkage, and the swelling. These three characteristics are affected by different conditions in the different way.

In industrial processing economy is a major concern. Due to this, accurate processing conditions may not be implemented by treating the relationship between alkaline concentrations and processing temperature of mercerization.

1.11.2 Softness:

It has been reported that mercerizing at room temperature produces the fabric with harsh feel. Therefore, it is necessary to find a method of hot mercerization and the parameters required for obtaining the soft hand values of the fabrics.

1.11.3 Constant Quality:

The heat generations due to the reaction of the cellulose fibre with the alkaline solution determined by different researchers vary significantly. While one reason of alkali processing at low temperature, produces a harsher hand is that, it is not able to produce the same degree of swelling as processing at room temperature or higher (5). Another important factor is considered that by lowering the temperature, the freedom of the cellulose molecular structure is in a restrained state. Therefore, it is difficult to obtain constant quality.
1.12 Scope of Present Investigation:

➢ The Indian Textile Industry is the oldest and largest industry, providing livelihood to over 35 million people.

➢ It has a unique position in the Indian economy as the largest manufacturing industry in terms of output, exports, and employment. Indian economy is targeting 8.5% growth rate. Therefore, export has to increase from $ 46 billion to $ 90 billion by 2012. This target could only be achieved by exporting value added products worth $ 50 billion.

➢ The process of mercerization is one of the important processes, responsible for value addition of textile goods. It enhances the luster, dye uptake, strength of cotton yarns and fabrics. Further, it imparts dimensional stability and extremely good feel to the fabrics.

➢ The better tensile strength, abrasion resistance and less pilling tendency are required properties for value added products. Similarly, drape and crease recovery angle, should be better, for garments as expected by quality conscious consumers.

➢ However tensile, bending, and shearing properties at low mechanical stress are needed for prestigious fashion garments.

➢ Yarn of modern technology, ‘Compact yarn’ has different structure than conventional ring yarn.

➢ Therefore, in the present work an attempt has been made to optimize the mercerizing conditions for the compact yarn fabrics and compare various physical and chemical properties of mercerize ring yarn fabrics and compact yarn fabrics.