

## Chapter 1

### KINDS OF FIBRES

#### 1.1 Introduction

Textile fibers consist of polymers. Polymers are long chain molecules which are formed by chemically joining the monomers and the process is known as polymerisation. The length of the chain is represented by degree of polymerisation (DP). If a polymer is formed from two or more monomers, it is called copolymer. To improve the properties of the fibre sometimes additional monomer is grafted on to the polymer chain.

With the introduction of new fibres during the last decade and increasing consumption of fibre blends it has become necessary to look at general fibre chemistry as the pre-treatment technology of one fibre is different to that of another. Table 1.1 gives some of the global textile fibre consumption data. The consumption of

TABLE 1.1  
Global Fibre Demand

(Unit : 1000 tons : share % in consumption)

Fiber Type	1994	2000	Annual Growth (%)
Cotton	15160 (41.3)	16530 (31.2)	1.5
Wool	1520 (4.1)	1720 (4.1)	2.1
Cellulosic	2320 (6.3)	2280 (5.4)	-0.3
Synthetic	17720 (48.2)	21640 (51.3)	3.4

Source : The Japanese Ministry of International Trade & Industry.

cellulosic fibres is expected to decline marginally at the rate of 0.3%. The interplay between fibre structure, morphology and chemical composition is an essential part of all pre-treatment processes and thus, it is necessary to know the differences in the structures of different polymers and their effects on the properties of the fibres. There are many good books on this subject and hence only general fibre chemistry and manufacturing processes are presented in reference form and then proceeded to discuss how preparatory processes are chosen for use as fibre processing.

#### 1.2 Classification of Fibres

Though textile fibres are classified by many systems, it is only in 1960, the Textile Fibre Products Identification Act (TFPIA) became effective. The classification shown in Table 1.2 is based on the principal origin of the fibre (natural or

TABLE 1.2  
Classification of Textile Fibres [1]

Fibre					
Natural Fibres	Cellulosic Fibres	Natural Protein Fibres	Regenerated Fibres	Natural Fibres	Synthetic Fibres
	<p><b>1. seed hairs :</b> (a) cotton (b) milk weed (c) kapok (d) cattail</p> <p><b>2. bast fibres :</b> (a) flax (b) remie (c) hemp (d) jute (e) sunn (f) kenaf (g) urena</p> <p><b>3. leaf fibres :</b> (a) abaca (b) pineapple (c) agave (sisal, henequen)(d) palm (e) New Zeland flax (f) yucca (g) palma istle</p> <p><b>4. fruit :</b> coir</p> <p><b>5. mineral :</b> asbestos</p>	<p><b>1. animal hair fibres :</b> (a) wool (sheep) (b) specialty hair fibres like alpaca, Camel, Cashmere, guanaco, llama, mohair (angora goat), vicuna (c) fur fibres like mink, muskrat, angora, rabbit.</p> <p><b>2. animal secretion :</b> (a) silk fibre like cultivated, dupioni, tussah, wild (b) spider silk.</p>	<p><b>1. rayon :</b> (a) Cuprammonium Bemberg (b) Viscose rayon like regular &amp; high tenacity, high wet modulus, hollow fibres.</p> <p><b>2. acetate :</b> (a) secondary acetate (b) tri-acetate.</p> <p><b>3. protein :</b> (a) casein (b) zein (c) peanut (d) soyabean.</p> <p><b>4. Miscellaneous :</b> (a) alginate (b) rubber.</p>	<p><b>3. elastomers :</b> (a) Spandex (b) rubber (c) lastrile.</p> <p><b>4. manmade mineral :</b> (a) glass (b) metallic.</p>	<p><b>5. other :</b> (a) alginate (b) inorganic like Avceram, Fibrefax, Thornel (c) Organic like PBI, Teflon (d) biconstituent.</p>
	<p><b>1. condensation polymer fibres :</b> (a) nylon 6,6, nylon 6, nylon type 11, 6, 10, aromatic type (Quina), bicomponent nylon (b) aramid like Kevlar and nomex (c) Polyester.</p>	<p><b>2. addition polymer :</b> (a) anidex (b) acrylics (c) modacrylic (d) novoloid (e) nytril (f) olefin fibres like polyethylene, polypropylene (g) Saran (h) Vinal (i) Vinyon.</p>			

man-made), chemical type (cellulosic, man-made cellulosic), generic term (seed, hair, rayon) and common names and trade names of the fibres (cotton, viscose, rayon). However, this list of fibres under such category is not complete and for complete list books are to be referred [2,3].

### 1.3 Chemical Composition, Morphology and Structure of Cotton

The apparel industry is pre-dominantly cotton based and the share of cotton in total fibre consumption is about 70-75%. The cotton productivity of major countries is depicted in Table 1.3.

TABLE 1.3

Cotton Productivity 1992-'93

Country	Kg/Hectares
India	304
Brazil	384
Pakistan	550
China	660
USA	728
CIS (Formerly USSR)	728
Israel	1830

Source : Indian Textile Commissioner Statistics.

Cotton is single cell fibre and develops from the epidermis of the seed [4]. An elongation period continues for 17-25 days after flowering. Cotton consists of cellulosic and non-cellulosic material. A morphological structure of the cotton fibre is given in Fig. 1-1. The outer most layer of the cotton fibre is the cuticle, covered by waxes and pectins, and this surrounds a 'primary wall', built of cellu-

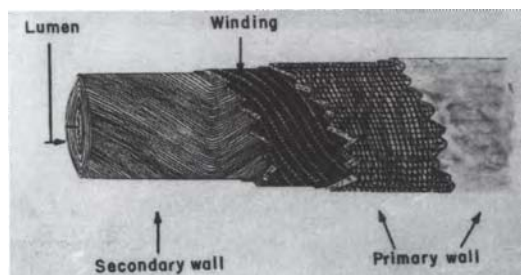


Figure 1-1. Concept of an idealized cotton fibre [5].

lose, pectins, waxes and proteinic material [6]. The inner part of the cotton fibre

comprises the 'secondary wall', subdivided into several layers of parallel cellulose fibrils, and the lumen. The smallest unit of the fibrils is the elementary fibril, consisting of densely packed bundles of cellulose chains [7], for which highly ordered (crystalline) regions alternate with less ordered (amorphous) regions in a longitudinal direction. Inside the microfibrils a microcapillary system is developed [8]. These two capillary systems are responsible for swelling and absorption processes which are important for the pre-treatment of cotton [9]. The primary and secondary wall cellulose result from different polymerisation mechanisms [10].

Cotton consists of practically pure cellulose and may be chemically described as poly (1, 4-B-D- anhydroglucopyranose) (Fig. 1-2). The helical reversal struc-

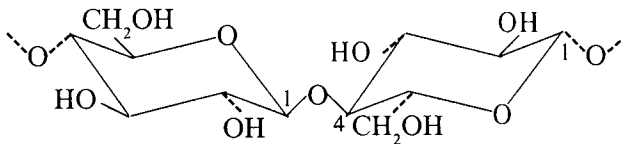


Figure 1-2. Molecular structure and configuration of cellulose [11].

ture of natural cellulose shows the constantly recurring cellobiose unit, consisting of two glucose units each with six carbon atoms. The length of unit cell along the fibre axis is  $10.4\text{\AA}$  calculated for the cellobiose unit. In natural cellulosic fibres there are 3000 - 5000  $C_6$  or glucose units joined together. This corresponds to a molecular weight of the order of 300,000 -500,000.

When cotton fibres dry from their initial fully swollen state, the cell wall collapse to give a typical kidney-shaped (Fig. 1-3) cross-sections and the different

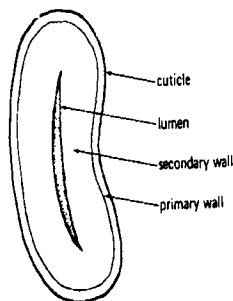


Figure 1-3. Diagram of a cotton fibre, cross-section.

regions of the cross-section have important differences in structure [12]. This is commonly referred to as 'bilateral structure' of the cotton fibre. The fibre is more

accessible to liquids on the concave side of the fibre, which could lead to uneven penetration. The spiral arrangement of microfibrils reverses direction on rotation periodically along the length of the fibre [13,14]. Accordingly, some relationship between convolution angle and fibre strength is established [15].

In the crystalline part, the cellobiose units are closely packed to form Cellulose I in native cellulose fibres and Cellulose II in regenerated cellulose fibres. In Cellulose I the chain molecules are parallel to one another [16]. The folded chain occurs at Cellulose II, in the crystalline regions the chain molecules are anti-parallel. Thus, the basis for helical structure for Cellulose I is preferably extended to the structure of Cellulose II [17].

### 1.3.1 Cotton impurities

The impurities in cotton fibre can range from 4 to 12% (o.w.f.) and the overall composition of cotton fibres are indicated in Table 1.4. Even after mechanical

TABLE 1.4

Composition of Mature Cotton Fibres

Constituents	Percentage by dry weight
$\alpha$ -cellulose	88.0 – 96.5
Protein	1.0 – 1.9
Wax	0.4 – 1.2
Ash (inorganic salts)	0.7 – 1.6
Pectins	0.4 – 1.2
Others (resins, pigments, hemi-cellulose, sugars, organic acids, incrustated ligneous substance)	0.5 – 8.0

ginning process, certain amount of seed-coat fragments, aborted seeds and leaves etc., cling (adhere) to the fibre and these impurities are called 'motes'. The impurities in cotton fibre vary according to the fibre maturity [18] (Table 1.5). Cotton impurities are located largely on the outer side of the fibre (Table 1.6). The non-cellulosic material is mainly situated in the primary wall and the secondary wall is mainly composed of cellulose. Their quantity is higher when the fibre is finer, that

TABLE 1.5.  
Influence of Maturity on the Impurities of Cotton Fibres  
(in percent of dry weight) [19]

Constituents	U. S. Cotton	
	Mature	Immature
Waxes	0.45	1.14
Proteins	1.01	2.02
Ash	0.71	1.32
Pectins	0.58	1.26

TABLE 1.6.  
Proportion of Cellulosic and Non-cellulosic Material in  
Whole of Cotton Fibre and in Primary Wall [20]

Constituents	Proportion (wt. %)	
	Of the whole fibre	Of primary wall
Cellulose	88 – 96	52
Pectins	0.7 – 1.2	12
Waxes	0.4 – 1.0	7
Proteins	1.1 – 1.9	12
Minerals	0.7 – 1.6	3
Other organic compounds	0.5 – 1.0	14

is to say when the specific surface area is large [21]. Other factors which influence the impurities in raw cotton are : geology of the cultivation area, soil constitution, weather conditions during the maturing period, cultivation technique, raw cotton treatment etc.

The proteins are situated in the central cavity of the fibre and are therefore relatively inaccessible to chemical attack. About 14% (on dry weight) proteins are concentrated in the primary wall of the cotton fibre, but their presence in the lumen are also reported [22]. The elements of protein components generally found to be are : leucine, valine, proline, alanine, oxyproteine, threonine, glutamic acid, glycine, serine, aspartic acid, aspergine, lysine and arginine [23]. The yellowish or

brown discolouration of the cotton fibre is related to the protoplasmic residues of protein [24,25] and the flavone pigments of cotton flowers [26].

Natural oils and waxes are mostly mixtures of fatty alcohols, fatty acids and esters of these carbohydrates [27]. Wax content varies greatly among the different varieties of cotton and also same variety grown in different locations. The wax is located on the outside of the cotton fibre and the quantity increases with surface area of cotton [28]. The composition and removal properties of cotton wax are given in Table 1.7. Cotton wax contain carbon (80.38%), hydrogen (14.51%) and

TABLE 1.7

Composition of Removal Properties of Cotton Wax [27]

Component	Content (%)
Wax ester	22
Phytosterols	12.14
Polyterpenes	1 – 4
Hydrocarbons	7 – 8
Free Wax alcohols	42 – 46
Saponifiable	36 – 50
Non-saponifiable	50 – 63
Inert	0 – 3

oxygen (5.11%) [30]. The linkage between cellulose and waxes are mainly due to phosphatides [31] and amino acids, glucose and wax acids [32]. Melting points of cotton waxes vary between 68 to 80°C.

The inorganic matters (residual ash) in cotton contain cation ( $K^+$ ,  $Na^+$ ,  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Fe^{2+}$ ,  $Fe^{3+}$ ,  $Al^{3+}$ ,  $Mn^{2+}$ ,  $Cu^{2+}$  and others) and anions ( $Cl^-$ ,  $CO_3^{2-}$ ,  $PO_4^{3-}$ ,  $SO_4^{2-}$  plus Fe, Mg, Ca as insoluble pectinates) [19]. The alkaline earth elements vary from fibre varieties and require appropriate treatments to reduce their presence on the fibre as far as possible. Any residue present in the fibre will lead to the formation of insoluble alkaline earth carbonates or hydroxides during alkaline scouring. These salts change the soft water to hard water rendering certain dyes insoluble which may be attached to the fiber surface [33].

Pectin is the name applied to impure methyl pectate. Pectins (0.4 - 1.2%) are

present in cotton as a poly -D - galacturonic acid in the form of insoluble salts of Ca, Mg and Fe [34, 35].

Chemically hemicelluloses are arabane, xylene, galactane, mannan, galactomannan, arabinomannan, as well as monosaccharides, disaccharides and digosaccharides. Hemicelluloses are easily soluble in alkali and hydrolysed by acids. Other substances are reducing sugars such as hexoses, pentoses, free glucose etc., constitute the base units of hemicellulose. Citric and malic acid, encrusted ligneous substances are coloured pigments.

#### 1.4 Natural Protein Fibres

Natural protein fibres are generally obtained from animal hairs and animal secretions. Protein fibres have higher moisture regain and warmth than natural cellulosic fibres. Natural protein fibres have poor resistance to alkalis but have good resiliency and elastic recovery. A good precaution is necessary during the chemical pre-treatment of natural protein fibres (except silk) due to its low strength.

##### 1.4.1 Molecular structure of wool fibres

Wool fibre grows from the skin of sheep. It is composed of protein known as keratin. Major varieties of wool come from Merino, Lincoln, Leicester, Sussex, Cheviot and other breeds of sheep. Different species of sheep produce different types of wool in fibre length, diameter and other characteristics. The modification of the fibre properties during growth by dietary additives to produce purpose-grown wools is possible. Generally fine wool fibres are 1.5 -5" in length and 14 - 40 $\mu$  in width. Wool fibres are roughly oval in cross-section and grows in a more or less wavy form with a certain amount of twist. The waviness is called crimp (Fig 1 - 4). The finer the wool the more is the crimp.

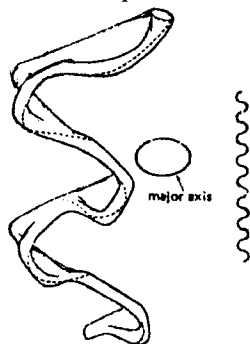


Figure 1-4. Diagram of wool fibre crimp and three-dimensional diagram of wool fibre, showing crimp.



The histological structure of wool fibre comprises consisting three layers : the scaly covering layer (cuticle), the fibrous fibrillar layer (cortex) and medullary layer ( medulla). Fig. 1 - 5 shows the diagarm of wool fibre showing fibre morphology

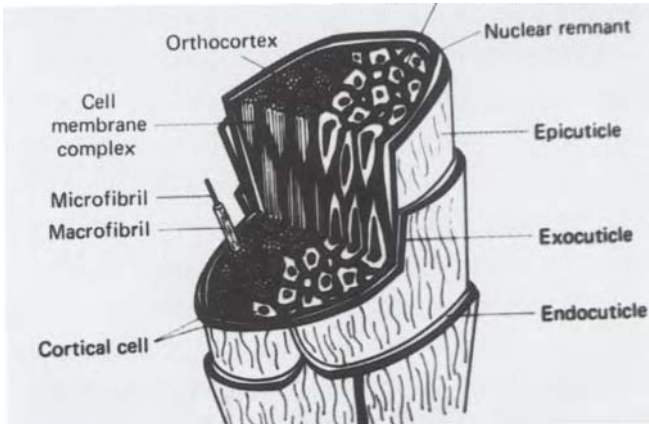


Figure 1-5. Diagrammatic representation of the morphological components of a wool fibre.

(medulla is not shown). The cuticle is sub-divided into two main layers, exocuticle (with A- and B- layers) and endocuticle, and has an outermost membrane called epicuticle. Beneath the epicuticle, there is a layer of flat, scale like cells which overlap like shingles on a roof.

Fig. 1 - 6 shows the longitudinal section of a wool follicle [36]. The sebaceous

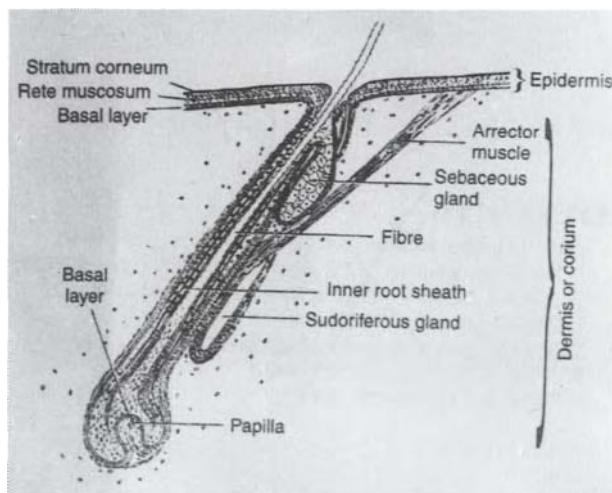


Figure 1-6. Longitudinal section of a wool follicle [36].

gland is believed to produce the wax [37-39], and the sudoriferous gland the suint [37, 39]. As the opening of the sebaceous gland is placed below that of the sudoriferous gland, the wax is deposited directly onto the growing fibre while the suint is deposited over the wax. This is the situation of the primary fibres; the secondary fibres differ in that they do not usually have a sudoriferous gland.

An important component of cuticle is 18 - methyl - eicosanoic acid [40]. Fatty acid is bound to a protein matrix, forming a layer in the epicuticle [41, 42], and this layer is referred to as F - layer [43]. The F - layer can be removed by treatment with alcoholic alkaline chlorine solution in order to enhance wettability. The cuticle and epicuticle control the rate of diffusion of dyes and other molecules onto the fibre [44]. The cortex, however, controls the bulk properties of wool and has a bilateral structure composed of two types of cells referred to as ortho and para [45, 46]. The cortical cells of both are enclosed by membranes of at least three distinct layers within which the microfibrils fit. Cells of intermediate appearance and reactivity designated meso - cortical have also been reported [47]. Cortical cells on the ortho side are denti-cuticle and thin, those on the para side are polygonal and thick [47]. Fig. 1-7 illustrates the bilateral structure which is responsible for the crimp of the

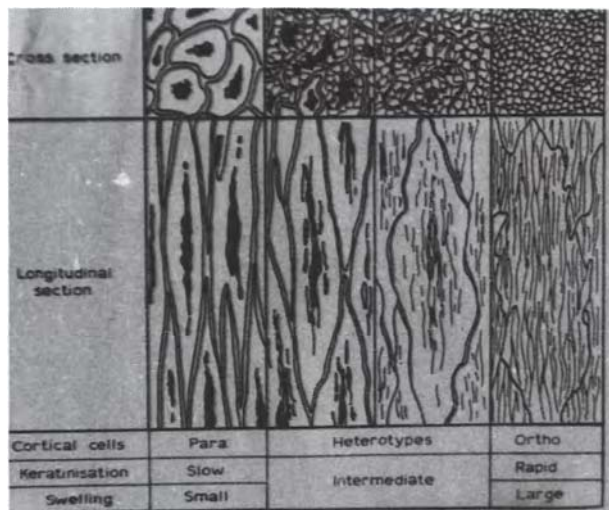
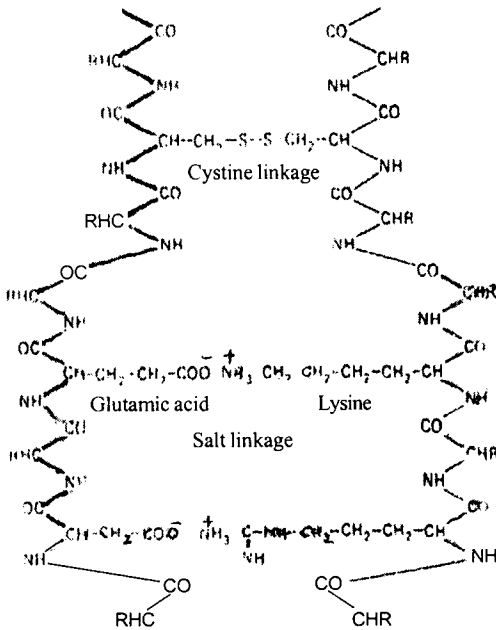


Figure 1-7. Comparison of cortical cells (Courtesy of l' Institut Textile de France).  
fibre. The two cells differ in chemical composition and density and can be differ-

entiated under the microscope using polarised light and also by selective staining techniques. The ortho cortex are chemically more reactive and have a greater receptivity to certain dyes. In the centre of the wool is the medulla, which consists of spiral-shaped, air-filled cells. The finer wools, having no medulla, absorbs dyes more rapidly. Medulla contains pigment that gives colour to fibre.

Keratin is of amphoteric in nature and is composed of 16 to 18 different  $\alpha$  - amino acids. The amino acid residues join together to give a polypeptide chain. There are two types of structure postulated for wool fibre : one is folded form of keratin ( $\alpha$  - form) [Fig. 1-8] and the other is helical or spiral structure (Fig. 1-9).



R = amino acid or other reactive groups

Figure 1-8. Folded chain characteristic of  $\alpha$ -keratin (After Asbury).

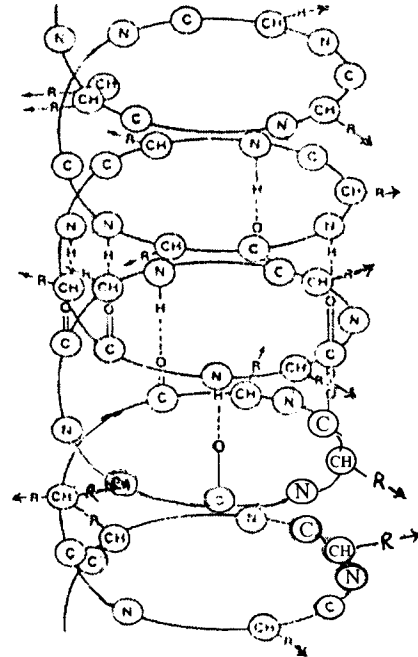
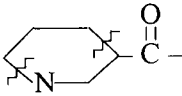
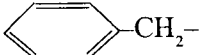
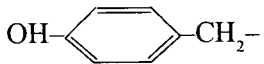
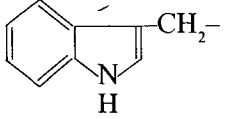
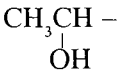

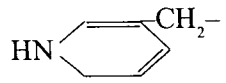


Figure 1-9. Helical or spiral structure of wool (After Pauling and Corey).

When the fibre is stretched, the coil extends to give  $\beta$ -keratin and on releasing the keratin back into  $\alpha$ -form [48]. The amino acid and sequence in wool varies with the variety of wool [49]. The average amino acid contents for major varieties of wool and silk are given in Table 1.8. R represents relatively large side chains which contain amino, carboxyl, sulphide groups and relatively 50% of the weight of wool

TABLE 1.8  
Amino Acid Content in Wool Keratin

R	Amino acid	Wool content (g/100 g fibre)	Fibrion content (g/100 g fibre)
H -	Glycine	5 - 7	36 - 43
CH <sub>3</sub> -	Alanine	3 - 5	29 - 35
(CH <sub>3</sub> ) <sub>2</sub> CH -	Valine	5 - 6	2 - 4
(CH <sub>3</sub> ) <sub>2</sub> CHCH <sub>2</sub>	Leucine	7 - 9	0 - 1
CH <sub>3</sub> CH <sub>2</sub> CH	Isoleucine	3 - 5	0 - 1
	Proline	5 - 9	0 - 1
	Phenylalanine	3 - 5	1 - 2
	Tyrosine	4 - 7	10 - 13
	Tryptophan	1 - 3	0 - 1
HOCH <sub>2</sub> -	Serine	7 - 10	13 - 17
	Threonine	6 - 7	1 - 2
-CH <sub>2</sub> SSCH <sub>2</sub> -	Cystine	10 - 15	0
CH <sub>3</sub> SCH <sub>2</sub> CH <sub>2</sub> -	Methionine	0 - 1	0
	Arginine	8 - 11	0 - 2
	Histidine	2 - 4	0 - 1
NH <sub>2</sub> (CH <sub>2</sub> ) <sub>4</sub> -	Lysine	0 - 2	0 - 1
HOOCCH <sub>2</sub> -	Aspartic acid	6 - 8	1 - 3
HOOC(CH <sub>2</sub> ) <sub>x</sub> -	Glutamic acid	12 - 7	1 - 2

is in the side chains. The cystine linkage and intermediate hydrogen bonding are

responsible for the shaping and setting characteristics of wool fibres and fabrics. Cystine linkages can occur within and between wool polymers. 35% of the exocuticle A-layer is made up of cystine residues and in addition to normal polypeptide bonds, the cuticle is cross-linked by isodipeptide bonds [ $\epsilon - (\gamma - \text{glutamyl}) \text{ lysine}$ ]. The polymer system of wool is extremely amorphous as it is about 25 - 30% crystalline and 70 - 75% amorphous. Modern views [50, 51] assert that two or three protein chains (some of which are  $\alpha$  - helical in structure) coil round to form a protofibril, a dozen of which aggregate to form micro-fibrils. These are located in close array within a matrix of protein material rich in cystine but with little structural regularity, para cortex containing more of the matrix. This two phase structure gives rise to the micro-fibrils observed in the cortex and points to the existence of more than one protein in wool.

#### 1.4.2 Impurities in raw wool

Raw wool is dirty and about 50% of its weight consists of natural and other impurities (Table 1.9). In general, the finer wools such as merino contains a higher

TABLE 1.9.

Impurities in Raw Wool (in %)

Type	Fat and suint	Sand and dirt	Vegetable matter	Wool fibre
Fine	20-50	5-40	0.5-2	20-50
Medium	15-30	5-20	1.5	40-60
Long	5-15	5-10	0.2	60-80

proportion of natural impurities than the coarse wool. The contaminants also vary according to breed, nutrition, environment and position of wool on the sheep. Wax, suint and dried perspiration are natural and dirt (adventitious), grass, seeds, straw, burrs, brambles, sticks etc. (vegetable matter) are acquired impurities. The presence of proteinaceous contaminant layer (PCL) is also found [50].

Chemically wool wax is a complex mixture of esters, diesters and hydroxy esters of high molecular weight lanolin alcohol and acids. The lanolin alcohol consists of three main types - aliphatic alcohols, sterols (such as cholesterol) and trimethyl sterols (such as lanosterols). The lanolin acid consists of four main types - normal, iso, anteiso and hydroxy acids. On exposure to the environment wool readily undergoes auto-oxidation. The reaction product (oxidised wool wax) be-

has differently from unoxidised material [51]. The differences manifest themselves in the scouring process of wool.

Suint is mainly water soluble constituents of raw fleece and is normally neutral or slightly alkaline in reaction. It contains potassium and to a certain extent sodium ions.

The cellulosic materials are finely entangled with the wool fibre and require chemical treatments for their removal. As well as the cellulose the wool burrs also contain hemi-cellulose and lignin.

### 1.4.3 Morphology and chemical structure of silk

Silk fibre is a fine continuous strand unwound from the cocoon of a moth caterpillar known as silkworm. The silkworm as a means of self-protection spins a cocoon around its body by extruding the contents of the two silk glands through a spinnerette at its mouth. The two filaments solidify on coming in contact with air and form a composite thread. The silkworms are generally cultivated. There are mainly four varieties of silk e.g. Mulberry, Tassar, Eri and Muga and each variety is produced by feeding on the leaves of certain plants. All the species of silk have four stages in their life cycles namely, the egg, larva, pupa and moth. The mulberry silkworm belongs to the species *Bombyx mori* and about 95% of the world's production is of this species. The other three varieties are produced by the worm *Antheraea mylitta* and are termed as wild silk. They are stiffer and coarser than mulberry silk. Raw silk thread is obtained from silk cocoons by reeling after boiling the cocoons in water. Several such threads are doubled together and twisted into a strong yarn necessary for weaving and knitting.

The morphological structure of raw silk fibre is given in Fig. 1-10. The actual fibre protein is called fibrion and the protein sericin is the gummy substance that holds the filament together. The average composition of raw silk is 70-75% fibrion ( $C_{15}H_{23}N_5O_8$ ), 20-25% sericin, 2-3% waxy substances extractable by ether and alcohol and 1 to 1.7% mineral matter. Sericin is amorphous and dissolves in hot soap solution. Fibrion is the form of a filament thread and dissolves in 5% sodium hydroxide solution at boil.

Both fibrion and sericin are protein substances built up of 16-18 amino acids, out of which only glycine, alanine, serine and tyrosine make up the largest part of the silk fibre (see Table 1.8) and the remaining amino acids containing bulky side groups are not significant. The chemical structure of fibrion and sericin for four

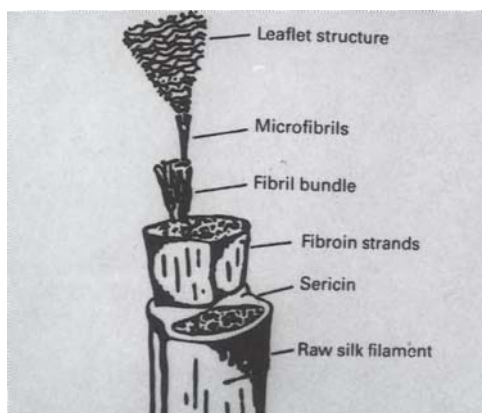


Figure 1-10. The structure of raw silk fibre.

amino acids is shown in Table 1.10. Fibroin contains hardly any sulphurous amino

TABLE 1.10

Amino Acid Composition of Sericin and Fibroin

Amino acids	Side groups	Sericin (% mol)	Fibroin (% mol)
Glycine	H –	14.75	45.21
Alanine	CH <sub>3</sub> –	4.72	29.16
Serine	CH <sub>2</sub> (OH) –	34.71	11.26
Tyrosine	OHC <sub>6</sub> H <sub>4</sub> CH <sub>2</sub> –	3.35	5.14

acids (cystine) and also only a minimal amount of amino acids as side chains. The low number of large side groups enables silk to be densely packed. The crystalline structure of the polypeptide chains in silk fibroin is shown in Fig. 1.11. Silk polymer occurs only in  $\beta$ -configuration. The important chemical groupings of the silk polymer are the peptide groups which give rise to hydrogen bonds, the carboxyl end amine groups which give rise to salt linkages and the Van der Waals' forces. It has high degree of molecular orientation which accounts for the excellent strength of the silk fibres. However, the polymer system of silk is now considered as being composed of layers of folded, linear polymer as shown in Fig. 1-12. Such a polymer system explains why silk is essential to be about 65-70% crystalline. The DP of silk fibroin is uncertain, with DP of 300 to 3000 having been measured in different solvents. Silk fibres are smooth surfaced and translucent with some irregularity

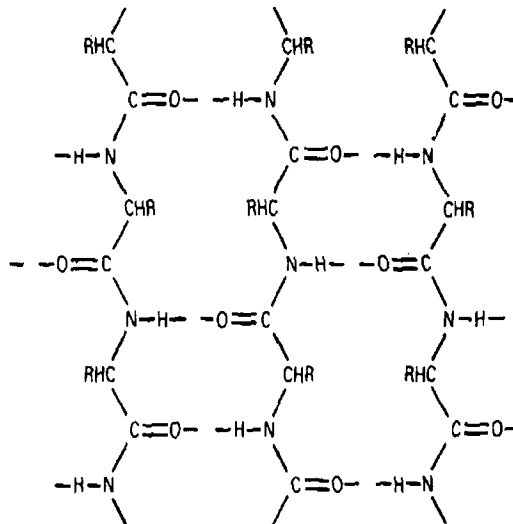


Figure 1-11. Crystalline structure of polypeptide chains in fibrin.

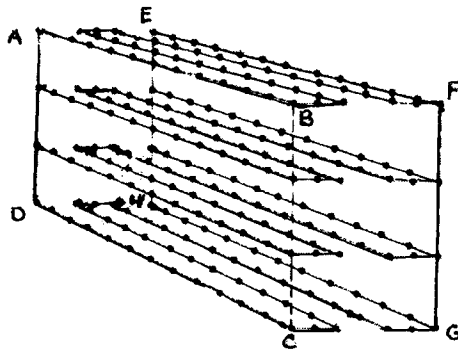


Figure 1-12. Laminated structure of silk.

in diameter along the fibre. The fibres are basically triangular in cross-section with rounded corners. The isoelectric point of silk is about 5.

### 1.5 Long Vegetable Fibres

The long vegetable fibres include various bast fibres, leaf fibres and fruit fibres. Among the bast fibres flax, remie, jute are the most important fibres. These fibres, which are used in cordage have suffered along with abaca, coir, henequen and sisal fibres as they are unable to withstand the onslaught of synthetic fibre cordage technology. Thus, the long vegetable fibres with their limited and fluctuating growth rates, cannot cope with rapid rise in global demand for industrial textiles. The advantage of these fibres is that they are eco-friendly fibres.



### 1.5.1 Flax (linen)

Flax is a bast fibre used to manufacture linen textiles. It is obtained from plant *Linum Usitatissimum* by a complicated process to separate fibre from the woody core. This process known as retting and can be done by dew retting [52], pool retting, tank retting, steam retting [53-55], chemical [56-59] and biochemical retting. After retting is complete, the stack is bundled together and passed between fluted rollers that breaks the outer woody covering into small particles. It is then subjected to scutching process, which separates the outer covering from the unusable fibre. After scutching, the flax fibres are hackled or combed to separate the short fibres (tow) from the long fibres.

Flax is considered to be the oldest fibre in the Western world and CIS (formerly USSR) grows most of the flax fibre. Linen has been gradually losing its position as an apparel fabric since 1950s, but the emergence of linen as a component of blends has stimulated considerable interest.

Flax fibres are multicellular, with each cell having tapering ends and a narrow lumen. The fibres show longitudinal striations and nodes (Fig. 1-13). The ultimate



Figure 1-13. Cross-section of flax fibre (E.I.DuPont de Nemours & Co.).

fibres are composed of elementary fibrils (microfibrils), which are spirally arranged [60]. The fibrils are held together by a bonding or gummy substances.

Cellulose is the main constituents of flax fibre (Fig. 1-14). The unretted flax contains about 16.7% hemicellulose, 1.8% pectins, 2% lignin and 1.5% fats and waxes. The polymer of flax consists with a degree of polymerisation of about 18000 cellobiose units. Flax is an assembly of ultimates cemented together within the fibres and an assembly of these fibres into bundles. These assemblies are prone

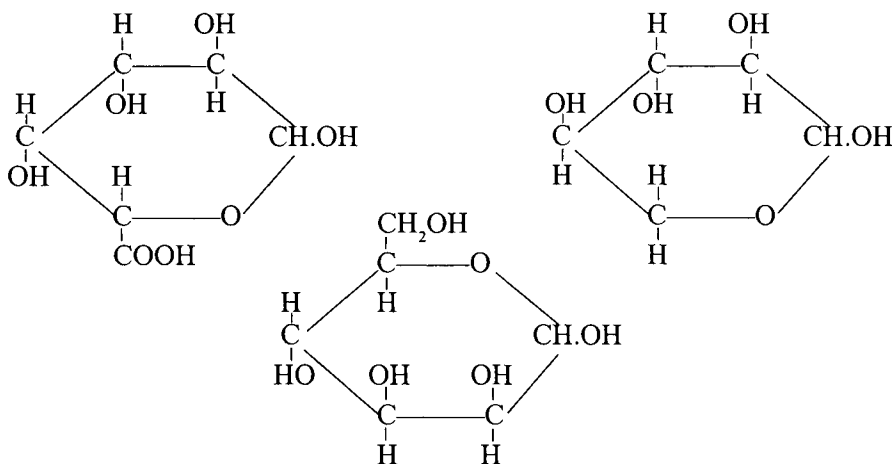


Figure 1-14. Chemical constitution of flax.  
(64% Cellulose + 16% Hemi-cellulose).

to discolouration [61]. It is the structure which makes linen feel like linen. Flax has relatively high strength. Disruption of structure by, for example, scouring referred to as cottonisation.

### 1.5.2 Remie

Remie fibre is white and lustrous and often referred to as china grass. Remie has been grown in Brazil to substitute flax. The fibre is stiff and fairly coarse like canvas. This fibre comes from plants *Boehmeria nivea* or *Boehmeria tenacissima* which belong to a family of stingless nettles. The remie fibres are removed from the stalks by the process of decortication. The fibres are released from ribbons or strands in which they are held together by natural gums. Commercial degumming is carried out by treating the fibres with caustic soda solution for 4 h. The use of mixed bacterial cultures [62] and enzymes [63] are also reported to remove the gum from remie fibre.

Purified remie fibre is composed of a single cellulose with wall with an S-spiral  $6^\circ$  to the axis [64,65]. Remie has the highest degree of both polymerisation and birefringences. The high strength of remie is attributed to its highly ordered structure. The crystalline areas increase in lateral size and decrease in crystalline orientation as the gum is removed from the intercrystalline areas [66].

Remie fibres tend to have a hairy feel which reduces their cohesion. They are smooth and cylindrical, with thick wall. The surface of the cell is marked by little

ridges. The cell of the fibre is long and the cross-section irregular in shape. The lumen narrows and disappears towards the ends of the cell. Remie fibre absorbs water rapidly and fabrics made from it will launder easily and dry quickly.

### 1.5.3 Hemp

Hemp comes from the plant, *Cannabis Sativa*, an annual of the family *Moraceae*, which grows to a height of 10 feet or more. The most important hemp producing countries are C.I.S., Yugoslavia, Rumania and Hungary. Fibre is freed from woody matter by a retting process, followed by breaking and scutching. This is then softened by pounding it mechanically or by hand. Hemp has cellulose content of about 67% and contains about 16% hemicellulose. Strands of hemp fibre may be 6 feet or more in length. The individual cell is, on average between 0.5 and 1 inch long. They are cylindrical in shape with joints, cracks, swelling and other irregularities on surface. Like flax, the cells of hemp fibre are thick walled, they are polygonal in cross-section. The central canal or lumen is broader than that of flax, however, the ends of the cells are blunt.

The fibre will not bleach easily and generally employed in the manufacture of ropes, twines, sacking, carpets, nets and tarpaulins. In addition, hemp also serves today as a raw material for paper industry. Cottonised hemp does not spin easily alone, but it gives useful yarn, when mixed with cotton (up to 50% hemp).

### 1.5.4 Jute

Jute is also a lignocellulosic bast fibre and is cultivated in a manner similar to that of flax. Jute is mainly grown in India, Bangladesh and Thailand. Jute fibre comes from herbaceous annual plant which grows as high as 20 feet. Jute fibres are extracted from the stem by retting which usually consists two stages : physical stage at which water is imbibed, swelling occurs, soluble substances are extracted and the microbial stage. Jute tends to be brown in colour due to about 20% lignin present in the fibre, but does have a silk like lustre.

The individual cells of jute are very short. Table 1.11 compares the dimension of ultimate from several sources. The cross-section of jute fibre is polygonal, usually with five or six sides. It has thick walls and a broad lumen of oval cross-section. By contrast with the regular lumen of flax, that of jute is irregular ; it becomes narrow in places quite suddenly. The lengths of various vegetable fibres varies considerably, whereas the diameter is moderately constant from fibre to fibre.

TABLE 1.11

Comparison of the Dimensions of Long Vegetable Fibres [67]

Fibre	Length (mm)	Diameter (nm)	Aspect ratio
Marino	4.6-5.2	17.0-21.4	255
Coir	0.9-1.2	16.2-19.5	60
Flax	27.4-36.1	17.8-21.6	1600
True Hemp	8.3-14.1	17.0-22.8	560
Sunn Hemp	3.7-6.0	23.0-35.0	170
Jute (Capsularis)	1.9-2.4	16.6-20.7	115
Jute (Cor. Olitorius)	2.3-3.2	15.9-18.8	160
Kenaf	2.0-2.7	17.7-21.9	120
Remie	12.5-12.6	28.1-35.0	4000
Mesta	2.6-3.3	18.5-20.0	150
Sisal	1.8-3.1	18.3-23.7	120
Urena	2.1-3.6	15.6-16.0	180

In flax the ultimates are much longer than those in jute, sisal and coir. The implication of this observation is that the 'cement' can be removed from the flax with little effect on tensile strength as hydrogen bonding still occurs over the large contact areas of the ultimates. In the case of fibres with short ultimates, such bonding does not occur and removal of the cement causes massive strength loss.

Jute fibres are bundles of fibrous material held together by a gummy substance of proteinaceous character. Chemically, jute fibres are composed of mainly polysaccharides and lignin, although the number of minor components, such as waxes, pectin, inorganic salts, nitrogenous substances, colouring matter etc., are also found. Table 1.12 compares the constitution of cotton with flax and jute. The total carbohydrate material is usually designated as holocellulose, which is further divided into two groups, namely  $\alpha$ -cellulose (true cellulose) and hemicellulose. Certain fractions of the hemicellulose may be chemically linked with the true cellulose. The formation of mixed crystals is postulated. Lignin is generally regarded as a

TABLE 1.12

Comparison of the Chemical Constitution of Jute with Flax and Cotton

Chemical constitution	Cotton average	Flax		Jute
		Retted	Unretted	
Cellulose	88-96	55.4	65.1	58-63
Hemicellulose	--	15.4	16.7	21-24
Pectins	0.7-1.2	2.5	1.8	0.2-15
Lignin	--	2.5	2.0	12-15
Proteins	1.1-1.9	--	--	0.8-1.8
Fats & Waxes	0.4-1.6	--	--	0.4-0.8
Ash (%)	--	--	--	0.6-1.2

three-dimensional polycondensate of dehydrogenation products of hydroxy and methoxy cinnamyl alcohols. The existence of ester-linkage between carboxyl groups in uronic acid of hemicellulose and hydroxyl groups of lignin is found. In general plant lignin resists the action of acids to a great extent. Coir with highest lignin content (35%) is most resistant to chemicals and micro-biological attack. Various properties of jute fibres are compared with flax in Table 1.13. Jute is not as strong

TABLE 1.13

Properties of Jute and Flax Fibres

Property	Evaluation	
	Flax	Jute
Lustre	High	Silky
Strength (tenacity)	6.5 g/d	3.5 g/d
Resiliency	Poor	Low
Density	1.54	1.50
Moisture absorption at 20°C	12%	13.7%

as flax or hemp. Jute fibres are stiff, but does have an unusually high moisture regain. Sunlight does not damage jute.

## 1.6 Regenerated Natural Fibres

There are three types of regenerated natural fibres - rayon, acetate and protein - the first two are derived from cotton linters or pine wood. Wool like protein based artificial fibres may be regenerated from animal and vegetable proteins.

### 1.6.1 Cuprammonium rayon

The preparation process of cuprammonium rayon is shown in Fig. 1-15. In

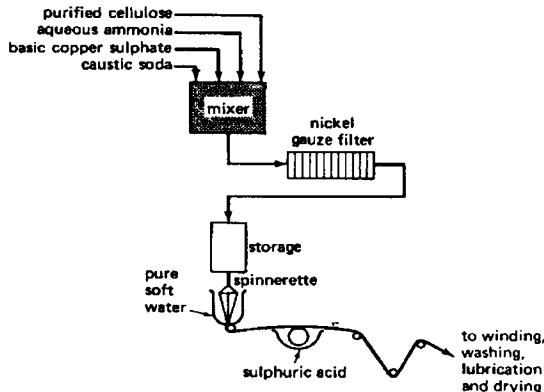


Figure 1-15. Flowchart showing process of cuprammonium manufacture.

order to make a spinning dope the basic copper sulphate is dissolved in ammonia, giving a solution of cupritetrammino hydroxide and sulphate in the molecular ratio of 3 : 1 and purified linters are added. Caustic soda is then added to convert the sulphate to corresponding hydroxide and filtered [68]. The chemical reactions are given in Fig. 1-16.

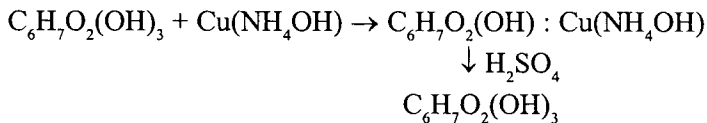


Figure 1-16. Formation of cuprammonium rayon.

The spinning solution is pumped through the spinnerette into a funnel through which soft water is running. The movement of water stretches the newly formed filament. The fibres then move to spinning machines, where they are washed, put through a mild acid bath to remove any adhering solution, rinsed and twisted into yarns.

### 1.6.2 Viscose rayon

Purified bleached wood pulp or sheets of cellulose are steeped in an alkali solu-

tion (17.5%) until the cellulose is converted to soda-cellulose. The alkali pulp is then shredded into alkali cellulose crumb, which is aged for specific time. The crumbs are then treated with carbon disulphide and produce sodium cellulose xanthate. This is dissolved in dilute sodium hydroxide and forms a honey coloured liquid and aged till required viscosity is obtained. The viscous solution is pumped to the spinning tanks, delivered to the spinning machines, forced by pump through a spinnerette into a dilute acid bath (Fig. 1-17). The method of making fibre is

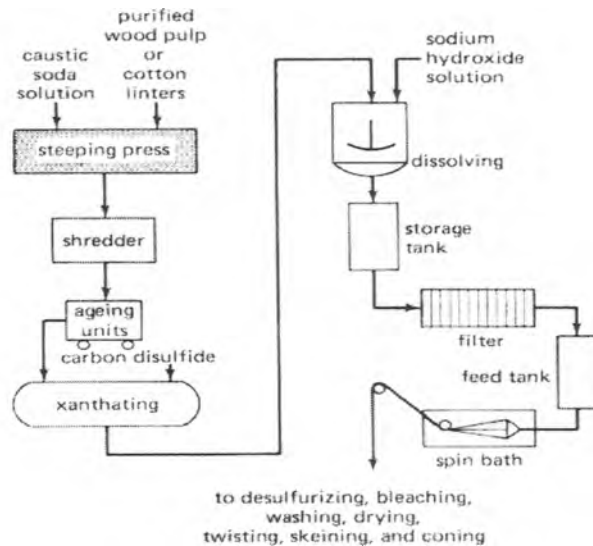
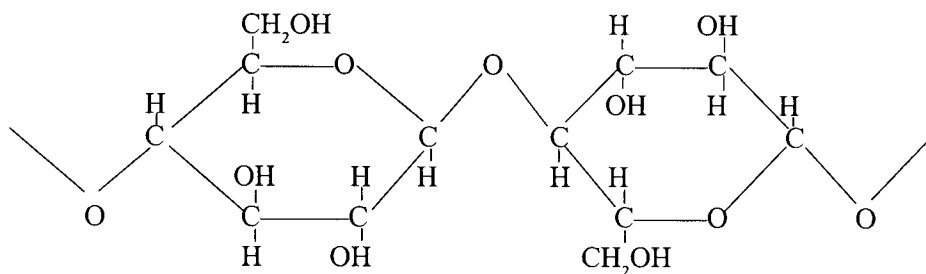


Figure 1-17. Viscose rayon manufacturing process.

called wet-spinning. The chemical changes that occurred in the process are outlined in Fig. 1-18. In the mid-1960s fibres with higher wet stretch, low wet extensibility and a high wet modulus (HWM) are produced and known as 'polynosic' or 'modal' type fibres. HWM fibres are generally produced [69,70] by adding modifiers, e.g. various amines or poly (ethylene) glycol to the viscose to control the rate of regeneration of the filament in the coagulation bath. They are usually produced as staple fibre.

Viscose and modified viscose are composed of cellulose and like cotton they are polymer of anhydroglucose unit. The significant physical differences between various regenerated cellulose and cotton polymers are listed in Table 1.14. HWM viscose rayon may appear nearly round in cross-section. Viscose polymers are very amorphous and have high moisture absorption capacity of 11 to 16%. Vis-



Each hydroxyl group is represented by :  $\begin{array}{c} \diagup \\ \text{C} \\ \diagdown \end{array} \text{-OH}$

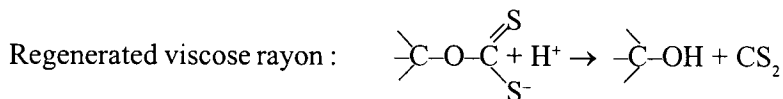
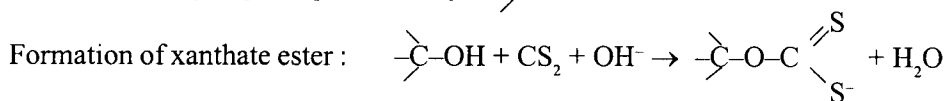


Figure 1-18. Viscose process.

TABLE 1.14

Significant Physical Differences Between Rayon and Cotton

Polymer	Approx. no. of cellobiose units	Approx. polymer length (mm)	Approx. polymer thickness (nm)	Approx. degree of polymerisation
Viscose	175	180	0.8	175
Polynosic	300	310	0.8	300
Cuprammonium rayon	250	260	0.8	250
Cotton	5000	5000	0.8	5000

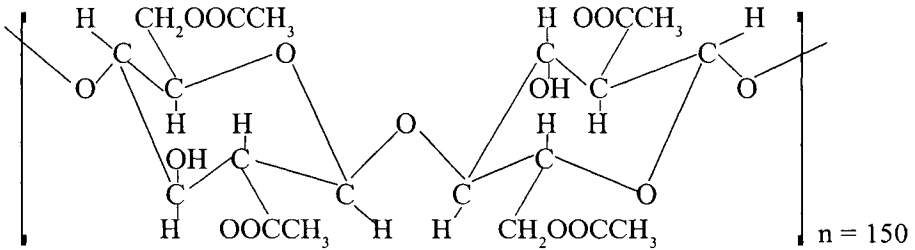
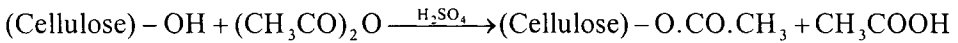
cose shows no discernible micro-structure, but polynosic shows a distinct fibrillar structure similar to cotton. Viscose fibres show longitudinal striations (tiny grooves), but cuprammonium and polynosic are coagulated much more slowly on extrusion, do not develop any striations. Folded chains model have been proposed [71] for the fine structure of viscose rayon (Cellulose II). The difference between Cellulose I and Cellulose II families appears in the arrangement of polarity of folded chains produced from the cellulose molecules [72].



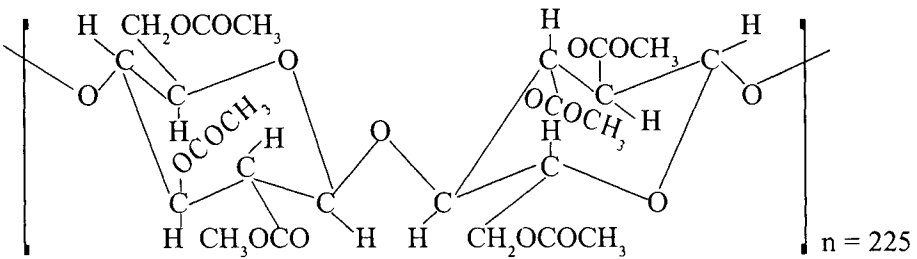
**1.6.3 Acetate fibres**

In this group there are two fibres : secondary cellulose acetate and triacetate fibres. Acetate fibres are produced from cotton linters or purified wood pulp, which are acetylated at temperature up to 50°C with acetic anhydride in presence of glacial acetic acid and concentrated sulphuric acid. It is then aged or ripened in presence of water and hydrolysis occurs during the ripening and results in the formation of secondary acetate. The flakes are then dissolved in acetone containing 4% water as the solvent to form the spinning dope, which is filtered and then forced through the spinnerette into a warm-air chamber and the method of spinning is called dry-spinning. Triacetate is manufactured from the same raw materials as secondary acetate, but the ripening stage in which hydrolysis occurs is omitted in triacetate production. To produce spinning solution, dried acetate flake is dissolved in methylene chloride and dry-spun into a warm-air chamber.

The chemical structure of acetate fibres are shown in Fig. 1-19. In secondary



Secondary cellulose acetate



Triacetate fibre

Figure 1-19. Formation of cellulose acetate fibres.

acetate polymer, it is the methylol hydroxyl group that is acetylated and one of the other hydroxyl group. Theoretically between 2.3 to 2.4 acetyl or acetal groups per glucose unit occur in secondary cellulose acetate polymer.

Both types of acetate fibres have a polymer "backbone" of hexagonal units. The macro structure of acetate fibres is very similar to that of viscose and displays no discernible micro-structures. Acetate fibre complicates close packing because of bulky structure. Both the fibres are amorphous (60% or less) and are held together by Van der Waals' forces. Triacetate has certain properties that are different from secondary acetate fibres (Table 1.15). Secondary acetate is about 160 nm

TABLE 1.15

Comparison of Physical Properties of Acetate Fibres

Property	Secondary acetate	Triacetate
Tenacity, g/den	1.2-1.5	1.2-1.4
Elongation, %	25-45	25-45 (filament)
Recovery (at 4% elongation), %	45-65	50-65 (at 5% stretching)
Moisture regain, %	6-6.5	2.5-3.0
Specific gravity	1.32	1.32
Melting point, °C	240	300

long and about 2.3 nm thick, whilst the triacetate is about 240 nm long and about 2.6 nm thick. Triacetates have much better resistance to boiling water and alkali. Triacetate is more expensive than secondary acetate. Both the fibres can be blended with cellulosic fibres to obtain special styling and performance characteristics. Tendency of acetate fibres to delustre in aqueous bath above 80°C force to dye these fibres at 75-80°C, giving poor wet-fastness properties. This short-coming of acetate has been removed recently (Xtol fibres) [73, 74].

#### 1.6.4 Regenerated portein fibres

The raw materials used for the preparation of regenerated protein fibres may be milk, soyabeans, peanuts and zein. Sometimes alkaline solutions of gelatin, albumin and other raw materials like waste wool, silk and feathers may be used. Fibrolane (Great Britain) and Merineva (Italy) are made by dissolving casein in sodium hydroxide, and then by extrusion into an acid/salt bath. The fibres formed in this way

is stretched as tow and partially stabilised by treatment with formaldehyde (Fig. 1-20).

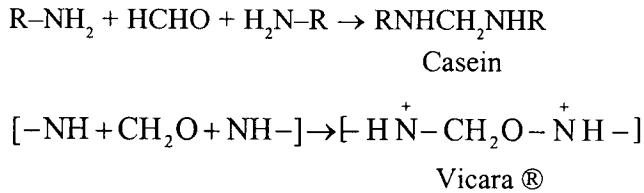


Figure 1-20. Regenerated protein fibres.

The general properties of regenerated protein fibres include the wool like attributes of resilience, warmth and soft handle. The strength is lower than wool. These fibres do not contain cystine linkage, which results in more open structure. These fibres are far less successful than hoped and never seriously challenged wool.

### 1.7 Synthetic Fibres

The classic researches of Wallace Hume Carothers on polymer synthesis started in the Du Pont (USA) in 1928 and bulk scale production of nylon 6 and nylon 6,6 started in 1939. J.R. Whinfield and J.T. Dickson discovered polyester in 1941 and was commercially manufactured by 1954. Yarn texturing and spin draw yarns produced at super high speeds have further increase the popularity of synthetic fibres [75, 76]. Polyester fibre accounts for more than 50% of the total synthetic fibre production.

#### 1.7.1 Polyester

Terephthalic acid or dimethyl terephthalate and ethylene glycol polymerise by condensation reaction to form the polyester polymer (Fig. 1-21). After

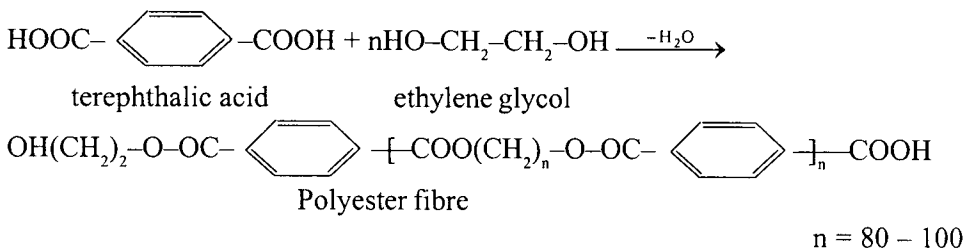


Figure 1-21. Chemical reactions in polyester formation.

polymerisation they are extruded in the form of ribbon, then cut into chips. The chips are dried and conveyed to a hopper, from which they are fed to the melt-spinning tank (Fig. 1-22). The hot solution is fed through the spinnerette and so-

lidifies into fibre form upon contact with air. It is stretched while hot to obtain strength.

Polyester is made up of fully extended planer chains and repeat unit along the chain is  $10.75\text{\AA}$  and the successive ester groups are essentially in the trans configuration of each other (Fig. 1-23). The polymer is held together mainly by Van der

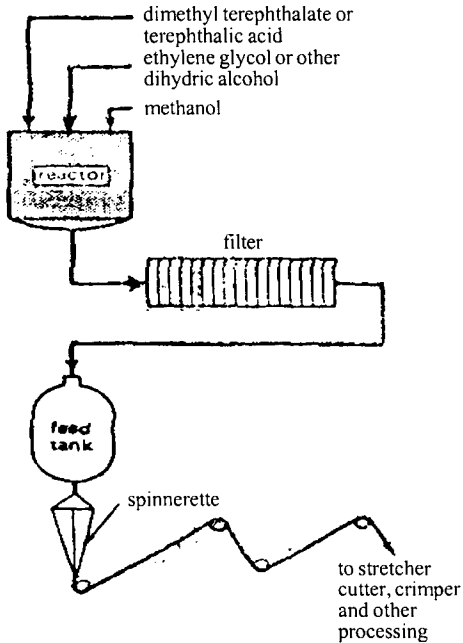


Figure 1-22. Flow diagram of polyester manufacturing process.

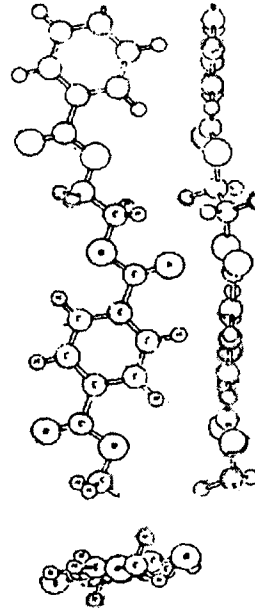


Figure 1-23. Structure of polyethylene terephthalate.

Waals' forces and to a lesser extent some weak hydrogen bonds. The polymer system is estimated to be about 65 to 85% crystalline.

The physical properties of polyester is given in Table 1.16. This fibre has high tensile strength, low moisture regain, high initial modulus and good crease recovery. Strong caustic alkalis at high temperatures hydrolyse and degrade the fibre and concentrated sulphuric acid disintegrates the fibre. Polyester dissolves in hot m-cresol, tri-fluoro acetic acid and o-chlorophenol.

The chemical modifications of polyester is mainly intended to overcome some of the inherent drawbacks of the fibre such as low dyeability, low moisture regain, static accumulation, soiling tendency, pilling property and flammability. Develop-

TABLE 1.16  
Physical Properties of Polyester

Property	Range
Tenacity, g/den	2.5-6.0
Elongation, %	12-15
Elastic recovery, %	90-96 at 2% extension
Average stiffness, g/den	8-25
Specific gravity	1.38
Moisture regain (standard condition), %	0.4

ments of both homo - and co-polyesters have continued and many modified polyesters have appeared with improved properties. The repeating units of some of the modified polyester are given in Fig. 1-24. Kodel II is based on 1,4 - dimethylcyclohexane terephthalate and give increased stability to hydrolysis. A-Tell is polyethyleneoxybenzoate (PEB) and has a silk like handle and drape, good wrinkle resistance and easy care properties. The self polymer of poly (pivalolactone) has better resistance to hydrolysis and a much higher melting point than the original aliphatic polyester. Polybutylene terephthalate (PBT) is a carrier free dyeable polyester with lower glass-transition temperature(Tg). Vycron (USA) is a modified polyester where terephthalic acid is partly reduced by isophthalic acid to open up the compact structure. Sulphonic acid group is introduced additionally into the isophthalic acid to dye with basic dye (CDPET). Similarly anionic dyeable polyester is also introduced containing nitrogenous compounds (polyamines) which offer basic group as sites for the adsorption of acid dyes. Thermotropic 'liquid crystal' philosophy has developed a fully aromatic polyesters like polyallylate fibres with very high tensile modulus (of the order of 100 Gpa). The cross-section of the regular polyester is round, of dacron (Du Point) is trilobal, of Fortel and Encron is T-shape, of Trevira (Hoechst) is pentalobal and of Kodel is trilateral. Changes that occur the cross-section produce fibres with different hand and appearance.

### 1.7.2 Nylon

The most popular of the aliphatic polyamides are nylon 6,6 and nylon 6. Nylon

Repeating unit	Fibre
$\left[ \text{O}-\overset{\text{O}}{\parallel}{\text{C}}-\text{C}_6\text{H}_4-\overset{\text{O}}{\parallel}{\text{C}}-\text{O}-\text{CH}_2-\text{C}_3\text{H}_5-\text{CH}_2\text{O} \right]_n$	Kodel II (Eastman Kodak)
$\left( \text{O}-\overset{\text{O}}{\parallel}{\text{C}}-\text{C}_6\text{H}_4-\text{O}-\underset{\text{H}}{\underset{\text{H}}{\text{C}}}-\underset{\text{H}}{\underset{\text{H}}{\text{C}}} \right)_n$	A - Tell (Japan)
$\left( \text{O}-\underset{\text{H}}{\underset{\text{H}}{\text{C}}}-\underset{\text{CH}_3}{\underset{\text{CH}_3}{\text{C}}}-\overset{\text{O}}{\parallel}{\text{C}} \right)_n$	poly (pivalolactone)
$\left[ \text{O}-\overset{\text{O}}{\parallel}{\text{C}}-\text{C}_6\text{H}_4-\overset{\text{O}}{\parallel}{\text{C}}-\text{O}-(\text{CH}_2)_4-\text{O} \right]_n$	polybutylene terephthalate
$\left[ \text{O}-\overset{\text{O}}{\parallel}{\text{C}}-\text{C}_6\text{H}_3(\text{SO}_3\text{H})-\overset{\text{O}}{\parallel}{\text{C}}-\text{O}-\text{CH}_2-\text{CH}_2 \right]_n$	Cationic dyeable polyester (CDPET)
$\left[ \text{O}-\overset{\text{O}}{\parallel}{\text{C}}-\text{C}_5\text{H}_4\text{N}-\overset{\text{O}}{\parallel}{\text{C}}-\text{O}-\text{CH}_2-\text{CH}_2 \right]_n$	Anionic dyeable polyester

Figure 1-24. Repeating units of some modified polyester [77].

6 is the polymerisation product made from  $\epsilon$  - caprolactum and nylon 6,6 is produced by polycondensation from adipic acid and hexamethylene diamine (Fig. 1-25). The 6,6 designation simply implies that each of the two raw materials

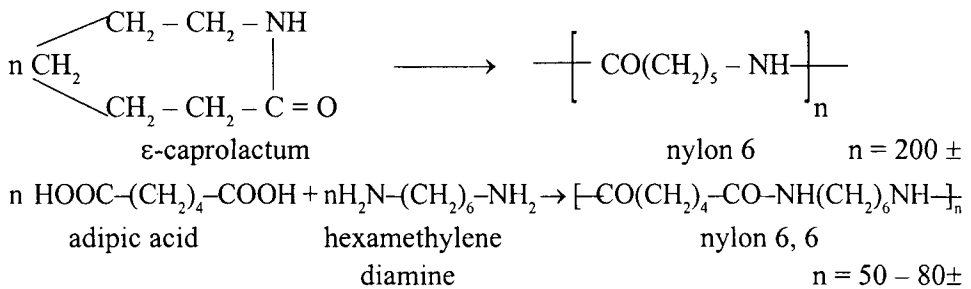


Figure 1-25. Chemical reactions in nylon 6 and 6, 6 manufacture.

contains 6 carbon atoms. Fig. 1-26 gives the flow chart showing steps in the manu-

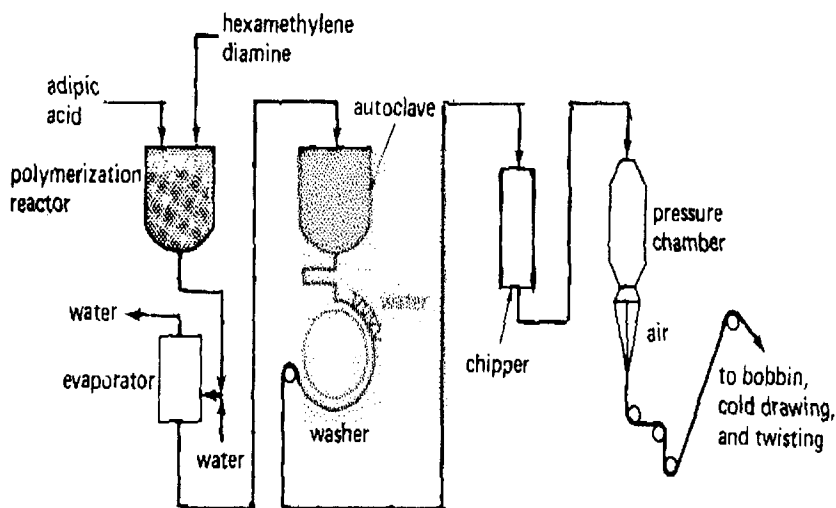


Figure 1-26. Flowchart showing steps in the manufacture of nylon 6, 6.

facture of nylon 6,6. Specific amounts of the two chemicals are combined in solution to form nylon salt. The salt is purified, polymerised, extruded in ribbon form and chipped into small flakes or pellets. The polymer is then melted and extruded through a spinnerette into cool air, where the filaments are formed. The filaments are then stretched or cold drawn to develop desired properties. Nylon staple is obtained by crimping filament tow and then cutting into short uniform lengths.

The estimated polymer length of nylon varies from 90 to 140 nm with polymer thickness of 0.3 nm. The amide linkage (-CO-NH-) owes its polarity to the slightly negative charge on its hydrogen atom, that is imino hydrogen. Many other nylons are synthesised (Fig. 1-27), amongst them 6, 10, 7, 11 etc. are marketed to some extent. Nylon filaments are smooth and shiny. When viewed in cross-section, nylon is usually perfectly round. They are highly resistance to alkalis and relatively less resistance to acids. The notable feature of various nylons is their moisture sorption and melting point (Table 1.17). The photochemical behaviour of nylon is less favourable and the fibre turns yellow on heat and oxidising agent treatments. Apart from these textured nylons are very popular.

The modified nylons can take several forms : changing cross-section of shape

Repeat unit	Fibre
$\left[ \begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ -\text{N}-\left( \begin{array}{c}   \\ -\text{C}- \\   \\ \text{H}_{10} \end{array} \right) -\text{C}- \\   \quad    \\ \text{H} \quad \text{O} \end{array} \right]_n$	Nylon 11
$\left( \begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \\ -\text{C}-\text{C}-\text{C}-\text{N}- \\   \quad   \quad    \\ \text{H} \quad \text{H} \quad \text{O} \end{array} \right)_n$	Nylon 3
$\left[ \begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ -\left( \begin{array}{c}   \\ -\text{C}- \\   \\ \text{H}_3 \end{array} \right) -\text{C}-\text{N}- \\   \quad    \\ \text{H} \quad \text{O} \end{array} \right]_n$	Nylon 4
$\left[ \begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ -\text{N}-\left( \begin{array}{c}   \\ -\text{C}- \\   \\ \text{H}_6 \end{array} \right) -\text{C}- \\   \quad    \\ \text{H} \quad \text{O} \end{array} \right]_n$	Nylon 7
$\left[ \begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ -\text{N}-\left( \begin{array}{c}   \\ -\text{C}- \\   \\ \text{H}_{11} \end{array} \right) -\text{C}- \\   \quad    \\ \text{H} \quad \text{O} \end{array} \right]_n$	Nylon 12
$\left[ \begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ -\text{N}-(\text{CH}_2)_6-\text{N}-\text{C}-\text{C}- \\   \quad    \quad   \quad    \\ \text{O} \quad \quad \text{O} \end{array} \right]_n$	Nylon 6, 10

Figure 1-27. Repeat units of various nylons.

TABLE 1.17  
Moisture Sorption of Various Nylons

Fibre	Moisture sorption (%) at 65% r.h.at 20°C	Sp. gr.	M. Pt. (°C)
Nylon 6	3.5-5.0	1.14	210
Nylon 6,6	3.8-4.5	1.14	250
Nylon 11	1.18	1.04	189
Nylon 4	Higher than cotton	--	--
Nylon 6,10	2.6	--	214

and changing the physical and chemical properties to improve dyeability, handle, tenacity, heat stability etc. The repeat units of some of the modified nylons are



given in Fig. 1-28. Both nylon 6T and Nomex have very high thermal resistance.

Repeat unit	Fibre
$\left[ \text{HN}(\text{CH}_2)_6\text{NHCO}-\text{C}_6\text{H}_4-\text{CO} \right]_n$	Nylon 6T
$\left( \text{N}(\text{C}_6\text{H}_4)_2\text{N}(\text{C}_6\text{H}_4)_2\text{C}(=\text{O}) \right)_n$	Nomex, Kevlar (Du Pont)
$\left( \text{C}_6\text{H}_4-\text{C}(=\text{N})\text{N}(\text{H})-\text{C}_6\text{H}_4-\text{C}(=\text{N})\text{N}(\text{H})-\text{C}_6\text{H}_4 \right)_n$	PBI (Celanese Corp.)
$\left[ \text{HN}(\text{C}_6\text{H}_9)\text{CH}_2\text{NHC}(=\text{O})(\text{CH}_2)_x\text{C}(=\text{O}) \right]_n$	Quina (Du Pont)
$\left( \text{N}(\text{C}_6\text{H}_4)_2\text{N}(\text{C}_6\text{H}_4)_2\text{C}(=\text{O}) \right)_n$	Polyimide
$\left( \text{C}_6\text{H}_4-\text{C}(=\text{O})\text{N}(\text{H})-\text{C}_6\text{H}_4-\text{C}(=\text{O})\text{N}(\text{H})-\text{C}_6\text{H}_4 \right)_n$	Kermel (Rohne-Poulenc)
$\left( \text{NH}-\text{C}_6\text{H}_4-\text{C}(=\text{O})-\text{NH}-\text{NH}-\text{C}(=\text{O})-\text{C}_6\text{H}_4-\text{C}(=\text{O}) \right)_n$	X-500 (Monsanto)

Figure 1-28. Repeat units of some modified nylons [78].

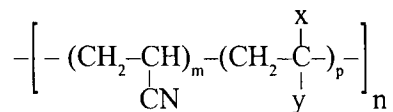
Nylon 6T melts at 370°C, Nomex is practically flameproof. Kevlar, poly(p-phenyleneterephthalamide) represents a break-through in high modulus aromatic polyamide fibre and mainly used as reinforcement tyres, conveyers belt etc., PBI is

obtained by reacting diaminobenzidine and diphenylisophthalate and is used as an alternate to asbestos in high temperature filtration and thermal protection clothing. Its moisture regain is high at 14.4%, which permits high degree of comfort [79]. Quina, with a trilobal cross section, is a polycondensate of diaminodiphenylmethane and decane dicarboxylic acid. It is distinguished by its silk-like handle and regarded as synthetic substitute for pure silk. Kermel is a polyamide-imide fibre made from either trimellitic anhydride chloride and a diamine or a diisocyanate. These polymers have reasonable thermal stability, very resilient and have excellent flame-resistance. The Monsanto's X-500 class of fibre, of which that prepared from polyamide-hydrazide is typical. Developments in melt-spinning have led to filaments with novel cross-sections or containing cavities to obtain improved properties, such as increased cover, a crisp, silk-like, firm hand, reduced pilling, increased bulk, sparkle effects and heightened resistance to soil. Generally, normal nylon has a rounded cross-section and Quina has trilobal cross-section. Cadon (Monsanto) has a rounded square cross-section with four cavities [80].

### 1.7.3 Acrylic fibres

Polyacrylonitrile (PAN) is a long chain polymer containing acrylonitrile [ $-\text{CH}_2-\text{CH}(\text{CN})$ ] as repeating unit in the polymeric chain and are formed by addition polymerisation. Acrylic fibre contains 15% or less copolymer. The modacrylic fibres are comprised of less than 85% but at least 35% by weight of acrylonitrile. The comonomers are added to increase the polymer thermoplasticity, solubility, dyeability, moisture regain, etc.

Thus, the molecular structure of copolymer of acrylonitrile and comonomer is represented as



$n = 150$  to  $200$  units

where  $m$  and  $p$  are number of monomer and comonomer units respectively in the polymer chain,  $n$  is the degree of polymerisation and  $x$  and  $y$  are the substituted groups of the comonomer. In general, there are three stages for the production of acrylic fibres, i.e., polymerisation, dope preparation and spinning (Fig. 1-29). Acrylonitrile is polymerised either by the suspension system in which water is used or

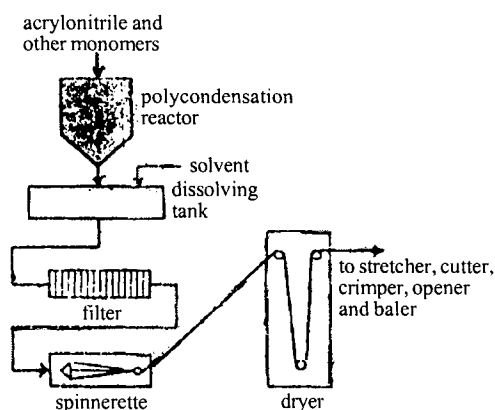


Figure 1-29. Stages for the production of acrylic fibres.

by the solution system where a solvent is used in the presence of suitable catalyst at appropriate temperature and time. The solution is then filtered and spun by the wet or dry-process. The yarn is drawn to increase the strength, twisted and coned. For the production of staple fibre tow is drawn, crimped, relaxed and cut into desired length and dried. Wet-spinning is preferred for large denier staple. Dry-spun fibres usually have a dog-bone cross-section and wet-spun have a round or bean shape.

Acrylic fibres have certain undesirable properties. To overcome such problems modifications of acrylics are made either chemically or physically (Table 1.18). Many vinyl compounds are listed in the literature [82]. The compounds possess a double bond which permits polymerisation by cleavage.

The acrylic polymer has a highly ordered structure in an oriented fibre, but only in lateral direction. The formation of radial pores during spinning has been attributed to the syneresis (or contraction forces) operating in the filament during coagulation. There is no evidence for a regular molecular arrangement along their lengths. Acrylic polymers are held together by Van der Waal's forces and it cannot be described as crystalline.

Acrylic fibres possess a very pleasing, warm and soft handle; fabrics made from it exhibit a silk-like lustre, hand and drape. An outstanding property of acrylic fibres is the comparatively low density which provides bulk and good coverage. The fibre has only 1.5% moisture regain and hence susceptible to static electricity. It has no definite melting point, it yellows on heating at 300°C and decomposes at

TABLE 1.18

Modification of Acrylic Fibres [81]

Modification	Means of Modification	Fibre obtained
Chemical modification	By comonomers	Enhanced dissolution and dyeing, Flame resistance, Antistatic, Improved hydrophilicity, Dyeing simultaneously with acid and basic colours.
	By polymer mixture	Graft polymerisation, Bicomponent fibres, Fibres from polymer mixture.
	Incorporation of additives	Enhanced whiteness and thermal stability, Flame retardant, Anti-soiling, Antistatic, Anti-pilling.
Physical modification	At polymerisation stage, dope preparation and spinning condition.	Hi-bulk fibres, Hollow fibres, Change of surface structure, Extreme denier fibre.

350°C. It has glass-transition between 85 and 100°C which appears to vary with molecular weight. It has poor resistance to strong acids, alkalies and to a few polar organic solvents. Its resistance to sunlight is good.

The modacrylic fibres have similar properties to those of acrylics and are flame resistant..Mostly this fibre is based on a 60/40 or 50/50 copolymer of acrylonitrile with vinylidene chloride ( $\text{CH}_2 = \text{CCl}_2$ ) together with small proportion of ternary monomer to improve ionic dyeability or hydrophilicity. The better known modacrylic fibres have a ribbon-shaped or pea-nut shaped cross-section. One problem encountered with modacrylic fibre is loss of lustre at the boil [83, 84]. This fibre is used for apparel, home furnishing, wigs etc.

### 1.7.4 Olefin fibres

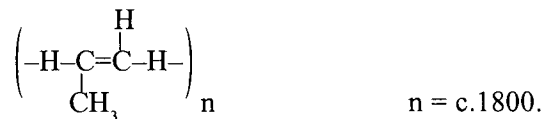
Polyethylene and polypropylene fibres are both used as fibre-forming for textile purposes. They are widely used in industrial fabrics. These two fibres can be bonded into non-woven fabric form and used as the base for tufted carpeting. Olefin fibres are relatively low in cost, but both the fibres have low melting points, low glass-transition temperatures and poor dyeability.

The polyethylene fibre is produced by either high pressure polymerisation of ethylene with a peroxide-catalysed process or low pressure polymerisation of ethylene using new catalysts systems. The molecular structure of polyethylene is a linear polymer of ethylene units with repeat unit of



Ordinary polyethylene of molecular weight ca  $10^4$  is drawn up to ten times in length but the gel-spinning method produces the fibre that can be drawn over thirty times and can yield a Young's modulus of 90 GPa. Fabrics made from this material possess high impact strength, high weather resistance and can be used for making bullet proof clothing, protective wear, filter, sailing cloth, parachutes etc.

The filaments of polypropylene fibre are produced from propylene using special catalysts. The polymerisation process involved is addition, as the double bond is broken in the propylene molecule, the monomer or single molecules join or add together. The filaments are produced by the melt-spinning process in a similar manner to polyester. The repeat unit of polypropylene is



When the propylene (monomer) polymerises, the pendent  $\text{CH}_3$  can lie in either direction. The randomly disposed  $\text{CH}_3$  group (atactic form) does not form good fibre. In the isotactic form the methyl groups are on the same side of the polymer backbone, but in syndiotactic arrangement the methyl groups lay alternately on either side of the polymer chain (Fig. 1-30). To produce this form of polypropylene, special catalysts are used.

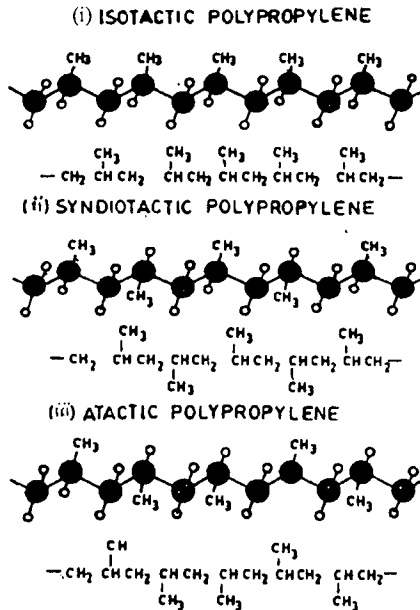


Figure 1-30. Stereostructures of polypropylene chain.

Unmodified polypropylene is highly crystalline. The absence of interchain hydrogen bonding effectively results in the fibre being a permanently swollen state. Stabilisation of polypropylene to heat, oxidation and light, particularly to ultraviolet radiation is extremely important and the patent literature on this subject is extensive. The unmodified polypropylene fibre is difficult to dye and extensive attempts have been made to modify the fibre structure by the introduction of dye-receptive sites [85-89]. Moisture absorption of polypropylene is virtually zero. The fibre has high tensile strength and good resistance to acids and alkalis. With a specific gravity of about 0.9, the fibre is the lightest fibre group. The melting point of polypropylene is 176°C. Polyolefin fibres resemble glass rod in longitudinal and cross-sectional view. The monofilament polypropylene is mainly used in outdoor furniture webbing, in car seat covers, swimming pool covers, filter fabrics, in the ropes and cordage fields etc. The multifilament yarns can be used as blankets, upholstery fabrics, sweaters, carpets, pile fabrics, stockings and can play a major role in non-woven fabrics.

### 1.8 Miscellaneous Synthetic Fibres

There are many other synthetic fibres have been developed over the years in

many countries, but only a few of them are used for apparel as well as commercial and industrial use. Though these fibres are not widely used but the science and technology of these fibres are briefly discussed from the academic point of view.

### 1.8.1 Chlorofibres

Poly (vinyl chloride) fibre used for textiles is manufactured from acetylene and hydrogen chloride which is dissolved in mixtures of carbon disulphide and acetone for dry-spinning of normal vinyl chloride (PVC) homopolymer. The fibres are copolymer of vinylchloride / vinylidene chloride and vinyl cyanide or vinyl acetate. The fibre is stretched to varying degrees as it leaves the spinning jet to give different types of filaments. The repeat units of some of the chlorofibres are shown in Fig. 1-31. The water absorption of these fibres are extremely low, softening

Fibre	Repeat unit
Dynel® (Union carbide)	$\left[ \left( \text{CH}_2 - \underset{\text{Cl}}{\text{CH}} \right)_x - \left( \text{CH}_2 - \underset{\text{CN}}{\text{CH}} \right)_y \right]_n$ <p style="text-align: right;">x = 60%, y = 40%</p>
Saran® (Dow Chem. Corpn.)	$\left[ \left( \text{CH}_2 - \underset{\text{Cl}}{\text{C}} \right)_x - \left( \text{CH}_2 - \underset{\text{Cl}}{\text{CH}} \right)_y \right]_n$ <p style="text-align: right;">x &gt; 80%, y &lt; 20%</p>
Vinyon® (Avtex Fibres Inc.)	$\left[ \left( \text{CH}_2 - \underset{\text{Cl}}{\text{CH}} \right)_x - \left( \text{CH}_2 - \underset{\text{OOCCH}_3}{\text{CH}} \right)_y \right]_n$ <p style="text-align: right;">x = 85%, y &lt; 15%</p>

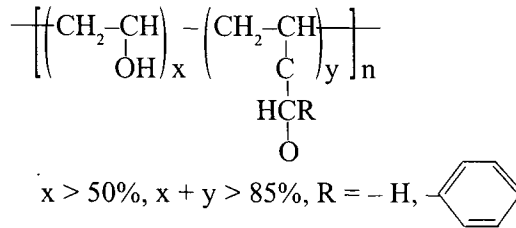
Figure 1-31. Repeat units of some chlorofibres.

temperature is low with considerable shrinkage at 70°C and have poor dyeability at moderate temperatures. These fibres are mainly used in filter cloths, flying suits (in which their property of non-flammability is an asset), curtains (owing to their resistance to degradation of light) and fishing nets (owing to their resistance to water). These fibres have regular round, dogbone or dumbbell shaped cross-section and transparent, even and smooth. They are highly lustrous and silky in hand.

### 1.8.2 Poly (vinyl alcohol) fibres

Polyvinyl alcohol is manufactured indirectly by the hydrolysis of poly (vinyl

acetate). The polyvinyl alcohol is solution-spun to form the fibres and hot stretched at 200°C. As extruded, the fibre is water soluble and must be treated with formaldehyde to make them insoluble. The repeat unit of Vinal® is



The crystalline poly (vinyl alcohol) has a kinked chain with three monomer per repeat [90]. This fibre possesses good resistance to acids, alkalies and most organic solvents except formalin, phenol, cresol and formic acid above 60°C. It can be blended with cellulosic fibres and dyed. Vinal does not support combustion; it softens at 200°C and melts at 220°C. Allied Inc. of USA has developed high modulus high tenacity super high molecular weight PVA fibre by gel-spinning and the properties of PVA are similar to those of Aramid fibres. This fibre is employed in protective apparel-rain coats, jackets, hats, umbrellas, suiting and lining fabrics, socks and gloves. Industrial uses include fishing nets, filter fabrics, tyre cord, tarpaulins and bristles.

### 1.8.3 Elastomeric fibres

Spandex is the generic term applicable to all elastomeric fibres in which the fibre forming substance consists of at least 85% of a segmented polyurethane. The first elastomeric fibre, Lycra was developed by Du Pont around 1958. The fibres are characterised by extremely high elongation and outstanding elastic recovery. The chain molecules are made up of hard segments - crystalline, high melting polyurethane - and of soft segments-low melting, amorphous polyester or polyethers. Hydrogen bonds are mainly formed between the hard segments [91.92]. Elastic hard fibres may be prepared from polypropylene, poly (3-methylbut-1-ene), poly (oxymethylene) [93] and poly (isobutene oxide) [94] and largely based on 4, 4' - methylenebis (4-phenylisocyanate), utilising diamine or glycol extenders. Fig. 1-32 provides a simplified outline of commercial chemistries and Fig. 1-33 shows an overview of dry-spinning process of Spandex.

Spandex fibres have dogbone to rounder cross-section and tend to be larger in



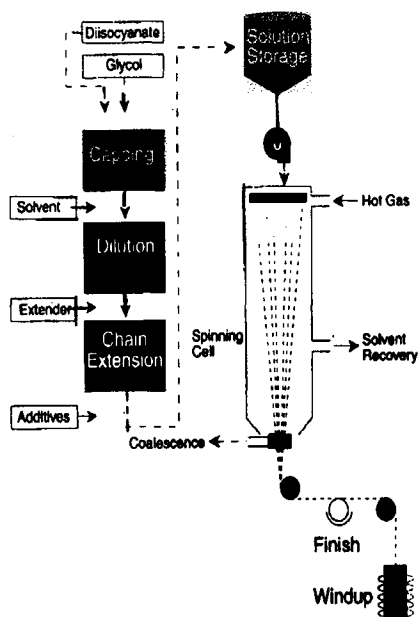
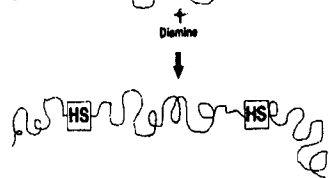
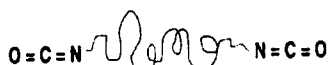
**Prepolymer reaction****Chain extension reaction**

Figure 1-32. Prepolymer reaction, chain extension reaction.

Figure 1-33. Dry-spinning process of Spandex.

diameter. Spandex have a density of  $1.0 - 1.2 \text{g/cm}^3$ , moisture absorption is  $0.3 - 3\%$ , while elongation at break amounts  $450 - 900\%$  and  $95\%$  elastic recovery from  $200\%$  extension. This fibre has glass-transition temperature below  $0^\circ\text{C}$ , so that soft components have a considerable freedom of movement at room temperature and above. Elastomeric fibres are resistant to dilute and cold acids, and also to alkalis. They can be ironed safely at temperatures below  $150^\circ\text{C}$ . They are used for such purposes as swimwear, foundation garments, sports wear, hosiery, bras, sock tops and medical products requiring elasticity.

#### 1.8.4 Carbon fibres

Carbon fibres are manufactured from rayon and polyacrylonitrile. Carbon fibres can be heated up to  $1500^\circ\text{C}$  and contains up to  $95\%$  of elemental carbon. Graphite fibres can be heated above  $2500^\circ\text{C}$  with  $99\%$  carbon. The formation of carbon fibres from polyacrylonitrile is outlined in Fig. 1-34. Carbon fibres are used in the aerospace industry, in compressor blade to jet engines, helicopter rotor-blades, aircraft fuselage structures, golf-club shafts, cross-bows for archery and in high speed reciprocating parts in loom.

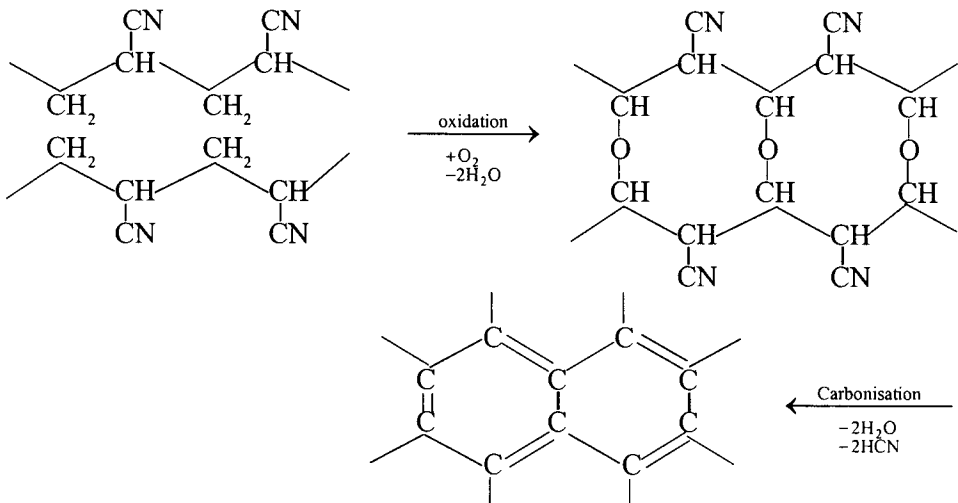


Figure 1-34. Formation of PAN based carbon fibres [95].

### 1.8.5 PTO fibres (Enkatherm)

Enkatherm, a high temperature flame-proof fibre is based on poly (terephthaloyl oxalic-bis-amidrazone) (PTO). This fibre is produced by wet-spinning and then drawn [96,97]. The formula of PTO and chelated forms of PTO is shown in Fig. 1-35.

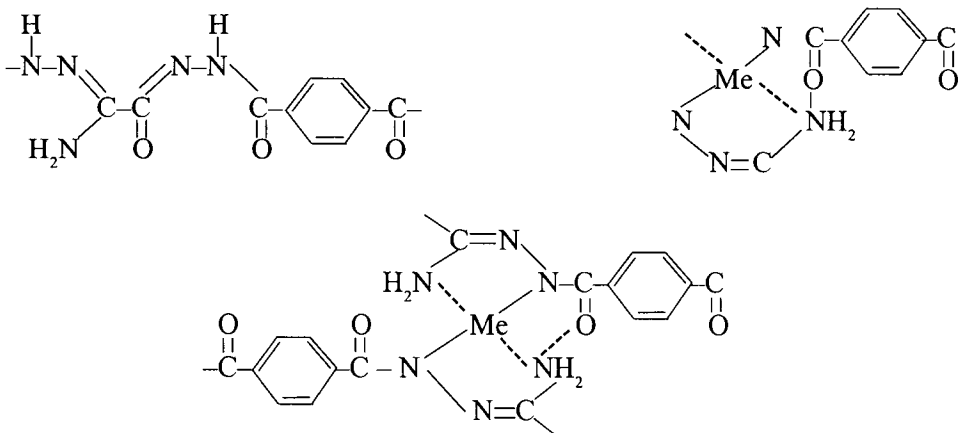


Figure 1-35. Formula of repeat unit of PTO fibre, showing possible chelated form.

### 1.8.6 Other synthetic fibres

Many other synthetic fibres are found in the literature, the trade names of some of them are Novoloid, PBI, Polycarbonate, Alginate, Fluorocarbon (Teflon), min-

eral fibres like glass, ceramic and asbestos fibres, bicomponent and biconstituent fibres etc.

Novoloid is the designation assigned for a class of flame retardant fibre made from cross-linked phenol formaldehyde polymers. Polybenzimidazole, or PBI is nonflammable, comfortable, flexible and used in apparel for space and for drogue chutes and undersuit for astronauts. Polycarbonate fibres are linear polyesters of aliphatic or aromatic dihydroxy compounds with carbonic acid [98] and has excellent resistance to heat and weathering. The raw materials for glass fibre are primarily silica, sand and lime stone with modifiers like aluminium hydroxide, sodium carbonate, and borax [99]. Major uses of the fibre are in window curtains, tablecloths, ironing board covers, lampshades screens etc. The production of electrically conductive fibres [100 - 102] and metallised fibres [103,104] are reported. In perfumed fibres (Mistubishi Rayon) the essence is captured in four pedal-like cavities arranged radially in a hollow fibre. The essence is gradually released through the fibre cross-section produces the refreshing effect typical of deep forests and induces good sleep. Apart from these, textile fibres for medical applications, artificial skin, fibres produced by bacterias like bacterial cellulose, polyester and Bioplastics and carbon fibres from wood, optical fibres and new polytetramethylene ether glycol (PTMEG) from tetrahydrofuran (THF) for elastomeric material (Tetrathene by Du Pont) etc. are the recent advances in the field of fibre science and technology.

Bicomponent fibres are synthetic fibres composed of two firmly but separately combined polymers of different chemical and physical structures. The structure of the bicomponent depends on the shape of the spinnerette orifice (side-by-side, sheath core, matrix - fibril and multi-fibrillary) and the type of spinning method. Due to the structural differences, the two components shrink differently on heat treatment and form crimp and greater bulk in the fibre. The first fully synthetic bicomponent was an acrylic (Sayelle, Orlon 21). The use of sheath-core fibres composed of nylon 6,6 and nylon 6 (Heterofil, ICI) for floor coverings is described.

Biconstituent fibres consisting fibrils of a polymer aligned parallel to the fibre length interspersed in a continuous matrix of another polymer and their structure, resembles the bilateral structure of wool. Clearly fibrillar-matrix ratio and the nature and relative dimension of the components can be altered to vary the physico-

chemical properties. Some of the important biconstituent fibres are Monvelle (Nylon/Spandex), Source (Polyester/Nylon), Chinon (Acrylonitrile/Casein), Mirafi 140 (Nylon / Olefin), Polychlal (Polyvinyl chloride/ Polyvinyl alcohol) etc. New and improved types of bicomponent and biconstituent fibres continue to find increasing application in knitting, hosiery and carpeting [105,106].

## REFERENCES

- 1 C. Z Carroll Porezynski, Natural Polymer & Man-made Fibres, National Trade Press Ltd., London, 1961.
- 2 A. A. Dembeck, Guide Book of Man-made Textile Fibres and Textured Yarns of the World, 3rd ed., United Piece Dye Works, New York, 1969.
- 3 Man-made Fibre Fact Book, Man-made Fibre Process Assoc., Inc., Washington, 1974.
- 4 M. L. Rollins, The American Cotton handbook, Dame S. Hamby, Ed., Interscience Publishers, New York, 1965.
- 5 J. Labarthe, Elements of Textiles, Macmillan Pub. Co., New York, 1975.
- 6 G. Tayme and K. L. Balsler, *Melliand Textilber.*, 51 (1970) 3.
- 7 K. Hess, H. Mahl and E. Güter, *Kolloid - Z. Z. Polymer*, 155 (1957) 1.
- 8 H. Ruck, *Faserforsch, Textiltech*, 14 (1963) 146.
- 9 M. L. Rollins and V.W. Tripp, *Textile Res. J.*, 24 (1954) 345.
- 10 M. Marx-Figini, *J. Polym. Sci.*, 28c (1969) 57.
- 11 G. Raes, T. Fransen and L. Verchraege, *Textile Res. J.*, 38 (1968) 182.
- 12 P. Kassenbeck, *Textile Res. J.*, 40 (1970) 330.
- 13 J. T. Hebert, R. Giardina, D. Mitcham and M.L. Rollins, *Textile Res. J.*, 40 (1970) 126.
- 14 N. Morrosoff and P. Ingram, *Textile Res. J.*, 40 (1970) 250.
- 15 R. Meredith, *J. Textile Inst.*, 42 (1951) 291.
- 16 A.K. Kulshershta , N.E.Dweltz and T. Radhakrishnan, *Indian J. Pure Appl. Phys.*, 9 (1971) 986.
- 17 A. Viswanathan, *Cellulose Chem. Technol.*, 9 (1975) 103.
- 18 G.V. Hornuff and R. Richter, *Faserforsch u. Textiltechn.*, 15 (1964) 165.

- 19 E.R.McCall and J.F.Jurgens, *Textile Res. J.*, 21(1951) 19.
- 20 G. Rosch, *Textile Praxis*, 43 (1) (1988) 61.
- 21 V. W. Tripp, A. T. Moore and M. L. Rollins, *Textile Res. J.*, 21 (1951) 880.
- 22 R. G.Fargher and J. C.Withers, *J. Textile Inst.*, 13 (1922) T 1.
- 23 V. Hornuff and H.Richter, *Faserforschung und Textiltechnik*, 15 (1964) 115.
- 24 E. Frieser, *Textil Rundschau*, 15 (1960) 472.
- 25 E. Frieser, *Textil Rundschau*, 16 (1961) 76.
- 26 L. F. Cavaliere and M. L. Welfrom, *J. Am. Chem. Soc.*, 68 (1946) 2022.
- 27 P. H. Clifford and H.E. Probert, *J. Textile Inst.*, 15 (1924) T401.
- 28 P. B. Marsh, H. D. Barker, T. Kerr and M. L. Butler, *Textile Res. J.*, 20 (1950) 288.
- 29 C. Zerbe, *Mineralole und Verwandte Produkte*, Springer Verlag, Berlin, 1952.
- 30 E. Frieser, *Textil Rundschau*, 16 (1961) 76.
- 31 K. Hess, *Melliand Textilber.*, 24 (1943) 384.
- 32 V. V. Safonov and L. V. Ahep'eva, *Khimichiskaya Premyshlennost*, 23 (1) (1991) 17.
- 33 R. Freytag, *Textilveredlung*, 11 (1976) 82.
- 34 A. C. Walkar and M. H. Quell, *J. Textile Inst.*, 24 (1933) T 131.
- 35 R. L. Whistler, A. R. Martin and M. Harris, *Am. Dyestuff Rep.*, 13 (1940) 252.
- 36 International Wool Secretariat cited by [37].
- 37 E. V. Truter, *Wool wax* (London Cleaver-Hume Press, 1956).
- 38 M. L. Schlossman and J. P. McCarthy, *J. Amer. Oil Chem. Soc.*, 55 (1978) 447.
- 39 H. R. Chipalkatti, A. D. Sule, K. K. Juneja and M. C. Aggarwal, *J. Textile Inst.*, 56 (1965) T 649.
- 40 U. Kalkbrenner, A. Kroner, H. Hocker and D. E. Rivett, *Schrift, DWI*, 105 (1990) 67.
- 41 A. P. Negari, H. J. Cornell, D. E. Rivett, *J. Soc. Dyers Colourists*, 109 (1993) 296A.
- 42 A. P. Negari, H. J. Cornell and D. E. Rivett, *Textile Res. J.*, 63(2) (1993) 109.
- 43 J. D. Leeder and J. A. Rippon, *J. Soc. Dyers Colourists*, 101 (1985) 11.

- 44 M. Ramanathan, T. Sikorski and H. J. Woods, *Int. Wool Text. Res. Conf.*, Aug. 1955, F 92.
- 45 M. Horio and T. Kondo, *Textile Res. J.*, 23 (1953) 373.
- 46 E. H. Mercer, *Textile Res. J.*, 23 (1953) 331.
- 47 Bone's and T. Sikorski, *J. Textile Inst.* 58 (1967) 521.
- 48 J. W. S. Hearle and R. H. Peters, *Fibre Science*, Butterworth & Co., London, 1963.
- 49 E. Bendit, *Textile Res. J.*, 38 (1968) 15.
- 50 C. A. Anderson, *J. Textile Inst.*, 73 (1982) 289.
- 51 S. R. Christoe, D. K. Pham and B. O. Bateup, *Textile Asia* (Apr 1994) 45.
- 52 A. M. Shisko et al., *Vetsi Akad. Navuk BSSR, Ser. Sci.*, 23 (1981) 197.
- 53 L. K. Minichev, *Technol. Textile Industr. USSR*, 5 (1969) 141.
- 54 L. K. Minichev, *Tekhnol Tekstil Prom.*, 72 (5) (1969) 139.
- 55 L. V. Yudaeva et al., *Tekhnol. Tekstil Prom.*, 157 (1) (1984) 46.
- 56 T. Todorov, *God. Sofil Univ., Biol. Fak.*, 59 (2) (1964/65) 59.
- 57 R. Kozłowski and J. Tabisz, *Proc. Inst. Prezm. Wlok Lykawych*, 15 (1968) 113.
- 58 H.S.S.Sharma, *Biotechnol.lett.*, 8 (1986) 219.
- 59 A. M. Shishko, *Khim. Drev.*, 1 (1984) 95.
- 60 J. A Turner, *J. Textile Inst.*, 39 (1948) 150.
- 61 C. Blum, *European Textile Research : Competitiveness through innovation*, Elsevier, London, 1985.
- 62 N. B. Paul and S. K. Bhattacharya, *J. Textile Inst.*, 70 (1979) 512.
- 63 G. B. Brav'ova, K. A. Kalunyants and R. N. Grebeshova, *Tr-Vses. Nauchno-Issled, Inst. Biosint. Bekovykh Veshchestv*, 2 (1974) 177.
- 64 P. A. Roelofosen, *Textile Res. J.*, 21 (1951) 412.
- 65 J. O. Warwick, *J. Polym. Sci, Part A-z*, 4 (1966) 571.
- 66 P. K. Roy, S. C. Bag and A. C. Chakraborty, *J. Appl. Polym. Sci.*, 19 (1975) 999.
- 67 D. H. Bowen, *Structure and morphology of vegetable fibres*, IJIRA, Golden Jubilee Seminar, 6-7th Nov. 1987.
- 68 German Patent 98642, *Manufacture of Cuprammonium Rayon Filaments*, Hermann Pauly.

- 69 Paul and Muller, *J. Appl. Polym. Sci.*, 12 (1968) 487.
- 70 Goldenberg, *Text. Chem. Color.*, 1 (1969) 394.
- 71 S. Watanabe, J. Hayshi and T. Akahori, *J. Polym. Sci., Polymer Chem. Edn.*, 12 (1974) 1065.
- 72 T. Akahori, J. Hayashi and S. Watanabe, *Sen - i Gakkaishi*, 30 (1974) 179.
- 73 J. M. Taylor and P. Mears, *J. Soc. Dyers Colourists*, 107 (1991)64.
- 74 P. Lennox - Kerr, *Textile Horizon*, 11 (1991) 33.
- 75 Du Pont, *British Patent*, 106810 (1972).
- 76 T. Kawaguchi and A. Zizbicki., (Ed), *High Speed Spinning*, J. Wiley & Sons, N. Y., 1986.
- 77 S. R. Karmakar, *Colourage, Annual* (1989/90) 73.
- 78 S. R. Karmakar, *Textiles and Dyestuff, Annual* (1978) 47.
- 79 L. R. Belohalv, *Angew. Makromol. Chem.*, 40/41 (1974) 465.
- 80 *Mod. Text. Mag.*, 50 (May 1969) 52.
- 81 S. R. Karmakar, *Colourage, Annual* (1986) 63.
- 82 J. J. Press, ed., *Manmade Textile Encyclopedia*, Wiley-Interscience, New York (1959).
- 83 R. O. Rutley, *Textile Mfgr.*, 94 (1968) 211.
- 84 H. Kellet, *J. Soc. Dyers Colourists*, 84 (1968) 257.
- 85 Asahi Kasaie Kogyo, *BP 1*, 148, 649 (1966).
- 86 Eastman, *USP 3*, 240, 551 (1961).
- 87 ACY, *USP 3*, 278, 255 (1964).
- 88 S. R. Karmakar and P. Kulkarni, *Synthetic Fibres*, 23 (4) (1994) 7.
- 89 S. R. Karmakar, and S. Singh, *Colourage, Annual* (1997) 20.
- 90 R. Meredith, *Textile Progress*, 7 (4) (1975) 36.
- 91 H. Oertel, *Melliand Textilber.*, 46 (1965) 51.
- 92 H. Rinke, *Chimia (Aarau)*, 16 (1962) 93.
- 93 R. G. Quynn and H. Brody, *J. Macromol Sci., (Phys.) B5* (1971) 721.
- 94 T. Yamazaki, S. Oya, N. Tsukani, K. Tanaka, M. Toba and K. Yamagishi, *Polymer*, 16 (1976) 425.
- 95 R. M. Gill, *Carbon Fibres in Composite Materials*, Iliffe Books, London, 1972.
- 96 D. W. Van Krevelen, *Angew Makromol. Chem.*, 22 (1972) 1333.

- 97 F. C. A. A., van Berkel and H. Grotjahn, *Appl. Polymer-Symp. No. 21* (1973) 67.
- 98 B. Von Falkai and E. C. Werner, *Melliand Textilber.*, 53 (1972) 1197.
- 99 H. L. Needles, *Textile Fibres, Dyes, Finishes and Processes - A concise Guide*, Noyes Pub., New Jersey, USA, p 117.
- 100 F. Marchini, *Chemiefasern / Textilindustrie*, 40/92 (1990) E 137.
- 101 G. Aviv, *J. Soc. Dyers Colourists*, 105 (1989) 406.
- 102 F. Marchini and V. Massa, *Chemiefasern / Textilindustrie*, 38/90 (1988) T5.
- 103 H. Ebneith, *Textilveredlung*, 21 (1986) 105.
- 104 K. V. Datye, *Rev. Prog. Col.*, 21 (1991).
- 105 H. Rest, *Hosiery Times*, No. 40 (1967) 75.
- 106 Anon, *Hosiery Trade J.*, (June 1966) 92.



## *Chapter 2*

### **PREPARATION BEFORE CHEMICAL PROCESSES**

#### **2.1 Introduction**

After the grey fabrics have been received in the grey room by the finishing enterprises, the bales are opened and inspected, a process which is increasingly mechanical, but much of it remains subjective. The most important point is to obtain fabrics “free from exterior impurities” in order to achieve smooth and trouble free results in the subsequent finishing systems.

#### **2.2 Inspection**

It is checked whether the grey fabrics are in conformity with standards, and all weaving faults are marked out. Fabric inspection involves three possible steps : perching, burling and mending. Perching is a visual inspection and the name derives from the frame, called a perch, of frosted glass with lights behind and above it. The fabric passes through the perch and is inspected (Fig. 2-1). Flaws, stains or



Figure 2-1. Perches used for inspection of fabric (Courtesy of Springs Mills).

spots, yarn knots and other imperfections are marked. Burling is the removal of yarn knots or other imperfections from the fabric. The faults are then mended and any knots in the material are then pushed to the back. Mending, is obviously, the actual repair of imperfections. Knotting should be done carefully and thoroughly so that the repair or holes is not visible.

The recent innovation is the cloth inspection by the use of laser beams. Stains, holes, thick and thin places, and warp or weft thread breaks are detected. The apparatus works by the on-line system and eliminates human error caused by tiredness, thus ensuring constantly uniform fabric quality. Such apparatus operates on three different principles, namely, the coaxial, remission and transmission methods. In the coaxial method the scanner light beam is reflected back to its source (retro-reflection) onto a receiver situated in the optical hand. In the remission method the emitted light beam is received at a freely adjustable angle by a light guide system and conducted to the signal converter. The transmission method uses a receiver system located below the path of the fabric which measures the light passing through the web. A system for surface monitoring of woven and knitted fabrics is shown in Fig. 2-2. The light source (1) is a heliumneon laser or a xenon high pressure lamp,

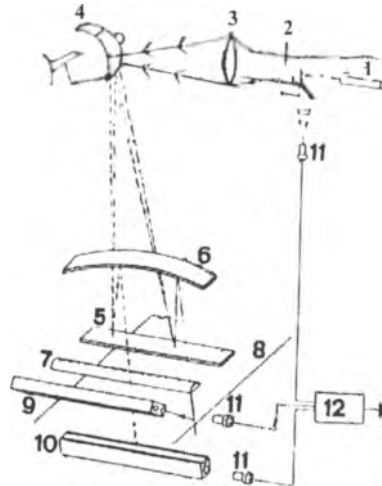


Figure 2-2. Cloth inspection by laser beams using the ‘‘Sick-Scan-System Ko-Re-Tra’’ (Courtesy of E.Sick, GmbH).

the light beam from which passes through an optical system (2) onto a lens (3). From here the light beam is projected onto a fast-rotating multiplanar mirror wheel (4). The light beam becomes a travelling beam by the rotation of the mirror wheel

and is deflected through the planar mirror (5) onto a parabolic reflector with axes parallel and focussed by the cylinder lens (7) onto the web path (8). The beam guiding system ensures that the light beam always strikes the cloth path at the same angle. The light receiver in the remission and transmission methods is a photoconductor [(9) for remission, (10) for transmission] which consists of an optically high grade light conducting material of high homogeneity and low absorption. The photoconductor is attached at the front surface to a planar mirror and at the other end to a photoreceiver (11) which converts the amount of light into signals. The fault signals pass from the monitoring apparatus through an amplifier to a central electronic unit to which may be connected to a data input, a display unit, a recorder, a counter with acoustic alarm, a marking device, a data store and/or a printer.

### 2.3 Sewing

After the goods have been inspected, checked and classed in the grey room, according to quality and stamped, they are sewn together, end to end, by sewing machines especially constructed for this purpose. There are various types of sewing machines [Fig. 2-3(a) & (b)]. The fabrics are usually sewn on circular machine.



Figure 2-3(a). Portable sewing machine (Courtesy of Gebr. Dohle GmbH & Co.).



Figure 2-3(b). Overlocking machines for joining piece lengths of fabric (Courtesy of Metalplast, Italy).

The portable Rotary Sewing Machine is very handy. The main difficulties are bent selvages. Stitching should be done in such a manner that the creases in fabric at the time of stitching should be avoided. The use of proper stitching thread is necessary to avoid stitch marks during colour padding. For heavy fabrics intended for mercerizing and continuous operations, the seam should be wider (15 mm) and stronger. Sometimes, glueing or bonding of fabrics to bind the end pieces by fusing polymer films under the action of high temperature is used instead of sewing to reduce the amount of rags. Goods of similar weight, width and construction and the goods which will receive a similar treatment is batched together and each lot is given a number.

#### **2.4 Mechanical Cleaning of Fabrics**

The pre-cleaning of grey fabrics may be carried out in a separate unit just before cropping and shearing operations. The efficiency of pre-cleaning is the foundation of good cropping and shearing. The pre-cleaning operation is achieved with :

- (i) Thorough grinding of the cloth surface by emery covered rollers.
- (ii) Scraping with suitable designed and located scraping blades.
- (iii) Efficient brushing on both sides of the cloth.

With the progress of grinding and scraping action, the cloth surface gets covered with thread ends, dust, fluff, dirt etc., thus the pre-cleaning unit should have a good dust exhausting system.

##### **2.4.1 Brushing**

The purpose of brushing is to remove the short and loose fibres from the surface of the cloth. It also removes husk particles clinging to the cloth. Brushing is mainly done to fabrics of staple fibre content, as filament yarns usually do not have loose fibre ends. Cylinders covered with fine bristles rotate over the fabric, pick up loose fibres, and pull them away by either gravity or vacuum. The raised fibre ends are cut off during shearing operation. Brushing before cropping minimise pilling.

##### **2.4.2 Cropping and shearing**

Shearing is an operation consists of cutting the loose strands of fibres from either surface of a fabric with a sharp edged razor or scissors. By manipulating the shearing it is also possible to cut designs into pile fabrics. Good cropping is perhaps, the simplest way of reducing the tendency of blended fabrics to 'pill'. In the case of cotton fabrics, in particular, care should be taken to see that the shearing

blades do not scratch the surface of the fabric, which otherwise can cause dyeing defects during subsequent dyeing.

Fig. 2-4 shows a four-cutter shearing machine and Figs. 2.5 and 2.6 show the

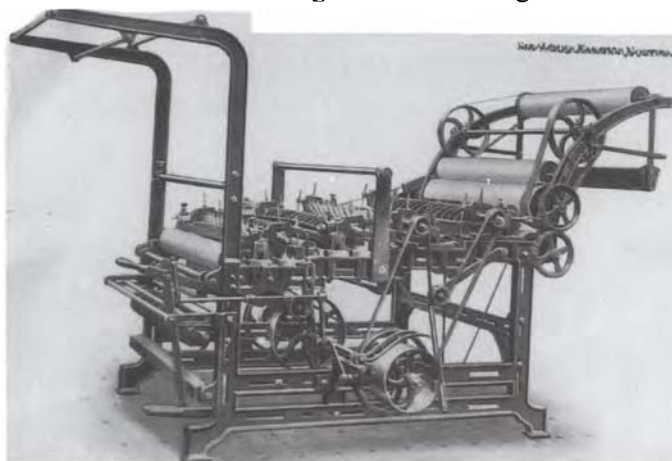


Figure 2-4. 4-cutter shearing machine (Courtesy of Farmer Norton & Co. Ltd.).

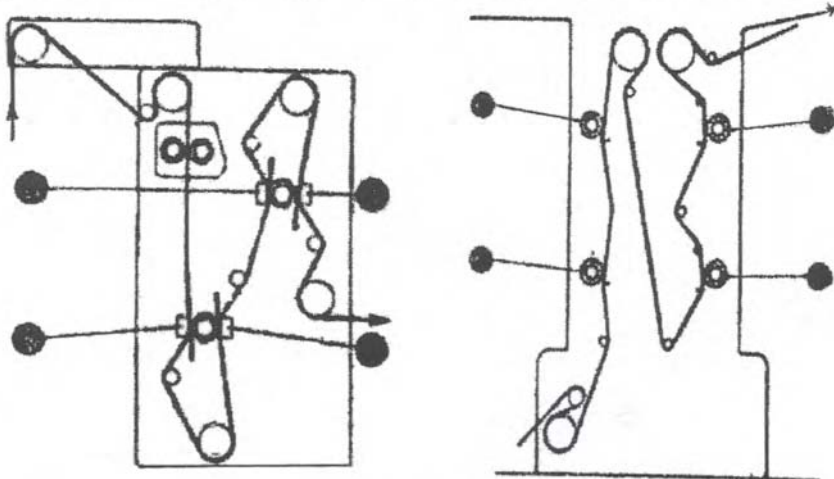


Figure 2-5. Typical 2-cutter cropping machine.      Figure 2-6. Typical 4-cutter cropping machine.

simplified line diagrams of 2 and 4-cutter machines which illustrate the shearing and cropping. The machine consists of a strong framing carrying four revolving cutters fitted with left and right hand spiral blades. A 4-cutter machine has four cutting points, two for the face and two for the reverse side. The term 'cutting

point' denotes the contact line between the spiral shearing cylinder and the ledger blade, over which the fabric has to pass during cropping and shearing operation. Each cutter is provided with adjustable ledger blade. Before leaving the machine, the cloth is brushed by a spiral revolving brush. The machines are of totally enclosed construction with exhaust channels. Although there have been no major changes in the latest cropping and shearing machines, a modern fully automatic shearing range (Fig. 2-7) has the following features :

- (i) Fabric feeding device (electronically controlled) ensuring the entry of crease free fabric.
- (ii) A soft bed under the cutters so that the blades which cut the fibres close to the surface do not damage the fibres in the yarn.
- (iii) Seam joint sensors (electronic) which lift the shearing rolls away from the fabric surface when a seam passes.
- (iv) Magnetic metal detectors sense the iron particles embedded with the cloth and activate the limiting switch, so that the machine stops, the concerned particles are removed and the machine restarted.
- (v) Hydraulic speed gear system has been replaced by suitable DC drives. Modern shearing machine can operate up to a speed of 100m/min. The units have been made more modular, in order to facilitate quick installation.

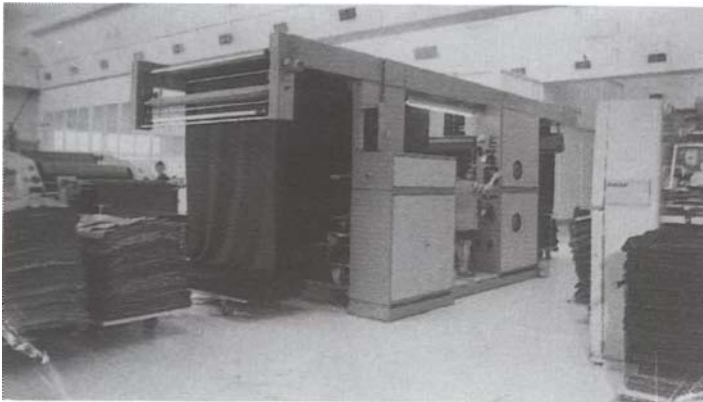


Figure 2-7. Fully automatic shearing range [Courtesy of Swiss Association of Machinery Manufacturers (VSM) ].

Shearing machines fitted with serrated blades have been found satisfactory for

the cutting of polyester materials. Polyester staple fibre fabrics are cropped and singed mainly to control the pilling tendency. For polyester/wool blended fibre fabrics a good cropping is essential if the fabric is not to be milled. If it is desired to finish simulating wool, loose polyester should first be removed by brushing, cropping and singeing and then the fabric is soap-milled to produce a wool cover, which can be cropped to give the required appearance and handle.

### 2.5 Singeing

The aim of singeing is to burn-off the protruding fibres and hairs from the fabric surface. The spinning process produces hairiness of the yarn and lower the yarn counts (Ne 26/1 – 36/1) greater is the degree of hairiness. Therefore the reasons for singeing should be considered more closely.

- (i) Singeing improves the end use and wearing properties of textiles.
- (ii) The burning-off of protruding fibres results in a clean surface which allows the structure of the fabric more clear.
- (iii) Singeing reduces the fogginess caused by differing reflection of light by the projecting fibre and the dyed fabrics appear brighter.
- (iv) Singeing is an effective means of reducing pilling in blended fabrics containing synthetic fibres.
- (v) Unsinged fabrics soil more easily than singed fabrics.
- (vi) A closely singed fabric is essential for printing fine intricate patterns.
- (vii) Singeing process facilitates and speeds up desizing, if the fabric is impregnated with desizing liquor immediately after singeing.

On the other hand there are singeing faults which are not visible and once occurred can no longer be repaired. They are :

- (i) Uneven singeing effect can cause streaks when the fabric is dyed, or bubbles when the fabric is finished.
- (ii) In the cotton system singeing is done on the grey cloth, but for blended fabrics containing synthetic fibres grey state singeing is not advisable because small globules of melted synthetic fibres absorb dye preferentially, giving cloth a speckled appearance.
- (iii) There is a possibility of thermal damage to temperature sensitive fibres, for instance polyester.
- (iv) Stop-offs can cause heat bars on fabrics. Creasing produces streaks which is magnified when dyed.

- (v) Protruding fibres are firmly bound by singeing on the surface by the sizing agent by hardening of the size and can lead to difficulties in desizing.
- (vi) When singeing is done after dyeing, heat can cause colour loss from polyester portion of the blend because of sublimation of dye.
- (vii) There may be reduction of tear strength due to oversingeing of the fabric.

Generally, singeing is done on both sides of the fabric. No chemical change occurs in the fabric during singeing and the reaction is basically one of oxidation. Singeing and desizing can be frequently combined by passing the singed cloth through the water bath which include enzymes. The enzymes digest the various sizing agents, making it easy to remove them during the scouring operation. The combined process also prevents possible latent damage to fabric from the singeing flame or heated plates.

### **2.5.1 Singeing different kinds of fibres fabrics**

In singeing the short fibres are burnt off from the surface of the fabric by direct or indirect heating systems without damage to the cloth by scorching or burning. The thermal behaviour of different kinds of fibres are different and singeing at higher temperature is naturally associated with greater hazards on excessive contact period and may cause thermal degradation of the fibre.

In case of vegetable fibres, grey singeing is necessary as it leads to slight yellowing which needs subsequent bleaching to get high degree of whiteness. Grey singeing is also economical as singeing at any other stages of processing requires additional washing and drying. Vegetable and regenerated fibres fabrics can be singed very strongly with maximum burner intensity to obtain good results. Regenerated fibres normally burn to a little less easily than natural fibres.

Wool has poor combustion properties and are very sensitive to temperatures and hence woollen materials are not subjected to intense flame like cotton. In woollen fabric flame is not generally allowed to penetrate the material and this can be obtained by blowing air through the fabric from the opposite side of the flame so that the flame will be restricted only on the surface of the fabric. Alternatively, the fabric can be guided to water cooled guide rollers allowing the flame to heat the cloth. When the flame strikes the fabric it is reflected by air/steam cushion created within the material.

Amongst the synthetic fibres polyester has the greatest significance. It melts at



280-290°C, but does not burn till about 500°C. 'Reflector' or 'refractory' singeing machines produce smears of fused polymer on the surface of the polyester cloth and therefore unsuitable for polyester material. Thus flame singeing machine with a powerful flame is needed and also helps in overcoming the problems of oligomers i.e. the small chain polymers that come to the surface. High temperature singeing process may sometimes change the glass-transition temperature ( $T_g$ ) of synthetic fibres that lead to uneven dyeing.

For blended fibre fabrics singeing conditions are to be selected depending on the sensitiveness of the kinds of fibres to heat, blend composition, weight of fabric and fabric geometry. For example, singeing should be carefully conducted to avoid heat damage of the acetate component of the acetate/viscose blended fibre fabrics. Though singeing improves the resistance to pilling of the polyester/wool blended fabrics, but should not be carried out on low weight fabrics because of risk of damage. In the case of 80/20 polyester/cotton blended fabrics or fabrics with dented pattern, sometimes, the cloth gets weakened only in the thinner or shadow portion. This is not detected until the material reaches to finish folding. If singeing is carried out after dyeing the sublimation fastness of disperse dyes used must be adequate to withstand the singeing conditions.

Singeing machineries are mainly based on direct and indirect singeing systems. The cloth is first passed over one or more steam-heated copper drying cylinders to remove the moisture and to raise the nap. The direct singeing may be done either on a hot plate, or on a rotary cylinder, or on a gas singeing machine or on a machine combining plates and gas burners. The special features of indirect singeing systems are no flame contact, uniform singeing, heat retention zone and singeing by means of heat radiations. The indirect system produces fabrics which have a softer touch as compared to other methods. Gas singeing is more convenient, more economical and more effective than other methods and is well accepted commercially. The plate singeing and roller singeing machines are now out of date. Clean singeing of potentially troublesome synthetic fibres can be achieved by using the scavenger tubes which are specifically designed to avoid thermoplastic melt (beading) problems.

### **2.5.2. Plate singeing machine**

The machine consists of two copper plates of about 1-2" thick. The plates are

heated to bright red from the opposite side. The furnaces are fired by heavy petroleum oil, which is vaporised through special nozzles, by the action of steam, into a fine spray. The properly dried cloth passes over the plates at speeds up to 200 yards per minute, according to quality. A special traversing arrangement for the cloth is supplied to prevent local cooling of the hot plate. The singed cloth is then run through water to extinguish the spark, passed through a padding mangle and delivered to a winch or plaiter. The machine is driven by electric motor, steam engine or belt pulleys.

### **2.5.3. Rotary cylinder machine**

In this type of singeing machine the cloth passes over a hollow cylinder which revolves slowly in the opposite direction of the goods. The hollow cast iron or copper cylinder may be fired internally. The cloth is drawn through the machine by a powerful squeezer nip, singed, run through water bath and plaited.

### **2.5.4 Gas singeing machine**

Old singeing machines are often used which in their time worked acceptably when only pure cotton materials were singed, but which, however are no longer suitable for singeing of newer fibres and their blends. New technologies and techniques have been developed to suit the modern requirements.

In gas singeing machine, the singeing flame must have the capacity to loosen the fibre ends from the body of the sized yarn to such an extent that the flame envelopes them to be burnt off. When the flame at a temperature of around 1300°C touches the cold and moist material, an air/steam buffer zone results between the material and the flame. This buffer zone hinders singeing down to the base of the material unless the singeing flame has certain features. The singeing flame has thermal and high mechanical energy. To burn the material energy is needed. Metering is only possible by controlling the energy supply within a given time. The problem of singeing gets even more difficult as one has to distinguish between two types of pyrolysis i.e. exothermic pyrolysis of cotton and endothermic pyrolysis of polyester. Polyester ignites only at a temperature of 480-500°C, while starts melting at a temperature of 250-270°C. So, in order to avoid the polyester starts melting before it gets ignited the energy has to be supplied in a shock form and the pyrolysis has to be like an explosion, igniting the protruding fibre end over all its length. Another area of development in the gas singeing machine are the burners, together

with the supply and control units for the gas/air mixture. The gas/air mixture supplied to the burner is prepared in a proportional mixing valve, which means that the ratio of gas and air is always in accordance with the stoichiometric value independent of the quality of the mixture supplied to the burner.

Figs. 2.8 and 2.9 illustrate 4-burner and 2-burner gas singeing machines respectively.

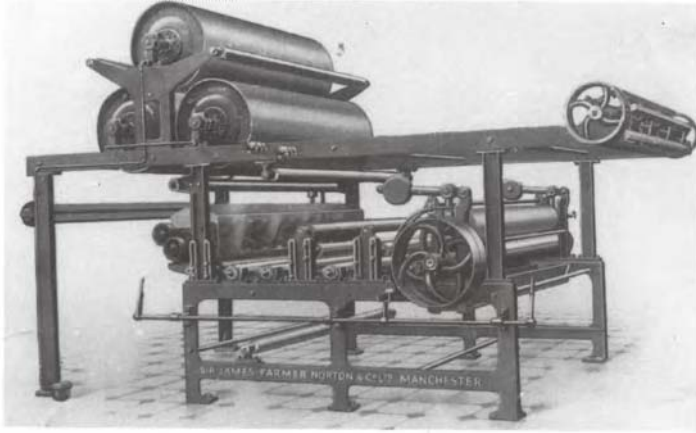


Figure 2-8. 4-burner gas singeing machine (Courtesy of Farmer Norton Co. Ltd.).

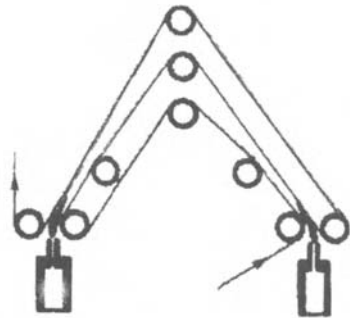
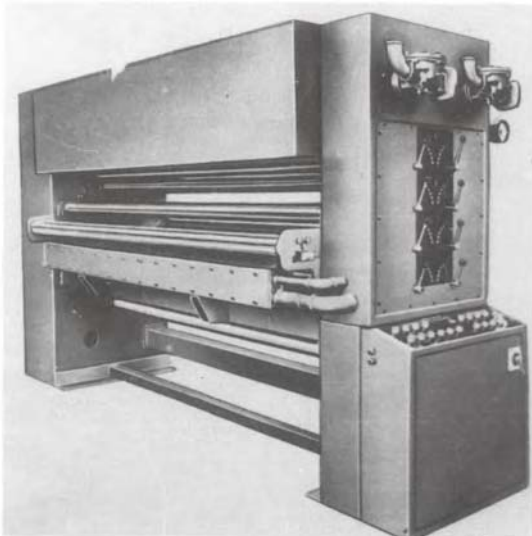


Figure 2-9. Two burner gas singeing machine (Courtesy of Ernest Turner (Parex) Ltd.).

tively. In order to avoid singeing streaks gas burners may be used for singeing with indirect system. In the indirect singeing, the temperature reaches the goods via heat stores-mainly infra-red radiation. Any variations arising from the burners are absorbed there and are compensated.

The schematic diagram of a modern metal burner ribbon type singer showing its component and fabric travel is shown in Fig. 2-10. In all types of burners, the gas

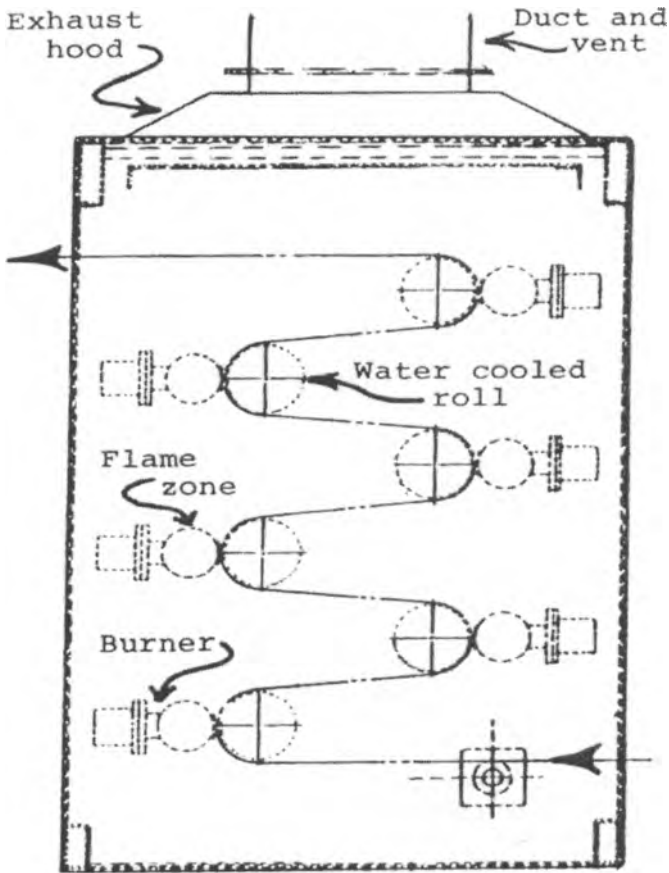


Figure 2-10. A typical singer showing its component and fabric travel (Courtesy of Menzel Inc.). singeing machine is equipped with mechanical threading devices. The cloth is passed over tension rails, adjustable tensioner and then over gas burners. The fabric passes

the burners at a distance of 6-8 mm, and depending on fabric weight and fibre blend. The speed varies between 50 and 160 m/min, thus leading to a short contact time between flame and material. The flame because of its high thermal energy supplies them with sufficient heat to simultaneously ignite the entire surface and burn away the protruding unanchored fibres. A gas jet singer contains a series of small openings or jets mounted on a gas supply pipe. The jets are spaced 1 to 2 inches apart on the pipe which is parallel to the cloth and perpendicular to the warp direction. The length of the slit may be adjusted according to the width of the cloth. Recently, a burner design is modified to give a higher temperature, say up to 1300°C and fully combusted flue is used instead of flame produced by gas-air mixture. The method gives a light blue to almost colourless flame.

The position of the burner must be taken into consideration according to the fabric to be singed (Fig. 2-11). There are three different methods of applying flame to the material by changing the position of the flame to offer :

- (i) Tangential singeing [Fig. 2-11(a)].
- (ii) Singeing onto water cooled rollers [Fig. 2-11(b)].
- (iii) Singeing into the fabric [Fig. 2-11(c)].

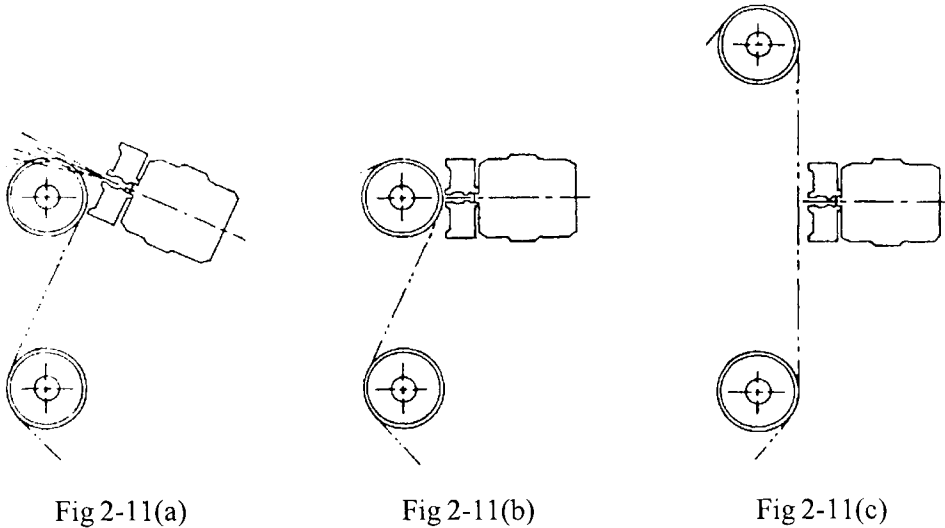


Figure 2-11. Position of the burner depending on the fabric.

In the tangential singeing position the flame touches the passing fabric only tangentially. Only the protruding fibres are burned-off, while the fabric itself has hardly any contact with the flame. This position is specially suitable for the singeing of light weight and sensitive fabrics as well as for the levelling of fabrics with broken filaments.

In the singeing on to a water-cooled roller, as indicated in the accompanying sketches in Figs. 2-9 and 2-11(b), the flame hits the fabric at a right angle, but the fabric itself lies flat on the off-side on a water cooled roller. An elastic steam and air cushion is formed inside the fabric structure which resist any possible penetration of flame into the fabric. The flame is thus effective only on the surface. In view of the cold water in the water-cooled roller, the fabric remains relatively cooled during the singeing process and temperature sensitive fabrics are thus protected from heat. This position is well suited for all blended and synthetic fibres fabrics as well as those with open design.

In singeing on to the free-guided fabric position [Fig. 2-11(c)] the flame hits also at a right angle the free-guided fabric and also passes through the fabric whereby even the interstices gets good singeing. The arrangement is well suitable for fabrics made from natural and regenerated fibres and for heavy technical materials made of all types of fibre blends. Fig. 2-12 shows the line diagram of a modern singeing machine disposing three singeing positions which can be pre-selected.

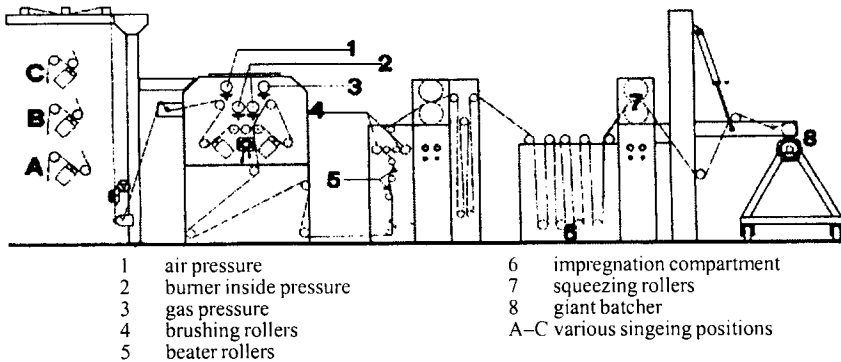


Figure 2-12. Line diagram of a gas singeing machine used for all kinds of fabric qualities (Courtesy of Osthoff KG, Germany).

The singeing machine is provided with a control over flame height. The flame height may become irregular due to clogging of nozzles. Flame intensity indicates energy, of the singeing flame, which is applied on a unit area of the fabric per unit

time. This depends on the speed of the flame and heat capacity of the flame. It is usually measured in millimeter head water of the combustible mixture of the burner. The actual flame intensity for singeing lies between 5 and 20 mbars which can be set steplessly in the described manner.

The burner should be capable of individual swivelling to and from the cloth. The swivelling mechanism is connected to the gas supply system, whereby the burners are automatically ignited or extinguished. Dust and gaseous combustion products are exhausted through a ventilation hood arranged above the singeing machine. Singeing room should be well ventilated, spacious and fire-proof.

Modern singeing machines include pneumatic adjustable firing position, ultra-violet flame scanner, built-in flame extraction system, flame shearing effect, improved guiding system, high frequency burners and variable speed and adjustable burners. The use of double jet burner initiates singeing by means of an intense concentrated and homogeneous flame and snagmetic control system for controlling all flame parameters. Singeing machine is equipped with meter counters, speedometer and a thermocouple with a stationary multivoltmeter for measuring the temperature of singed surface. All modern singeing machine is electronised, with added device of warning noise or fire alarm in the case of a fire. As an added precaution, wet sprinklers and unburnt gas detectors have also become necessary due to stringent safety regulations. Apart from these features, singeing machineries should also have steam quenching for those sorts of fabric which are not to be wetted, e.g. grey mercerized fabrics.

#### **2.5.5. Singeing circular knit fabrics**

As with woven fabrics, hairiness of the face of knitted fabrics is seldom desirable. There are various ways to avoid this problem. The yarn quality, uniform face appearance and proper yarn count are important factors where the quality of knitted fabric is concerned. The quality can be further improved by additional process stage such as, for instance, singeing.

The singeing machine for circular knit fabric differs from the well-known singeing machine for woven fabrics only in guiding and transport of the fabric. The real problem consists in properly opening out the tubular fabric. The distance between burner and fabric must be exactly the same at every point. The burner must be so designed that there is an uniform flame intensity over the entire tube circumfer-

ence. The burner may be ring-shaped, and the tubular fabric too must be opened out in a circular form. A high capacity double jet burners can also be used. Based on the automatically adjustable system, Dornier (Germany) and other manufacturers like Rimmer, Brazzoli, Osthoff etc. have developed a circular singeing concept to singe knit goods in tubular form without edge marks. The fabric is guided to the circular expander via turntable and detwister (Fig. 2-13). The fabric runs through

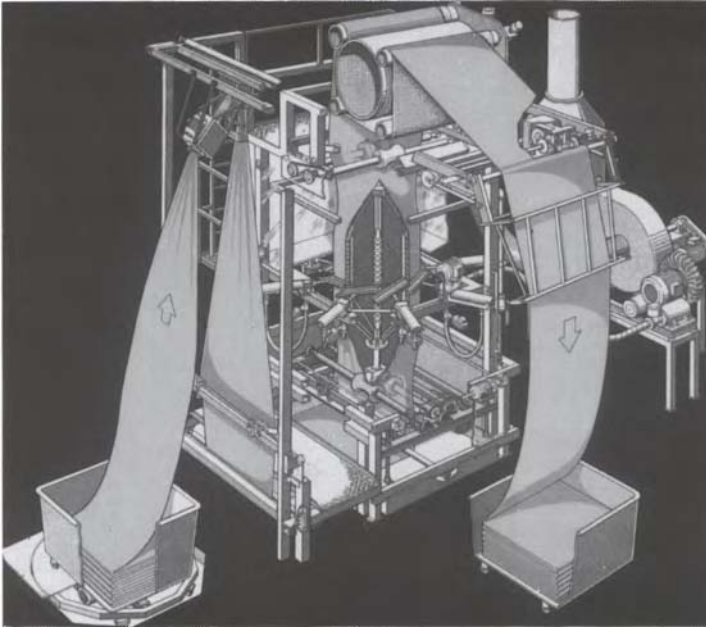


Figure 2-13. Singeing machine for circular knit fabric (Courtesy of Dornier Gassellschaft mbH).

the machine in an upward movement, thereby aiding the effect of the exhaust device, which is also fitted above the burner in circular arrangement. The expander applies tension, while eight swivelling burners are arranged on a ring in such a manner that, even with width adjustments, the full width of the flame of each segment is applied to the fabric. In the gas singeing process, the flame intensity of 70 to 100 mm water column is suitable. In the singeing area there is practically no longitudinal tension. After leaving the guide expander the fabric is then taken over by the driven spark extinguishing and plaiting unit. All data such as diameter, burner distance, burner intensity and speed are controlled from a computer terminal. Singeing and cellulase enzyme treatment to defuzz and improve the visual appearance is thus a best choice to give the consumer a value-added quality of knit fabrics.



## 2.6 Process Sequence

The selection of correct process sequence has a direct bearing on the quality of further processing operations such as dyeing, printing, finishing etc. Some 60% of all the problems occurring in subsequent processing generally originate from a wrong and inadequate selection of process sequence. Precise requirements of fabric preparation depend on the kind of fibre and its proportion contained in the blends, fabric construction, size type and loading and the end use. Cotton knitted fabrics are subjected to a modified routine in which singeing and desizing stages are sometimes omitted, whereas for woven fabrics desizing cannot be omitted. Synthetic fibres are produced under controlled conditions and contain only added impurities, their cleaning is comparatively easy. However, when they are used in admixture with natural fibres, the problems aggravate. Preparation of fabric also depends on the end requirement. For example, ‘full white bleach’ is done in the case of goods which are to be supplied white, ‘half bleach’ for over dyeing or whenever big blotch and fully covered designs are to be printed and ‘full bleach’ whenever pastel shades are to be dyed. Cotton fabrics to be dyed in deep shades will most likely require mercerization in order to improve their dyeability.

Fabric preparation is a costly series of energy consuming processes. Economic consideration, thus, have led to considerable modification of the existing processing sequences. The traditional sequence of pre-treatment is shortened by single stage bleaching, where kiers are still in use. It is therefore necessary to balance the cost of preparation by optimizing the process sequence, conditions and development of shorter routes. Furthermore, several new types of machineries and newer processes have been evolved to meet the requirement of efficient but economical and rapid preparation of cloth. All these factors necessitate the alteration of process sequence to get the optimum results and the technologists can decide as and when any of the stages are to be by-passed without compromising the quality of the goods. The sequence given in this chapter, therefore, serves only a general guidance.

### 2.6.1 Process sequence for cotton fabric on kier

**Method A :** For white/printing : (Poplin, Cambric, Rubia, Mulls etc.) Grey mercerize → Scour in kier → Rinse in kier → Wash → Chemicking in Cistern → Wash → Open boil in kier using  $H_2O_2$  → Rinse in kier → Wash → Scutch → Dry.

**Method B :** For dyeing : (Poplin, Cambric, Rubia, Mulls, Sheetings etc.) Grey

mercerize → Desize in Cistern → Wash → Scour in kier under pressure → Wash → Open boil in kier using  $H_2O_2$  → Rinse in kier → Wash → Scutch → Dry.

### 2.6.2 Process sequence for cotton fabric on J-Box

**Method A :** For white/printing : Grey mercerize → Desize in J-Box Cistern → Wash → Caustic Saturator → Steam in J-Box → Wash → Chemick Saturator → Store in J-Box → Peroxide Saturator → Steam in J-Box → Wash → Scutch → Dry.

**Method B :** For dyeing : Grey mercerize → Wash → Caustic Saturator → Steam in J-Box → Wash → Chemick Saturator → Store in J-Box → Wash → Antichlor → Wash → Neutralise → Scutch → Dry.

### 2.6.3 Process sequence for cotton fabric on Pad-Roll/Thermoreaction Chamber (T.R.C.)

**Method A :** For white/printing : Singeing cum Desizing → Wash → Scour on Pad-Roll (T.R.C.) → Wash → Dry → Mercerize → Bleaching on Pad-Roll (T.R.C.) → Steaming → Wash → Dry.

**Method B :** For dyeing : Grey mercerize → Scour on Pad-Roll (T.R.C.) → Wash → Bleach on Pad-Roll (T.R.C.) → Wash → Dry.

### 2.6.4 Process sequence for cotton fabric on Jumbo Jigger

**Method A :** For white goods : Grey mercerize → Scour on Jigger → Wash → Chemicking → Wash → Peroxide Boil → Wash → Neutralise → Unload.

**Method B :** For dyeing : Grey mercerize → Scour at boil → Wash → Chemicking → Wash → Antichlor → Wash → Neutralise → Unload.

**Method C :** For coloured woven sorts : Grey mercerize → Desize → Wash → Chemicking → Wash → Peroxide Boil → Wash → Neutralise → Dry → Mercerize → Dry.

### 2.6.5 Process sequence for knitted cotton goods

**Method A :** For white goods : Hypochlorite Bleach → Reduction or Peroxide Bleach + Fluorescent Whitening Agent (FWA).

**Method B :** For white goods : Demineralization acid medium (metals) → Peroxide Bleach + FWA.

**Method C :** For white goods : Alkaline treatment + Demineralization (oils, paraffin spots + metals) → Peroxide Bleach + FWA.

### 2.6.6 Process sequence for woollen fabric

**Method A :** For dyeing in the worsted routine : Greasy wool → Scouring → Carding → Gilling → Combing → Combed Tops → (Top Dyeing) → Gilling → Recombing → Drawing and Spinning (Yarn Dyeing) → Weaving/Knitting → Fabric Dyeing → Finishing.

**Method B :** For dyeing in the woollen routine : Greasy wool → Scouring (loose stock dyeing) → Oiling → Willeying → Carding → Spinning → (Yarn dyeing) → Weaving → Scouring and Milling → Fabric Dyeing → Finishing.

### 2.6.7 Process sequence for silk fabric

**Method A :** Grey Inspection & Stitching → Singeing → Washing → Degumming → Bleaching → Dyeing → Padding mangle (apply some adhesive also) → Stentering → Felt Calendering → Curing → Decatising (to impart fluffy & soft feel).

### 2.6.8 Process sequence for polyester fabric

**Method A :** Heat setting → Scouring → Bleaching → Weight reduction → Dyeing → Drying on stenter.

### 2.6.9 Process sequence for nylon fabric

**Method A :** Ordinary woven fabric : Heat-set → Desizing & Scouring → Bleaching → Fluorescent Whitening → Pre-setting.

**Method B :** Hard twisted woven fabric (Gorgette) : Embossing → Creping (relaxing) → Desizing & Scouring → Bleaching → Fluorescent Brightening → Pre-setting.

**Method C :** Knitted goods : Desizing and Scouring → Bleaching → Fluorescent Whitening → Pre-setting.

### 2.6.10 Process sequence for polyester/cotton blends

**Method A :** For yarn : Scouring → Bleaching → Dyeing → Anti-static finishing.

**Method B :** For White goods : Desize → Scour → Mercerizing → Heat-set → Anti-pilling i.e. Brushing, Cropping and Singeing → Bleaching and Optical Whitening → Stentering or Sanforizing.

**Method C :** For deying : Desizing → Scouring → Mercerizing → Heat-setting → Bleaching → Dyeing → Anti-pilling i.e. Brushing, Cropping and Singeing → Stentering or Sanforizing.

Grey singeing of polyester/cotton blended fabrics may be carried out only on

goods that are to be dyed by continuous processes or by high temperature batch processes using non-critical dyes. If the warp is heavily sized, singeing will be ineffective in the beginning and inset later in the routine. Goods that are to be prepared on J-Box range in rope form, may be heat-set in the grey state if they are reasonably free from loom stains. Unmodified sizes are also difficult to be removed from the fabric after heat-setting.

#### 2.6.11 Process sequence for polyester/viscose blends

**Method A :** Desizing → Washing → Heat-setting → Singeing → Drying.

**Method B :** Singeing → Desizing → Washing → Drying → Heat-setting.

The process of mercerizing is omitted when viscose is present in the blends. Sometimes singeing operation is done after dyeing to avoid sooty appearance or dye specks arisen from melted beads of polyester.

#### 2.6.12 Process sequence for polyester/wool blends

**Method A :** General : Grey Inspection → Removal of stains → Scouring → Pre-setting (Setting of wool component by crabbing) → Drying → Heat-setting → Dyeing → Brushing & Cropping → Singeing → Light scour (if necessary) → Steam or Damp → Decatising or Pressing.

**Method B :** Knitted goods (Crisp handle) : Open steam (allowing full relaxation) → Light brushing → Close Cropping on face side of fabric → Decatising.

**Method C :** Knitted goods (Soft handle) : Heavy Scour → Cropping on face side of fabric → Open Steam → Decatising.

A worsted polyester/wool blended fabric is prepared by crabbing or blowing and then Scoured → Dry → Heat-set (on pin stenter) → Brushed and Cropped → Press or Decatise.

If it is desired to finish a simulating wool, the loose fibre from the surface of the blended fabric is first removed by brushing, cropping and singeing and then soap milled to produce a wool cover, which can be cropped to give required appearance and handle. Heat-setting after milling is an optional process.

#### 2.6.13 Process sequence for diacetate/viscose blends

Most blends for shirtings consists of 50% each of diacetate and viscose in plain weaves and the sequence of operations may be as follows :

Singeing (where necessary) → Contraction or relaxation → Scouring and Desizing → Dyeing → Finishing.