Chapter - 2
LITERATURE REVIEW

2.1 WAX, SUINT AND VEGETABLE MATTER

Wool, mohair and rabbit hair fibres, all of them, are keratinous fibres with similar nature of impurities of wax, suint and vegetable matter, although obtained from different animals. Because of biological, genetic and environmental influences including geographical, climatic and nutritional factors, the quantities of these materials vary widely. Wool waxes are fatty products viz. esters of water insoluble alcohols and higher fatty acids whereas suint is that part of the raw fleece which is soluble in cold water while burrs or vegetable matter, like thorns or seed coats, is picked up by the animals from grazing fields and animal houses.

The chemical characteristics of wool wax have been described in a thorough fashion by Truter. It has been claimed that there is a correlation between wool quality and wool wax content. Some data in this regard have been published by Raymond and Mandell and O'Connell and Lundgren to show that wax content of finer wool is greater than coarser wool. Over fairly wide ranges of fibre diameter the finer fibres contain more wax, however, over narrower ranges of diameter this relationship may not stand. Marston
and Lifschuetz\(^5\) have shown that percentage of grease and suint varies in fleeces of various breeds of sheep, in a sheep of the same breed and even within a single staple. Some work has been initiated in China\(^6\) to study the relation between wax and weathering properties of wool. In practice it is normal to scour wool to predetermined residual grease level (approximately 0.5\%).

Generally, mohair contains 4-5\% grease, whereas in rabbit hairs it is almost negligible. The scouring loss in rabbit hair is only 2-2.5\%, while in wool it may be 50-55\%\(^7\). It has been observed that the mohair fleece is exposed to considerably more weathering than a merino fleece. The wax from the mohair fleece could, therefore, be expected to be heavily oxidized. Although the percentage grease on mohair is much lower than on wool, scouring of mohair to relatively low residual grease levels poses a difficult problem, since the lustre of mohair, most desirable and valuable characteristic, has to be retained.

Careful studies on the composition of suint by Freney\(^8\) have shown that it consists of a mixture of potassium soaps of fatty acids ranging from valeric to palmitic acids. In addition it contains minor amounts of lactic, hippuric and succinic acids, urea

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and lanolin.

Most of these wools and speciality hairs contain a varying amounts of vegetable matter such as burrs, seeds, twigs leaves or straw picked up by the animals in grazing. Their composition depends on several factors including animal houses and grazing fields etc. Vegetable matter in mohair has been observed quite low because of smooth surface and low wax content. The low amount of vegetable matter in mohair indicates that it can be removed by combing in place of carbonising. Turpie and Godawa have clearly shown that seedy mohair up to 15% vegetable matter could be combed almost clean by using French comb. In addition, uncarbonised mohair appears more lustrous, had a longer mean fibre length and a better colour than carbonised mohair. D. Charlton et al. have described the effect of vegetable matter level on worsted processing. It is generally expected that increasing levels of vegetable matter reduce processing rates for scouring and carding and increase fibre loss and amount of short fibres produced during carding and combing. Although the composition of raw wool and speciality hair is almost similar with respect to fibre constitution, wax, suint and vegetable matter, the difference expresses itself in terms
of quantities of impurities, which in turn influence processing performance and yarn and fabric properties like evenness, flex abrasion, crease recovery and elasticity etc. Strydom et al.\textsuperscript{11} have shown the influence of grease content, suint content and scoured yield of cape mohair on top making and spinning performance.

**CHEMICAL COMPOSITION**

Both, wool and speciality fibres, are regarded as keratin fibre which is a polymer consisting of polypeptide chains. These are formed by the condensation of amino-acids and have the general formula:

\[
\begin{align*}
\text{H} & \quad R_1 \quad \text{H} \\
\text{O} & \quad \text{H} \\
\sim & \quad \text{C'}-\text{N}-\text{CH}-\text{C'}-\text{N}-\text{CH} - \sim \\
\text{H} & \quad \text{O} \\
\text{R}_2
\end{align*}
\]

The constituent amino-acids are determined by cleaving the C-N bond of the polypeptide chain with acid, alkali or enzymes. These polypeptide chains, upon hydrolysis yield back amino-acids. Out of the 25 different known \(\alpha\)-amino acids, only 19 of that have been reported\textsuperscript{12} to be found in wool keratin. The most important amino-acids which govern most of the physical and chemical properties of these fibres are cystine, lanthionine, tryptophan and tyrosine. Different types of physico-chemical techniques viz. HPLC, GC, ion - exchange resin chromatography, high
voltage paper electrophoresis and automatic amino-acid analyser, have been used\textsuperscript{13,14} for amino acid analysis of proteins extracted from keratin fibres.

Amino acid sequence data on the high sulphur proteins from the 16,000 dalton groups of wool and mohair are presented by Swart et al.\textsuperscript{15} in which a high degree of homology was confirmed between the proteins of different molecular weights and between wool and mohair. The half-cystine content of merino wool falls in the range 8.4 to 14.8\%, and that of tyrosine 2.9 to 4.7\%. The helical sections of low sulphur proteins from micro fibrils which are set in a non-filamentous matrix composed of high-sulphur and high-tyrosine of proteins. There are striking differences in amino-acid composition between the three major groups of proteins. The low-sulphur proteins are enriched in lysine, aspartic acid, glutamic acid, alanine and leucine, the high-sulphur proteins enriched in half-cystine and proline, and the high-tyrosine proteins enriched in glycine and tyrosine\textsuperscript{16}. The high sulphur proteins of reduced mohair have been fractionated by DEAE-Cellulose chromatography, gel filtration, electro-phoresis and combination of these methods, which suggested on the basis of their molecular weight and amino acid that mohair generally
comprised five major groups of proteins. Wool and mohair fibres were determined individually or in mixtures by electrophoresis of extracted proteins and detection by silver staining. The intensity and distribution of the SDS/PAGE patterns was different in mohair. Mohair also had additional multiple faint bands of intermediate molecular weight (19,000-28,000) and these were detected in the mohair-wool mixtures.

**MORPHOLOGY AND ANATOMY**

The animal fibre consists of three components, cuticle, cortex and medulla. Cuticle, the outermost layer, composed of flat plate like cells, called scales which overlap on each other, with the free ends pointing towards fibre tip. The scale arrangements are of different geometrical designs, named coronal, reticulate, coronal-reticulate etc. Attempts have been made to identify different types of fibres on the basis of their characteristic geometrical pattern of scale, dimensions of width, height from fibre surface and angle with respect to fibre axis. These dimensions may differ from fibre to fibre or within a fibre. These scales are responsible factors for fibre friction and cohesion when they are twisted together during spinning.
The most common types of scale pattern observed in wool are coronal, coronal-raticulate and reticulate scaling. These patterns are not unique, but all types of intermediate forms may coexist. If each scale forms a complete ring around the fibre, the top of one scale overlapping the bottom of the next, the pattern is called coronal. When the scales form a band around the fibre, but each band contains more than one scale the pattern is known as coronal-raticulate scaling, while the irregular network of scales is named reticulate scaling.

Another important characteristic feature of the scale is the shape of the margin. Out of the four types of margins, smooth, crenate, rippled and scalloped, the smooth form is most prevalent in fine wool and mohair. In addition to scale pattern and scale margin, the scale length is a useful but by no means infallible to fibre identification. If the mean scale length is below 17 µm it is assumed that the fibre is a sheep's wool fibre, and if it is above 18.5 µm the fibre is mohair, because the scale length of fine wool fibres and mohair ranges in between 8-10 µm and 18-22 µm respectively. When the value of S is between 17 µm and 18 µm, the hair is probably mohair. These borderline fibres can more precisely be identified by applying Skinkle's rule which states that
if the cube of the scale length divided by fibre diameter \((S^3/D)\) exceeded 160 \(\mu\text{m}^2\), the fibre should be considered to be wool and if below 160 \(\mu\text{m}^2\) the hair is mohair. It has been observed that these rules can not always be applied with confidence.

The cross section of the fibre varies from circular to highly irregular shape from fine to very coarse fibres. Below the cortical is the cortex made up of spindle shaped cortical cells. These cells consist of macro-fibrils containing microfibrils embedded in an amorphous matrix\(^{22}\). The amorphous portion is easily accessible to liquids. On the basis of the arrangement of the microfibrils in the matrix and also of the arrangement of the macrofibrils within the cells, three cortical cell types have been described for wool - orthocortical, paracortical and mesocortical\(^{23}\). Sometimes, in between the cortical cells, air filled cigar shaped packets or vacuoles of varying length are seen. Mostly, mohair consists of orthocortex and sometimes in adult mohair fibres a ring of paracortex covers the orthocortex. This results in a low crimp factor as compared to wool where both types of cortex-ortho and para contribute significant part of the cortex.

In the centre there is a medulla or core which is a
network of air-filled cells or in some cases a completely hollow tube. In fine wool the medulla is absent and even in the coarse wool only some of the fibres are partially medullated. Thus wool fibres generally consists of only cuticle and cortex. A schematic representation of non-medullated fibre has been published by Reunuth\textsuperscript{24} and all the three components of a medullated fibre are shown in the perspective drawing of McMurrie\textsuperscript{25}. As in wool, three types of medulla viz. unbroken, interrupted and fragmental types have been observed in mohair. Out of which unbroken type is most common in mohair, while the shape and size of medulla in rabbit hair is quite different from that found in wools. In this case, ladder type medulla appears as a series of evenly placed dark patches. These patches may be arranged in a single longitudinal series i.e. uniseria1 or they may be multiseria1\textsuperscript{26}.

The morphological structure of both wool and mohair\textsuperscript{27-31} has been studied in detail whereas Angora rabbit hairs\textsuperscript{32} are yet to be worked out under this aspect. In mohair the scale length varies from 18-22 \textmu m with about 5 scales per 100 \textmu m. The scale pattern is smooth wave mosaic, and of medium depths as compared to wool\textsuperscript{33}. In cross section, mohair fibre is
highly circular in comparison to wool. The height of the scale at its edge has been used as an objective criterion for distinguishing between wool and mohair fibres in the quantitative analysis of wool blends by scanning electron microscopy (SEM)\textsuperscript{34-36}. It was indicated that hairs can be differentiated in scale edge thickness, being ~0.4 and 1.0 µm for goat hair and sheep wool respectively.

**PHYSICAL PROPERTIES**

Characteristics that make wool and speciality fibres a unique textile fibre lie more in their physical properties viz. diameters, fibre length, staple length, crimp, yield or clean wool content, moisture relation etc. The importance of these features depends upon the variety of wool or speciality fibres being assessed and their uses. One very important component of quality is mean fibre fineness, which influences the softness of subjective handle and is also of paramount importance in spinning. Judgements of quality are also influenced by fibre crimp and the woools with a high crimp consistency command higher prices. Fibre length along with diameter affects the spinning limits of fibre including strength and extensibility of yarns. These fibres absorb moisture from the atmosphere very readily and among them wool has the highest regain at a particular relative
humidity. This hygroscopic nature makes them comfortable to wear. The bulk of these fibres, given to it by its bilateral structure (and the resulting fibre crimp), adds to warmth as a greater volume of air entrapped than in a yarn of the same weight but of other fibres. These characteristics of hairs vary with respect to different types of animals, their breeds, environment, nutritional factors etc.

**Colour, Size and Shape**

Generally, the colour in animal fibres is due to two types of pigments non-granular melano-proteins and granular melanin. Melanin granules are present principally in the cortex\(^\text{37}\). Speciality hairs differ from wool and are usually of natural colour, predominantly white, although there are animals that produce brown or grey fibres. Angora rabbit hairs are exclusively white and valued for their colour.

The mean fibre diameter of animal hair is its most important property to determine grade and quality. Van Wyk\(^\text{38}\) showed that loose wool harshness increases with an increase in mean fibre diameter and to a lesser extent with an increase in resistance to compression. Diameter has some effect on loose wool felting and resistance to compression although its effect is secondary to the crimp characteristics of
the fibre\textsuperscript{39}. Wool ranges in mean diameter from (16-17\(\mu m\)) in fine merino to over 40 \(\mu m\) in coarse long wool. There are variations in fibre diameter within a staple and even along the length of single fibre. Matthews\textsuperscript{19} and Wildman\textsuperscript{20} were the first to point out fibre unevenness. Langley and Kennedy\textsuperscript{40} have tried to establish it as criterion for differentiating speciality fibres. Dimensional nonuniformity has been shown to influence mechanical properties of the fibres also\textsuperscript{41,42}. The diameter dispersion is determined in a lot in terms of co-efficient of variation which ranges 14-24\% in wool, whereas Hunter\textsuperscript{43} has reported that coefficients of variation of mohair ranges between 20-40\%. Many processing characteristics and fabric qualities are affected by fibre diameter and its dispersion.\textsuperscript{44,45} The diameter of mohair fibres cover a range from 10-90 \(\mu m\) in which kid mohair ranges 10-40 \(\mu m\), whereas the coarse adult ranges from 25-90 \(\mu m\). In South Africa the fineness classing categories are distinguished by using the symbols FK, K, YG, FH, H and R to indicate Fine Kid, Kid, Young goat, Fine Adult, Adult and Coarse hair, respectively. Where K only extends as far as 30 \(\mu m\) whereas young goat extends upto 34 \(\mu m\), FH upto 36 \(\mu m\) and H upto 39 \(\mu m\). Any hair coarser than 39 \(\mu m\) must go into the R category. The fineness of Angora
Rabbit fibre is one of the features that contribute to the desirable texture of the articles made. The range of diameters in Angora rabbit hairs has been established to 10-18 µm. A specified fibre fineness distribution analyser for Angora rabbit hair has been reported by Strobino et al.\textsuperscript{47}

The crimp frequency has an important bearing on the properties of the resultant textile products.\textsuperscript{48} In merino, the staple crimp frequency and fibre fineness are positively correlated.\textsuperscript{49-51} Initial work on the effect of staple crimp on processing performance and yarn and fabric properties was not very conclusive, partly because it is extremely difficult to select wools that differ only in crimp\textsuperscript{52} and any other property which always changes with crimp. The variations in fibre crimp are generally associated with variations in the fibre structure\textsuperscript{53} and mechanical properties\textsuperscript{38}. For many end-uses, crimp is a desirable characteristic\textsuperscript{54} particularly for carpets\textsuperscript{55} where artificial crimping of low crimp wools can prove beneficial. It assists in processing and also improves fabric bulk and comfort properties. Fibre crimp could be beneficial in reducing fibre breakage during carding. Fibre crimp has an important effect on the inter-fibre friction and cohesion which could
be reflected in processing, particularly drafting. Increasing crimp levels can also adversely affect worsted processing and certain yarn and fabric properties. An increase in crimp generally increases resistance to compression and reduces felting of loose wool\textsuperscript{53}. Although, waviness is a natural characteristic of mohair, this cannot be compared to crimp in the true sense of the word and some interesting work has been performed on the artificial crimping of mohair and its effect on spinnability\textsuperscript{56-57}. It was found that crimped mohair had a poor spinning performance. Angora rabbit hairs are generally straighter and smoother than wool which makes it difficult to spin, the fibres tend to slip out of the yarn and shed from the fabric. It has been commonly believed that the low coefficient of friction of rabbit hairs is responsible for the defect that the hairs would be easily falling off during wearing. Whereas it was observed by Hu Zhao Geng et al.\textsuperscript{58} that the falling rabbit hair consists of breaking ones and slipping ones and because the average frictional force of rabbit hairs is much larger than average breaking strength, the number of breaking hairs is much more than that of slipping ones during wearing. Thus the mechanism of falling hairs during wearing is breaking rather than slipping. The staple length of
the wool is governed by inheritance and environmental conditions. For fine wools staple length ranges from 1.5-5 inches for medium 2-7 inches and for coarse 5-14 inches. In general, the staple length increases with increase in fibre diameter and is lower than the mean fibre length because of crimp. From the point of view of objective measurement, staple length is correlated with mean fibre length in the top, although tenderness, entanglement of the scoured wool, diameter, crimp, processing conditions and various other factors will affect the relationship.

Length is regarded as being second in importance to diameter as far as wool fibre quality is concerned. The processing, particularly carding, generally modifies with respect to fibre length characteristics. An increase in the fibre length generally improves worsted yarn regularity and tensile properties, reduced yarn hairiness and also improves abrasion resistance. Although raw wool is fairly uniform in fibre length but the spread is greatly increased by fibre breakage in processing. Length is also very important characteristic in mohair and it is perhaps therefore an advantage that mohair grows at the rate of 25 mm per month under good conditions. This is the reason
for shearing Angora goats at least twice per annum. The length classing symbols used in South Africa are as A, B, C, D, and E, where A represents lengths of 15.0 cm and over, B represents lengths between 12.5 to 15.0 cm, C applies to lengths between 10.0 and 12.5 cm, D lengths between 7.5 and 10.0 cm and E length hair shorter than 7.5 cm. Generally, the fibre length of kid mohair ranges from 10 to 15 cm for six monthly growth and 20 to 30 cm for full year growth. The length is also an important aspect for processing Angora fibre in the woollen industry. No authentic grading procedure is available for Angora fibres. These fibres can be graded as A, B, and C depending on the length of the fibre. Fibre, 5 cm or above in length is graded as A, 3 to 5 cm as B and less than 3 cm as C grade. Angora rabbit hair produces long hair which is generally clipped after every 3 to 4 months, so the length depends on the period of shearing of animals and could be about 4 to 7 cm.

The silver, silky and glassy lustre of wool locks, yarns or fabrics is dependent on structure of fibre surface, size and straightness of fibres. The mild silver lustre is observed with finest and highly crimped wools, silky lustre in long stapled whereas
glassy lustre occurs in straight, smooth hairs. The light reflecting properties i.e. lustre of mohair is one of the main attributes of this fibre and differentiates mohair from other keratin fibres. Fine fibres generally gave higher lustre values than coarse fibres. Solvent extraction, heating and steaming of mohair samples decreased the lustre value when compared to untreated (scoured) samples.\textsuperscript{67}

**Moisture Relations**

Wool is hygroscopic and this characteristic influences practically every property of the fibre. The equilibrium regain is primarily governed by relative humidity. The moisture regain of wool and relative humidity is dependent on temperature, previous moisture content, pH and chemical treatments. Speakman's\textsuperscript{68} studies have shown that the moisture relations of a wide range of wools are very similar. The affinity for water is reduced by drying at an elevated temperature. This reduction occurs only when the material is dried from regains below saturation, while it does not occur when wool is dried from saturation. Normal affinity for water may be restored for the wool by exposure to water vapour or water\textsuperscript{69}. The equilibrium regain depends also on the chemical state of the wool such as its pH; it is lower under acidic conditions and higher in alkali.
than in neutral state.\textsuperscript{70-72} The pH effect is reversible provided the wool has not been exposed to sufficiently extreme conditions to alter it permanently. The presence of extraneous material naturally influences the regain also; the most common adjuncts of wool, grease and combing oil, are nonhygroscopic and simply act as diluents.

In consequence of the oriented structure of the fibre, the result from moisture absorption is highly anisotropic. The increase in diameter effects much greater than that in length.\textsuperscript{73,74} The absorption of moisture by fibres is accompanied by evolution of heat, conversely loss of moisture i.e. dehydration is accompanied by heat absorption and contraction of keratin fibres.\textsuperscript{75} The heat of wetting per gram of water absorbed is similar in all textile fibres. Since wool has a considerable higher regain at saturation, its heat of wetting per gram of fibre is high. Cassie\textsuperscript{76,77} has suggested that the heat of wetting is an important factor in imparting to textile fibres a thermal buffering action under certain conditions.

The average moisture content in mohair fibre is found to be equal to that of wool when exposed to standard conditions while in case of Angora rabbit hair it is
approximately 2% lower than that of wool. An automatic elemental analyser has been used to determine moisture content of wool and mohair, even of a single fibre. 78

2.5

MECHANICAL PROPERTIES

Spinning, weaving, knitting and the end-product behaviour is significantly dependent on the mechanical properties like tensile properties, resilience, fibre friction etc. of these keratin fibres. Both, wool and speciality fibres are characterised by high extensibility and relatively low breaking strength and its unusual elastic properties, particularly when wet. Actually, woollen fibres can be so elastic that a wet fibre can be stretched to 70% extension without breaking and on release, fibre will return to its original length. Moreover, humidity and dry or wet state is the most important factor to affect tensile properties besides temperatures, pH and previous chemical treatments of fibre. Usually, the tensile strength of keratin fibres is reflected in their breakage during processing and provides a good prediction of fibre length in the top for average processing conditions. The differences in fibre strength may also be reflected during carding and combing and higher strength results in lesser breakage. 79
Fibre Strength

Fibre strength is largely a function of the fibre diameter. The wool fibre is anisotropic\textsuperscript{80} i.e. it has different properties in the direction of fibre axis and in the plane of right angles to it and practically all the work has been done in the fibre axis direction. Wool is generally characterised by a high extensibility and low breaking strength. The energy needed to rupture the fibre or toughness\textsuperscript{81}, because of its high extensibility, is quite large. The breaking stress of wool fibres is independent of fibre size over a wide range, but the extension at break increases slightly with increase in fibre diameter.\textsuperscript{82}

The ability of fibres to recover from small deformations is an important characteristic. When wool fibres are stretched in cold water and released, they recover their original length very rapidly and even when stretched in air they recover completely when released in cold water.\textsuperscript{83} The fibre though perfectly elastic, is not perfectly resilient. The recovery behaviour of textile fibres has been studied by a number of investigators.\textsuperscript{84-86} Study of creep and relaxation phenomena furnishes an insight into the molecular organisation of the material\textsuperscript{87}. The rate
of relaxation in water increases rapidly with rise in temperature\textsuperscript{88}. The fibres stretched at relative humidities below 100\% do not recover their original length completely on release, the same effect holds when a fibre is extended wet and dried under strain. This is a temporary set and lost on exposure to water. A very short exposure to steam followed by release from strain, results in a contraction to less than the initial length of the fibre known as super-contraction.\textsuperscript{89}

The mean tenacity of mohair fibres\textsuperscript{90} is approximately 14.7 CN/tex as compared with wool being approximately 11.4 CN/tex. Both bundle and single fibre tenacity was found to be independent of linear density\textsuperscript{91}. Wool and mohair can be differentiated on the basis of differences in elastic moduli. Vigo et al.\textsuperscript{92} claim that for extensions varying from 8\% to 2.5\%, the elastic modulus of mohair in the Hookean region is greater than that for wool. The mean breaking extension for mohair is 42\%, kemp 45\% and for wool it is approximately 42\%. Smuts and Hunter\textsuperscript{93} found that although the absolute breaking strength of kemp was higher, the tenacity of true mohair fibres was nearly always higher than that of kemp fibres. Comparing young's modulus for bending and extension of mohair and kemp fibres, King\textsuperscript{94} found that the
moduli for bending and stretching of mohair did not differ significantly, whereas for kemp two distinct bending moduli groups, depending on the structure of the medulla, were obtained. On the other hand, the stretching moduli for various kemp fibres did not differ significantly.

Kando et al. 95 and Susich et al. 86 have studied the stress-strain curves for wool and mohair and found them distinctly different. At an elongation of approximately 2%, mohair has a much higher stress than wool. The shoulder of the stress-strain curve is much more angular for mohair. However, if mohair is stretched beyond the yield point and then restretched a smooth shoulder, similar to that of wool, is obtained. The elastic modulus is nearly 40% more than wool. The tenacity at 65% RH is 45% more than wool. The elongation is 31% more at 65% RH and only 5-6% more in the wet state. These facts indicate that mohair is more ortho-oriented fibre. Comparable to mohair produced in other notable countries, mohair produced in India through crossbreeding local goats with Texas angora bucks is found to produce a fibre having tenacity of around 14 g/tex. 96

The breaking strength of the rabbit hair is low and lies in between cotton and wool 19. This leads to the
the breaking elongation of wool and rabbit hair is almost the same 30 to 35%. The mechanical characteristics of Angora rabbit hair have been investigated to a limited extent.97-99 The recovery properties of these speciality hairs, mohair and rabbit hairs, are poor as compared to wool in the dry state. Whereas in wet state, the work recovery is poor in all these keratin fibres after 2% extension. After 10% extension, speciality hairs are similar to wool in recovery.

**Fibre Friction**

The surface frictional properties of the keratin fibres are unusual due to the arrangement of the cuticular scales. A fibre rubbed along the direction of its axis tends to move in the direction of its root - end and the scales act as ratchets. The phenomenon is named directional friction effect (DFE) or scaliness.100,101 The coefficient of friction decreases with increasing applied load.102-104 In comparison with other textile materials, the friction of wool fibres is low and it depends on the medium and the coefficient of friction. Generally, it is found greater in water than in air. The removal of
the DFE from the rootward portion of the fibres inhibits felting and a stiffening of the root portions enhances felting\(^{101}\). An increase in fibre diameter generally increases single fibre friction.\(^{105}\) This having been ascribed to a concomitant change in the number of scales per unit length\(^{106}\), changes in scale height and shape.\(^{107}\)

The identification of mohair in blends with other animal fibres can be achieved by using their frictional properties.\(^{108,109}\) The method is based on the lower against-scale frictional forces of mohair as compared to wool. The measure of scale engagement is used to characterise and identify wool and mohair as well as other keratin fibres.\(^{110}\) A sensitive instrument has been described\(^{111}\) that measures the frictional and normal forces when nearly parallel fibres are rubbed in various media. The instrument detects wool and mohair scale engagement, the effect of medium on engagement and on the coefficient of friction.

**Resilience**

Measuring the resistance to compression (resilience) at lower pressure generally differentiates more clearly between different wools.\(^{112}\) It has been found\(^{113}\) that the resistance to compression of
commercially scoured wools is higher than that of the laboratory scoured wool or steam-relaxed tops. Resistance to compression decreases as processing progresses, although steam-relaxation (or hot water-relaxation) returns it to very nearly that of the laboratory scoured raw wool, the resistance to compression of steamed tops being somewhat (8%) higher than that of the raw wool. It has been shown that resistance to compression is mainly a function of the product of staple crimp frequency and fibre diameter. Fibre surface characteristics appear to have little effect on loose wool resistance to compression, although for carpet wools, the degree of medullation is reflected in this property. Fibre length has little effect on resilience. The resistance to compression of a blend of two components is proportional to their individual percentages. Resistance to compression plays an important role in the assessment of loose wool handle. Diameter and resistance to compression combined, can explain some 80% of the variation in loose wool handle.

The resistance to compression characteristics of loose fibre masses are used to determine the suitability of a fibre for a particular end-use, e.g. carpet pile or knitted fabric and are particularly
important in hand knitting yarns, mattresses, quilt filling etc.\textsuperscript{118,119} For carpet yarns the resistance to compression of the loose wool affects the yarn bulk as well as carpet covering power and resistance to compression.\textsuperscript{115}

Resistance to compression is correlated with loose wool felting, it alone or in combination with diameter and crimp.\textsuperscript{120-122} Low crimp fibres exhibit low resistance to compression.\textsuperscript{123} Highly crimped fibres, on the other hand, are claimed to resist compressive forces as they do not entangle easily.\textsuperscript{124} The relationship of resilience has been established with yarn irregularity, frequency of thin and thick places, hairiness, breaking strength and extension,\textsuperscript{125} fabric thickness, air permeability and felting shrinkage\textsuperscript{122,126} etc. By using a reference curve, for example representative of wools obeying the Duerden\textsuperscript{127} crimp-diameter-relationship, the resistance to compression can indicate whether a wool of a certain diameter is relatively overcrimped or under-crimped. The study conducted by Mody et al.\textsuperscript{128,129} reveals that Indian wools and carpets made of these wools are more resilient than New Zealand wool and carpets.
ELECTRICAL AND THERMAL PROPERTIES

Conductivity

The electrical conductance of wool fibres varies with moisture content. The resistance of wool reaches the critical value at 65% RH when wool fibres are rubbed on each other, the magnitude and sign of the charge depend on the relative orientation of scales. The presence of extraneous materials and antistatic agents, usually present on the fibres, improve the conductivity.

Although the thermal conductivity of these keratin fibres is considerably greater than air, the heat insulating properties of the fabrics made out of these fibres are mainly due to the air entrapped within the interstices of the structure rather than properties of the fibre substance. The conductivity increases with increasing fabric density and the most efficient heat insulation is therefore given by a low-density structure. Because the warmth retention is influenced by its air permeability, uniformly distributed small pores are required for minimum air permeability and in turn better thermal retention ability.

Thermal Stability

Thermal stability of these keratin fibres is also one
of the important characteristic which ultimately plays an important role during yarn processing particularly carding and combing where mechanical friction causes sufficient amount of heat to effect adversely on the basic inherent characteristics of fibre under processes. Thermoanalytical measurement such as thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) are relatively fast and exact methods, which can be used for determination of kinetics of thermal degradation of these fibres. Thermogravimetric analysis of natural wool and chemically modified wool have been reported by number of workers, but the similar studies on mohair and Angora rabbit hair have not yet get any significant attention. In case of wool, three different stages of decomposition have been identified from their thermograms. The first region shows the inflexions due to moisture. In the primary thermograms of wool this region lies between 150 and 250°C. The second stage of decomposition begins at 251°C with 20% weight loss. After that the decomposition continues at constant rate and reaches a stage where final decomposition starts. The final decomposition temperature (FDT) of wool was observed at 520°C with 85% weight loss upon further heating up to 725°C rapid decomposition occurs, and the residue left at
725°C is 15% only.

Felix et al.\textsuperscript{136} have performed thermal analysis of variety of wools under nitrogen atmosphere. They stopped the procedure at approximately 260°C (the point of wool liquefaction). They described three components of wool thermal decomposition (i) the loss of small molecular species including H\textsubscript{2}O, H\textsubscript{2}S, CH\textsubscript{3}SH, CO\textsubscript{2} and NH\textsubscript{3} from reactive amino-acid side chains (ii) the destruction of crosslinks -S-S bonds, H-bonds, and salt linkage by a process called denaturation and (iii) the rupture of peptide bonds producing wool liquefaction. Below 300°C, degradation reactions involve side chains either singly or in mutual interactions, while above 300°C, degradation with cleavage of peptide bonds occurs.\textsuperscript{137} Denaturation of keratin fibres\textsuperscript{138} with bilateral structure e.g. wool, involves straightening and then reversal of the normal direction of curl (ring formation) as the orthocortex contracts, followed by straightening as the more stable para-cortex contracts. Mohair, which does not have the bilateral structure, is converted to an irregular coil-like form when heated.

In DSC analysis, keratin fibres had a large water-loss endotherm. Wool-water vapour isotherms,\textsuperscript{139} in the temperature range 20-100°C, were found to be
affected mainly by the previous history of the sample, the amount by which the vapour pressure was changed, and the time allowed for equilibrium to be established. The influence of these factors was more marked at higher temperatures. Between approximately 175 and 400°C, additional endothermic responses have been recorded. Two endothermic peaks between 230 and 260°C represent a microfibriller (helix) peak and a matrix peak. The lower peak has been assigned to the microfibril peak, while the upper peak is a matrix peak (cystine decomposition peak).\textsuperscript{140,141} The matrix peak only appears in isolation in particularly high cystine fibre keratins\textsuperscript{142}. In lower cystine fibre keratins such as mohair the intensity of the matrix peak is too weak to profile itself clearly against the other amino-acid decomposition reaction which form the heavy background of the thermogram. Due to the superimposition in the DSC curves of peaks of cystine decomposition and other irreversible decomposition processes, the DSC investigations of the helical content of mohair should be cautiously interpreted.\textsuperscript{143}

DSC analysis of wet-heated (120-140°C) aqueous keratin fibres showed that there were no true melting point, but there were irreversible decomposition points. DSC
analysis of isolated microfibriller proteins and matrix proteins in the disulphide form supported this hypothesis. Intramolecular disulphide bonds exhibited greater thermal stability than intermolecular ones. DSC studies of annealed samples of wools, low-S and high-S wool proteins in the disulphide form were performed by Spei et al. in which a lowering of the decomposition temperature with increasing annealing time was found. Cystine-free, helix-rich, globular proteins exhibited only one helical peak and no helical melting peak.

**WET PROCESSING**

The types of various impurities present in animal hair fibres include grease, suint and vegetable matter. After preliminary sorting, dusting and opening of raw fleeces, the removal of impurities is one of the most intricate and important operations in the manufacture of woollen and worsted materials. Manifold difficulties may be encountered in the subsequent operations such as carding, combing, drawing, spinning and even finishing which may be attributable, wholly or in part, to improperly/over scoured, carbonised and bleached fibres.

**Scouring**

Scouring, generally, performed just after preliminary
sorting, dusting and opening of raw fleece, vary widely depending on the ease with which wool can be cleansed. The scouring of greasy wool may be accomplished by both aqueous and solvent degreasing methods. The actual conventional scouring operation is accomplished in a series of 3-4 individual vats or bowls through which the wool is propelled by mechanical rakes with intermediate squeezing. The final phase of scouring steps is drying of stock in dryers, designated, to deliver a uniform product to the succeeding operations. The degree of saponification and/or neutralisation of the free fatty acids of raw wool grease will be a function of the percentage of wool grease present on the wool fibre and environmental factors affecting the chemical composition of the wool grease such as grade, feed and climatic conditions. A good summary of the experimental and technical investigations of raw wool scouring is given by Howitt. The scouring of raw wool using aqueous alkaline conditions is still of a reasonable interest since probably the greater proportion of wool being washed in the world continues to be treated in solutions of soap of one kind or another. Scoured animal hairs, particularly wool, retaining 1-3% residual soapy substance and 0.3-5.0% residual fatty substance is prepared by treating open
loose fibres with a scouring composition comprising 
$CCl_3CH_3$ and/or $CH_2Cl_2$ and 0.1 - 10% raw animal hair 
grease extracted from the same type of animal hair as that being scoured. Purification of wool by scouring 
in combination with ultrasound treatment giving better results has been recently reported.$^{149}$ Scouring 
in a pilot scale Lo-flo machine under conditions 
designed to achieve minimum water consumption and 
uniformly high quality of scoured wool have been 
also dealt to optimise operating conditions.$^{150}$ 
Scouring efficiency of the Lo-flo scouring system has 
been shown to depend on electrolyte concentration.$^{151}$ 

Current developments in raw wool scouring technology 
and waste water treatments were discussed with per-
formance characteristics of major scouring systems, 
and methods for reducing erosion caused by dirt 
accumulations$^{152}$. It has been shown that the treat-
ment of wool with sodium and potassium terbutoxide 
altered the surface properties (felting, shrinkage, 
wetting time and abrasion resistance) without causing 
internal fibre damage.$^{153}$ The neutral scouring 
process involves the use of nonionic detergents 
classified as polyethylene glycol, monononyl phenyl 
ether and used in combination with electrolytes like 
sodium sulphate and sodium chloride. A comparison 
between alkaline and neutral scouring with respect to 

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proteinaceous contaminant layer has been reported. The cloud point and wettability have a major effect on washing of wool. The effect of electrolytes on whiteness of scoured wool during nonionic scouring has been demonstrated recently.

Virtually, no scientific research work has been carried out on mohair scouring. Only a few studies were initiated at SAWTRI in mid sixties. Not only, the total amount of extraneous matter viz. wax, suint and vegetable matter differ between wool and mohair but also the nature of the wax is by no means same. Due to the more exposure of mohair fleece to weathering in comparison to merino, the wax in the mohair fleece is expected to be heavily oxidized. Although, the percentage grease on mohair is much lower than on wool, still scouring of mohair, in getting required residual grease levels, poses a difficult problem. Since the lustre of mohair has to be retained, special precautions have to be taken to ensure that prevailing scouring conditions are not detrimental to this property. Lower temperature and lower amounts of soda ash are preferable.

An unconventional scouring procedure was adopted by Turpie for mohair in which effect of various concentrations of wool grease (0-22%) and detergent
(5% and 7.5% on mass of grease) was observed on scouring efficiency. At concentration of detergent above 0.5% all the grease appeared to be scoured from the mohair fibres. Mohair fibres are scoured with an emulsion containing water, a nonionic surfactant and as the sole non-aqueous solvent. The emulsion treated fibres which contain 2-8% fatty matter are washed with aqueous detergent, squeezed and dried to reduce the fatty matter content to 0.8%. As the amount of grease, dirt and vegetable matter are negligible in rabbit hair there appears to be no need of scouring.

Many techniques have been used for the examinations of fibre surface damage during scouring or other chemical treatments. The bulk of the information has been obtained by the methods of either light microscopy or conventional electron microscopy. Results provided by light microscopy suffer because of the very restricted depth of field and low resolution. The importance of the scanning electron microscopy (SEM) in wool surface damage research during processing was highlighted by Sikorski. But the similar studies with mohair and Angora rabbit hair have not been yet given a significant attention.
**Carbonisation**

The elimination of extraneous vegetable matter from wool is generally performed chemically and the process is known as carbonisation. Studies made on the chemical treatment for removing the vegetable contaminants indicate that 3.5% sulphuric acid treatment is suitable for wool having less than 5% vegetable matter and 4.5% sulphuric acid is appropriate for wools having more than 5% vegetable matter. The process involves immersion of wool in acid at room temperature followed by baking at 110-120°C, crushing, dusting, neutralisation and hydroextraction etc. Complete removal of the vegetable matter is essential for manufacturing of quality products, woollen yarns in particular used in worsted suiting. Knitted garments also require complete vegetable matters free wool.

Although, carbonisation is a well established chemical process but loss of strength in traditional method of carbonisation is around 15-40% \(^{167}\), which needs to be minimised. In addition, weight loss is 15-20% depending upon the severity of the process and type of wool. Crewther and Pressley\(^{168}\) reported that addition of certain wetting agents to the acid bath protected the loss of wool strength during carbonisation.
ing. Rapid carbonising process has been developed by Nossar et al. 169,170 to minimise wool fibre entanglement which reduces the breakage of fibre in mechanical processing. Besides, the effectiveness of different surfactants for rapid acidification in carbonising process has been reported.171 Knot172 conducted trials, to minimise acid content, on solvent acidising of wool. The process consists of treating the wool with anhydrous mixture of perchloroethylene/ gaseous HCl had observed as an effective process for degradation of vegetable matters.

In a study of wool carbonising, causes and prevention of localised acid damage has been investigated and critical concentration of acid and its effects on wool have been reported.173,174 Recently, factors influencing the neutralisation of acidified wools with ammonia solution also have been reported175 and it is proposed that a flat-bed neutralising machine that employs ammonia solution could be effective in a commercial operation. Instead of H₂SO₄, SOCl₂ vapours have been suggested for carbonising to reduce damage to wool fibres.175

After acidising, drying and baking are the most critical phases177 of carbonisation. Patel and Ramamurthy178 found with Indian wools having high
burr contents (>6%) that satisfactory carbonisation was achieved at drying temp. of 70-80°C and baking temperature of 130°C. Yellowing of wool occurred only at 160°C. Once the vegetable matter has been carbonised, it is passed through properly set burr crushing rollers. To increase the burr removing efficiency, burr crushing and dedusting process were separated. Wool after dedusting has high acid content which can cause damage to fibre if not properly removed by neutralization.

As there is very little adhesion due to lack of grease, both in mohair and rabbit hair the amount of vegetable matter is low and hence the mechanical means such as carding and combing are satisfactory enough for its removal. It has been shown that mohair containing 15% of vegetable matter by mass could be converted successfully into tops either via a carbonising process or without carbonising. The tops produced from the uncarbonised hair were longer, more lustrous, and of better colour than those produced from the carbonised hair. Turpie has performed some laboratory and pilot scale work on mild carbonising of mohair.

**Bleaching**

Bleaching, generally followed by scouring, is carried
out to reduce the natural yellowish tinge of fibre. The colour of scoured wool and mohair varies from cream to yellowish white, depending on the type and geographical and climatic conditions, in which the fibre is grown. The colouration is due to the presence of certain pigments and may be increased by the action of light, heat and certain industrial treatments, giving the phenomenon termed 'yellowing'. The bleaching of wool can be achieved by two types of processes, oxidation and reduction. The oxidising agents employed for carrying out the bleaching of wool are hydrogen peroxide or potassium permagnate. Reductants used for bleaching of wool are either sulphurous acid, sodium hydrosulphite or some derivatives of these stabilized with formaldehyde. In some cases, wool bleaching is carried out by a combined method often involving initial oxidative treatment and subsequent reduction.

Peroxide bleaching is the most common approach. Continuous process using hydrogen peroxide has been recently introduced. In order to achieve the best possible white, with the least amount of fibre damage, it was established by the results of Ziegler that the prebleaching with hydrogen peroxide followed by their reduction after bleach with sodium hydrosulphate works best. Serafirnoff et al. have shown
that urine-stained white wool may be bleached with sodium chlorate. Work to analyse the reaction behaviour of some oxidising agents with the surface of wool fibre has been reported.\textsuperscript{187} Observations on bleaching of wools of different geographical origin with hydrogen peroxide have been made\textsuperscript{188} at Politec. Barcelona University, Spain. Yellowness of wool can also be eliminated by bleaching first with Na\textsubscript{2}S\textsubscript{2}O\textsubscript{4} and then with fluorescent brightness\textsuperscript{189}. It has been shown that the presence of hexadecyl trimethyl ammonium bromide during bleaching of wool with hydrogen peroxide in alkaline medium facilitates both alkaline and oxidative attack on the disulphide crosslinks.\textsuperscript{190}

The colour of scoured mohair also sometimes carries a yellow tinge. Usually mohair colouration is scorable and bleaching is not required and also this creamy colour bears a characteristic lustre which can get destroyed by severe wet processing conditions. Still, by bleaching the yellowish tinge can be improved to white colour having better aesthetic appeal. Bereck\textsuperscript{191} has performed some experiments on the selective bleaching of undyed wool fabrics containing mohair. Catalytic bleaching of wool fabric containing mohair in which the fabric is pretreated with metal salts before the peroxide bleach, has been
developed by Blankenburg.\textsuperscript{192} On the other hand, rabbit hair itself is the whitest fibre, thus there is no need to bleach these hairs.

\textbf{Dyeing}

Depending upon the end-use requirements, acid, chrome, metal complex, reactive and reactive disperse dyes are used for dyeing wools. Traditionally, wool is dyed in batch operations in which the textile is boiled in aqueous solutions of dye for a period of at least one hour. Techniques have been developed for continuously dyeing wool in loose or sliver form.\textsuperscript{193} Factors influencing fibre-dye interactions include pH and temperature of the dye solutions, the nature and concentration of electrolytes in the solution, hydration of dyes and auxiliaries, effects of contaminants and pretreatments on the fibre surface, affinity of the dye for wool, and mode and depth of penetration of the dye into the fibres.\textsuperscript{194,195} It has been recognised that dyeing behaviours are correlated with structural transformation of wool fibres from $\alpha$- to $\beta$-form.\textsuperscript{196} Reactive dyes, usually anionic in nature, are important for wool.\textsuperscript{197} The resistance to wet treatments of some dyes can be improved by treatment of metal salts, usually those of chromium to reduce their solubility. These chrome dyes have been supplemented by metal complex dyes\textsuperscript{198} of very
high affinity for wool. Wool is dyed in loose, sliver, yarn, fabric or garment form depending on the nature of product, the equipment available, requirement of the market and other factors.

The technical limitation of conventional dyeing is caused by chemical damage to the wool fibres that results in loss of strength due to the deleterious effect of acid used at boil. Strength and elongation of dyed yarns are typically reduced by 20% and 50% respectively and more end-breaks are encountered in weaving. Fabric strength and abrasion resistance losses may be as high as 50%. Weight losses of upto 5% are commonly found, depending on the previous history of wool. This degradation is due to the partial or sometimes complete removal of the epicuticle which normally acts as a barrier to the entry of chemicals into the fibre. For minimising the chemical damage to wool, cost of fuel and other technical limitations, methods have been proposed for the colouration of wool at temperatures below boil or the use of continuous pad system dyeing e.g. the use of high concentration of urea in the dye solution allows dyeing of tops or fabric in the cold. Several other methods have been developed involving the use of special auxiliaries in the dye solution
below the boil e.g. ethoxylated nonyl phenol surfactants\textsuperscript{206} and n-butyl alcohols.\textsuperscript{207,208} The mechanism by which certain surfactants function as low temperature dyeing assistants was investigated.\textsuperscript{209} Surfactants were found to enhance exhaustion and level uptake of dye at low temperatures by a surface adsorption mechanism. Diffusion of dyes into the interior of wool fibres was unaffected by the presence of the surfactants. Dyes with relatively low molecular weights, which are able to penetrate wool fibres adequately below the boil, can be used with surfactant to achieve satisfactory dyeings with beneficial reductions in damage, compared with dyeing at the boil. Scouring wool with nonionic detergent in the presence of salt and ammonia has been claimed to produce wool which may be dyed at lower than normal temperature.\textsuperscript{210} The process for simultaneous felting and dyeing of wool and hair in aqueous perchloroethylene solutions and the fastness properties achieved has also been tried.\textsuperscript{211}

Mohair is often used as a blend with wool and the dyeing behaviour is usually studied as wool/mohair blend. Swanepool\textsuperscript{212} found that when mohair of similar diameter to wool is compared in respect of dye absorption, mohair has a higher rate of dye
uptake. Moreover, for the same amount of dye-uptake, the mohair had a deeper shade than the wool. This difference in shade is usually attributed to the difference in lustre of wool and mohair fibres. On the other hand, Rensburg\textsuperscript{213} observed that lustre had no effect on the lightfastness ratings or rate of fading. Roberts\textsuperscript{214} has confirmed the observations made earlier that the mohair tends to lose its lustre when dyed for prolonged periods at the boil. Strydom\textsuperscript{215} found that time, temperature and pH of dyeing liquor severely influence the lustre of mohair. The former two have the largest effect on the degree of yellowing in long liquor dyeing within the pH range 2.0 - 6.0 (using buffer solutions). To retain lustre of mohair, short dyeing cycles and low temperatures are employed.

Rabbit hair products are valued for their natural whiteness and are used as such and sometimes blended with other coloured fibres. It can be dyed to get more market to offer variety of products. Literature on dyeing behaviour of rabbit hair and blends is rare. Dyeing of rabbit hair and wool mixtures with both acid and chrome dyes produces a two tone effect. Fumoto\textsuperscript{216} compared the acid dyeing behaviour of Angora rabbit hair with those of wool in reference to aminoacid composition, crystallinity, Zeta potential
and fibre fine structure. The dye uptake by rabbit hair and wool showed large difference under acid dyeing conditions beginning at 40°C and finishing at 80°C at a rate of 1°C/min, which was much higher for rabbit fibres than for wool. The rate of dyeing or exhaustion for rabbit fibres with a dibasic acid dye to buffer solution under restricted condition was rather slower than that for wool, this may be affected by the higher negative surface potential of rabbit hairs. As the rabbit hair dyes lighter because of greater fibre medullation, the blend ratio of undyed rabbit hair and wool can be determined by quantitative analysis based on the gradient distribution of dye uptake.

The dyeing temperature has been specified by Gu et al. for rabbit hair, which should not exceed 100°C with suitable pH 3-4 when rabbit hair was treated in acid solution and the pH ≤8 when treated in alkaline solution. Effect of mordanting of hair on quality of dyeing of rabbit hair was studied by Witczak. Overall, rabbit hair fabrics showed better dyeability in comparison with wool fabrics.

**YARN PROCESSING**

The significance of most of the physical properties of fibres is reflected during processing to yarn and
Two main types of yarns are manufactured in the wool textile industry, woollen yarns and worsted yarns. Woollen yarns can be made from relatively shorter fibres. The optimum length of the fibre is about 2-3 inches but much shorter fibres down to 1/4 inch in length are commonly used for cheaper fabrics. Worsted yarns are finer, smoother, and more compact than woollen yarns. The fibres lie parallel along the length of the yarn. Woollen yarns are used in fabrics such as tweeds and blankets, whereas, worsted are used in smooth suiting cloths and knitwears. Conventionally, only longer fibres greater than 2-1/4 inches in length are spun into worsted yarns, but the French comb allows as short as 1-1/2 inch to be spun on the worsted system to make knitted goods with a soft handle.

In general, processing of fibres to yarn involves carding, combing and spinning. Wool stock or mixtures of wool with other textile fibres, before going to the mechanical processing, must be lubricated to minimise breakage of wool fibres during carding as well as to reduce fly waste, and static electricity. An emulsion of oil and water is sprayed which, in the case of woollen spinning, is upto 3% and for worsted processing 1/2 to 1%. In spinning, the lubricant
enables the wool fibres to slide over one another more easily during drawing and twisting, resulting in more even yarns. Reydberg\textsuperscript{225} has discussed the important characteristics of wool oils. The developments of wool lubricant which brought about a radical change in the field were discussed by Terry\textsuperscript{226} and Buck\textsuperscript{227}. Mineral oils emulsified with water\textsuperscript{228} have been developed to a very high standard of efficiency and ease of removal and now command the bulk of the market. Earlier, Dobson\textsuperscript{229} has described the use of water soluble lubricants.

Several additives and combinations of additives have been used to study their performance in the carding gilling, combing and spinning of mohair\textsuperscript{230,231} and their effect on yarn friction and fibre breakage. The use of antistatic agent was observed to be essential. It is suggested that in mohair/wool blend yarns, it was not inherent differences between the mohair and wool fibres which influenced the yarn friction, but it was the ether extractable matter present on mohair which adversely affected lubricating efficiency of the paraffin wax.\textsuperscript{232} Kul et al.\textsuperscript{233} have correlated the effectiveness of lubricating oils with their viscosity and surface tension, while processing mohair slivers.
In the case of woollen carding, the machine is of roller and clearer type of 2 - 1/2 to 3-1/2 set card with cross-lappers and final roving for twisting is prepared here itself. In the case of worsted carding, instead of around 144 slubbings, only one or two slivers are prepared suitable for feeding the next machine autoleveller. Modern developments have concentrated mainly on improving the accuracy with which these carding machine works and increase its production capacity. The extent of breakage of wool fibres during carding, while ultimately determined by the speed and setting of card, is also influenced by the degree of entanglement of the wool that occurs during scouring and by the temperature and regain of the wool during carding. These objectives of carding can be achieved by a two, three, or four card system depending on the stock and type of yarn to be spun. Earlier research work on carding has been covered by Thorndike,234,235 Richards236,237 and Jowett238,239. Their findings have indicated that opening power was improved by speeding up the whole set maintaining the production constant. The relationship between fibre breakage at the card and fibre diameter, fibre strength and fibre length has been studied, by Towend et al.79 and Wall.240
In mohair carding, besides normal functions of the process, a special function of removal of unwanted kemp fibres is performed. Kruger and Albertyn\textsuperscript{241} found that due to the difference in specific gravity between mohair and kemp, later tend to migrate more deeply into the card clothing. The lower stretch-break characteristics of the kemp or heavily medullated fibres in mohair have also been used as a means of removing them in combing. Kruger\textsuperscript{242} has found that in Nobel Combing, using Mark VI Nobel comb, removal of kemps is not significantly affected by changes in dabbing depth. The rectilinear comb\textsuperscript{243} has been found inferior to Noble comb in respect to kemp removal. While, French comb\textsuperscript{244} was found effective for removing vegetable matter. A significant proportion of the kemp fibres was broken by passing slivers through the back and front rollers of a gill box, the ratch being 4 inch and the draft about 1.5.\textsuperscript{245} The broken kempy fibres were later removed as noil in combing.

Mohair can be processed into yarn by either the English system or the French system.\textsuperscript{246-248} Traditional English system of processing of mohair into yarn is quite prevalent and a lot of published work is available regarding this process. However,
some work has also been carried out on the Continental system of processing, while data on the so-called modified American worsted system \(^{249}\) is also available to a limited extent. In English system the twist inserted in the slivers helps to overcome the lack of cohesion. The twisted rovings can be spun on cap, ring or flyer frames. The choice of the frame depends on the quality of mohair to be spun and spindle speeds-usually cap frames can be run faster than ring which in turn, can be run faster than flyer frames. Normally, cap spun yarns are stronger and can be spun to finer linear densities than ring or flyer yarns. \(^{250}\) Cap spun yarns have been observed more hairy, whereas, flyer spun yarns are least hairy. When mohair is spun on the French system, the use of additives at the optimum levels is essential. \(^{251}\)

Comparative processing studies for combed mohair processed on either the English system or the French system has been carried out by Gurcon et al. \(^{252}\), where neither system was found better than the other on the basis of the quality of the resultant yarns. Further, Marthinus et al. \(^{253}\) processed different types of mohair, varying widely in length and diameter, into yarn on the Continental worsted system for analysing processing effects of basic raw hair
properties and observed that longer, finer fibres spin better at a given yarn linear density. Turpie and Hunter\(^{254}\) have made an extensive investigation of the parameters affecting yarn hairiness which increases with increase in mean fibre diameter. Increase in mean fibre diameter also adversely effects the yarn tensile properties and evenness properties.\(^{255}\) Further, Hunter et al.\(^{256}\) correlated the increase in mohair fibre diameter with a deterioration in yarn physical properties along with increase in woven fabric's air permeability, abrasion resistance, stiffness and drape coefficient but had little effect on tensile properties. Fibre length, within the range 84 to 113 mm, appeared to have little effect on the yarn quality\(^ {254}\), although, for a constant fibre diameter, an increase in mean fibre length has shown the decrease in frequency of thick places in the yarn and increase in yarn breaking strength, extension at break and hairiness. The effect of length gets generally reduced by an increase in yarn twist. Still a very little work is available on processing of mohair and its blends with wool, which largely depends on accumulated skills and experience in relatively small sector of the worsted processing industry.\(^ {257}\)
Rabbit hair creates difficulties in processing due to its typical surface structure\textsuperscript{258} and static generation. By using suitable antistat\textsuperscript{259} the processing of rabbit hair is possible on cotton\textsuperscript{260}, woollen\textsuperscript{261} and decentralised khadi system.\textsuperscript{262} It is usually applied in blends with other synthetic and natural fibres, both in the decentralised and the organised sectors. A major problem in processing of Angora fibres is the result of its lower inter fibre cohesion which creates difficulty when processed alone and fibres tend to slip out of the yarn and shed from the fabric. Surface treatment\textsuperscript{263} has been recommended during processing to improve the spinnability of rabbit hair. Little systematic work has been reported on the processing of these fibre,\textsuperscript{264-266} specifically there is no machine available for processing of rabbit hairs. It may be due to the fact that with its limited production it can not meet the requirement of large mills and therefore provides a small potential for the machine manufacturers. Arora\textsuperscript{267} has suggested the use of khadi system hand spinning because it requires less quantity of fibres for processing with negligible waste and is a high labour intensive and light capital system. He has also tried rabbit hair/ wool blends and results of tensile properties of yarns prepared on Ghantaria and
Bhageshwari charkhas have been reported. Recently, studies have also been made on processing and product performance of rabbit hair and its blends with polyester, acrylic, wool, cotton and silk on both woollen and cotton system of machinery.\textsuperscript{268}

\textbf{UTILIZATION}

The heterogeneity in its diameter, length and crimp and high degree of medullation and resilience make the Indian wool mainly applicable in carpet manufacturing. They are unsuitable for worsted segment because the product like shirting, suiting, shawls and hosiery goods need the finer count yarn which is not possible to be spun out from the Indian wool. Therefore, the spinnability of these Indian wool can be improved by blending with polyester and viscose staples etc. The speciality hairs because of their smooth surface and low crimp are difficult to spin as such.\textsuperscript{258,269,270} However, their blends with wool, polyester and cotton are utilized commonly.

Mohair is an important fashion fibre, both in woven and knitted goods. In wovens, men's suitings are an important end-uses.\textsuperscript{271} When mohair is used in knitwear it is normal to produce what is often referred to as the shaggy brushed look.\textsuperscript{272} Non-brushed types of plain knitted fabrics in mohair are not widely
used mainly because of price and problems with scratchiness. Otherwise, specifically, mohair has been largely utilized as an upholstery material, usually, in the form of pile fabrics. To a limited extent mohair is also being used as an apparel fibre. It is being increasingly used for outerwear coatings. Mohair fabric can be employed widely for furnishings such as those in theaters, cars and other public vehicles for such purposes its hard-wearing properties are a special advantage. Mohair is also being used to manufacture hard wearing and crease resistant ties for which the warp is of highest quality merino wool and the weft of mohair or mohair/wool blends with 30-60% wool.

Because of its lustre and brilliant dyeability and the power of retaining colours, mohair fibres serves admirably for nets, laces and drapery materials and produces many novel effects in decorative trimmings for coats, hats and shoes. The long fibre of mohair is particularly useful in manufacturing of wigs and switches. The demand of mohair is greatly affected by fashion change and is comparatively more expensive than wool. Mohair, being a cold fibre, is generally used for suitings only in hot countries.

In the recent years, however, mohair has been mainly
used as an apparel fibre, efforts have been made specifically on different end-applications of mohair with respect to improved fabric performance. Hunter et al. observed that felting shrinkage of non-shrink proofed fabrics decreased with increasing mohair content and was close to zero for the pure mohair fabrics. Further, Kowalewski has shown that wool fabrics, with an increased mohair contents, are characterised by less shrinkage on the warp yarns. Because of lesser adhesion of mohair fibre, such fabrics collect less dust than wool and whatever dirt settles on the fabric is very easily removed.

The speciality hairs production by Angora rabbits and its utilization in the woollen industry has been going on far many years in developed countries like Germany, France, U.K., Italy, Russia and U.S.A. etc. In India, isolated efforts have been made to introduce Angora rabbit farming in the temperate regions for the production of fine Angora hairs. It is lighter, lustrous and more warmer than sheep wool and used for fabrication of fine woollen apparels. Rabbit hair, as such, creates difficulty in processing due to its typical surface structure. Since the scales of rabbit hair are much inclined towards the axis of the fibre and protrude very little from
the surface, the surface becomes smooth and makes the binding of the fibres difficult. Such fine fibres also produce, high static charges at the time of fibre processing. To reduce the static charges, the addition of some antistat and moisture is practised. 259

The fibres are often blended with wool for hosiery yarns and are widely used in the manufacture of garments for babies' wear, special types of ladies' wear 280 etc. Its blending imparts unique virtues to the end-product like smoothness, warmth, light weight and extrawhiteness. Further, due to its typical structure, it provides comfort to the body and also used in health therapy specially in kidney trouble. Blending of Angora hairs with various qualities of wool in different proportions have been tried for spinning yarns for apparel fabrics such as shawls, chaddars and mufflers etc. 265 and knitted fabrics such as sweaters. 281 Incorporation of higher proportions of Angora fibres increases the cost, warmth and fluffiness and acceptability of apparel, however, with respect to durability and non-shedding of Angora fibres only 25% Angora incorporation gives best results. 268 Hu Zhao et al. 58 have performed a detailed study of shedding behaviour of rabbit hair in
fabric made of rabbit hair/wool blends. Angora hairs can also be used in conjunction with polyester, acrylic, cotton and silk fibres.