also essentially distinguish the worsted from the semi-worsted processing route.

There are basically three different routes or systems used in the mechanical processing of wool (Fig. 6.1), namely worsted, semi-worsted and woollen. The essential differences in the products of the three systems are the levels of short fibres and the alignment of the fibres in the yarn, the fibres in worsted yarns being far more parallel than those in either semi-worsted or woollen yarns, resulting in a far leaner (less bulky) and less hairy yarn. Close on 90% of Australian and South African Merino type apparel wools are processed on the worsted system while some 80% of New Zealand wool is processed on the woollen system.

It should be mentioned that short wools, mainly in blends with either cotton or polyester, are also processed on the cotton (short staple) system, being occasionally rotor-spun (open-end) rather than ring spun. Wool with a mean fibre length around 40 mm can generally be processed without any major alteration to the cotton machinery, while wool with a mean fibre length of around 50 mm generally requires slip drafting at the drawframe, speedframe and ringframe. Iype et al. have reviewed the processing of wool and wool-rich blends on the cotton system and this processing route will not be dealt with in this chapter.

6.2 Worsted processing system

6.2.1 Introduction

The name ‘Worsted’ is a slight corruption of ‘Worstead’, the name of a village in Norfolk where expert cloth-workers who entered England in the early fourteenth century, introduced novel methods for the production of superior and finer cloth than was previously produced in Britain. As already mentioned, the essential and differentiating element of the worsted system is combing. Generally, only virgin wool, typically ranging in length from about 40 to 100 mm, is used in manufacturing worsteds, the term worsted-spun yarn, as opposed to worsted yarn, being used for the yarns in those cases where man-made fibres are processed.

Virtually since the start of worsted processing, two main systems have been used, namely the English (oil combed or Bradford) system, involving Noble combing, and the French or Continental (dry-combed) system, involving Rectilinear combing. The former was primarily developed and used for longer wools and the latter for shorter wools. Nevertheless, Noble (and also Lister) combs, employed in the Bradford system, are no longer being manufactured and the industry has moved almost entirely to the Rectilinear or French combing route. Essentially, the latter route entails carding followed by Intermediate or Preparer Gilling, then Rectilinear
6.1 Processing routes for wool. [From Oxtoby.]

**Worsted flow chart**

1. Raw wool and hairs
   - Blending
   - Dust removal (if needed)
   - Scouring
   - Drying

2. Fibres shorter than 200 mm maximum fibre length
   - Carding
   - Intermediate gilling (usually 3 gill boxes)
   - Combing (usually rectilinear, sometimes Noble)
   - Top finishing (usually 2 gill boxes)
   - Top dyeing (or bleaching)
   - Backwashing
   - Drying
   - Blending

3. Fibres longer than 200 mm maximum fibre length
   - Preparer gilling (6 operations)
   - Combing (Lister or Noble)
   - Top finishing (usually 2 gill boxes)
   - Drawing (2 to 5 operations)
   - Spinning
   - Winding and clearing
   - Folding and re-winding if required

**Woollen flow chart**

1. Raw wool
   - Scouring
   - Drying

2. Remanufactured fibres
   - Rags
   - Threads
   - Worsted by-products (soft waste)
   - Carbonizing if required
   - Dyeing if required
   - Blending
   - Carding
   - Spinning
   - Winding and clearing
   - Folding and re-winding if required

3. Other fibres (e.g., hairs, cotton, silk, man-made fibres)
   - Blending
   - High-production carding
   - Drawing (2 or 3 gill boxes)
   - Spinning
   - Winding and clearing
   - Folding and re-winding if required

**Semi-worsted flow chart**

1. Raw wool
   - Dust removal (if required)

2. Man-made fibres
   - Scouring
   - Drying

3. Blending
   - High-production carding
   - Drawing (2 or 3 gill boxes)

4. Roving (bobbin lead, for knitting yarns and some upholstery)
   - Spinning
   - Winding and clearing
   - Folding and re-winding if required

*Processing routes for wool. [From Oxtoby.]*
Combing (very occasionally Noble combing) and then Top Finishing, which usually comprises two Finisher Gilling operations. The stage from greasy wool to top is referred to as the ‘early processing’ or ‘topmaking’ stage. Papers at the Top-Tech ’96 Conference in Australia\textsuperscript{4} dealt with various aspects of topmaking, including the potential and merits of automation in topmaking, cost and flexibility being important aspects in this regard.

The Worsted Flow Chart is shown in Fig. 6.1.\textsuperscript{1}

6.2.2 Carding

Carding generally represents the first stage of the mechanical processing of scoured wool, worsted cards typically being available in widths between 2.5 and 3.5 m. If any opening is applied prior to carding, care must be taken not to entangle the fibres, particularly for fine wools. Lubricants (generally 0.4 to 0.5\%) are applied prior to carding to provide a well-balanced static and dynamic fibre-to-fibre and fibre-to-metal friction, and cohesion and anti-static properties.\textsuperscript{5} Best results are generally obtained with boundary layer lubrication for carding, the main effect being at the swift. The lubricants should be emulsifiable and preferably bio-degradable, and often also contain bactericides/fungicides, complexing agents and anti-odourants.

The worsted, semi-worsted and woollen cards entail similar carding principles, although the last has more carding elements as well as an intermediate feed. Automatic linkages between carding, intermediate gilling and combing have also been developed. In essence, carding is aimed at opening up or disentangling the scoured wool staples (clusters or tufts), individualizing the fibres, mixing the fibres, removing residual dirt and vegetable matter, such as burrs and seeds, and forming the wool fibres into a continuous form (web); this is then condensed into a card sliver, and, in the case of worsted carding (Fig. 6.2), delivered into a ball or can. These actions need to be carried out in such a way that fibre breakage is minimised and as even a web and sliver as possible are produced. In the case of the worsted route, the wool is virtually always carded in the undyed state.

The card essentially consists of the following separate mechanical sections, each playing a different part in the process:\textsuperscript{7}

- Feeding
- Licker-in, including burr removal etc.
- Swift-worker-stripper section
- Fancy doffer section

The exact configuration of the card (Fig. 6.2) depends upon the nature of the fibre being processed, notably the level of vegetable matter. For example, when wools of relatively high vegetable matter levels are carded, the card could have more morels and burr-rollers.
The feed system plays a critical role in the uniformity of the card web and sliver. Examples are continuous flow volumetric feeders or gravimetric feeders, incorporating automatic monitoring and regulating devices (autolevelling).

The card essentially consists of rollers with surfaces covered in pins (card clothing). There are two main types of card clothing, flexible steel wire mounted into a firm foundation and rigid (non-flexible) metallic wire. The latter is a continuous steel ribbon with saw teeth which is wound around the card rollers, and this form of card clothing is presently the most popular.

The following carding actions take place (Fig. 6.3):

- Carding (working)
- Dividing
- Stripping
- Doffing
- Brushing or Raising

The action on the fibres present between the pins of two adjacent rollers on a card is determined by the following factors:¹

- Relative speed and direction (i.e. same or opposite) of the movement of the roller surfaces
- Direction of inclination of the pins, i.e. points leading or backs leading
- Distance (setting) between points on the adjacent rollers

The intensity of the carding action can be altered by changing one or more of the above factors. Increasing the overall speed of the card generally does not increase the carding action (or fibre breakage) as such, although it can increase fly waste and air currents. There are three pin relationships in carding, namely point to point, point to back and back to back ¹ (Fig. 6.3):
Point to point, when used to open and disentangle the tufts of fibres, is called working or carding (e.g. at the licker and divider). This action always results in some fibres being retained on both surfaces. It is also used by the doffer to collect fibres from the fast moving swift, normally following the action of the fancy.

Point to back provides a stripping action, i.e. transfers all the fibres from the one surface to the other.

Back to back results in a raising action, which moves the fibres carried by the swift towards the tips of the pins by the action of the long fancy wire pins as they intersect with the pins on the swift.¹

Burr beaters are used to remove burrs and other vegetable matter. They have steel blades and are usually run at the highest feasible speed in the opposite direction to the card roller surface. They are at their most effective during the earlier stages of the carding process, before the burrs have been opened out, and when they are used in conjunction with Morel rollers. Morel rollers are clothed with rigid wire clothing that cause the fibres to bed into the wires (assisted by the action of brush rollers) whereas the vegetable matter particles protrude from the surface and are knocked off into trays by fast revolving burr beaters, sharp blades offering certain

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¹ From Oxtoby.
advantages. A modern card with two Morels typically removes over 90% by weight of burr and close on 90% of shive.

The full width web from the doffer, which can be monitored and corrected for evenness, is condensed into a sliver as it passes through a funnel and between a pair of pressure rollers, the latter running at a slightly higher speed than the doffer. Card sliver linear density monitoring and autoleveling (open and closed loop) take place at this stage, a drafting head at the delivery end of the card allowing the sliver linear density to be controlled.

When carding with rigid metallic wire clothing, wool regain should not exceed 25%, and ideally should be between 20 and 25%. Residual grease content of the wool should not exceed 0.6%.

Carding is a fairly severe action, typically breaking between about 20 and 40% of the fibres, with an average breakage rate of about 30%; as much as 90% of the fibre breakage that takes place in converting scoured wool into top takes place during carding. The card also breaks about 90% of the weathered wool tip. These short degraded fibre fragments either fall from the web as carding waste or are taken out of the sliver when subsequently combed. The level of fibre breakage is influenced by the degree of fibre entanglement developed during scouring, the fibre fineness, strength, length (Fig. 6.4) and friction (lubrication), as well as on the thickness of the fibre layer on the swift, an increase in fresh fibre density on the swift increasing fibre breakage. It is perhaps worth noting that storage and pressing of scoured wool to high density, lead to additional fibre breakage during subsequent processing. Table 6.1 illustrates the potential effects of changes in certain parameters on fibre breakage during carding, summarising results obtained during various experimental studies (some on processed wool) at SAWTRI.

The disentangling and opening processes may be inadequate to the extent that small tangled balls (tight clusters) of fibres, described as neps, are present in the card web. Poor carding, often indicated by increasing nep content, can be due to damaged or inadequately ground (blunt) card clothing and incorrect settings. Card wire should not be blunt, bent over, flattened or damaged in any other way. Incorrect setting of burr-beaters and crushing rollers may also lead to unacceptable levels of vegetable matter. Reducing the ‘fresh fibre density’ by increasing swift speed, reduces neps and combing waste.

The quality of the carding operation can be assessed in terms of the following web characteristics:

- Degree of individualisation of the fibres.
- Uniformity in weight per unit area.
- Uniformity of blending.
- Degree of alignment of the fibres.
6.4 Mean Fibre Length of Card Sliver after 3rd Gilling vs Mean Fibre Length of Raw Wool. [From Aldrich et al.\textsuperscript{10}]

Table 6.1 Summary of breakage results obtained in various experimental carding studies at SAWTRI\textsuperscript{11}

<table>
<thead>
<tr>
<th>Parameter*</th>
<th>Change in value of parameter</th>
<th>Change in fibre breakage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Style</td>
<td>Spinners to Inferior</td>
<td>6% to 36%</td>
</tr>
<tr>
<td>Length</td>
<td>57 mm to 109 mm</td>
<td>19% to 43%</td>
</tr>
<tr>
<td>Vegetable impurity</td>
<td>0.5% to 2.0%</td>
<td>10% to 19%</td>
</tr>
<tr>
<td>Temp. of scouring</td>
<td>45°C to 70°C</td>
<td>12% to 18%</td>
</tr>
<tr>
<td>pH of scour liquor</td>
<td>3.4 to 10.8</td>
<td>10% to 24%</td>
</tr>
<tr>
<td>Residual grease</td>
<td>0.4% to 1.6%</td>
<td>26% to 40%</td>
</tr>
<tr>
<td>Lubricant added</td>
<td>0.4% to 2.1%</td>
<td>2% to 10%</td>
</tr>
<tr>
<td>Worker settings</td>
<td>26 gauge to 30 gauge</td>
<td>27% to 42%</td>
</tr>
</tbody>
</table>

* Only one parameter changed in each case.
• Level of hooks (most hooks occur at the trailing ends of the fibres as they leave the card).
• Level of neps and vegetable matter.

Although the card can remove pre-existing neps resulting from fibre entanglement in the scoured wool it also forms new neps and fibre structures that tend to form neps during subsequent gilling. The number of neps decrease with an increase in the number of workers, sharpness of card wire, closer worker settings and with a decrease in recycled fibre density/swift load. The number of neps also increase with increasing scoured wool entanglement and with increasing fibre fineness, crimp and length. Neps generally increase from the card to the comb (i.e. during gilling), affecting the amount of noil. Reducing neps by 50% could reduce noil by some 25%.

The basic principles of carding remained virtually unchanged for the entire 20th century, probably the most notable changes taking place in the last two decades of the 20th century. These include the development of Very High Speed Carding (VHSC) by the CSIRO (Australia), the IWS and G H Michell (Australian topmaker) in collaboration with Thibeau (France), and the high speed Hercules card by Octir. The former development virtually doubled the carding speed and resulted in the Thibeau CA7 Card, which was exhibited at the 1995 ITMA, a compact version being shown at the 1999 ITMA. On such a card (2.5 m wide), typical production rates achieved are 220 kg/hr for 22 μm wool and 160 kg/hr for 19.5 μm wool. This substantial increase in speed was brought about essentially by two breakthroughs. The first was the development of tandem burr beaters, which overcame the speed limitations of the single burr beater and enabled much higher carding speeds without any sacrifice in vegetable matter removal efficiency. The second innovation involved the use of two doffers at the swift, which maintained the transfer efficiency from swift to doffer (traditionally about 50%) at the higher carding speeds used.

Overall, the increase in production speed was achieved by:
• Increase in swift speed and diameter.
• Increase in the number of carding points.
• Optimising speed ratios between different rollers and fibre diameters.
• Improved vegetable matter removal.
• Double doffer.
• Efficient suction systems to keep the environment clean.

For superfine wools to achieve the longest Hauteur* and lowest noil, the ratio of swift worker pinning density to fibre density should be as high as

*Hauteur is the mean fibre length of a top, based upon a length biased distribution.
possible; this can be achieved by increasing pin density or reducing fibre density, but it is not sufficient to reduce fibre density at some stage before the final swift.¹³

Developments that have helped to reduce the number, frequency and time required for setting and maintenance include:

- Centralised read-out and control of the different production parameters from the operator console.
- Variable-speed motor drive to allow operational changes of sliver weight, rate of production and carding intensity.
- Automatic doffing of full cans.
- Remote card (gap) settings.

Meng et al.¹⁴ critically reviewed the studies undertaken on fibre distribution and movement on the various carding elements, these governing carding efficiency, fibre mixing and levelling, productivity and web quality. They noted the pioneering work of Montfort¹⁵ in mathematically modelling the fibre transfer process in a roller-top card as a finite Markov chain, this having been extended by other workers to cover other stochastic features of carding. They concluded that, according to theory, fibre mixing and equalising are improved by increasing the collecting power of workers and decreasing doffer transfer efficiency, but that the theory was not always supported by experimental work. Work has also been done to measure the fibre density on the various carding elements, one example being the optical system developed by Rust and Koella.¹⁶

The combined carding and combing operations remove some 99.5% of the vegetable matter present in the scoured wool.¹⁷ Particularly troublesome, however, is contamination by polypropylene fibres from twine and by polyethylene wool pack fragments; the latter can be avoided by the use of nylon packs.

### 6.2.3 Preparer (intermediate) gilling

Generally, three preparer (intermediate) gilling operations follow carding (i.e. precede combing), coarser pinning generally being used for preparer than for finisher gilling.

The purpose of gilling the card sliver prior to combing is to remove hooks, align, straighten and blend the fibres and improve sliver uniformity (by doubling) so as to reduce fibre breakage and noil during combing as well any excessive extensibility of the card sliver. The more aligned the fibres and the fewer the fibre hooks, the lower the chances of fibre breakage during combing. Significant fibre breakage, however, can occur on high-speed intersecting gill boxes when using close front-roller settings.¹⁸ Gilling tends to increase nep ups from fibre structures formed during carding. The gilling
operation mostly removes trailing hooks, hence the need to reverse the direction of the sliver in subsequent operations. Gilling also creates some hooks.¹⁹

It is generally recognised that, in terms of the gilling operations, intersecting pins are necessary to ensure the proper drafting of wool. Intersecting (or intersector) gills (Fig. 6.5) generally have either screw-driven or chain-driven fallers or pinned rollers and rotary gills, and can have either single or double heads. Very few screw gills are now manufactured, chain gills dominating the market. The latter are versatile and have a production rate around double that of the screw gills, the pin paths being similar. Screw gills are, however, still preferred for very short fibres and where high loads are required. There are essentially four gilling machine manufacturers, namely NSC Schlumberger, OKK, Cognetex and Sant’ Andrea Novara.

Gills can be equipped with either mechanical or electronic autolevellers and also can be fitted with spraying devices. Adding moisture during high speed gilling, e.g. by spraying, is important for achieving the desired regain for subsequent processing. A lubricant (0.1 to 0.3%) can also be sprayed onto the sliver during the first or second gilling operations, to assist in maintaining or increasing regain, minimising static and modifying static fibre-to-fibre cohesion.⁵ Integrated suction and blowing systems keep the heads clean.

Okamura et al.²⁰ investigated the competing effects of draft and doubling on sliver evenness, evenness improving with doubling up to 12 slivers, after which it remains largely constant.
Direct linking of the card to the first gill and the third gill to the comb was found to reduce Hauteur but did not affect noil, neps, vegetable matter or fibre length distribution. Introducing a fourth gilling operation in such a set up had a beneficial effect on Hauteur and noil.

6.2.4 Combing

Combing enables finer, stronger more uniform and less hairy yarns to be spun at better efficiency. Combing aligns the fibres and removes, as noil, fibres generally shorter than about 20 to 30 mm, vegetable matter and neps. Typically, Hauteur is increased by 10 to 15 mm and its coefficient of variation (CVH) is reduced by 10 to 20%, while more than 95% of VM and neps are generally removed. Most of the short fibres removed by the comb as noil arise from fibre breakage during carding. Noil removed during combing has a market value about 40% of that of the top and is mainly utilized by the woollen industry.

Originally, four types of combing machines, namely Noble (circular), Rectilinear (intermittent), Lister (nip-motion) and Holden (square motion), were used, but today combing is largely done on the rectilinear comb, also called a Continental, French, Heilmann or Schlumberger comb, the other types of combs no longer being manufactured. The move to rectilinear combing is mainly due to the increasing use of dry-combed as opposed to oil-combed tops and the shorter mean fibre lengths of the wool typically being processed nowadays. Rectilinear combing is the only type described here.

The principles of combing introduced during the mid 1800s were so good that they are still used today. The rectilinear comb was invented by Heilmann around 1845 and there are now two main manufacturers of wool combing machines, namely NSC Schlumberger and Sant’ Andrea Novara. Examples of modern rectilinear combs are the Sant’ Andrea P100 (production 1.2 to 1.6 kg/m) and the Schlumberger PB33, combing speeds being as high as 260 nips/min and visual readout providing instant information on virtually all aspects of the combing operation.

The basic operations of a combing machine are:

- Feeding the slivers, typically 24 to 32, from balls or cans into the machine.
- Holding the fibres and combing the free fibre ends by means of a cylinder covered with progressively finer pins, any fibres not held being combed out as ‘noil’, along with neps and vegetable matter (Fig. 6.6).
- Gripping, by means of detaching (drawing off) rollers, and detaching the combed fringe of parallel fibres (which is now free of short fibres and entanglements), holding it, inserting the top comb, and pulling the
fibres through the pins of the top comb, which consists of a single row of pins, thereby removing any ungripped fibres as noil as well as neps and vegetable matter (Fig. 6.6).

- Laying the combed fringe on the previously combed fringes and forming a continuous ‘combed’ sliver from the tufts that have just been combed.

Brushes play an important role in combing; for example, in cleaning the circular and top combs and drawing-off cylinder, and pressing the fibres into the circular comb. Automatic adjustment of brushes, such as the nipper and circular brushes, and the simplified reversal and removal of the latter represent important developments.
A good measure of combing quality for Merino type wools is the percentage of fibres shorter than 15 mm in the top, which should preferably be below 1.8 to 2.0%.\textsuperscript{22} It is affected by the total fatty matter content of the sliver (minimum 0.6 to 0.7%), the relative humidity (ideally 70 to 75%) and temperature (ideally 20° to 24°C) of the combing shed, as well as by the regain of the wool (ideally around 20%) and the comb setting. The comb also breaks fibres, the breakage rate decreasing with decreasing fibre length, friction, combing intensity and with increasing fibre alignment and fibre strength. Fibre breakage during combing can range from around 17 to 31%.\textsuperscript{23} Trailing hooks in the sliver fed to the comb are less likely to be broken during combing,\textsuperscript{19} hence the importance of an uneven (odd) number of gilling operations between carding and combing, assuming cans are used.

The percentage of fibres shorter than 30 mm and of noil are influenced by the following factors:\textsuperscript{24}

- Raw wool characteristics (e.g. fineness, staple length uniformity, staple strength, character or style, including levels of vegetable matter and other impurities).
- Quality of scouring and associated processes (greasy wool opening, wool felting, etc.).
- Quality of carding (card production, setting, speed).
- Quality of combing (comb setting, maintenance).

The amount of noil removed during combing may be expressed either as percentage noil or Tear (ratio) as follows:

\begin{align*}
\text{Noil (\%)} &= \frac{\text{mass of noil} \times 100}{\text{mass of (noil + comb sliver)}} \quad \text{[6.1]} \\
\text{Tear ratio} &= \left(\frac{\text{mass of comb sliver}}{\text{mass of noil}}\right) : 1 \quad \text{[6.2]}
\end{align*}

It follows that:

\[
\text{Noil (\%)} = \frac{100}{(\text{tear} + 1)} \quad \text{[6.3]}
\]

5.2.5 Backwashing

Backwashing is the process of treating wool slivers and tops in an aqueous detergent solution to remove any remaining unwanted impurities, such as residual grease and lubricants, and also to straighten the fibres (i.e. reduce fibre crimp). A lubricant is added at the end of the process, and also a fugitive tint to produce a temporary improvement in the colour (whiteness) of
the wool. Typically, 36 slivers are fed to the backwashing machine, which consists of two scouring bowls and one rinse bowl followed by a suction drum dryer. A gilling process normally follows the backwashing process. Backwashing can either precede or follow the combing process, the former option normally being used for oil-combed tops (e.g. to remove dirt prior to Noble combing) and the latter for dry-combed tops (e.g. to reduce residual fatty matter and improve the appearance of the top). Top shrink-resist treatment (e.g. chlorine-Hercosett) is carried out in a machine similar to a backwashing machine except that there are extra bowls for chlorine and resin application (i.e. a total of five bowls) and an extra dryer to cure the resin.

6.2.6 Recombing

Recombing was originally introduced for dyed tops, in order to separate and align fibres which became entangled during dyeing and also to remove neps and slubs formed during dyeing, as well as any other remaining short fibres and neps; the neps in the top are generally reduced by over 80% (small neps by 70 to 80% and larger neps by 90 to 95%). A crimping box was introduced at the comb delivery to improve the cohesion and crimp of dyed tops and it is today often also used in first combing, particularly if chain gills are to be used subsequently.

Recombing is carried out after top-dyeing, when fibre blends are involved and also when producing high quality tops, and is particularly important when spinning fine high quality weaving yarns (25 tex and finer). In fact, recombing is increasingly being regarded as a cost-effective means of improving spinning and weaving efficiencies and improving fine yarn and fabric quality in terms of yarn faults (neps and slubs).

In the case of pure wool, a recombing line typically has four operations, two preparatory gillings preceding combing (often three in the case of dyed tops and four where different fibre types and colours are involved). Combining is followed by two finisher gillings, the chain gill increasingly being preferred. Six operations are typical for wool/polyester blends.

The two gillings prior to recombing are aimed at improving fibre alignment, thereby reducing noil, as well as achieving the correct fibre regain and sliver linear density (weight). The first finishing gill after recombing needs to randomize the fibre ends, which have been aligned at the comb, so as to facilitate subsequent drafting.

On modern combs, recombing production (kg/hr) for ecru wool is around 2.3 times the mean fibre diameter of the wool being processed. Noil produced during recombing varies from about 2 to 5%, depending upon factors such as the degree of entanglement of the top.
6.2.7 Top finishing (finisher gilling)

Top finishing refers to the ‘finisher’ gilling operations (generally two) subsequent to combing. Combing aligns the leading ends of the fibres, which adversely affects the sliver cohesion and subsequent processing. One of the main objectives of finisher gilling is to again randomise the leading fibre ends by drafting. Additional objectives are further blending, straightening and aligning of the fibres, the addition of moisture (and oil) according to the trade allowances and producing a top of the required linear density and evenness. A sliver (top) that is uniform in its linear density (weight per unit length) is produced and formed into a ball or bump top of specified size and weight. The main actions are drafting and doubling with pin control. Normally, the first finisher operation (gill box) has an auto-leveller unit. The first gilling operation generally involves up to 30 doublings and drafts of between 5 and 10, with the second only involving around 4 or 5 doublings.

6.2.8 Prediction of top properties

A quality specification for tops could include the following:\footnote{25}

- Mean fibre diameter
- Fibre diameter distribution (e.g. CV and Coarse Edge)
- Minimum (or mean) fibre length (Hauteur)
- Fibre length distribution (e.g. Max CV and Short Fibres)
- Oil (extractable or total fatty matter) content (IWTO value is 1%, but normally around 0.7% for dry-combed tops)
- Moisture content (18.25% IWTO)
- Colour
- Maximum coloured (dark) fibres (e.g. 100/kg)
- Neps and vegetable matter content
- Linear density
- Evenness
- Ash content
- pH

Considerable experimental work has been done at the CSIR in South Africa\footnote{26} and the CSIRO in Australia to quantify the effects of raw wool properties on top properties. These studies have led to empirical equations (e.g. CSIRO TEAM formulae) being derived that quantitatively relate the top properties, such as Hauteur, to those of the raw or greasy wool. Two examples are given for purposes of illustration:
The constant of 3.5 in eq. [6.5] can be adjusted according to the mill specific conditions.

Also \[ H = \frac{1.17 \times SL}{1 + p} \]  
where \[ p = \frac{e^Y}{1 + e^Y} \]  
\[ Y = 0.561 - 0.113 \times D + 0.0276 \times SL - 0.0331 \times SS + 0.0125 \times M \]  
and \( 1 - p \) is the probability that a fibre will not break during processing.
Another formula, requiring a computer program, also provides a measure of fibre length distribution.\textsuperscript{28,29} The work carried out at the CSIRO led to the development of the Sirolan-TOPSpec processing prediction software,\textsuperscript{30} which allows Hauteur, CV(H), Noil, short and long fibres and the shape of the fibre length distribution graph to be predicted from the raw wool test results for mean fibre diameter, VM base, staple length, staple strength and the position of staple break. A Topmaker System software was also developed; this also includes a Topmaker Data Management Program.\textsuperscript{31} These have now been combined in the Topspin computer program, which can be used to predict and model an infinite array of performance and costs for greasy wool, tops and yarn. It is PC-based and can be configured for network. The Internet-based program can be licensed (desk-top licensing model).

Generally, Merino type tops for the pastel trade are expected to have fewer than 100 dark fibres per kilogram to be deemed ‘commercially free from dark fibre’. Longree and Delfosse\textsuperscript{32} reported on the latest results obtained with the Optalyser measurement of dark fibre and other contaminants, including neps, in wool tops. The Optalyser is an instrument that automatically measures and grades into different classes, coloured fibres, neps and vegetable matter particles in wool tops.

6.3 Preparation for spinning (drawing)

Although direct spinning of sliver into relatively coarse yarn is carried out on the semi-worsted system, thereby eliminating intermediate stages such as the roving stage, this requires high drafts, precise drafting and also good fibre control. Nevertheless, it is not yet possible to spin good quality and relatively fine yarn in this manner, partly because it eliminates the beneficial effects of sliver feed reversal and doubling. A sequence of processes, called drawing, is required to gradually and in a controlled manner, through a process of drafting, reduce the sliver linear density while controlling the movement and alignment of the fibres and the sliver linear density and evenness. This enables a roving (twisted or twistless) to be produced, of the linear density and evenness required for the efficient spinning of a yarn of the desired linear density and quality. Worsted drawing is the process of converting the top into a roving suitable for spinning, this also being referred to as ‘preparation for spinning’. Within the present context, drawing can be defined as the series of operations involving doubling and drafting, the machines which work together for this purpose being called the ‘drawing set’.\textsuperscript{1}

Drafting essentially involves two sets of rollers that run at different surface speeds, the surface speed of the front rollers (delivery) being higher than that of the back (feed) rollers. The ratio of the surface speed of the
delivery rollers to that of the feed rollers represents the numerical draft. The difference in surface speed causes the fibres to slide past one another, thereby reducing the number of fibres in the sliver cross section and its linear density correspondingly. It also helps to align the fibres. The distance between the nips of the front and back rollers is termed the ratch. The amount of draft which can be applied at any one stage is dependent upon the degree of fibre control, and can vary from as low as four to over 25, there generally being an optimum draft, depending upon the fibres and type of system used.

The fibres that are not held by either the front roller nip or the back roller nip are called floating fibres; these fibres are not positively controlled, being controlled only by the frictional forces of adjacent fibres. It is these uncontrolled floating fibres that prevent perfect drafting (i.e. where the random fibre arrangement is preserved). Various techniques are used to improve control over the floating fibres, including additives to increase interfibre friction, pins, twist and direct pressure (e.g. double aprons) and certain combinations of these. Most commonly, pins are used to control the fibres during the early stage of drawing and aprons during the final stages, pinned drafting systems generally being able to handle heavier loads and delivery than apron drafting systems (whereas the latter can handle higher drafts). Accurate settings on apron drafting systems are generally also more critical than on pinned drafting systems because the latter tend to be a more ‘tolerant’.

Although drafting is an effective means of aligning the fibres and reducing sliver linear density, it increases sliver unevenness. This problem is overcome by combining the actions of doubling and drafting. Doubling is the action of combining (feeding) two or more slivers into a drafting zone, which results in a more even output sliver. If no draft is applied, the irregularity of the output sliver equals that of the input sliver divided by the square root of the number of input slivers, assuming all input slivers have the same linear density. Nevertheless, to achieve the main objective of drawing, namely to reduce the sliver linear density, the overall draft needs to exceed the number of doublings. Typically, four operations, more for finer yarns and for finer and shorter wools, are used – for example, three gillings (e.g. screw or chain gills) and one roving. Factors, such as lower drafts, individual fibre movement, parallel fibres, fibre control, good lubrication and fewer short fibres, contribute towards good roller drafting and evenness of the drafted material. The reversal of the slivers, and consequently also the direction of fibre hooks, improves fibre randomisation during roller drafting and the removal of fibre hooks. This reduces the short-term irregularity of the sliver.

Autolevellers, introduced in the early 1950s, are used to improve the evenness of slivers by measuring the sliver thickness/linear density variation and then continuously altering the draft in such a way that more draft is applied to the thicker than to the thinner sections. Autolevellers, using
either mechanical or electronic measurement and draft control systems, can correct short, medium and long term variations, including the mean sliver linear density.

The final stage of spinning preparation is the roving or finisher stage. The roving is given the required cohesion, either by inserting low levels of twist (flyer) or, more commonly, by a twistless rubbing action (rubbing-frame), illustrated in Fig. 6.7.33

In the case of the production of twisted rovings, the sliver is generally drafted using an apron drafting system, after which twist is inserted by means of a flyer that inserts one turn of twist per revolution. The twisted roving is then wound onto the bobbin, which rotates with a higher surface speed than the flyer. The flyer also avoids balloon formation and any adverse effect on the fibre assembly due to air currents. Electronic flyer roving frames with integrated automatic doffing are amongst the latest developments.

In the case of the rubbing-frame, two slivers are normally fed to each drafting head, the strands remaining separate as they are consolidated and given cohesion by means of the oscillating rubbing action of the aprons. The pairs of consolidated rovings are cross-wound onto a double-mech package which is then used to feed two spindles on the spinning frame. In some cases, e.g. for automatic spinning frames, it is also possible to produce a single meche package from a single sliver. Horizontal and vertical rubbing frames are available. High-speed finisher rubbing frames can now also incorporate automatic bobbin doffing (and ticketing) and have spiral guides after the rubbing zone that improve roving cohesion and enable high-speed winding and also trouble-free unwinding on the spinning frame. Electronic
contactless stop motions between the rubbing aprons and winding rollers can be fitted. Suction systems achieve good cleaning. Speeds of up to 275 m/min can be achieved on vertical rubbing frames with one rubbing zone (single pair of aprons), and up to 220 m/min on horizontal rubbing frames. Different drafting systems are also interchangeable.

Flyer rovings and rubbed rovings essentially produce yarn of virtually equivalent quality, although the former generally enable higher drafts, fewer end breakages and higher speeds in spinning. However, the capital investment costs for rubbing-frames are considerably lower than for flyer frames and the production higher, while fibre breakage also tends to be lower. The flyer roving frame, which can accommodate heavier packages (bobbins), has certain advantages over the rubbing-frames when processing fibres with low cohesion and crimp, such as mohair and certain coarse wools, and in some cases also when using spinning frames with broken end detectors or automatic pieceners.

6.4 Semi-worsted processing system

The semi-worsted system, developed in the first half of the 20th century mainly for synthetics and blends, essentially consists of carding, gilling and spinning, and, when spinning medium and fine yarns, also a roving process prior to spinning. Raw wools are scoured and dried, opened, blended and lubricated prior to carding. The machinery used is very similar to that employed in worsted processing. This system has production and economic advantages over both the woollen and worsted system, but generally cannot produce yarns of the same fineness, character or quality. The character of semi-worsted yarns is somewhere between that of the worsted and woollen yarns, being bulkier, weaker and less regular than worsted yarns.

A flow chart for the Semi-Worsted System is shown in Fig. 6.1, the absence of a combing operation being the main feature that distinguishes it from the Worsted System. The absence of combing and the very high production levels make it economically attractive and suitable for producing relatively coarse yarns (about 50 to 500 tex) destined for certain end-uses, particularly carpets but also upholstery and hand-knitting yarns. Best results are generally obtained with between about 80 and 120 fibres in the yarn cross-section, the latter being more typical. The Semi-Worsted System is used for medium to long, relatively coarse wools and man-made fibres, and it handles fibres with finenesses between about 9 and 16.5 dtex and with mean fibre length ranging roughly between 150 and 75 mm (but generally not shorter than 60 mm, and with 15% or fewer of fibres shorter than 30 mm).

The semi-worsted system does not offer the opportunity to remove post-carding short fibres and neps, making the carding operation a very critical
one, nep removal increasing with increasing carding power. The subsequent gilling operations can reduce vegetable matter slightly but can also create neps. The configuration of the high-production semi-worsted cards, which are generally covered with rigid metallic wire, depends upon fibre type and characteristics, such as length and fineness, as well as upon the production rate required. A semi-worsted card typically has only one swift, with four or five sets of workers and strippers and usually twin doffers to ensure high production rates.\(^1\) Depending upon applications, they can be supplied with morel rollers, a burr roller on the licker-in, with a fancy, with an intermediate doffer and with one or two delivery doffers.

Carding is followed by two to three drawing operations, mostly using chain gills, preferably three if no roving operation is involved, so that a majority of trailing hooks enter the spinning frame as leading hooks. The first and/or second passages can be autolevelling. The sliver is then either attenuated further into roving or spun directly on a ring frame, where drafts can be as high as 300 in a multiple (e.g. three) drafting zone, the main drafting taking place in the final double apron drafting zone.\(^34\)

Correct fibre lubrication, for low fibre-to-metal dynamic friction, good fibre-to-fibre static friction and antistatic properties, is important. The optimum fatty matter content lies between about 0.7 and 1.2\%.\(^35\) A regain of about 19.5\% appears acceptable for carding. Atmospheric conditions of 23 to 24°C and 70 to 75% RH can be regarded as suitable for the processing of wool, while for spinning it is 21 to 25°C and 55 to 60% RH.\(^35\)

Elliott et al.,\(^35\) building upon the work of Richards and Batwin to develop the concept of ‘Total Carding Power’, describe a computer model based upon published empirical and theoretical studies, for simulating the semi-worsted processing of wool, which predicts how changes in scoured wool properties and processing variables affect yarn irregularity, breaking strength and bulk, spinning performance, card waste and card mixing power. They assumed that most fibre breakage occurred when fibres were withdrawn from tufts during opening. Maddever et al.\(^36\) reported on an Expert System which can be used to determine a suitable objective blend specification for the manufacture of wool carpet yarn by the woollen or semi-worsted routes, the fibre property specification depending upon the processing route, product specification and technical data.

### 6.5 Woollen processing system

#### 6.5.1 Introduction

The woollen system represents the shortest processing route for staple fibres, essentially entailing only two primary stages, namely carding and spinning, although there is an important preliminary stage involving blend-